Application manual

REC 561*2.3
Control terminal

About this manual

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Chapter 1 Introduction

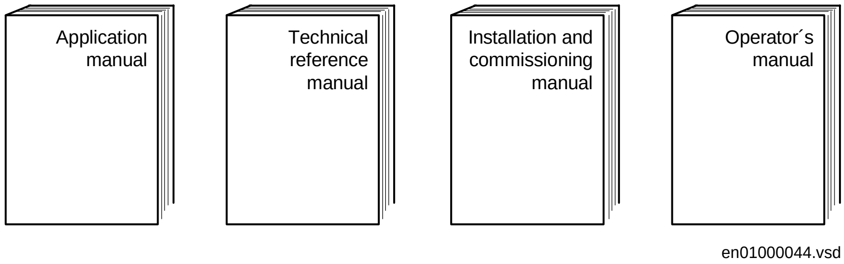
About this chapter

This chapter introduces you to the manual as such.

1 Introduction to the application manual

1.1 About the complete set of manuals to a terminal

The complete package of manuals to a terminal is named users manual (UM). The *Users manual* consists of four different manuals:



The Application Manual (AM) contains descriptions, such as application and functionality descriptions as well as setting calculation examples sorted per function. The application manual should be used when designing and engineering the protection terminal to find out when and for what a typical protection function could be used. The manual should also be used when calculating settings and creating configurations.

The Technical Reference Manual (TRM) contains technical descriptions, such as function blocks, logic diagrams, input and output signals, setting parameter tables and technical data sorted per function. The technical reference manual should be used as a technical reference during the engineering phase, installation and commissioning phase and during the normal service phase.

The Operator´s Manual (OM) contains instructions on how to operate the protection terminal during normal service (after commissioning and before periodic maintenance tests). The operator´s manual could be used to find out how to handle disturbances or how to view calculated and measured network data in order to determine the reason of a fault.

The Installation and Commissioning Manual (ICM) contains instructions on how to install and commission the protection terminal. The manual can also be used as a reference if a periodic test is performed. The manual covers procedures for mechanical and electrical installation, energising and checking of external circuitry, setting and configuration as well as verifying settings and performing a directionality test. The chapters and sections are organised in the chronological order (indicated by chapter/section numbers) the protection terminal should be installed and commissioned.

1.2 Intended audience

1.2.1 General

The application manual is addressing the system engineer/technical responsible who is responsible for specifying the application of the terminal.

1.2.2 Requirements

The system engineer/technical responsible must have a good knowledge about protection systems, protection equipment, protection functions and the configured functional logics in the protection.

1.3 Related documents

Documents related to REC 561*2.3	Identity number
Operator’s manual	1MRK 511 091-UEN
Installation and commissioning manual	1MRK 511 093-UEN
Technical reference manual	1MRK 511 092-UEN
Application manual	1MRK 511 101-UEN
Technical overview brochure	1MRK 511 090-BEN

1.4 Revision notes

Revision	Description
2.3-00	First revision

Chapter 2 General

About this chapter

This chapter describes the terminal in general.

1 Features

- Open terminal with extensive configuration possibilities and expandable hardware design to meet specific user requirements
- Additional protection function library available
- Extensive disturbance report with:
  - 10 most recent disturbances recorded
  - 40 seconds disturbance recorder
- Wide range of control functionality available
- 18 LEDs for extended indication capabilities
- Versatile local human-machine interface (HMI)
- Simultaneous dual protocol serial communication facilities
- Extensive self-supervision with internal event recorder
- Time synchronization with 1 ms resolution
- Four independent groups of complete setting parameters
- Powerful software ‘tool-box’ for monitoring, evaluation and user configuration
- Control functionality for single, double, triple, and ring busbar arrangements, and for single, double, and 1 1/2 circuit breaker arrangements including apparatus control and interlocking
- Complete autoreclosing function for up to six circuit breakers
- Synchrocheck with phasing and energizing check

2 Application

The main purpose of the REC 561 terminal is control related applications, with included protection and monitoring functions, in substations at all voltage levels. The terminal is specially suitable for applications in distributed control systems with high demands on reliability. It provides extensive logic capabilities for user specific applications.

3 Design

Type tested software and hardware that comply with international standards and ABB´s internal design rules together with extensive self monitoring functionality, ensure high reliability of the complete terminal.

The terminal’s closed and partly welded steel case makes it possible to fulfill the stringent EMC requirements.

All serial data communication is via optical connections to ensure immunity against disturbances.

An extensive library of protection, control and monitoring functions is available. This library of functions, together with the flexible hardware design, allows this terminal to be configured to each user´s own specific requirements. This wide application flexibility makes this product an excellent choice for both new installations and the refurbishment of existing installations.

4 Requirements

4.0.1 General

The operation of a protection measuring function is influenced by distortion, and measures need to be taken in the protection to handle this phenomenon. One source of distortion is current transformer saturation. In this protection terminal, measures are taken to allow for a certain amount of CT saturation with maintained correct operation. This protection terminal can allow relatively heavy current transformer saturation.

Protection functions are also affected by transients caused by capacitive voltage transformers (CVTs) but as this protection terminal has a very effective filter for these transients, the operation is hardly affected at all.

4.0.2 Voltage transformers

Magnetic or capacitive voltage transformers can be used.

Capacitive voltage transformers (CVTs) should fulfil the requirements according to IEC 186A, Section 20, regarding transients. According to the standard, at a primary voltage drop down to zero, the secondary voltage should drop to less than 10% of the peak pre-fault value before the short circuit within one cycle.

The protection terminal has an effective filter for this transient, which gives secure and correct operation with CVTs.

4.0.3 Current transformers

Classification

The performance of the REx 5xx terminal depends on the conditions and the quality of the current signals fed to it. The terminal REx 5xx has been designed to permit relatively heavy current transformer saturation with maintained correct operation. To guarantee correct operation, the CTs must be able to correctly reproduce the current for a minimum time before the CT will begin to saturate. To fulfil the requirement on a specified time to saturation the CTs must fulfil the requirements of a minimum secondary e.m.f. that is specified below.

There are several different ways to specify CTs. Conventional magnetic core CTs are usually specified and manufactured according to some international or national standards, which specify different protection classes as well. However, generally there are three different types of current transformers:

- high remanence type CT
- low remanence type CT
- non remanence type CT

The high remanence type has no limit for the remanence flux. This CT has a magnetic core without any airgap and a remanence flux might remain for almost infinite time. In this type of transformers the remanence flux can be up to 70-80% of the saturation flux. Typical examples of high remanence type CT are class P, TPS, TPX according to IEC, class P, X according to BS (British Standard) and nongapped class C, K according to ANSI/IEEE.

The low remanence type has a specified limit for the remanence flux. This CT is made with a small airgap to reduce the remanence flux to a level that does not exceed 10% of the saturation flux. The small airgap has only very limited influence on the other properties of the CT. Class TPY according to IEC is a low remanence type CT.

The non remanence type CT has practically negligible level of remanence flux. This type of CT has relatively big airgaps in order to reduce the remanence flux to practically zero level. At the same time, these airgaps minimize the influence of the DC-component from the primary fault current. The airgaps will also reduce the measuring accuracy in the non-saturated region of operation. Class TPZ according to IEC is a non remanence type CT.

The rated equivalent limiting secondary e.m.f. E_{al} according to the IEC 60044-6 standard is used to specify the CT requirements for REx 5xx. The requirements are also specified according to other standards.

Conditions

The requirements are a result of investigations performed in our network simulator. The tests have been carried out with an analogue current transformer model with a settable core area, core length, air gap and number of primary and secondary turns. The setting of the current transformer model was representative for current transformers of high remanence and low remanence type. The results are not valid for non remanence type CTs (TPZ).

The performance of the distance protection was checked at both symmetrical and fully asymmetrical fault currents. A source with a time constant of about 120 ms was used at the tests. The current requirements below are thus applicable both for symmetrical and asymmetrical fault currents.

Both phase-to-earth, phase-to-phase and three-phase faults were tested in fault locations backward, close up forward and at the zone 1 reach. The protection was checked with regard to directionality, dependable tripping, and overreach.

All testing was made without any remanence flux in the current transformer core. The requirements below are therefore fully valid for a core with no remanence flux. It is difficult to give general recommendations for additional margins for remanence flux. They depend on the reliability and economy requirements.

When current transformers of low remanence type (TPY) are used, practically no additional margin is needed.

For current transformers of high remanence type (e.g. TPX), the small probability of a fully asymmetrical fault, together with maximum remanence flux in the same direction as the flux generated by the fault, has to be kept in mind at the decision of an additional margin. Fully asymmetrical fault current will be achieved when the fault occurs at zero voltage (0°). Investigations have proved that 95% of the faults in the network will occur when the voltage is between 40° and 90°.

Fault current

The current transformer requirements are based on the maximum fault current for faults in different positions. Maximum fault current will occur for three-phase faults or single-phase-to-earth faults. The current for a single phase-to-earth fault will exceed the current for a three-phase fault when the zero sequence impedance in the total fault loop is less than the positive sequence impedance.

When calculating the current transformer requirements, maximum fault current should be used and therefore both fault types have to be considered.

Cable resistance and additional load

The current transformer saturation is directly affected by the voltage at the current transformer secondary terminals. This voltage, for an earth fault, is developed in a loop containing the phase and neutral conductor, and relay load. For three-phase faults, the neutral current is zero, and only the phase conductor and relay phase load have to be considered.

In the calculation, the loop resistance should be used for phase-to-earth faults and the phase resistance for three-phase faults.

Current transformer requirements for CTs according to the IEC 60044-6 standard

The current transformer ratio should be selected so that the current to the protection is higher than the minimum operating value for all faults that are to be detected. The minimum operating current is 10-30% of the nominal current.

All current transformers of high remanence and low remanence type that fulfil the requirements on the rated equivalent secondary e.m.f. E_{al} below can be used. The current transformers should have an accuracy class comparable to 5P or better. The characteristic of the non remanence type CT (TPZ) is not well defined as far as the phase angle error is concerned, and we therefore recommend contacting ABB Automation Products AB to confirm that the type in question can be used.

The current transformers must have a rated equivalent secondary e.m.f. E_{al} that is larger than the maximum of the required secondary e.m.f. E_{alreq} below:

$$E_{al} > E_{alreq} = \frac{I_{kmax} \cdot I_{sn}}{I_{pn}} \cdot a \cdot \left(R_{CT} + R_L + \frac{0.25}{I^2_R}\right)$$

(Equation 1)

$$E_{al} > E_{alreq} = \frac{I_{kzone1} \cdot I_{sn}}{I_{pn}} \cdot k \cdot \left(R_{CT} + R_L + \frac{0.25}{I^2_R}\right)$$

(Equation 2)

where

I_{kmax}	Maximum primary fundamental frequency current for close-in forward and reverse faults (A)
I_{kzone1}	Maximum primary fundamental frequency current for faults at the end of zone 1 reach (A)
I_{pn}	The rated primary CT current (A)
I_{sn}	The rated secondary CT current (A)
I_R	The protection terminal rated current (A)
R_{CT}	The secondary resistance of the CT (Ω)
R_L	The resistance of the secondary cable and additional load (Ω). The loop resistance should be used for phase-to-earth faults and the phase resistance for three-phase faults.
a	This factor is a function of the network frequency and the primary time constant for the dc component in the fault current, see figure 1.
k	A factor of the network frequency and the primary time constant for the dc component in the fault current for a three-phase fault at the set reach of zone 1, see figure2. The time constant is normally less than 50 ms.

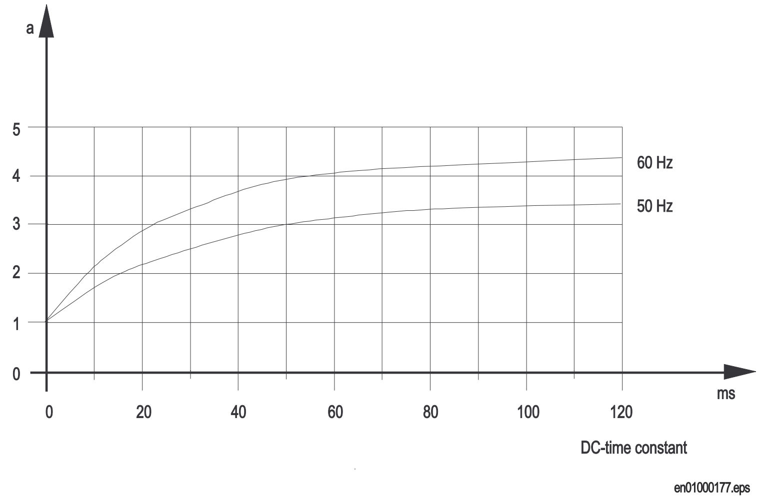


Figure 1: Factor a as a function of the frequency and the time constant

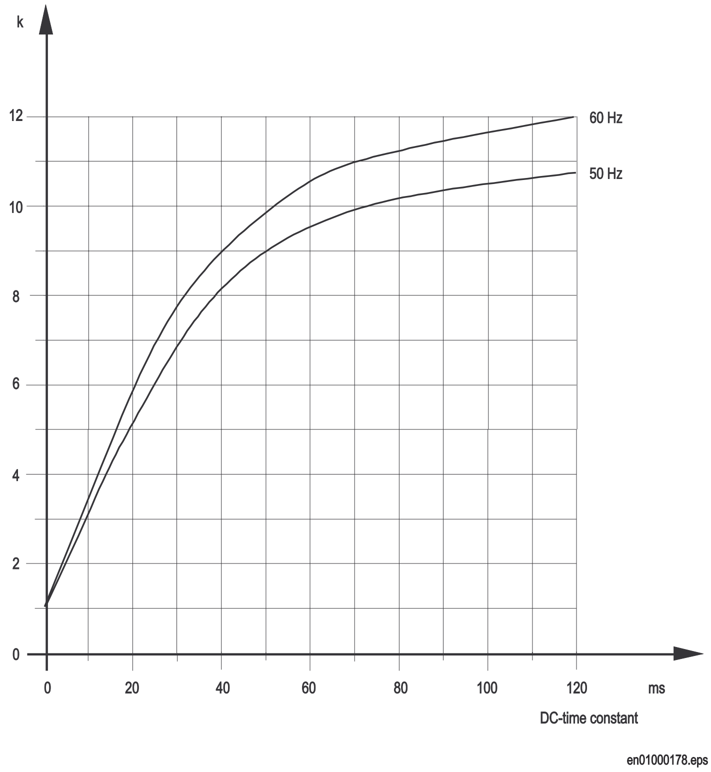


Figure 2: Factor k as a function of the frequency and the time constant

Current transformer requirements for CTs according to other standards

All kinds of conventional magnetic core CTs are possible to be used with REx 5xx terminals if they fulfil the requirements that correspond to the above specified according to the IEC 60044-6 standard. From the different standards and available data for relaying applications it is possible to approximately calculate a secondary e.m.f. of the CT. It is then possible to compare this to the required secondary e.m.f. E_{alreq} and judge if the CT fulfils the requirements. The requirements according to some other standards are specified below.

Current transformer according to IEC 60044-1

A CT according to IEC 60044-1 is specified by the secondary limiting e.m.f. E_{2max}. The value of the E_{2max} is approximately equal to E_{al} according to IEC 60044-6.

$$E_{al} \approx E_{2max}$$

(Equation 3)

The current transformers must have a secondary limiting e.m.f. E_{2max} that fulfills the following:

$$E_{2max} > \text{maximum of } E_{alreq}$$

(Equation 4)

Current transformer according to British Standard (BS)

A CT according to BS is often specified by the rated knee-point e.m.f. E_{kneeBS}. The value of the E_{kneeBS} is lower than E_{al} according to IEC 60044-6. It is not possible to give a general relation between the E_{kneeBS} and the E_{al} but normally the E_{kneeBS} is 80 to 85% of the E_{al} value. Therefore, the rated equivalent limiting secondary e.m.f. E_{alBS} for a CT specified according to BS can be estimated to:

$$E_{alBS} \approx 1.2 \cdot E_{kneeBS}$$

(Equation 5)

The current transformers must have a rated knee-point e.m.f. E_{kneeBS} that fulfills the following:

$$1.2 \cdot E_{kneeBS} > \text{maximum of } E_{alreq}$$

(Equation 6)

Current transformer according to ANSI/IEEE

A CT according to ANSI/IEEE is specified in a little different way. For example a CT of class C has a specified secondary terminal voltage U_{ANSI}. There is a few standardized value of U_{ANSI} (e.g. for a C400 the U_{ANSI} is 400 V). The rated equivalent limiting secondary e.m.f. E_{alANSI} for a CT specified according to ANSI/IEEE can be estimated as follows:

$$E_{alANSI} = \left|20 \cdot I_{sn} \cdot R_{CT} + U_{ANSI}\right| = \left|20 \cdot I_{sn} \cdot R_{CT} + 20 \cdot I_{sn} \cdot Z_{bANSI}\right|$$

(Equation 7)

where

Z_{bANSI}	The impedance (i.e. complex quantity) of the standard ANSI burden for the specific C class (Ω)
U_{ANSI}	The secondary terminal voltage for the specific C class (V)

The CT requirements are fulfilled if:

$$E_{alANSI} > \text{maximum of } E_{alreq}$$

(Equation 8)

Often an ANSI/IEEE CT also has a specified knee-point voltage $U_{kneeANSI}$. This is graphically defined from the excitation curve. The knee-point according to ANSI/IEEE has normally a lower value than the knee-point according to BS. The rated equivalent limiting secondary e.m.f. E_{alANSI} for a CT specified according to ANSI/IEEE can be estimated to:

$$E_{alANSI} \approx 1.3 \cdot U_{kneeANSI}$$

(Equation 9)

The current transformers must have a knee-point voltage $U_{kneeANSI}$ that fulfills the following:

$1.3 \cdot U_{kneeANSI} > \text{maximum of } E_{alreq}$

5 Terminal identification

5.1 Application

Serial number, software version and the identification names and numbers for the station, the object and the terminal (unit) itself can be stored in the REx 5xx terminal. Also the serial numbers of included modules are stored in the terminal. This information can be read on the local HMI or when communicating with the terminal through a PC or with SMS/SCS.

The base currents, voltages and rated frequency must be set since the values affect many functions. The input transformers ratio must be set as well. The ratio for the current and the voltage transformer automatically affects the measuring functions in the terminal.

The internal clock is used for time tagging of:

- Internal events
- Disturbance reports
- Events in a disturbance report
- Events transmitted to the SCS substation control system

This implies that the internal clock is very important. The clock can be synchronized (see Time synchronization) to achieve higher accuracy of the time tagging. Without synchronization, the internal clock is useful for comparisons among events within the REx 5xx terminal.

5.2 Calculations

Uxr and Ixr (x = 1-5) are the rated voltage and current values for the analog input transformers within the REx 5xx terminal. UxScale and IxScale are the actual ratio for the main protection transformer at the protected object. These values will be used to calculate the present voltage and current in the protected object. Uxb and Ixb defines base voltage and current values, used to define the per-unit system used in the terminal for calculation of setting values.

The current transformer secondary current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 10)

where:

I_{SEC} = secondary rated current of the main CT

I_{PRIM} = primary rated current of the main CT

Is = primary setting value of the current

The relay setting value IP>> is given in percentage of the secondary base current value, Ixb, associated to the current transformer input Ix:

$$IP{>}{>} = \frac{Is_{SEC}}{Ixb} \cdot 100$$

(Equation 11)

The value of Ixb can be calculated as:

$$Ixb = \frac{\text{Rated primary current}}{\text{CT ratio}}$$

(Equation 12)

Chapter 3 Common functions

About this chapter

This chapter presents the common functions in the terminal.

1 Time synchronisation (TIME)

1.1 Application

Use time synchronisation to achieve a common time base for the terminals in a protection and control system. This makes comparision of events and disturbance data between all terminals in the system possible.

Time-tagging of internal events and disturbances is an excellent help when evaluating faults. Without time synchronisation, only the events within the terminal can be compared to one another. With time synchronisation, events and disturbances within the entire station, and even between line ends, can be compared during an evaluation.

1.2 Functionality

Two main alternatives of external time synchronisation is available. Either the synchronisation message is applied via any of the communication ports of the terminal as a telegram message including date and time, or as a minute pulse, connected to a binary input. The minute pulse is used to fine tune already existing time in the terminals.

The REx 5xx terminal has its own internal clock with date, hour, minute, second and millisecond. It has a resolution of 1 ms.

The clock has a built-in calendar for 30 years that handles leap years. Any change between summer and winter time must be handled manually or through external time synchronisation. The clock is powered by a capacitor, to bridge interruptions in power supply without malfunction.

The internal clock is used for time-tagging disturbances, events in Substation monitoring system (SMS) and Substation control system (SCS), and internal events.

1.3 Calculations

The internal time can be set on the local human-machine interface (HMI) at:

Settings
  Time

The time is set with year, month, day and time.

The source of the time synchronisation is set on the local HMI at:

Configuration

Time

When the setting is performed on the local HMI, the parameter is called TimeSync-Source. The time synchronisation source can also be set from the CAP 531 tool. The setting parameter is then called SYNCSCR. The setting alternatives are:

- None (no synchronisation)
- LON
- SPA
- IEC
- Minute pulse positive flank
- Minute pulse negative flank

The function input to be used for minute-pulse synchronisation is called TIME-MIN-SYNC.

The internal time can be set manually down to the minute level, either via the local HMI or via any of the communication ports. The time synchronisation fine tunes the clock (seconds and milliseconds). If no clock synchronisation is active, the time can be set down to milliseconds.

2 Setting group selector (GRP)

2.1 Application

Different conditions in networks of different voltage levels require high adaptability of the used protection and control units to best provide for dependability, security and selectivity requirements. Protection units operate with higher degree of availability, especially, if the setting values of their parameters are continuously optimised regarding the conditions in power system.

The operational departments can plan different operating conditions for the primary equipment. The protection engineer can prepare in advance for the necessary optimised and pre-tested settings for different protection functions. Four different groups of setting parameters are available in the REx 5xx terminals. Any of them can be activated automatically through up to four different programmable binary inputs by means of external control signals.

2.2 Functionality

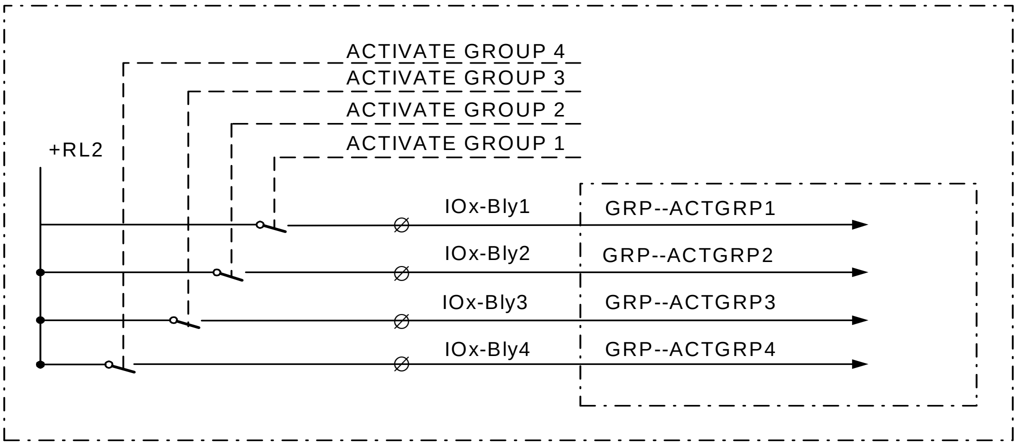
Select a setting group by using the local HMI, from a front connected personal computer, remotely from the station control or station monitoring system or by activating the corresponding input to the GRP function block.

Each input of the function block is configurable to any of the binary inputs in the terminal. Configuration must be performed under the menu:

Configuration
    Functions
        Active Group
            FuncInputs

Use external control signals to activate a suitable setting group when adaptive functionality is necessary. Input signals that should activate setting groups must be either permanent or a pulse longer than 200 ms.

More than one input may be activated simultaneously. In such cases the lower order setting group has priority. This means that if for example both group four and group two are set to activate, group two will be the one activated.



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2.3 Design

The GRP function block has four functional inputs, each corresponding to one of the setting groups stored within the terminal. Activation of any of these inputs changes the active setting group. Four functional output signals are available for configuration purposes, so that continuous information on active setting group is available.

3 Setting lockout (HMI)

3.1 Application

Unpermitted or uncoordinated changes by unauthorized personnel may cause severe damage to primary and secondary power circuits. Use the setting lockout function to prevent unauthorized setting changes and to control when setting changes are allowed.

By adding a key switch connected to a binary input a simple setting change control circuit can be built simply allowing only authorized keyholders to make setting changes. Security can be increased by adding SA/SMS overrides that prevents changes even by keyholders.

3.2 Functionality

Activating the setting restriction prevents unauthorized personell to purposely or by mistake change terminal settings.

The HMI--BLOCKSET functional input is configurable only to one of the available binary inputs of a REx 5xx terminal. For this reason, the terminal is delivered with the default configuration, where the HMI--BLOCKSET signal is connected to NONE-NOSIGNAL.

The function permits remote changes of settings and reconfiguration through the serial communication ports. The setting restrictions can be activated only from the local HMI.

All other functions of the local human-machine communication remain intact. This means that an operator can read all disturbance reports and other information and setting values for different protection parameters and the configuration of different logic circuits.

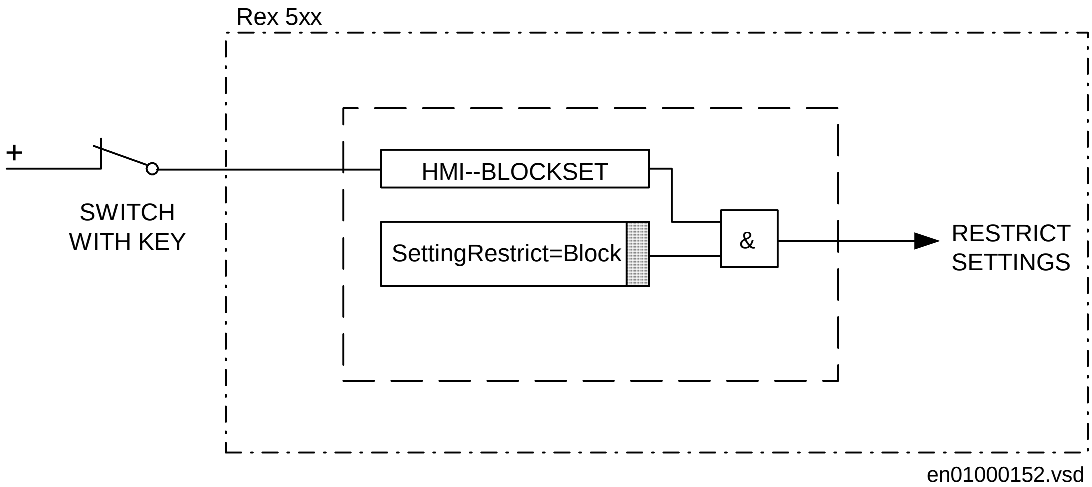

Figure 3: Connection and logic diagram for the BLOCKSET function

4 I/O system configurator (IOP)

4.1 Application

The I/O system configurator must be used in order to recognize added modules and to create internal adress mappings between modules and protections and other functions.

4.2 Functionality

The I/O system configurator is used to add, remove or move I/O modules in the REx 5xx terminals. To configure means to connect the function blocks that represent each I/O module (BIM, BOM, IOM, IOPSM, DCM and MIM) to a function block for the I/O positions (IOP1) that represent the physical slot in the rack.

Available I/O modules are:

- BIM, *B*inary *I*nput *M*odule with 16 binary input channels.
- BOM, *B*inary *O*utput *M*odule with 24 binary output channels.
- IOM, *I*nput/*O*utput *M*odule with 8 binary input and 12 binary output channels.
- MIM, *m*A *I*nput *M*odule with six analog input channels.
- IOPSM, *I*nput *O*utput *Power S*upply *M*odule with four inputs and four outputs.
- DCM, *D*ata *C*ommunication *M*odule. The only software configuration for this module is the I/O Position input.

An REx 5xx terminal houses different numbers of modules depending of the casing size and which kind of modules chosen.

- The 1/1 of 19-inch size casing houses a maximum of 13 modules. But when Input/Output- or Output modules are included, the maximum of these modules are six. The maximum number of mA Input modules are also limited to six.
- The 3/4-size casing houses a maximum of eight modules. The limitation is four modules for Input/Output- or Output modules. The maximum number of mA Input modules are three.
- The 1/2-size casing houses a maximum of three binary modules or one analogue mA Input module.

It is possible to fit modules of different types in any combination in a terminal, but the total maximum numbers of modules must be considered.

Each I/O-module can be placed in any CAN-I/O slot in the casing with one exception. The DCM-module has a fixed slot position which depends on the size of the casing.

To add, remove or move modules in the terminal, the reconfiguration of the terminal must be done from the graphical configuration tool CAP 531.

Users refer to the CAN-I/O slots by the physical slot numbers of the CAN-I/O slots, which also appear in the terminal drawings.

If the user-entered configuration does not match the actual configuration in the terminal, an error output is activated on the function block, which can be treated as an event or alarm.

The BIM, BOM, IOM, IOPSM and DCM share the same communication addresses for parameters and configuration. So they must share I/O module 1-13 (IOxx), which are the same function block. A user-configurable function selector per I/O module function block determines which type of module it is.

All names for inputs and outputs are inputs on the function blocks and must be set from the graphical tool CAP 531.

I/O position

The IOP1 (I/O position) function block is the same for the different casings, independent of the number of slots available. Anyway, it looks different depending of actual configuration. All necessary configuration is done in the CAP 531 configuration tool.

The Sxx outputs are connected to the POSITION inputs of the I/O Modules and MIMs.

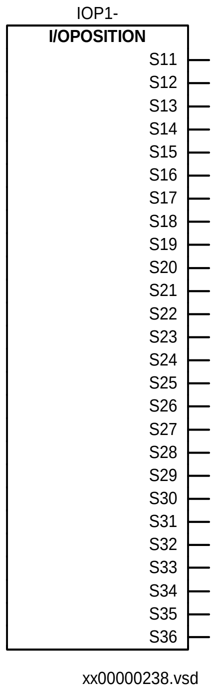

Figure 4: Function block of the I/O position block (IOP1-).

Configuration

The I/O-configuration can only be performed from CAP 531, the graphical configuration tool.

To configure from the graphical tool:

- First, set the function selector for the logical I/O module to the type of I/O module that is used, BIM, BOM, IOM, IOPSM or DCM.
- Secondly, connect the POSITION input of the logical I/O module to a slot output of the IOP function block.

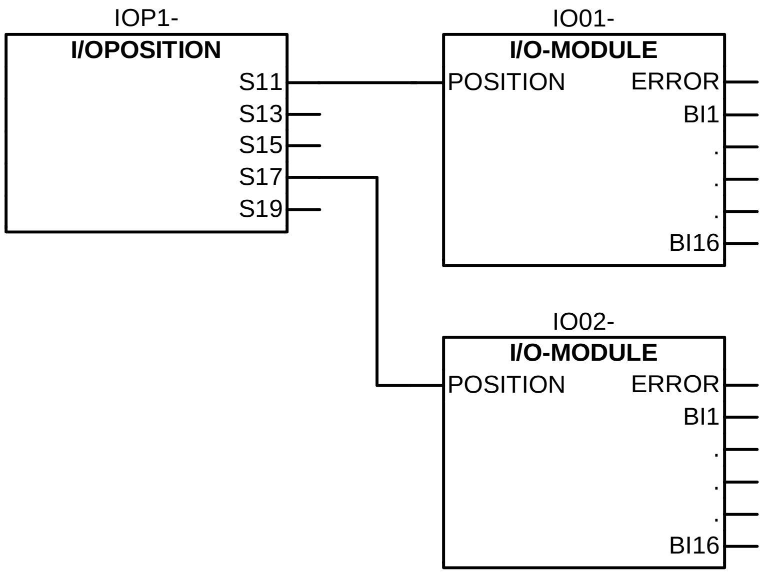

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Figure 5: Example of an I/O-configuration in the graphical tool CAP 531 for a REx 5xx with two BIMs.

5 Logic function blocks

5.1 Application

5.1.1 Application

Different protection, control, and monitoring functions within the REx 5xx terminals are quite independent as far as their configuration in the terminal is concerned. The user cannot enter and change the basic algorithms for different functions, because they are located in the digital signal processors and extensively type tested. The user can configure different functions in the terminals to suit special requirements for different applications.

For this purpose, additional logic circuits are needed to configure the terminals to meet user needs and also to build in some special logic circuits, which use different logic gates and timers.

5.2 Functionality

Inverter (INV)

The INV function block is used to invert the input boolean variable. The function block (figure 6) has one input designated IVnn-INPUT where nn presents the serial number of the block. Each INV circuit has one output IVnn-OUT.

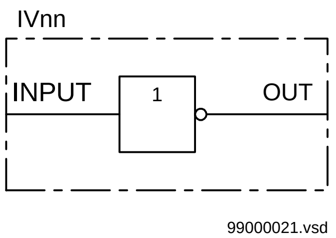

Figure 6: Function block diagram of the inverter (INV) function

Table 1: Truth table for the INV function block

INPUT	OUT
1	0
0	1

Controllable gate (GT)

The GT function block is used for controlling if a signal should be able to pass or not depending on a setting. The function block (figure 7) has one input, designated GTnn-INPUT, where nn presents the serial number of the block. Each GT circuit has one output, GTnn-OUT. Each gate further has a Operation On/Off which controls if the INPUT is passed to the OUT or not.

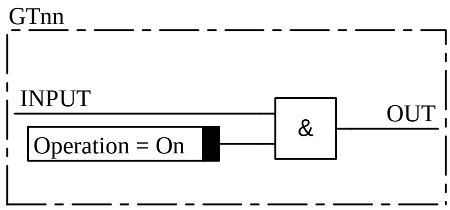

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Figure 7: Function block diagram of the controllable gate (GT) function

The output signal from the GT function block is set to 1 if the input signal is 1 and Operation = On elsewhere it is set to 0. See truth table below.

Table 2: Truth table for the GT function block

INPUT	Operation	OUT
0	Off	0
1	Off	0
0	On	0
1	On	1

OR

OR function blocks are used to form general combinatory expressions with boolean variables. The function block (figure 8) has six inputs, designated Onnn-INPUTm, where nnn presents the serial number of the block, and m presents the serial number of the inputs in the block. Each OR circuit has two outputs, Onnn-OUT and Onnn-NOUT (inverted).

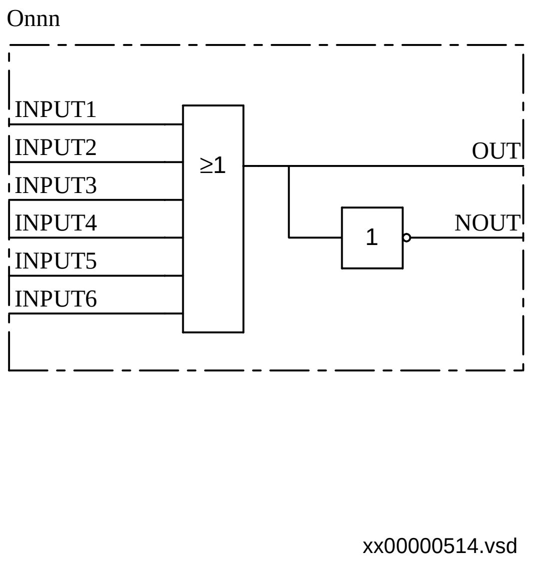

Figure 8: Function block diagram of the OR function

The output signal (OUT) is set to 1 if any of the inputs (INPUT1-6) is 1. See truth table below.

Table 3: Truth table for the OR function block

INPUT1	INPUT2	INPUT3	INPUT4	INPUT5	INPUT6	OUT	NOUT
0	0	0	0	0	0	0	1
0	0	0	0	0	1	1	0
0	0	0	0	1	0	1	0
...	...	...	...	...	...	1	0
1	1	1	1	1	0	1	0
1	1	1	1	1	1	1	0

AND

AND function blocks are used to form general combinatory expressions with boolean variables. The function block (figure 9) has four inputs (one of them inverted), designated Annn-INPUTm (Annn-INPUT4N is inverted), where nnn presents the serial number of the block, and m presents the serial number of the inputs in the block. Each AND circuit has two outputs, Annn-OUT and Annn-NOUT (inverted).

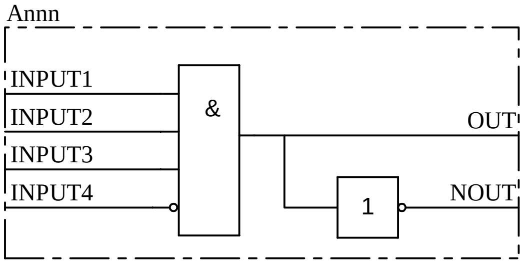

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Figure 9: Function block diagram of the AND function

The output signal (OUT) is set to 1 if the inputs INPUT1-3 are 1 and INPUT4N is 0. See truth table below.

Table 4: Truth table for the OR function block

INPUT1	INPUT2	INPUT3	INPUT4N	OUT	NOUT
0	0	0	1	0	1
0	0	1	1	0	1
0	1	0	1	0	1
0	1	1	1	0	1
1	0	0	1	0	1
1	0	1	1	0	1
1	1	0	1	0	1
1	1	1	1	0	1
0	0	0	0	0	1
0	0	1	0	0	1
0	1	0	0	0	1
0	1	1	0	0	1
1	0	0	0	0	1
1	0	1	0	0	1
1	1	0	0	0	1
1	1	1	0	1	0

Timer

The function block TM timer has outputs for delayed input signal at drop-out and at pick-up. The timer (figure 10) has a settable time delay TMnn-T between 0.00 and 60.00 s in steps of 0.01 s. The input signal for each time delay block has the designation TMnn-INPUT, where nn presents the serial number of the logic block. The output signals of each time delay block are TMnn-ON and TMnn-OFF. The first one belongs to the timer delayed on pick-up and the second one to the timer delayed on drop-out. Both timers within one block always have the same setting.

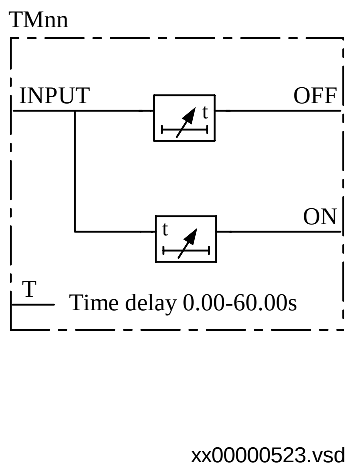

Figure 10: Function block diagram of the Timer function

The function block TL timer (figure 11) with extended maximum time delay at pick-up and at drop-out, is identical with the TM timer. The difference is the longer time delay TLnn-T, settable between 0.0 and 90000.0 s in steps of 0.1 s.

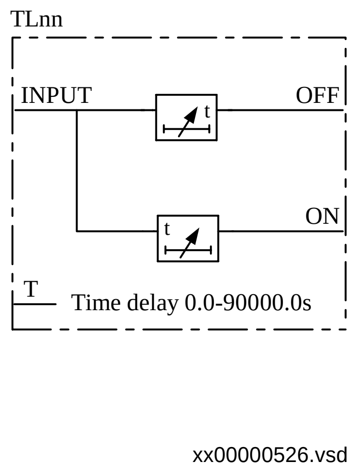

Figure 11: Function block diagram of the TimerLong function

The input variable to INPUT is obtained delayed a settable time T at output OFF when the input variable changes from 1 to 0 in accordance with the time pulse diagram, figure 12. The output OFF signal is set to 1 immediately when the input variable changes from 0 to 1.

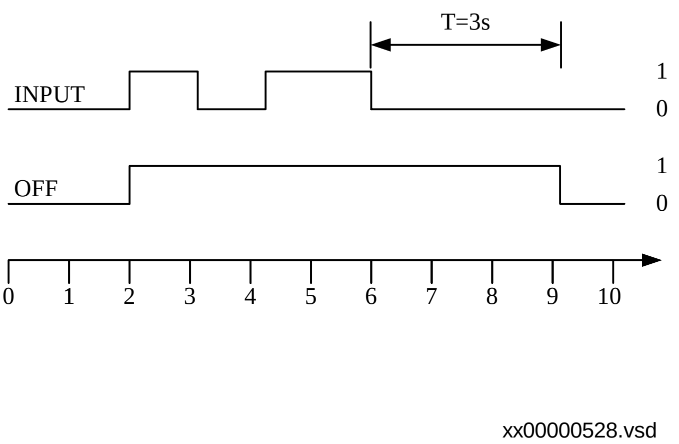

Figure 12: Example of time diagram for a timer delayed on drop-out with preset time T = 3 s

The input variable to INPUT is obtained delayed a settable time T at output ON when the input variable changes from 0 to 1 in accordance with the time pulse diagram, figure 13. The output ON signal returns immediately when the input variable changes from 1 to 0.

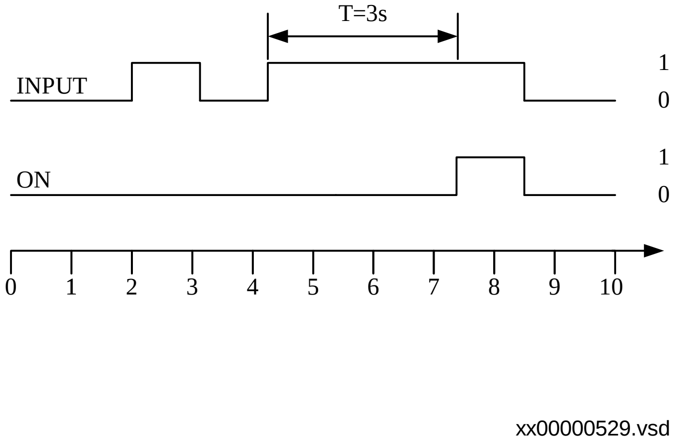

Figure 13: Example of time diagram for a timer delayed on pick-up with preset time T = 3 s

If more timers than available in the terminal are needed, it is possible to use pulse timers with AND or OR logics. Figure 14 shows an application example of how to realize a timer delayed on pick-up. Figure 15 shows the realization of a timer delayed on drop-out. Note that the resolution of the set time must be 0.2 s, if the connected logic has a cycle time of 200 ms.

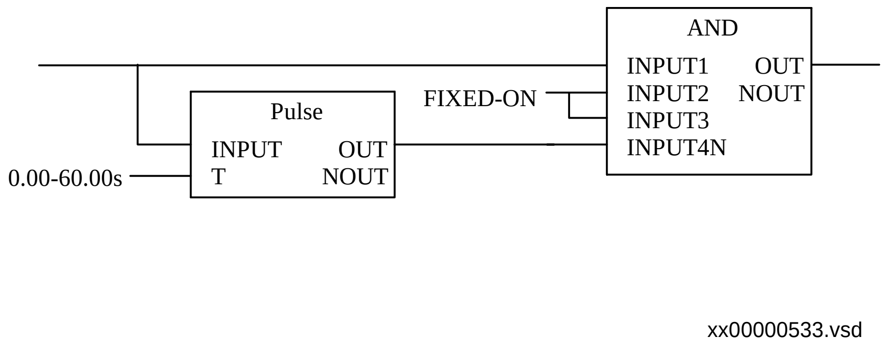

Figure 14: Realization example of a timer delayed on pick-up

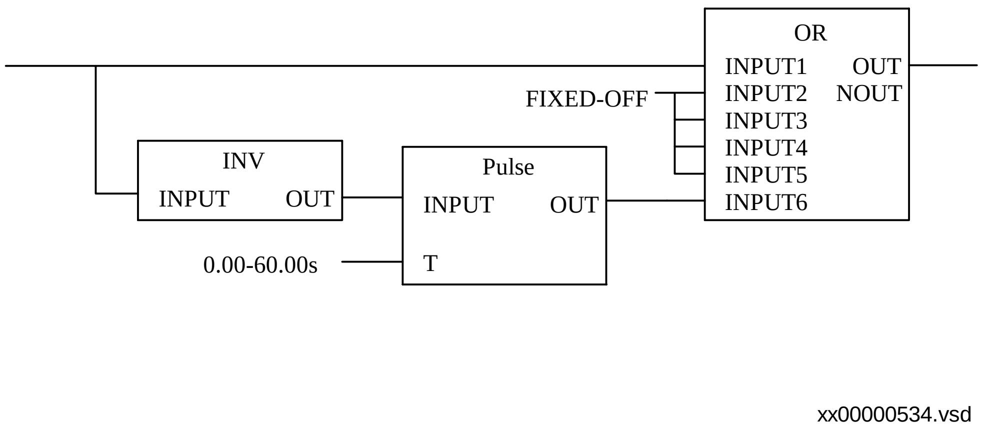

Figure 15: Realization example of a timer delayed on drop-out

Timer settable through HMI/SMS/PST

The function block TS timer has outputs for delayed input signal at drop-out and at pick-up. The timer (figure 16) has a settable time delay TSnn-T between 0.00 and 60.00 s in steps of 0.01 s. It also has an Operation setting On, Off which controls the operation of the timer.The input signal for each time delay block has the designation TSnn-INPUT, where nn presents the serial number of the logic block. The output signals of each time delay block are TSnn-ON and TSnn-OFF. The first one belongs to the timer delayed on pick-up and the second one to the timer delayed on drop-out. Both timers within one block always have the same setting.

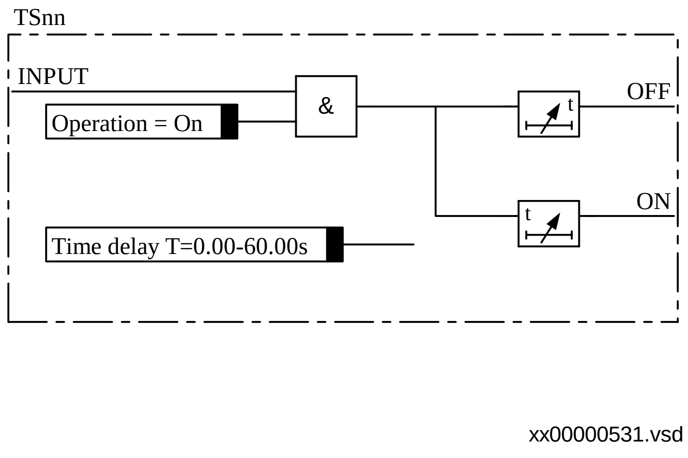

Figure 16: Function block diagram of the Settable timer function

For details about the function see the description of TM Timer.

Pulse

The pulse function can be used, for example, for pulse extensions or limiting of operation of outputs. The pulse timer TP (figure 17) has a settable length of a pulse between 0.00 s and 60.00 s in steps of 0.01 s. The input signal for each pulse timer has the designation TPnn-INPUT, where nn presents the serial number of the logic block. Each pulse timer has one output, designated by TPnn-OUT. The pulse timer is not retriggable, that is, it can be restarted first after that the time T has elapsed.

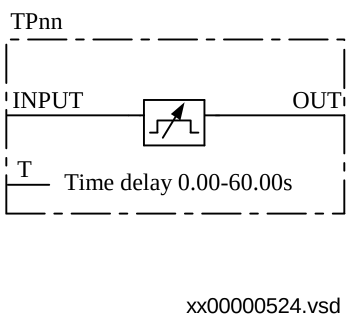

Figure 17: Function block diagram of the Pulse function

The function block TQ pulse timer (figure 18) with extended maximum pulse length, is identical with the TP pulse timer. The difference is the longer pulse length TQnn-T, settable between 0.0 and 90000.0 s in steps of 0.1 s.

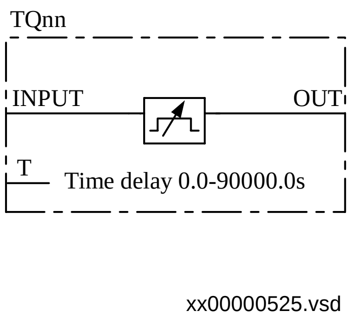

Figure 18: Function block diagram of the PulseLong function, TQ

A memory is set when the input INPUT is set to 1. The output OUT then goes to 1. When the time set T has elapsed, the memory is cleared and the output OUT goes to 0. If a new pulse is obtained at the input INPUT before the time set T has elapsed, it does not affect the timer. Only when the time set has elapsed and the output OUT is set to 0, the pulse function can be restarted by the input INPUT going from 0 to 1. See time pulse diagram, figure 19.

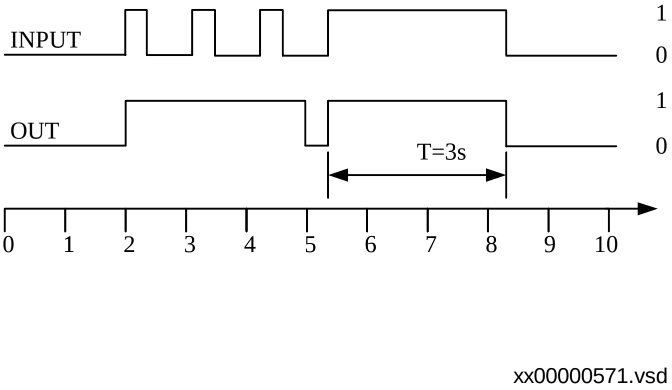

Figure 19: Example of time diagram for the pulse function with preset pulse length T = 3 s

Exclusive OR (XOR)

The function block exclusive OR (XOR) is used to generate combinatory expressions with boolean variables. XOR (figure 20) has two inputs, designated XOnn-INPUTm, where nn presents the serial number of the block, and m presents the serial number of the inputs in the block. Each XOR circuit has two outputs, XOnn-OUT and XOnn-NOUT (inverted). The output signal (OUT) is 1 if the input signals are different and 0 if they are equal.

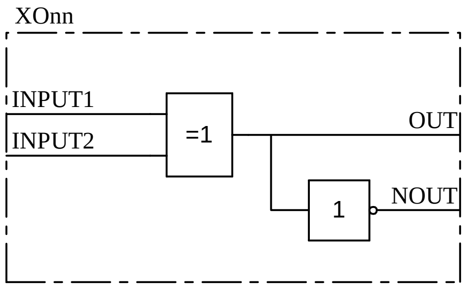

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Figure 20: Function block diagram of the XOR function

The output signal (OUT) is set to 1 if the input signals are different and to 0 if they are equal. See truth table below.

Table 5: Truth table for the XOR function block

INPUT1	INPUT2	OUT	NOUT
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	1

Set-Reset (SR)

The function block Set-Reset (SR) (figure 21) has two inputs, designated SRnn-SET and SRnn-RESET, where nn presents the serial number of the block. Each SR circuit has two outputs, SRnn-OUT and SRnn-NOUT (inverted). The output (OUT) is set to 1 if the input (SET) is set to 1 and if the input (RESET) is 0. If the reset input is set to 1, the output is unconditionally reset to 0.

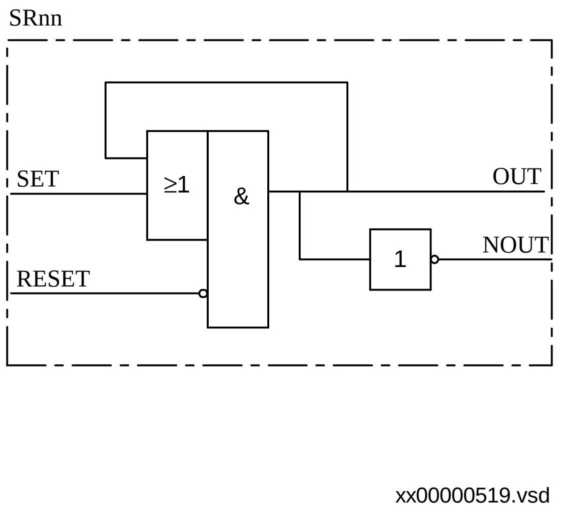

Figure 21: Function block diagram of the Set-Reset function

Set-Reset with/without memory (SM)

The function block Set-Reset (SM) (figure 22) with/without memory has two inputs, designated SMnn-SET and SMnn-RESET, where nn presents the serial number of the block. Each SM circuit has two outputs, SMnn-OUT and SMnn-NOUT (inverted). The output (OUT) is set to 1 if the input (SET) is set to 1 and if the input (RESET) is 0. If the reset input is set to 1, the output is unconditionally reset to 0. The memory setting controls if the flip-flop after a power interruption will return to the state it had before or if it will be reset.

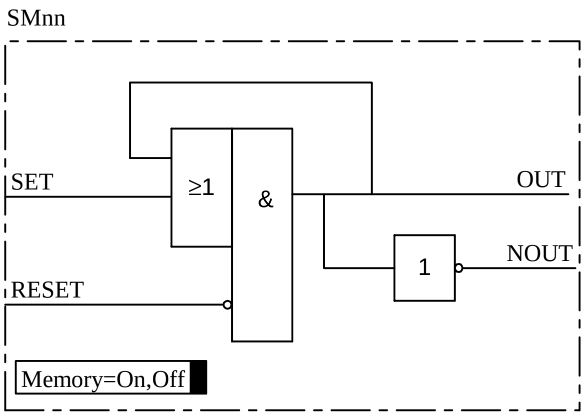

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Figure 22: Function block diagram of the Set-Reset with/without memory function

MOVE

The MOVE function blocks, also be called copy-blocks, are used for synchronization of boolean signals sent between logics with slow execution time and logics with fast execution time.

There are two types of MOVE function blocks - MOF located First in the slow logic and MOL located Last in the slow logic. The MOF function blocks are used for signals coming into the slow logic and the MOL function blocks are used for signals going out from the slow logic.

The REx 5xx terminal contains 3 MOF function blocks of 16 signals each, and 3 MOL function blocks of 16 signals each. This means that a maximum of 48 signals into and 48 signals out from the slow logic can be synchronized. The MOF and MOL function blocks are only a temporary storage for the signals and do not change any value between input and output.

Each block of 16 signals is protected from being interrupted by other logic application tasks. This guarantees the consistency of the signals to each other within each MOVE function block.

Synchronization of signals with MOF should be used when a signal which is produced outside the slow logic is used in several places in the logic and there might be a malfunction if the signal changes its value between these places.

Synchronization with MOL should be used if a signal produced in the slow logic is used in several places outside this logic, or if several signals produced in the slow logic are used together outside this logic, and there is a similar need for synchronization.

Figure 23 shows an example of logic, which can result in malfunctions on the output signal from the AND gate to the right in the figure.

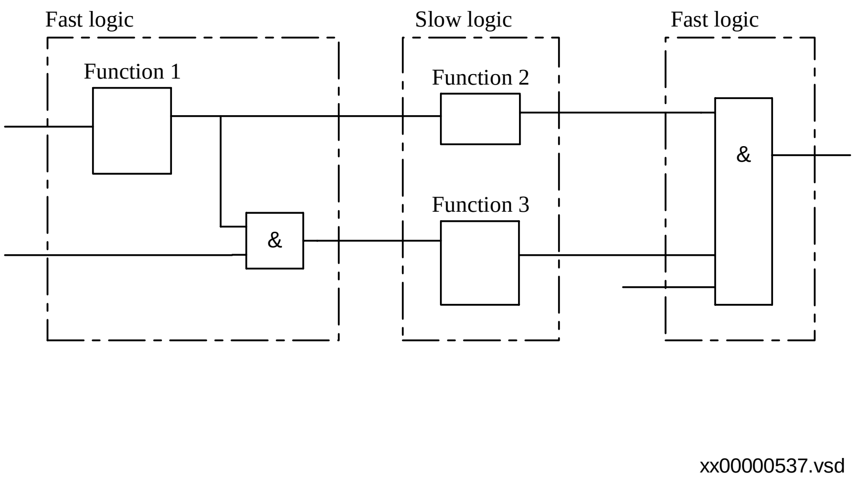


Figure 23: Example of logic, which can result in malfunctions

Figure 24 shows the same logic as in figure 23, but with the signals synchronized by the MOVE function blocks MOFn and MOLn. With this solution the consistency of the signals can be guaranteed.

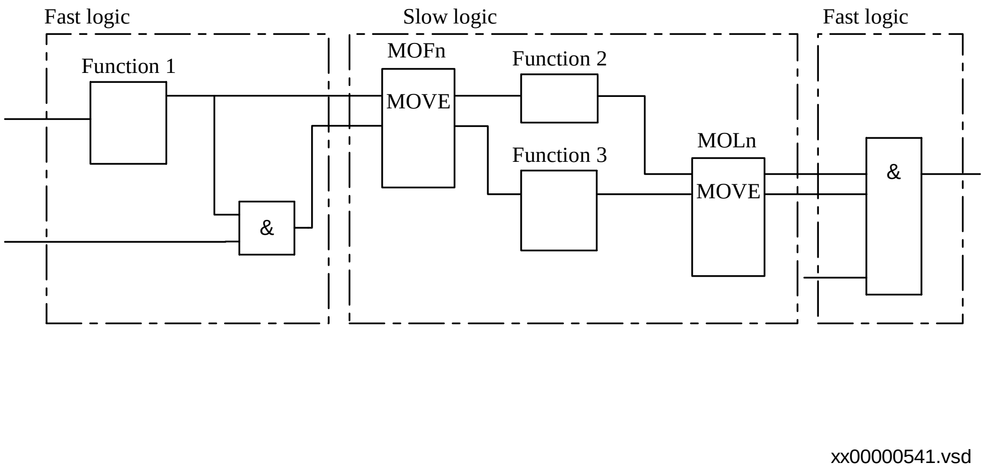


Figure 24: Example of logic with synchronized signals

MOFn and MOLn, n=1-3, have 16 inputs and 16 outputs. Each INPUTm is copied to the corresponding OUTPUTm, where m presents the serial number of the input and the output in the block. The MOFn are the first blocks and the MOLn are the last blocks in the execution order in the slow logic.

5.3 Calculations

For the AND gates, OR gates, inverters, normal SR (Set-Reset) flip-flops, XOR gates and MOVE elements no settings exist.

For the normal On/Off delay timers and pulse timers the time delays and pulse lengths are set from the CAP 531 configuration tool.

Both timers in the same logic block (the one delayed on pick-up and the one delayed on drop-out) always have a common setting value. Setting values of the pulse length are independent of one another for all pulse circuits.

For the controllable gates, settable timers, SR flip-flops with/without memory the setting parameters are accessible through the HMI and SMS.

Configuration

The configuration of the logics is performed from the CAP 531 configuration tool.

Execution of functions as defined by the configurable logic blocks runs in a fixed sequence in two different cycle times, typical 6 ms and 200 ms.

For each cycle time, the function block is given an execution serial number. This is shown when using the CAP 531 configuration tool with the designation of the function block and the cycle time, for example, TMnn-(1044, 6). TMnn is the designation of the function block, 1044 is the execution serial number and 6 is the cycle time.

Execution of different function blocks within the same cycle time should follow the same order as their execution serial numbers to get an optimal solution. Always remember this when connecting in series two or more logical function blocks. When connecting function blocks with different cycle times, the MOVE function blocks can be used. These function blocks synchronize boolean signals sent between logics with slow execution time and logics with fast execution time. The MOVE functions are available as additional configurable logic circuits.

Note!

Be always careful when connecting function blocks with a fast cycle time to function blocks with a slow cycle time.

So design the logic circuits carefully and check always the execution sequence for different functions. In other cases, additional time delays must be introduced into the logic schemes to prevent errors, for example, race between functions.

6 Self supervision (INT)

6.1 Application

The REx 5xx protection and control terminals have a complex design with many included functions. The included self-supervision function and the INTernal signals function block provide good supervision of the terminal. The different safety measures and fault signals makes it easier to analyze and locate a fault.

Both hardware and software supervision is included and it is also possible to indicate possible faults through a hardware contact and/or through the software communication.

Internal events are generated by the built-in supervisory functions. The supervisory functions supervise the status of the various modules in the terminal and, in case of failure, a corresponding event is generated. Similarly, when the failure is corrected, a corresponding event is generated.

Apart from the built-in supervision of the various modules, events are also generated when the status changes for the:

- built-in real time clock (in operation/out of order).
- external time synchronization (in operation/out of order).

Events are also generated:

- whenever any setting in the terminal is changed.
- when the content of the Disturbance report is erased.

The internal events are time tagged with a resolution of 1 ms and stored in a list. The list can store up to 40 events. The list is based on the FIFO principle, that is, when it is full, the oldest event is overwritten. The list cannot be cleared and its content cannot be modified.

The list of internal events provides valuable information, which can be used during commissioning and fault tracing.

The information can only be retrieved with the aid of the SMS. The PC can be connected either to the port at the front or at the rear of the terminal.

6.2 Functionality

The self-supervision status can be monitored from the local HMI or via the PST Parameter Setting Tool or a SMS/SCS system.

Under the Terminal Report menu in the local HMI the present information from the self-supervision function can be viewed. A detailed list of supervision signals that can be generated and displayed in the local HMI is found in the Installation and Commissioning Manual.

In the PST under Terminal Report these summary signals are available:

- InternalStatus
- CPU-Status

When an internal fault has occurred, extensive information about the fault from the list of internal events can be retrieved from the PST under the menu Terminal Report - Internal Events.

A self-supervision summary can be obtained by means of the potential free alarm contact located on the power supply module. The function of this output relay is an OR-function between the INT--FAIL signal (figure 27) and a couple of more severe faults that can happen in the terminal (figure 26).

Some signals are available from the function block InternSignals (INT), see figure 25. The signals from this function block can be connected to an Event function block, which generates and sends these signals as events to the station level of the control system. The signals from the INT-function block can also be connected to binary outputs for signalization via output relays or they can be used as conditions for other functions if required/desired.

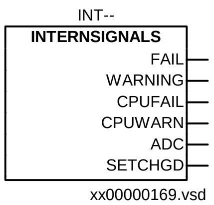


Figure 25: Function block INTernal signals.

Individual error signals from I/O modules and time synchronization can be obtained from respective function block of IOM-, BIM-, BOM-, MIM-, IOPSM-modules and from the time synchronization block TIME.

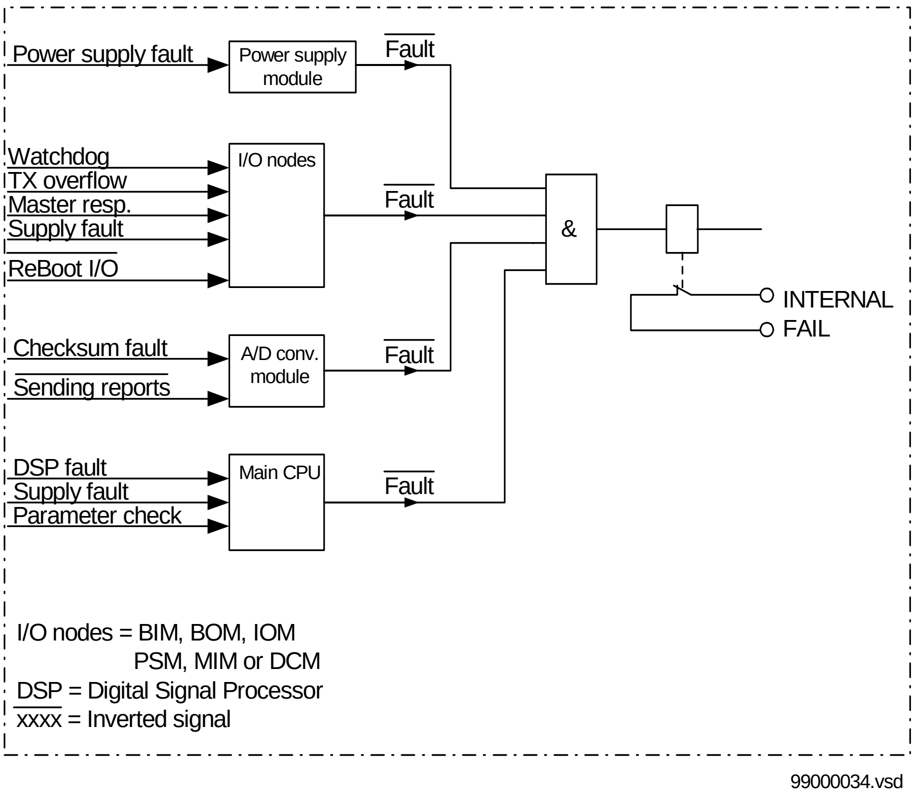


Figure 26: Hardware self-supervision, potential-free alarm contact.

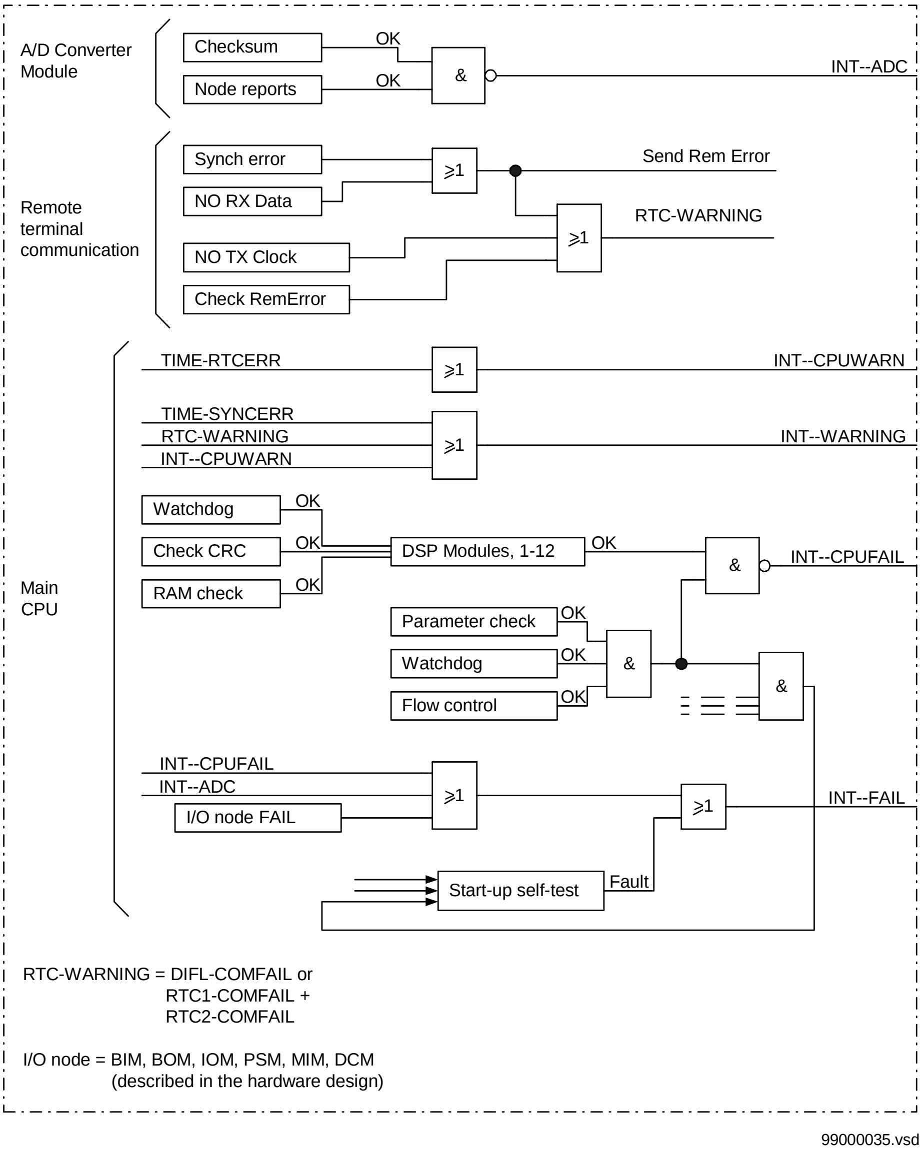


Figure 27: Software self-supervision, function block INTernal signals.

7 Blocking of signals during test

7.1 Functionality

This blocking function is only active during operation in the test mode, see example in Figure 28. When exiting the test mode, entering normal mode, this blocking is disabled and everything is set to normal operation. All testing will be done with actually set and configured values within the terminal. No settings etc. will be changed. Thus no mistakes are possible.

The blocked functions will still be blocked next time entering the test mode, if the blockings were not reset.

The blocking of a function concerns all output signals from the actual function, so no outputs will be activated.

Each of the terminal related functions is described in detail in the documentation for the actual unit. The description of each function follows the same structure (where applicable).

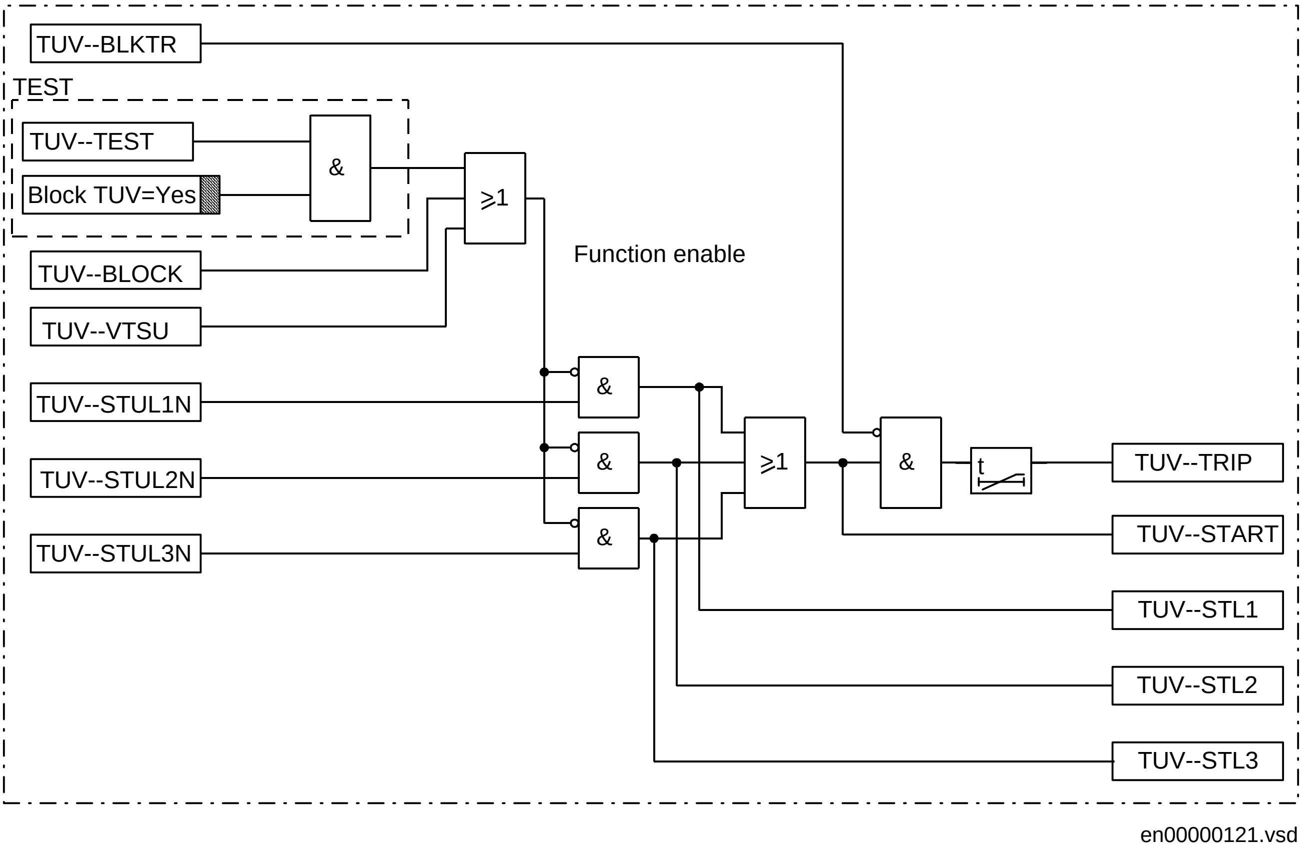


Figure 28: Example of blocking the Time delayed Under-Voltage function.

Chapter 4 Line impedance

About this chapter

This chapter describes the line impedance functions in the terminal.

1 Distance protection (ZM1-5)

1.1 Functionality

Directional lines

The results of impedance measurement are combined in “and” combination with the directional measurement, to obtain the desired directionality for each distance protection zone separately, see figure in “Phase-to-earth measurement”.

The directional measurement is based on the use of a positive-sequence voltage for the respective fault loop. For the L1-N element, the equation for forward direction is:

$$-ArgDir < \arg\frac{0.8 \cdot U_{1L1} + 0.2 \cdot U_{1L1M}}{I_{L1}} < ArgNegRes$$

(Equation 13)

For the L1-L2 element, the equation in forward direction is:

$$-ArgDir < \arg\frac{0.8 \cdot U_{1L1L2} + 0.2 \cdot U_{1L1L2M}}{I_{L1L2}} < ArgNegRes$$

Where:

ArgDir	is the setting for the lower boundary of the forward directional characteristic, by default set to 15 (= -15 degrees) and
ArgNegRes	is the setting for the upper boundary of the forward directional characteristic, by default set to 115 (degrees)

The reverse directional characteristic is equal to the forward characteristic rotated by 180 degrees.

The polarizing voltage is available as long as the positive-sequence voltage exceeds 4% of the rated voltage Ur. So the directional element can use it for all unsymmetrical faults including close-in faults.

For close-in three-phase faults, the U_{1L1M} memory voltage, based on the same positive sequence voltage, ensures correct directional discrimination.

The memory voltage is used for 100 ms or until the positive sequence voltage is restored. After 100 ms, the following occurs:

- If the current is still above the set value of the minimum operating current (between 10 and 30% of the terminal rated current Ir), the condition seals in.
- If the fault has caused tripping, the trip endures.
- If the fault was detected in the reverse direction, the measuring element in the reverse direction remains in operation.
- If the current decreases below the minimum operating value, the memory resets until the positive sequence voltage exceeds 10% of its rated value.

2 Pole slip protection (PSP)

2.1 Application

Sudden events in an electrical power system such as large jumps in load, fault occurrence or fault clearance, which disturb the balance of energy in the system, can cause oscillations of mechanical masses referred to as power swings. In a recoverable situation the oscillations will decay and stable operation will be resumed; in a non-recoverable situation the power swings become so severe that the synchronism is lost between the generators of the system, a condition referred to as pole slipping. In the case of pole slipping, the excitation of the machines is generally intact, but there are strong oscillations of real and reactive power.

Even though the modern power systems are designed and operate with high degree of security against power swings and even more against pole slipping, these two phenomena may occur especially during abnormal system conditions.

If the pole slipping condition is allowed to persists in smaller parts of a power system than other machines may follow and the stability of a system as a whole is in danger. Apart from the electrical phenomena, oscillations of mechanical masses also expose the generators and other equipment to considerable pulsating mechanical stresses.

Available technology and the costs of the corresponding protection devices dictated in the past the use of the pole slip protection relays only close to the power generators. They were for this reason treated as a part of a generator protection scheme. Their use deeper in the network was not so common. Such approach resulted often in unselective splits of already troubled power systems, which have lost some valuable generating capacities.

Modern, functional library oriented approach within the microprocessor based protection terminals makes it possible to utilize the pole slip protection function more often and deeper in the power network. This way it enables better selectivity of the pole slip protection and intact power generation in different islands. A separate pole slip protection function still remains as a dedicated generator protection in the vicinity of synchronous machines, to protect them against the oscillations which could harm in great extent their functionality

The Pole Slip Protection (PSP) function as built in REx 5xx protection, control and monitoring terminals, and described in this document comprises all functionality necessary for the detection, evaluation and corresponding reaction on the pole slipping phenomena in power systems. It is applicable together with different line protection functions (distance protection, line differential protection) deeper in the power network as well as a part of a generator protection system in power plants.

Oscillations of mechanical masses in power system

Figure 29 presents a two machine system with a power line between busbars A and B. The electromotive forces E_A and E_B can differ in their magnitude. It is important, that their relative phase angle

$$\delta = \delta_A - \delta_B$$

(Equation 14)

changes with time. The voltage difference

$$\dot{U}_D = \dot{E}_A - \dot{E}_B$$

(Equation 15)

changes in its magnitude and direction and causes this way the current between both generators to change accordingly.

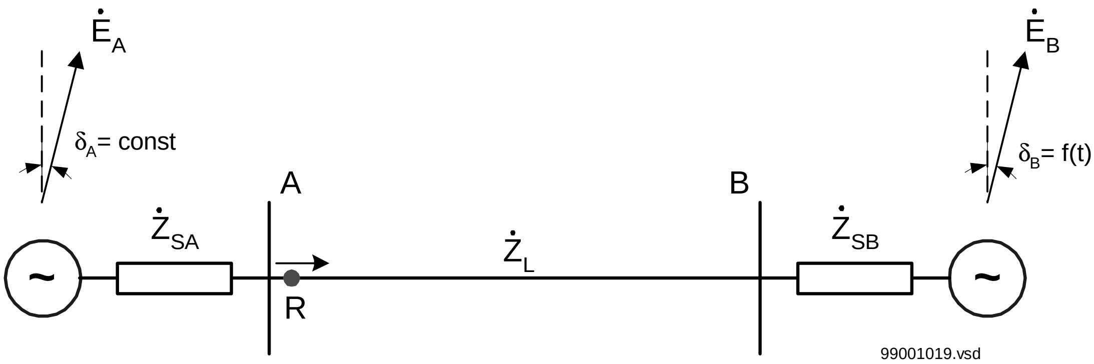


Figure 29: Two machine system.

Figure 30 presents an example of the voltage and current measured in one phase of a line between two generators during the oscillations caused by the changing of the relative angle δ. The minimum value of current corresponds to the minimum angle between the electromotive forces. The maximum value of the current corresponds to the condition when the voltages

$$\dot{E}_A$$

(Equation 16)

and

$$\dot{E}_B$$

(Equation 17)

have the opposite direction.

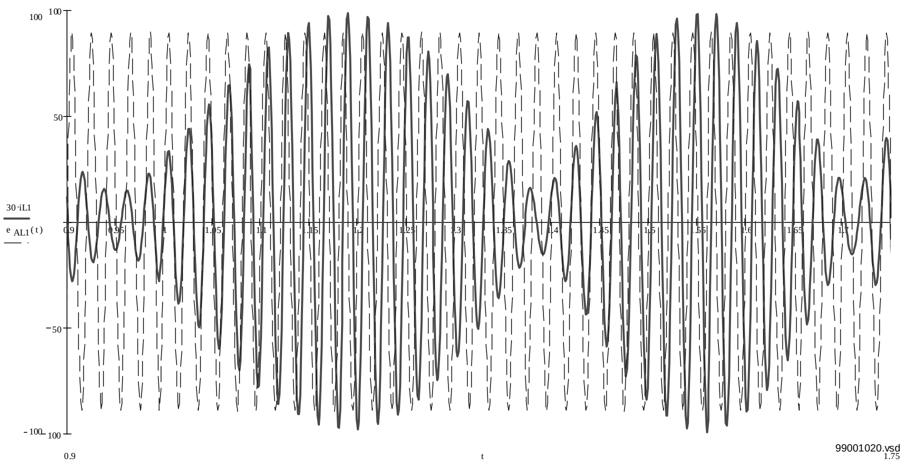


Figure 30: Current (solid line) and voltage (dashed line) in relay point during the pole slip condition.

Oscillations in measured voltage and current reflect naturally also in impedance, measured by the impedance (distance) relays.

Figure 31 a) and 31 b) present two examples of the impedance trajectories in impedance plane during the system oscillations. Both figures include also the example of an operating characteristics of a modern distance protection. The measured impedance can enter the operating area of the distance protection and causes its unwanted operation. It is for this reason necessary to detect the oscillations and prevent such unwanted operations before the measured impedance enters the distance protection operating characteristics.

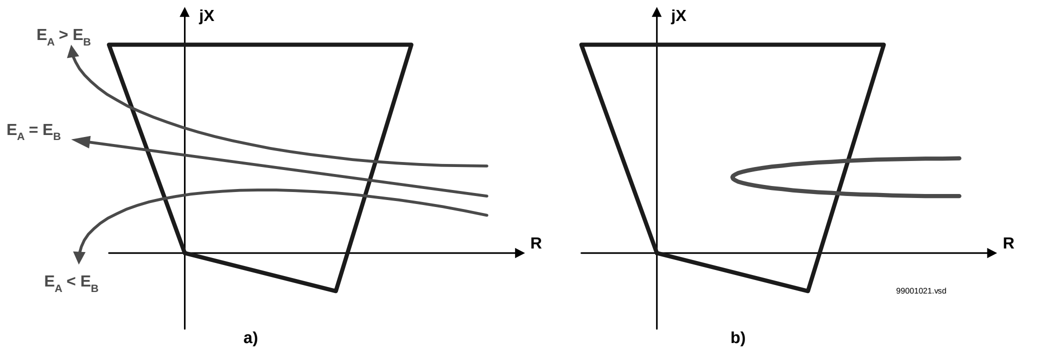


Figure 31: Impedance trajectories in relay point during the pole slip (figure a) and power swing (figure b) phenomena.

The recoverable oscillations are understood under the expression "power-swing". The generators in a two-machine system remain during the disturbance in synchronism. They only change their relative angle δ from one to another value over a transient period. The impedance locus might enter the operating characteristic of the distance relay (see Figure 31 b), but generally does not cross the complete R-X plain.

In a non-recoverable situation the oscillations are so severe, that the synchronism is lost between the generators of a system. The condition is referred to as a pole-slip. At least one generator starts to change its frequency and the resulting slip frequency may increase up to 10 Hz (in 50 Hz system).

The measured impedance usually enters the distance relay’s operating characteristic and crosses the complete impedance plain, as presented schematically on Figure 31 a.

Oscillations during abnormal system conditions

Modern power systems operate very close to their technical limits but are also built with higher security against the mechanical oscillations than ever before. Today it is nearly impossible to start the oscillations only by very big difference in produced and consumed power. At the same time some short oscillations are much more frequent than before. They are initiated by some bigger events (faults) in power systems and disappear relatively fast after the normal operating conditions have been restored (e.g. single-pole autoreclosing).

Figure 32 presents an impedance trajectory as seen on protected power line by a distance protection function in phase L2 during the dead time of a single pole autoreclosing, after the single phase-to-earth fault L1-N has been cleared. The circuit breaker has been successfully closed after the dead time of the single pole autoreclosing has expired.

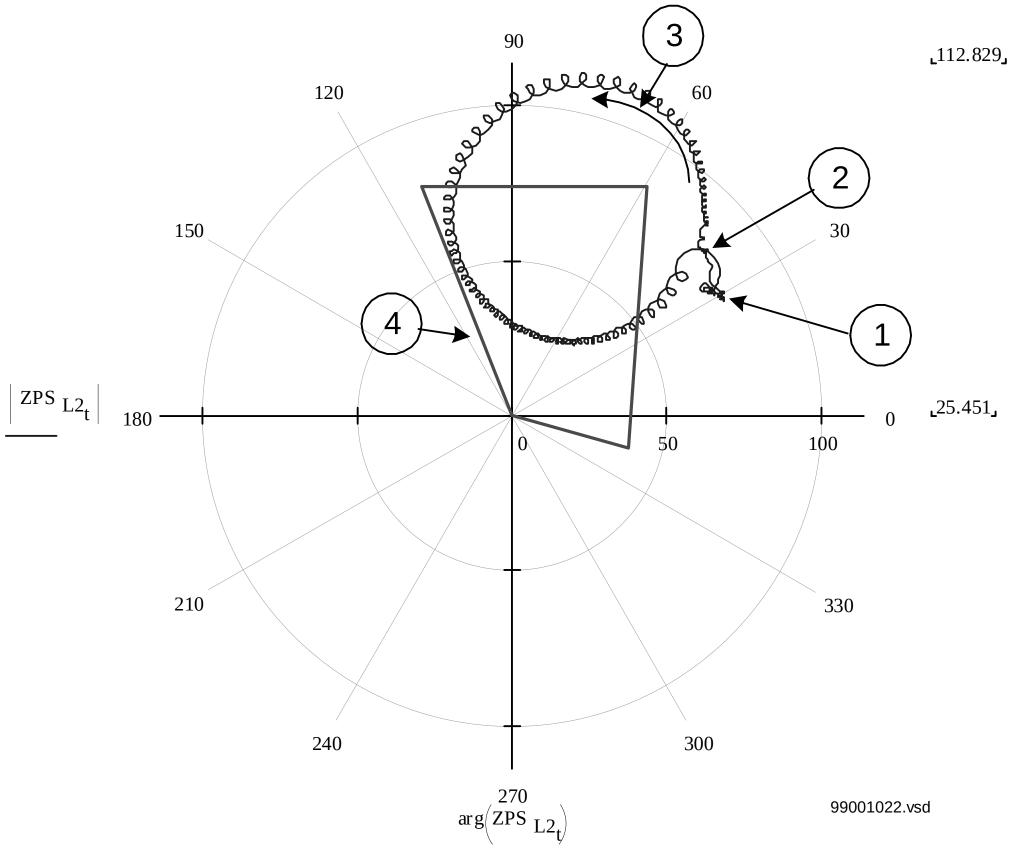


Figure 32: Impedance trajectory as seen by a L2-N impedance measuring element.

The remarks on Figure 32 have the following meaning:

1. Load impedance in phase L2 during normal operating conditions.
2. Impedance measured during the L1-N fault.
3. Impedance trajectory and its direction during the dead time of a single pole autoreclosing in phase L1.
4. Operating characteristic of the line distance protection.

The impedance as measured by a healthy phase measuring elements (phase L2 in case on Figure 32 might enter the operating area of the distance protection in impedance plain and initiate an unwanted trip. Modern distance protection devices must incorporate a corresponding functionality, which detects the oscillations in each phase separately and prevents the unnecessary operation of the main protection function.

The oscillation in power system should be recognized preferably by the measuring elements, if detected simultaneously in more than one phase. The operating logic, which requires the detection in two out of three phases increases in great extent the security and dependability of an applied protection scheme in special operating conditions, like:

- Oscillations during dead time of single pole auto-reclosing.
- Slow increase of initial fault currents at different kinds of high resistive earth faults.

A special logic circuit, as applied in the pole slip protection used by the REx 5xx terminals makes possible an adaptive use of the so called "one out of three" or "two out of three" phase detection criteria. This possibility becomes important for the correct detection of the oscillations in power systems with multipole tripping and reclosing function applied on double-circuit parallel operating EHV transmission lines.

Speed of oscillations

Figure 33 presents informatively the phase currents as recorded at one end of the protected 500 kV transmission line during the pole-slip situation in a power system. The oscillations have been initiated by a single-phase-to-earth fault in phase L1 (increased magnitude of the phase current).

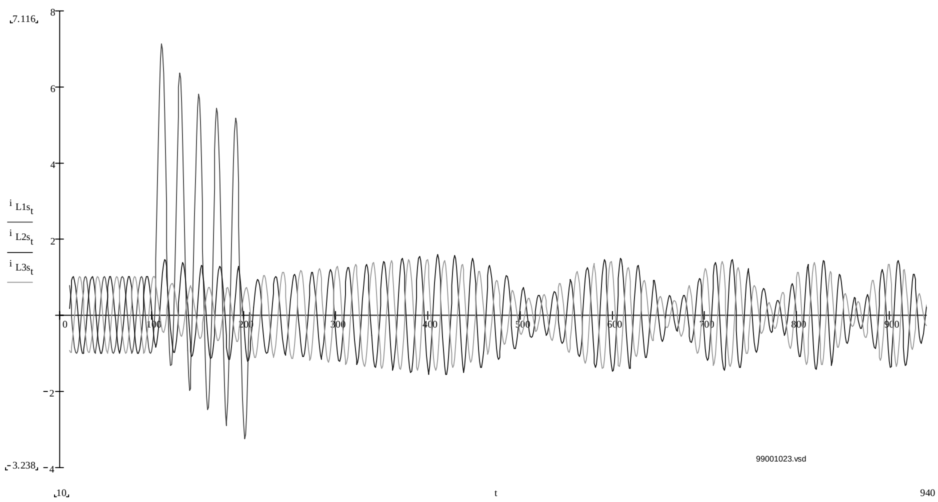


Figure 33: Phase currents in relay point during the pole slip conditions caused by a L1-N fault.

The pole-slip frequency is in most cases not constant. The initial oscillation speed is generally low and increases with time if the system starts the non recoverable oscillation.

The described dependency might influence the dependability of the distance protection scheme at slowly developing single-phase-to-earth faults. It can at the same time jeopardize the security of the same protection scheme when the oscillations obtain higher speed. The pole slip protection in REx 5xx terminals uses the adaptive criteria for the impedance speed to distinguish between the slow initial faults and increased speed of the measured impedance at consecutive oscillations.

Requirements on protection systems during pole slip conditions in network

Two, generally contradictory requirements apply today on the protection systems when mechanical masses in power systems start to oscillate. The requirements depend on the general role, which the protected element plays within the power system.

Figure 34 presents a transmission line connecting a big production (power plants) with the rest of the power system, which depends very much on the delivered electric energy from the external resources.

The goal in such case is to keep the protected element (power line) of a power system in operation under all system conditions as long as possible. This requirement is extended even to emergency conditions, i.e. two phase operation of power line during dead time of a single-pole autoreclosing. It is at the same time expected from the line protection system to operate selectively for all line faults, which may occur during the oscillations. In such case it is recommended to use within the REx 5xx terminals the so called Power Swing Detection (PSD) function together with Power Swing Logic (PSL).

Figure 34: Power line delivering the electrical power to the consuming area.

Generator protection must prevent damages to the generators in the power plant independent of all other system conditions. The pole slip protection is in such case used closed to the generators.

The second typical network configuration is presented in Figure 35. Inter-connection transmission lines connect two big and generally independent power systems. Mechanical oscillations appear in this case between two different systems and are dangerous for the stability of each system separately.

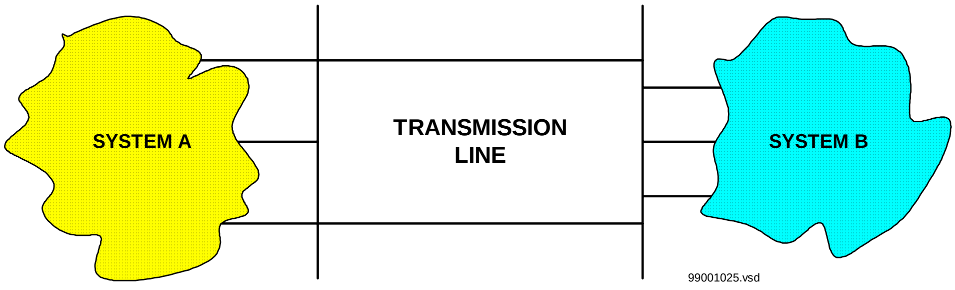


Figure 35: Transmission lines interconnecting two big power systems.

The goal in this particular case of a pole slip situation is to trip selectively (from the power system point-of-view) the connecting element(s) between two different systems. The disconnection of a healthy power line is not selective in a classical way of understanding, but prevents the total collapse of at least one independent system. The pole slip protection is in such case installed on the interconnection lines and sometimes even deeper in each power system.

Oscillations and faults in power system

It has been already mentioned that the oscillations in modern power systems appear as the consequences of sudden changes, caused either by big changes of a load or by different faults. Faults on different elements may appear also during the mechanical oscillations. Very high demands are put today in such cases on modern protection equipment. The modern power utilities permit no more any decrease of either dependability or security of the protection systems for the faults in primary system when their mechanical masses oscillate due to one or another reason. The protection system must remain stable for all kinds of external faults and must operate reliably for all internal faults. Some longer operating times are acceptable but should not jeopardize the complete system selectivity.

Integration of different protection functions within the same modern numerical protection terminals makes it possible to combine their operation and program their interdependence under different system operating conditions. Fast development of modern digital communication systems increases additionally the application of such adaptive functionality.

2.2 Functionality

2.2.1 Theory of operation

Measured impedance in relay point on a protected power line (see figure in "Application") may follow different trajectories when the generators of a two machine system start to oscillate. Some of the most characteristic trajectories are presented on figure 36.

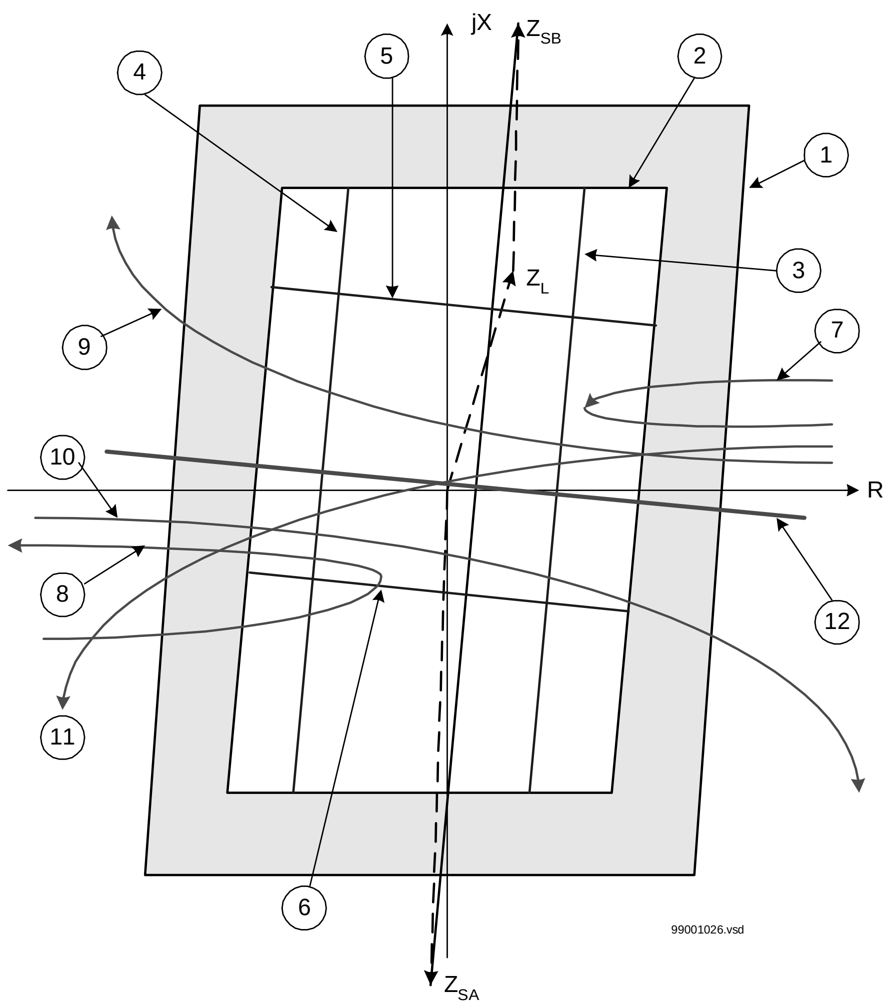


Figure 36: Impedance trajectories during oscillations in power system and basic operating characteristics of the pole slip protection.

The impedance measuring device is located in the origin of the R-X plane. The Z_{SA} source impedance is located behind the relay. The Z_{SB} source impedance presents the continuation of the line impedance Z_L. The complete impedance between the ends of vectors Z_{SA} and Z_{SB} is called a system impedance Z_S. The magnitude and the position of the system impedance within the impedance plain determines the electrical centre of the possible oscillation. The electrical center Z_{CO} is located in the middle of the system impedance, when both EMFs have the same magnitude.

$$\dot{Z}_S = \dot{Z}_{SA} + \dot{Z}_L + \dot{Z}_{SB} = R_S + jX_S$$

(Equation 18)

$$\dot{Z}_{CO} = \frac{1}{2} \cdot \dot{Z}_S - \dot{Z}_{SA} = R_{CO} + jX_{CO}$$

(Equation 19)

The following equation apply in general conditions, when the EMFs at both generators are not equal:

$$\dot{Z}_{CO} = \frac{\dot{Z}_S}{1 + \frac{|\dot{E}_B|}{|\dot{E}_A|}} - \dot{Z}_A$$

(Equation 20)

The oscillation detection characteristics 1 and 2 in figure 36 are in their resistive part parallel to the system impedance as long as its characteristic angle φ_S exceeds 75 degrees. The same applies also to the resistive tripping characteristics 3 and 4.

$$\varphi_S = \operatorname{atan}\left(\frac{X_S}{R_S}\right)$$

(Equation 21)

The reactive tripping characteristics 5 and 6 (see figure 36) are rectangular on the system impedance characteristic and form with the R axis an angle of

$$\varphi_S - 90^O$$

(Equation 22)

as long as

$$\varphi_S \geq 75^O$$

(Equation 23)

Impedance trajectory 7 on figure 36 presents a typical trajectory during a (probably) recoverable power swing, when the load current flows from A towards B (see figure in “Application”). Similarly presents the impedance trajectory 8 a power swing, which started from the reverse load condition. Characteristic for both trajectories is that they do not pass the complete system impedance, which means that there is no pole slip condition in power system. The second trajectory passes the left tripping characteristic (4 on figure 36), which could be a necessary condition for the non-recoverable oscillation and might require a tripping action.

Impedance trajectories 9, 10, 11, and 12 on figure 36 are characteristic for the pole slip conditions. They pass the system impedance line and complete impedance plain. Their shapes depend on particular system conditions. The measured impedance would follow the 12 trajectory only in case, when E_A and E_B voltages have exactly the same magnitude. Trajectory 9 is characteristic for the case when

$$|\dot{E}_A| > |\dot{E}_B|$$

(Equation 24)

and trajectory 11 for the opposite case.

The results of system studies should determine the necessary operating conditions for the pole slip protection in different situations.

Detection of the oscillations and transitions

The operating principle used for the detection of the oscillations over the protected primary element is based on a well proven

$$(\Delta\dot{Z})/(\Delta t)$$

(Equation 25)

method as presented schematically in figure 37.

An oscillation is recognized by the measuring element if the measured impedance needs to change from a ZEXT external impedance boundary to a ZINT internal impedance boundary (se also boundaries 1 and 2 on figure 36) a time, which is longer than the time Δ_t set on the corresponding timer. Faster changes of the measured impedance are recognized as faults.

Power swing and pole slip are not only a three-phase phenomena. It is for this reason necessary to monitor the impedance in each phase separately. The pole slip protection in REx 5xx terminals has built-in oscillation detectors in each phase separately.

Impedance may change relatively slow also at developing high resistive faults, which might influence the unwanted operation of the oscillation detectors, when set to detect the oscillations with the highest possible speed (slip frequency up to 10Hz). The pole slip protection in REx 5xx terminals has a built in adaptive criterion. The operation of this criterion is based on the fact that the initial oscillations are usually slow. They increase their speed after a certain number of slips. First oscillations are this way detected by a timer (see figure 37) with longer set time delay. The consecutive oscillations are detected by an additional timer, which has its operating time set shorter to be able to detect also the high speed oscillations

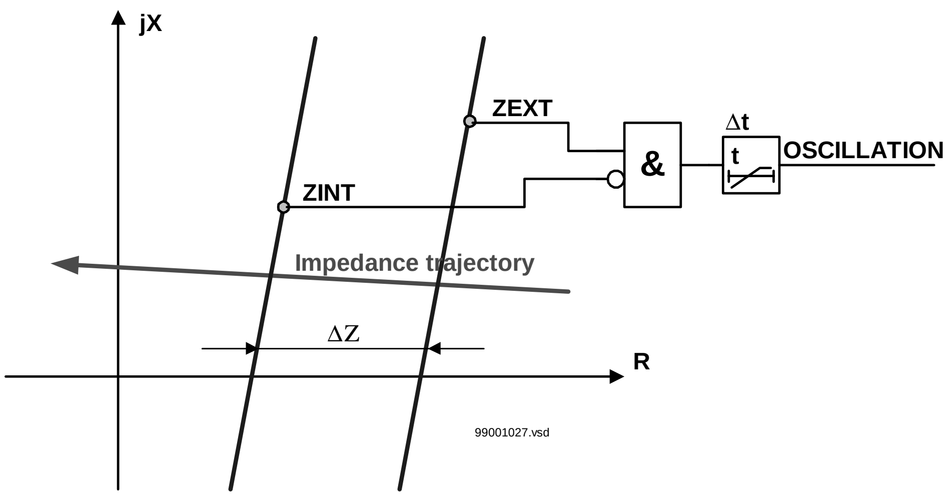


Figure 37: Detection of the oscillation by the (DZ)/(Dt) method.

The oscillation is recognized as a transition only, if the transition impedance enters the impedance operating characteristic (see figure 36) at one side of the impedance plane and leaves it on the other side. Two different transitions are recognized by the PSP:

- Transition from forward to reverse (FwRv), when the measured impedance first enters the right side (R) or upper part (X) and leaves at the left (-R) or bottom (-X) part of the oscillation detection characteristic.
- Transition from reverse to forward (RvFw), when the measured impedance first enters the left (-R) or bottom (-X) part and leaves at the right (R) or upper (X) part of the oscillation detection characteristic.

It is not always necessary to trip the circuit breaker after that the first pole slip has been detected. This especially applies to recoverable slips, which occur during the abnormal system conditions. If one slip occurs during the dead time of a single pole autoreclosing on a power line it is still possible that the system will recover after the circuit breaker reconnects the third phase (see example in figure in “Oscillations during abnormal system conditions” in “Application”). However, if more consecutive slips occur, than it is better to disconnect the line and prevent this way the collapse of a complete system as well as big electrical and mechanical stresses of the primary equipment. The PSP in REx 5xx terminals has built in counters, which count the number of the consecutive slips in the system. Separate counters count:

- The slips which enter the impedance area between the reactive tripping characteristics 5 and 6 (see figure 36).
- The slips with remote electrical centers, which enter the inner boundary of the oscillation detection characteristic (boundary 2 on figure 36), but remain outside the first operating area.

Settings of the resistive reach for the external and for the internal boundary of the oscillation detection element depend on the minimum load impedance Z_{Lmin} of the protected element, which is calculated according to the equation:

$$\dot{Z}_{Lmin} = \frac{(\dot{U}_{min})^2}{\dot{S}_{max}}$$

(Equation 26)

Where:

U_{min}[kV]	Minimum possible system phase to phase voltage (real value).
S_{max}[MVA]	Maximum possible loading of a protected element.

The resistive reach of the external boundary depends on the line length as follows.

$$R1EXT = |\dot{Z}_{Lmin}| \cdot K_L$$

(Equation 27)

The K_L factor depends on the line length and has the following values:

- K_L=0.9 for lines longer than 150 km
- K_L=0.85 for lines longer than 80 km and shorter than 150 km
- K_L=0.8 for lines shorter than 80 km

The corresponding load angle is this way equal to:

$$\delta_{ext} = 2 \cdot \operatorname{atan}\left[\frac{|\dot{Z}_{SA} + \dot{Z}_L + \dot{Z}_{SB}|}{2 \cdot R1EXT}\right]$$

(Equation 28)

Maximum frequency f_{si} of the initial slips is mostly between 2Hz and 3Hz. It should be known from the system stability studies. The suggested setting value for the initial timer tP1 is 45ms. The corresponding value of the internal load angle is this way equal to:

$$\delta_{int} = 360^{\circ} \cdot f_{si} \cdot tP1 + \delta_{ext}$$

(Equation 29)

This determines the required setting of the internal resistive boundary:

$$R1INT = \frac{|\dot{Z}_{SA} + \dot{Z}_L + \dot{Z}_{SB}|}{2 \cdot \tan\left(\frac{\delta_{int}}{2}\right)}$$

(Equation 30)

Setting for the tP2 timer, determining the maximum slip frequency for the consecutive slips, follows the equation:

$$tP2 = \frac{\delta_{int} - \delta_{ext}}{360^{\circ} \cdot f_{sm}}$$

(Equation 31)

f_{sm} is a maximum slip frequency of the consecutive slips, which are still supposed to be detected by the pole slip protection.

The PSP issues a tripping command after any of counters reaches the set number of consecutive slips and the measured impedance passes one of the resistive tripping characteristics (3 and 4 on figure 36).

Tripping on way in and on way out

The PSP protection in REx 5xx terminals has built-in two resistive tripping characteristics (see figure 38):

- Right tripping characteristic, which passes in the impedance plain the first and the fourth quadrant.
- Left tripping characteristic, which passes in the impedance plain the second and the third quadrant.

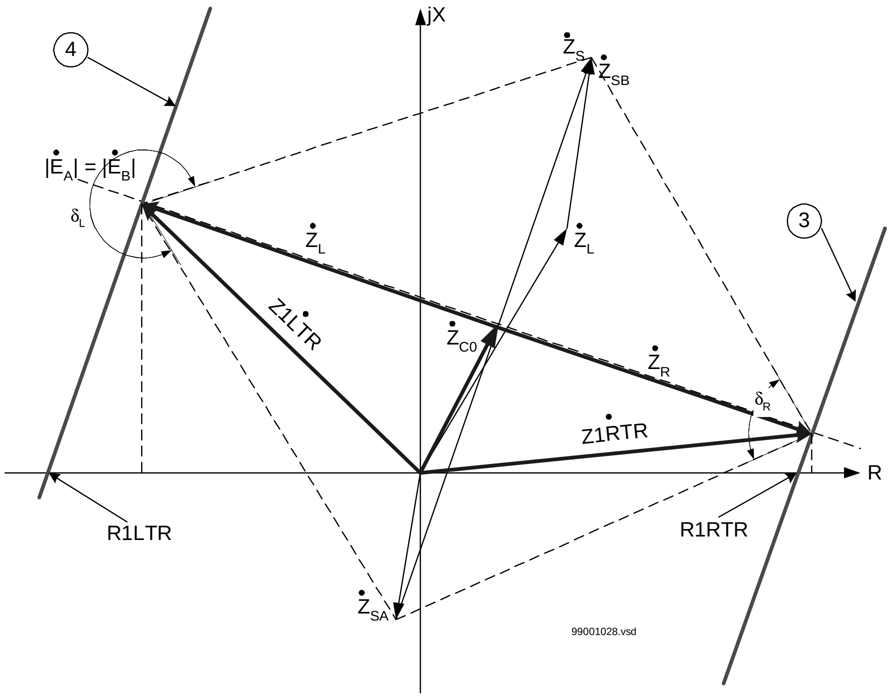


Figure 38: Left (4) and right (3) tripping characteristics and setting of their resistive reach R1LTR and L1RTR respectively.

Both tripping characteristics are parallel with the system impedance Z_s as long as the system characteristic angle

$$\varphi_S \geq 75^{\circ}$$

(Equation 32)

In other cases the declination angle is automatically set equal to 75°.

The resistive tripping characteristics make possible to control the tripping angle between the EMFs of both generators and this way prevent extremely high electrical and mechanical stresses of circuit breakers. Two operating modes are available, dependent on which characteristic is selected for tripping at particular type of the impedance transition. If we simplify the expressions and equalize the characteristics with their resistive reach settings R1LTR and R1RTR respectively, than the following operating modes are possible:

- Operation “on way in” for the transition from forward to reverse (FwRv). The PSP will issue the tripping command, if the necessary number of FwRv transitions has been detected and the measured impedance enters the area left of the R1RTR operating characteristic (3 in figure 36 and figure 38).
- Operation “on way out” for the transition from forward to reverse (FwRv). The PSP will issue the tripping command, if the necessary number of FwRv transitions has been detected and the measured impedance enters the area left of the R1LTR operating characteristic (4 in figure 36 and figure 38).
- Operation “on way in” for the transition from reverse to forward (RvFw). The PSP will issue the tripping command, if the necessary number of RvFw transitions has been detected and the measured impedance enters the area right of the R1LTR operating characteristic (4 in figure 36 and figure 38).
- Operation “on way out” for the transition from reverse to forward (RvFw). The PSP will issue the tripping command, if the necessary number of RvFw transitions has been detected and the measured impedance enters the area right of the R1RTR operating characteristic (3 in figure 36 and figure 38)

It is possible to activate each operating mode separately, to suit the operation the best to the particular system conditions.

Setting of the resistive reach for the left resistive tripping characteristic follows the equations:

$$R1LTR = Re(Z1\dot{L}TR) + Im(Z1\dot{L}TR) \cdot \tan(90^o - \varphi_S)$$

(Equation 33)

$$Z1\dot{L}TR = \frac{1}{2} \cdot \dot{Z}_S \cdot \left[1 + \frac{j}{\tan\langle 180^\circ - \frac{\delta_L}{2}\rangle}\right] - \dot{Z}_{SA}$$

(Equation 34)

See in figure 36 and figure 38 for the explanation of different parameters.

Setting of the resistive reach for the right tripping characteristic follows the equations:

$$R1RTR = Re\langle Z1\dot{R}TR\rangle - Im(Z1\dot{R}TR) \cdot \tan(90^\circ - \varphi_S)$$

(Equation 35)

$$Z1\dot{R}TR = \frac{1}{2} \cdot \dot{Z}_S \cdot \left[1 - \frac{j}{\tan\left(\frac{\delta_R}{2}\right)}\right] - \dot{Z}_{SA}$$

(Equation 36)

Equations 13 to 16 are derived according to in figure 38, which means when

$$|\dot{E}_A| = |\dot{E}_B|$$

(Equation 37)

This calculation satisfies also in great extent the system requirements, when both EMFs differ in their magnitude.

Close-in and remote end tripping areas

The number of slips usually permitted by the pole slip protection is lower for the slips with electrical center closer to the relay point (within the protected element) and higher for the slips with electrical center deeper in the network (external to the protected element). The PSP in REx 5xx terminals has for this reason built-in a possibility to distinguish between the slips with close-in and remote electrical centers as well as to distinguish the number of slips required for the tripping command in one or another region. Two reactance characteristics (5 and 6 in figure 36) divide the complete operating area into two different parts.

The first area is a so called close-in operating area. This area is limited in the impedance plain by four operating characteristics (3, 4, 5, and 6 in figure 36). The number of required slips for tripping within this area is usually lower than the number of slips required for tripping in the remote tripping area.

The second area is a so called remote tripping area. This area is limited in the impedance plain by the operating characteristics 2, 3, 4, and 5 in forward direction as well as 2, 3, 4, and 6 in reverse direction (see figure 36).

PSP also provides a delayed back-up trip (TRIPSUM) for oscillation in close-in operating area or remote tripping area. This trip will work when the center of the oscillation is detected either on the protected line or on the neighbor line or next zone. In both cases PSP compares the number of slips to nDel, therefore, to enable this functionality TRFast and TRDel should be set to ON.

2.3 Design

The pole slip protection in REx 5xx terminals measures the phase impedance separately in each phase according to the following equation:

$$\dot{Z}_{mLn} = \frac{\dot{U}_{Ln}}{\dot{I}Ln}$$

(Equation 38)

Where:

U_{Ln}	are measured phase voltages (n = 1, 2,3)
ILn	are measured phase currents (n = 1, 2, 3)

Figure 39 presents the operating characteristic for the pole slip protection in impedance plane with all the corresponding setting parameters. For detailed information on setting parameters see the setting parameters in the “Technical reference manual”.

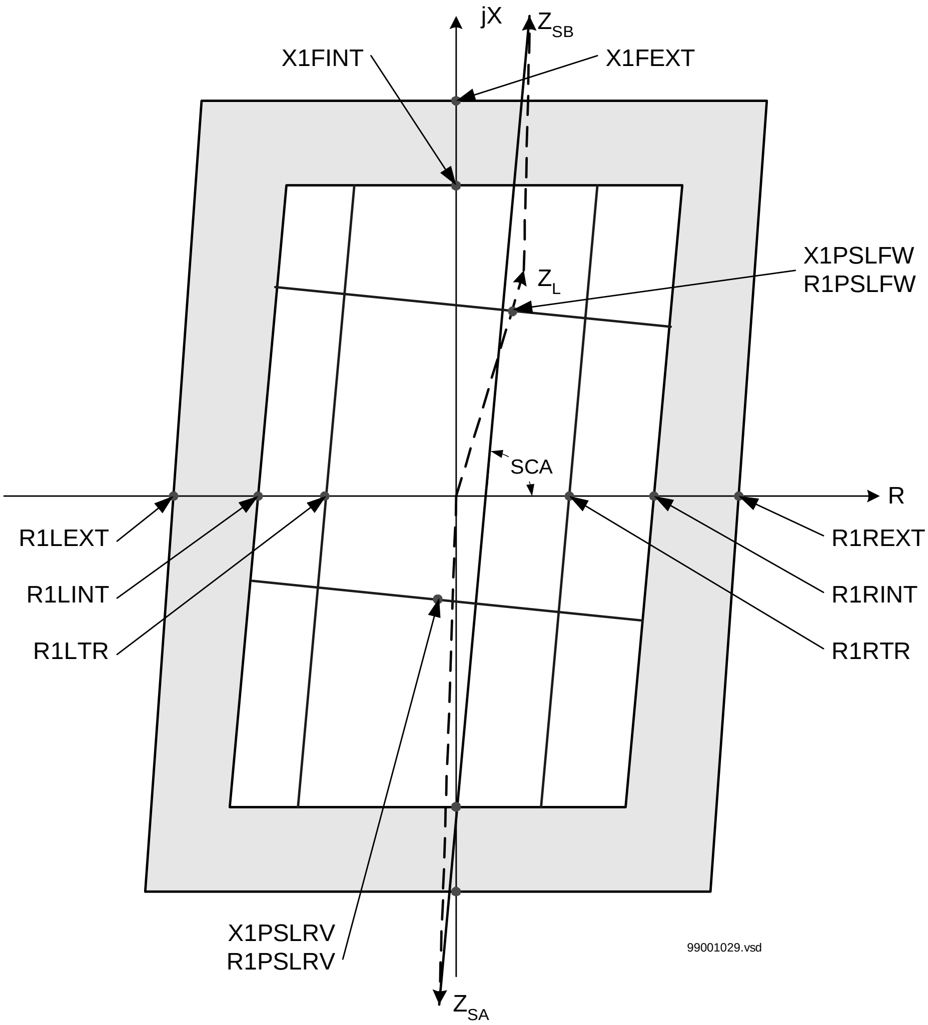


Figure 39: Operating characteristic of the pole slip protection with corresponding settings in the impedance plane.

The phase impedances are calculated in a digital signal processor and the following binary signals are used later on within the functional logic:

- ZOUTPSLn when the measured impedance enters the external impedance detection boundary in phase Ln (n = 1, 2, 3). See figure in “Application”.
- ZINPSLn when the measured impedance enters the internal impedance detection boundary in phase Ln (n = 1, 2, 3). See figure in “Application”.39
- FwRvLn when transition from forward to reverse direction has been detected in phase Ln.
- RvFwLn when transition from reverse to forward direction has been detected in phase Ln.
- Additional signals, which determine the position of the measured impedance regarding all specified operating characteristics. The positioning is performed in each phase separately.

Detection of oscillations

The oscillations are recognized, if detected in one or two out of all three phases. The user can select by the configuration, which of the operating modes is active during different system conditions. It is possible to have the “one out of three” mode active during normal three-phase operating conditions and switch to “two out of three” mode during the dead time of the single pole autoreclosing on a protected line

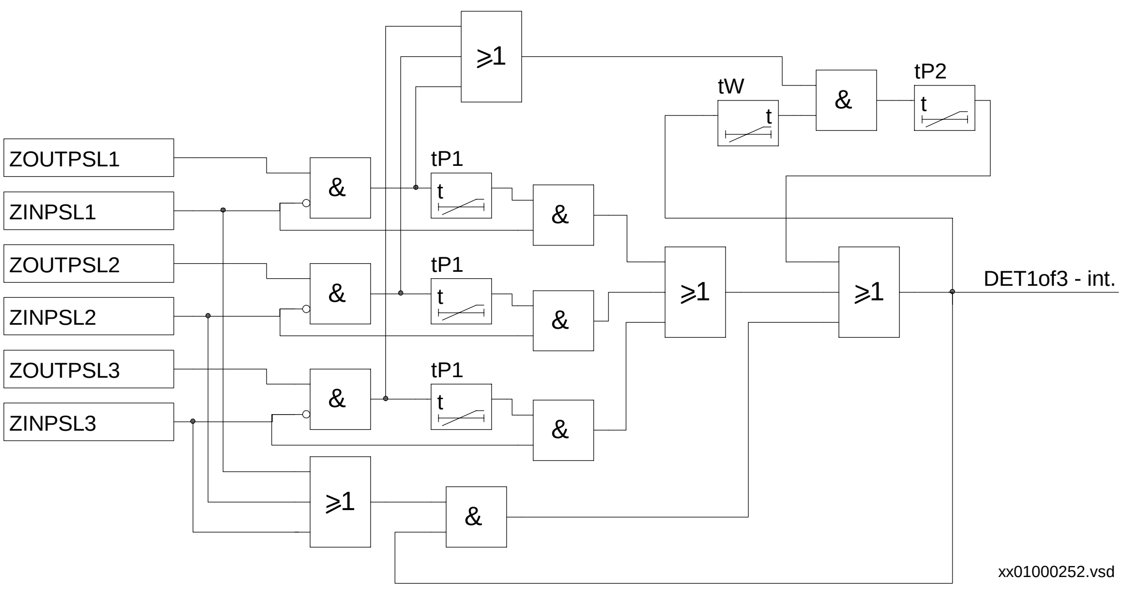


Figure 40: Simplified logic diagram for a one-out-of-three oscillation detection logic

The oscillation is detected in “one out of three” operating mode (see figure 40 and 41) if in at least one phase the time difference, when the measured impedance enters the external (ZOUTPSLn) and the internal (ZINPSLn) impedance boundary, is longer than the time set on the tP1 timer. The output signal DET1of3 remains logical one as long as the measured impedance in at least one phase remains within the external boundary.

The oscillation is recognized as the consecutive one, if the measured impedance re-enters in at least one phase the external boundary within the time interval set on tW waiting timer. In such case the tP2 timer becomes the relevant one for the determination of a consecutive oscillation. This makes it possible to detect the consecutive slips with higher speed than the initial one.

Figure 41 presents a simplified logic diagram for the “two out of three” operating mode of the oscillation detection logic. The basic operating principle is the same as for the “one of three” operating mode with the difference that the initial oscillation must be detected in at least two phases, before the DET2of3 output signal becomes logical one.

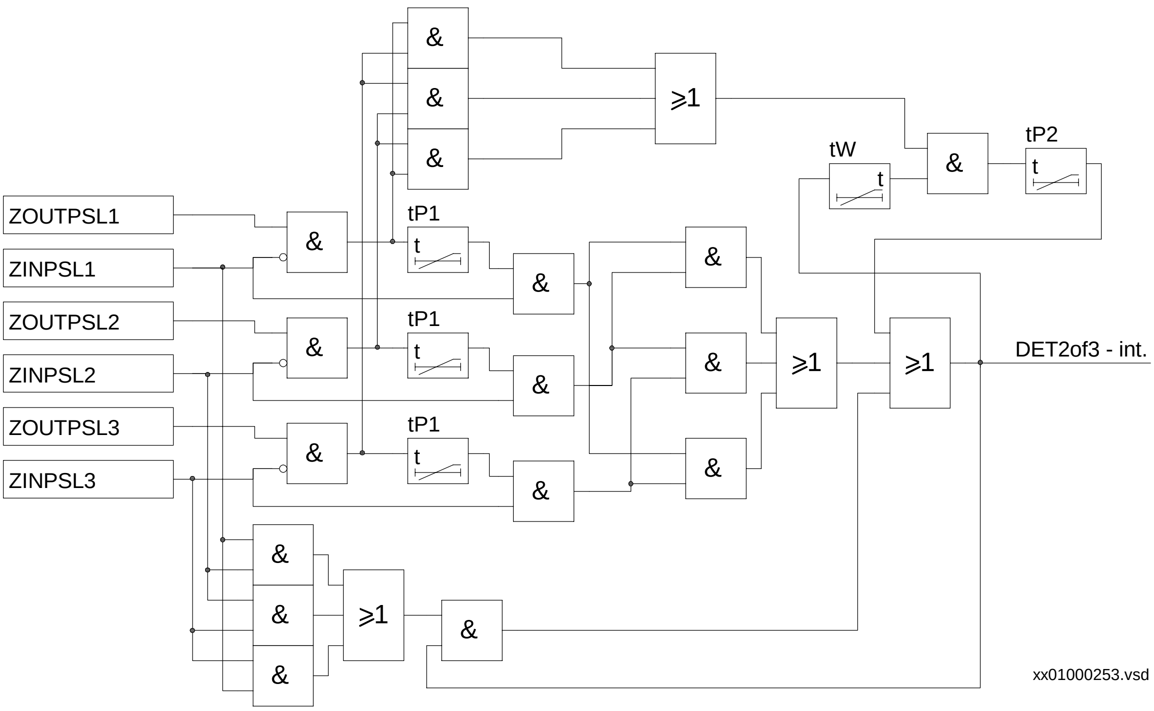


Figure 41: Simplified logic diagram for a two-out-of-three oscillation detection logic.

Logic for cooperation with the line distance protection

It has already been mentioned that the transition impedance might enter the operating area of the line distance protection function and cause its unwanted operation, if the necessary counter measures have not been provided. The pole slip protection detects the transient impedance and can be used as a disabling function for the line distance protection function within the same REx 5xx protection and control terminal.

Figure 42 presents in simplified form the logic diagram used for the cooperation with the associated line distance protection, when necessary.

The PSP-START output logical signal can be used within the terminal configuration, to block the operation of different distance protection zones. Its appearance depends on the selection of the “one out of three” or “two out of three” operating mode, which is possible by the corresponding connection of the following functional input signals:

- PSP--REL1P, which releases the “one out of three” operating mode.
- PSP--BLK1P, which blocks the “one out of three” operating mode.
- PSP--REL2P, which releases the “two out of three” operating mode.
- PSP--BLK2P, which blocks the “two out of three” operating mode

The following conditions block the PSP--START output signal and might this way release the operation of the distance protection function even during the oscillation conditions.

- PSP--BLOCK - input functional signal, which blocks the operation of the complete pole slip protection
- The PSP--START signal is disabled, if the measured impedance remains within the external impedance boundary for the time, which is longer as the time interval set on tR2 timer. It is possible to disable this functionality by the continuous presence of a logical one signal on functional input PSP--BLK1.

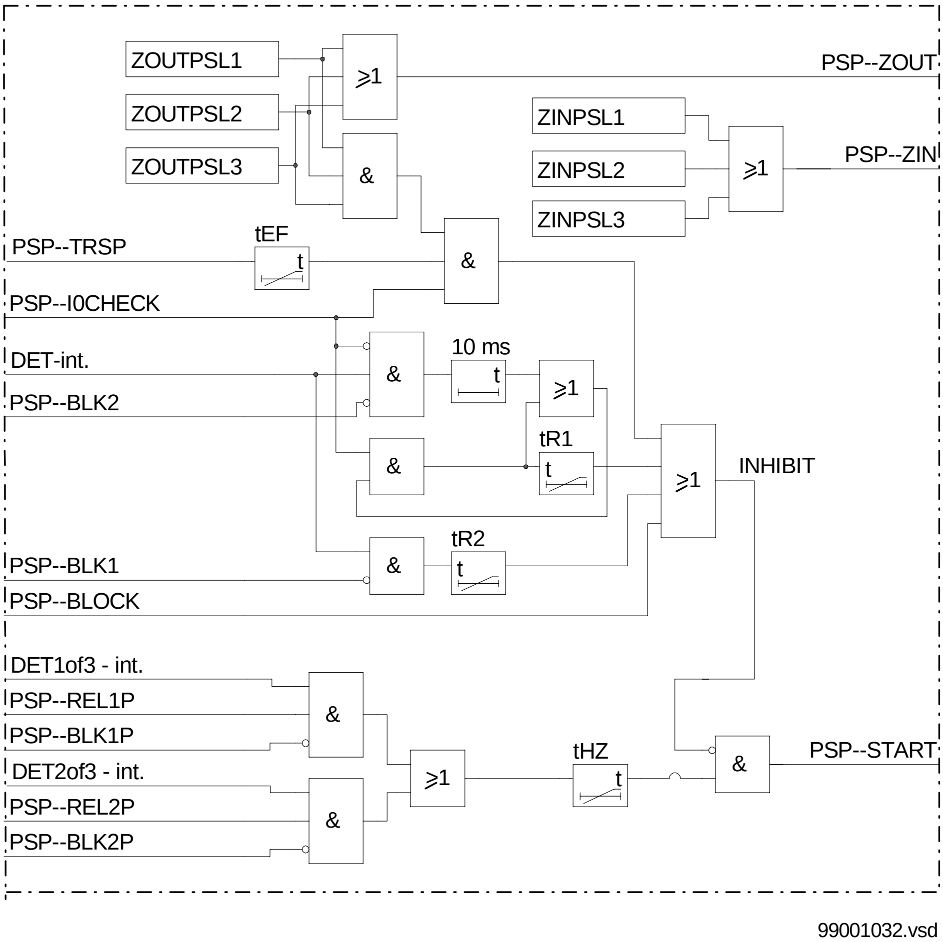
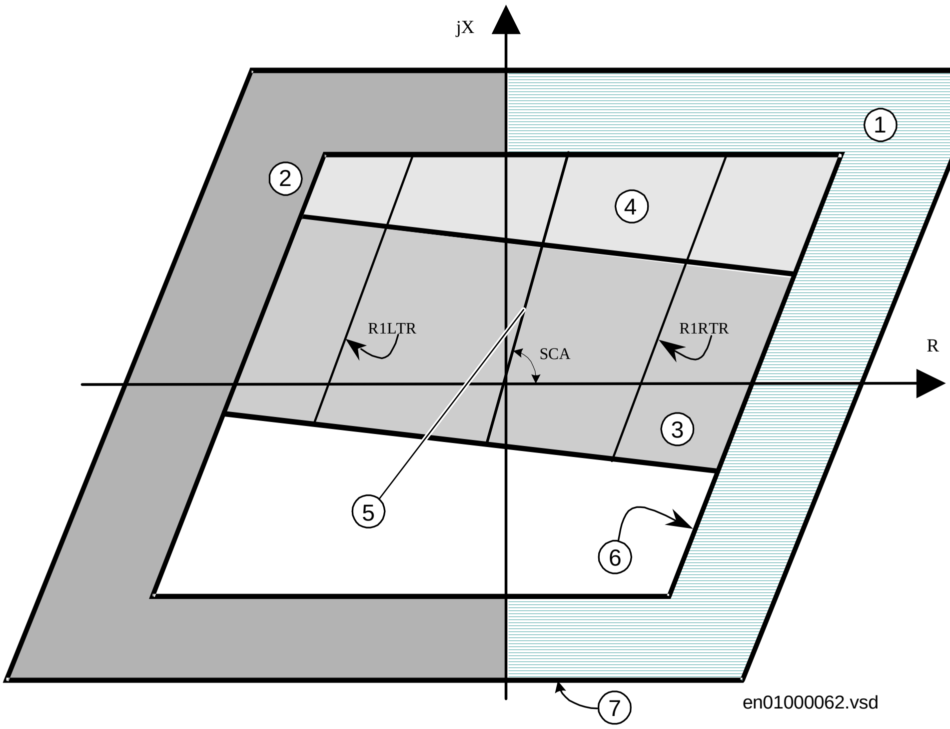


Figure 42: Logic for cooperation with distance protection function.

- The PSP--START output signal is disabled after the time delay set on the tR1 timer, if the oscillation appears before the functional input signal PSP--I0CHECK becomes logical one. This way it is possible to block the PSP function and release the operation of the line distance protection, if for example, an earth fault appears in the network during the oscillations. This functionality can be disabled by the logical one signal on the PSP--BLK2 functional input.
- The PSP--START functional input is disabled, if the measured impedance have been detected within the external operating boundary in all three phases and the PSP--I0CHECK functional input signal became logical one within the time interval shorter than the time delay set on timer tEF after the PSD--TRSP logical input changed from logical one to logical zero. This function prevents the appearance of the PSP--START output signal in cases, when one pole of the circuit breaker closes on persistent single phase fault after the single pole autoreclosing dead time, if the initial single phase fault and single pole opening of the circuit breaker causes the power swinging in the remaining two phases.

Tripping criteria

The complete impedance operating area is divided on two detection and two trip regions as presented schematically on figure 43. Detection area is divided on forward-reverse detection region i.e transition from forward to reverse (TRANFwRv) and reverse-forward detection region i.e transition from reverse to forward (TRANRvFw). Trip area is divided on fast trip region and delayed trip region.



Where:

1	Forward - reverse detection region
2	Reverse - forward detection region
3	Fast trip region
4	Delayed trip region
5	System impedance
6	Internal operating boundary
7	External operating boundary

Figure 43: The impedance operating plain is divided on two detection regions and two trip regions.

The flow charts on figure 44 and figure 45 present completely the operation of the PSP for the FwRv transitions and the RvFw transitions respectively.

PSP also provides a delayed back-up trip (TRIPSUM) for oscillation in fast or delayed region. Summation trip will work if the center of the oscillation is detected either on the protected line (fast region) or on the adjacent line (delayed region). In both cases PSP compares number of slips to nDel, therefore to enable this functionality TRFast and TRDel should be set to On. Summation trip operation is shown on figure 46 and figure 47 for the FwRv transitions and the RvFw transitions respectively.

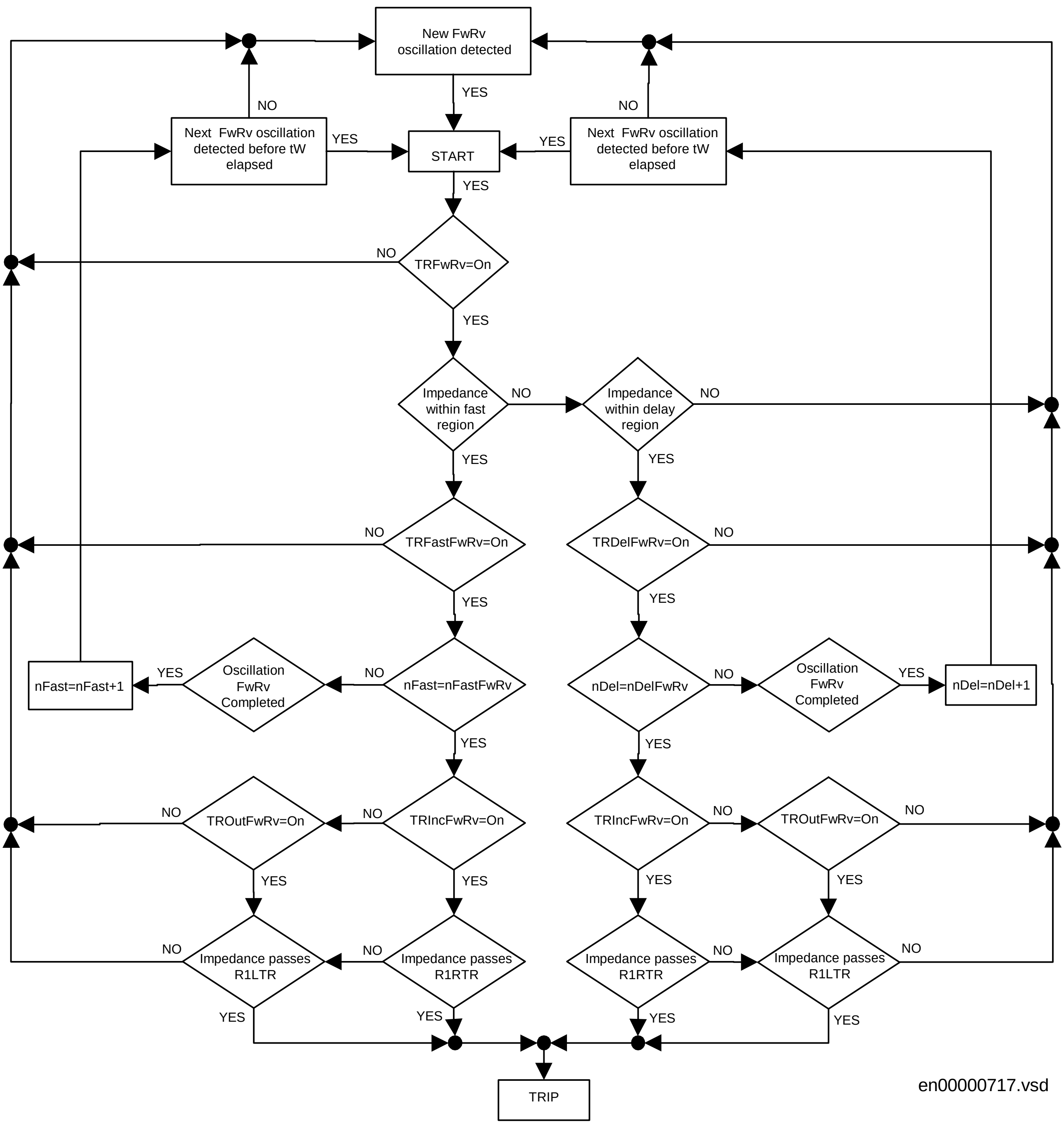


Figure 44: Flow-chart presenting the operation of the pole slip protection for the forward to reverse transition (FwRv) after the oscillation has been detected.

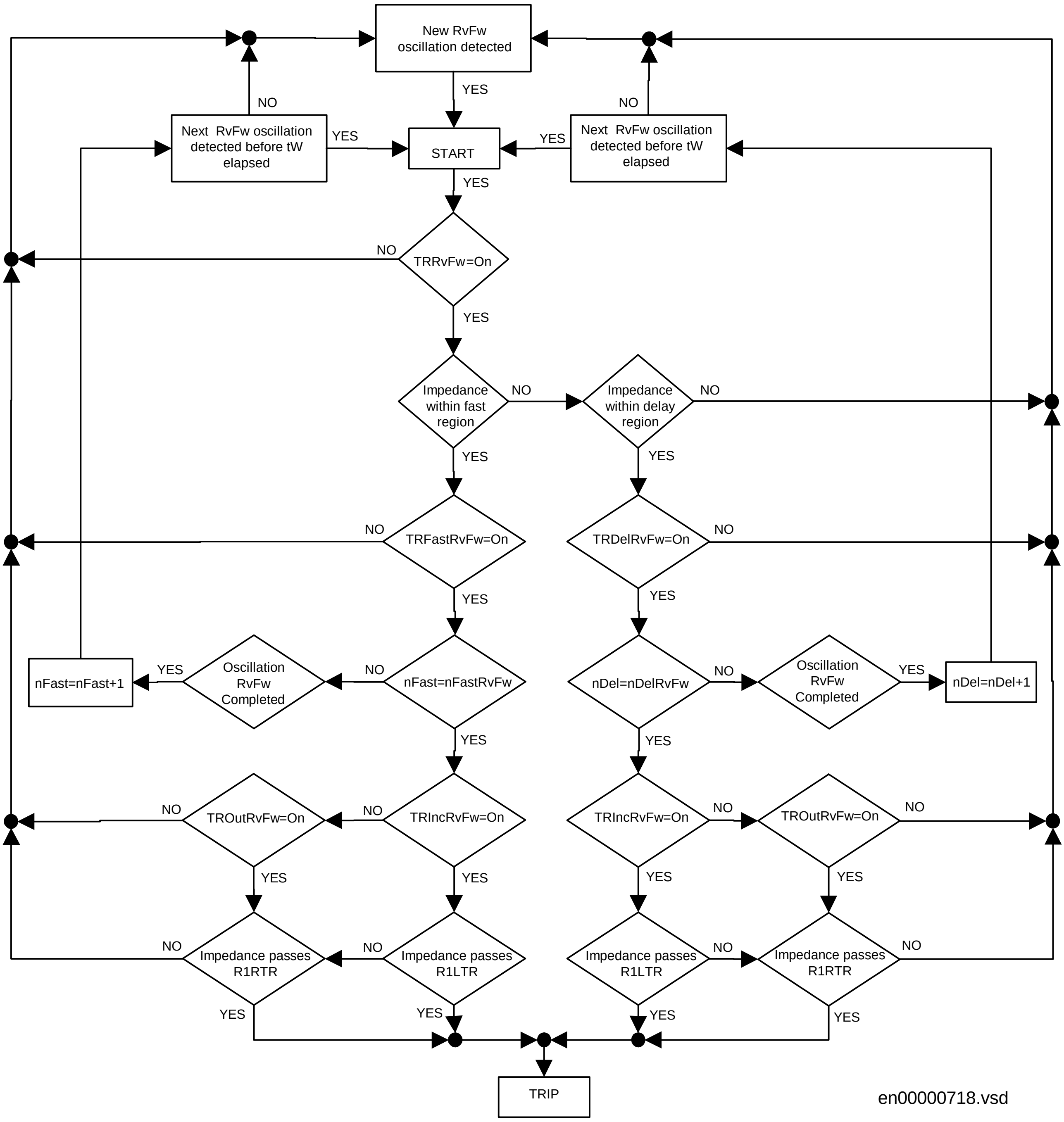


Figure 45: Flow-chart presenting the operation of the pole slip protection for the reverse to forward transition (RvFw) after the oscillation has been detected.

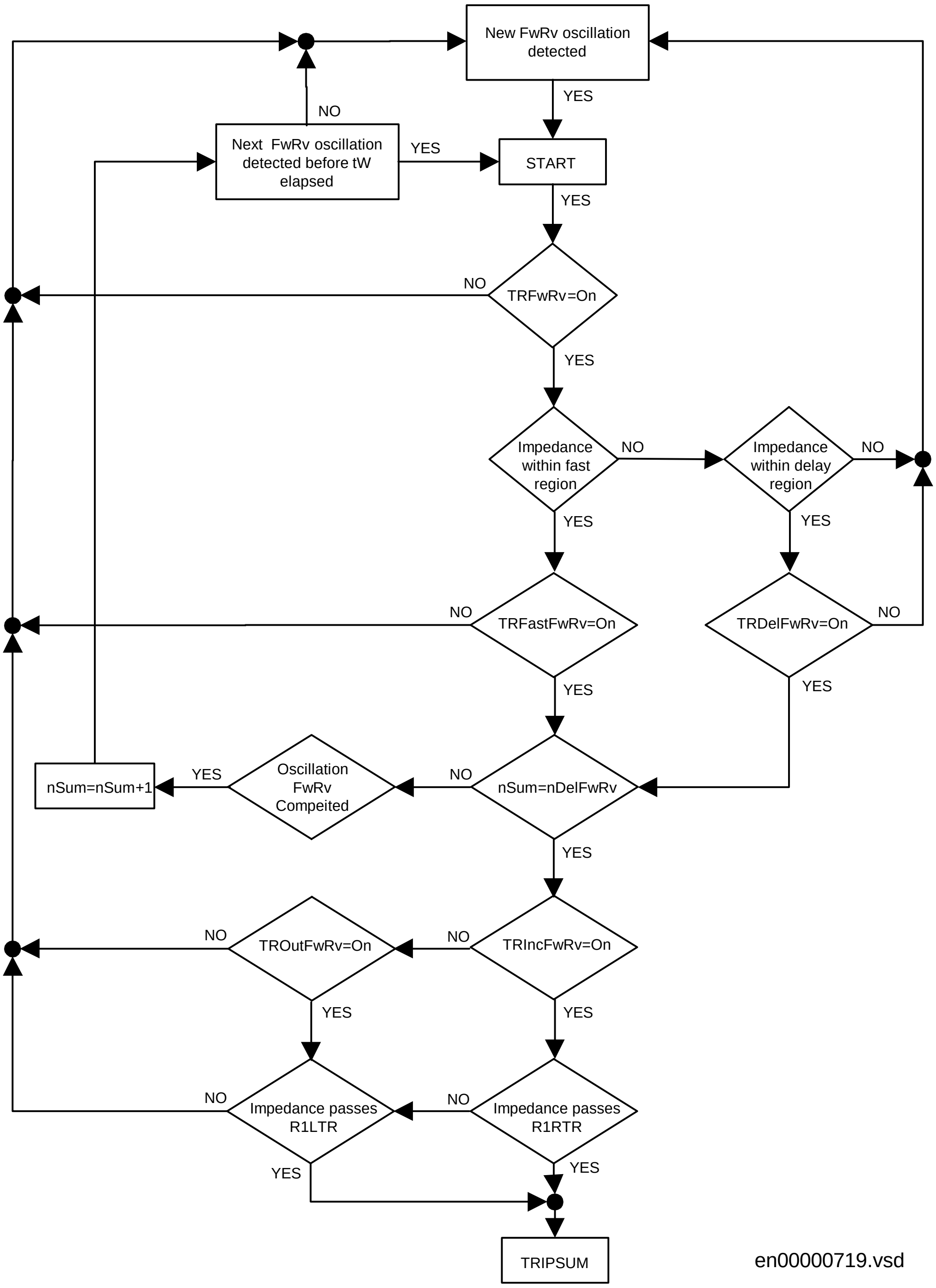


Figure 46: Flow-chart presenting summation trip (TRIPSUM) of the pole slip protection for the forward to reverse transition (FwRv).

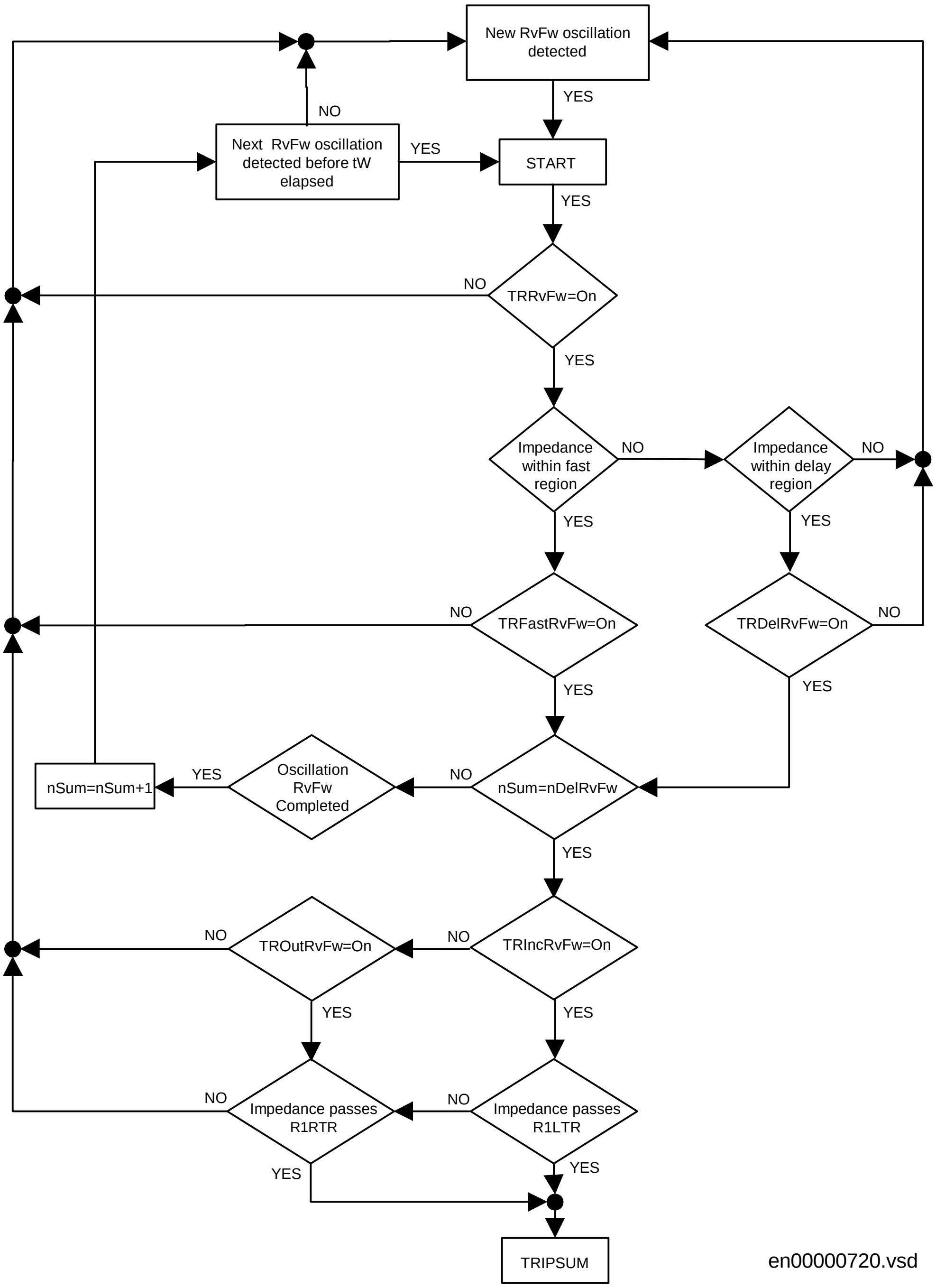


Figure 47: Flow-chart presenting summation trip (TRIPSUM) of the pole slip protection for the reverse to forward transition (RvFw).

2.4 Calculations

2.4.1 Setting instructions

The complete operation together with reach setting of the pole slip protection can locally be set under the menu:

Settings
Functions
Group n
Impedance
PoleSlipProt

Necessary technical data

These setting instructions are prepared as a setting example for the power network reduced to the two machine system as presented on figure 48.

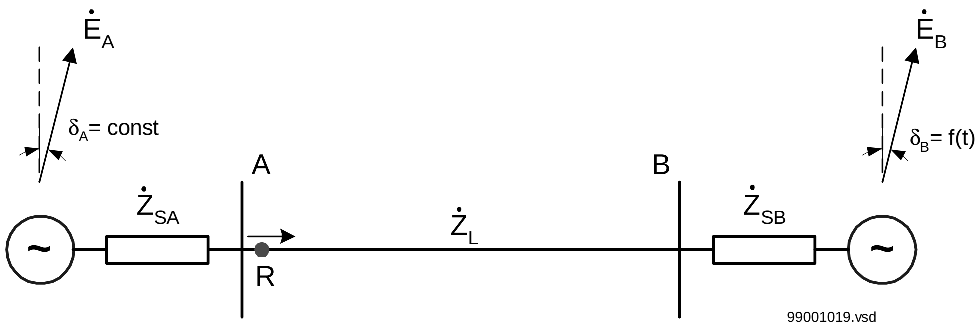


Figure 48: Power system reduced to a two machine system.

Following are the necessary technical data:

Rated system voltage:

$$U_r = 400kV \qquad \text{(Equation 39)}$$

Minimum expected system voltage:

$$U_{min} = 380kV$$

(Equation 40)

Rated system frequency:

$$f_r = 50Hz$$

(Equation 41)

Ratio of voltage instrument transformers:

$$\frac{U_p}{U_s} = \frac{\frac{400}{\sqrt{3}}[kV]}{\frac{0.11}{\sqrt{3}}[kV]} = 3636$$

(Equation 42)

Ratio of current instrument transformers used:

$$\frac{I_p}{I_s} = \frac{1200[A]}{1[A]} = 1200$$

(Equation 43)

Line length:

$$L = 210km$$

(Equation 44)

Line positive sequence impedance:

$$\dot{Z}_{Lp} = (10.71 + j75.6)ohm$$

(Equation 45)

Source A positive sequence impedance:

$$\dot{Z}_{SAp} = (1.15 + j43.5)ohm$$

(Equation 46)

Source B positive sequence impedance:

$$\dot{Z}_{SBp} = (5.3 + j35.7)ohm$$

(Equation 47)

Maximum expected load in forward direction (at minimum system voltage U_{min}).

$$\dot{S}_{max} = 1000MVA$$

(Equation 48)

with power factor

$$\cos(\varphi_{max}) = 0.95$$

(Equation 49)

Maximum expected slip frequency for consecutive slips:

$$f_{smax} = 8Hz$$

(Equation 50)

Expected initial slip frequency:

$$f_{si} = 2.5Hz$$

(Equation 51)

The required tripping angle at pole slip conditions must be between the following values (determined by the system studies and electrical characteristics of the used primary equipment):

$$\delta_{trL} \le 115^{\circ}$$

(Equation 52)

$$\delta_{trR} \ge 245^{\circ}$$

(Equation 53)

It is supposed that similar pole slip protection device will be used on the remote line end. In such case it is suggested to program the operation of the pole slip protection for the slips in forward direction only.

The result of the system studies has shown that:

- It is possible to have one slip over the remaining two phases between both systems during the dead time of the single pole autoreclosing. It is a high probability that the system will remain stable after the successful single pole autoreclosing.
- The second slip, if detected on the protected line, should be disconnected as fast as possible. For this reason the trip in incoming mode of operation is suggested.
- The selective operation of the pole slip protections in the complete network is obtained, if the number of the remote slips is less than four, before the system is split by the pole slip protection in the observed point.

Impedance transformation factor

System data are generally presented by their primary values. This is also the case for this setting example. The corresponding impedance transformation factor is equal to:

$$KIMP = \frac{\frac{I_p}{I_s}}{\frac{U_p}{U_s}} = \frac{\frac{1200[A]}{1[A]}}{\frac{\frac{400}{\sqrt{3}}[kV]}{\frac{0.11}{\sqrt{3}}[kV]}} = 0.33$$

(Equation 54)

The secondary values of the corresponding impedances are equal to:

$$\dot{Z}_L = KIMP \cdot \dot{Z}_{Lp} = (3.53 + j24.95)ohm$$

(Equation 55)

$$\dot{Z}_{SA} = KIMP \cdot \dot{Z}_{SAp} = (0.38 + j14.36)ohm$$

(Equation 56)

$$\dot{Z}_{SB} = KIMP \cdot \dot{Z}_{SBp} = (1.75 + j11 - 78)ohm$$

(Equation 57)

Minimum load impedance

Minimum load impedance appears in forward direction and is calculated according to equation 58:

$$\dot{Z}_{Lmin} = \frac{(U_{min})^2}{\dot{S}_{max}} \cdot KIMP = 47.63ohm$$

(Equation 58)

System impedance and center of oscillations

The system impedance is according to equation 54 equal to:

$$\dot{Z}_S = \dot{Z}_{SA} + \dot{Z}_L + \dot{Z}_{SB} = (5.63 + j51.08)ohm$$

(Equation 59)

The system characteristic angle (equation 57) is equal to:

$$\varphi_S = \operatorname{atan}\left(\frac{X_S}{R_S}\right) = 83.7^\circ$$

(Equation 60)

The corresponding setting of the system characteristic angle is this way:

$$SCA = 83.7^\circ$$

(Equation 61)

The center of the oscillation has the coordinates (equation 55):

$$\dot{Z}_{CO} = \frac{1}{2} \cdot \dot{Z}_S - \dot{Z}_{SA} = (2.45 + j11.19)\mathrm{ohm}$$

(Equation 62)

Resistive reach of the external boundary in forward direction

The external boundary for the oscillation detection characteristic in forward direction (right side boundary) has its resistive reach equal to (equation 59).

$$R1REXT = |\dot{Z}_{Lmin}| \cdot K_L = 42.87\mathrm{ohm}$$

(Equation 63)

We considered in this case

$$K_L = 0.9$$

(Equation 64)

because the line is longer than 150km.

The corresponding load angle is according to equation 60 equal to:

$$\delta_{ext} = 2 \cdot \mathrm{atan}\left[\frac{|\dot{Z}_{SA} + \dot{Z}_L + \dot{Z}_{SB}|}{2 \cdot R1REXT}\right] = 61.88^{\circ}$$

(Equation 65)

Resistive reach of the internal boundary in forward direction

We assume the setting of the first transition timer tP1 = 45ms. This brings the necessary load angle for the right internal boundary of the oscillation detection characteristic (equation 60):

$$\delta_{int} = 360^{\circ} \cdot f_{si} \cdot tP1 + \delta_{ext} = 102.4^{\circ}$$

(Equation 66)

The corresponding resistive reach setting is this way (equation 61):

$$R1RINT = \frac{|\dot{Z}_{SA} + \dot{Z}_L + \dot{Z}_{SB}|}{2 \cdot \tan\left(\frac{\delta_{int}}{2}\right)} = 20.69ohm$$

(Equation 67)

It is necessary to check that this operating characteristic (see “Application”, boundary 2 on figure 1) covers completely the distance protection zones, which should be blocked during the power swings in system, if the pole slip protection is used also for these purposes. In this particular case we check only the primary fault resistance, which could be covered by the corresponding distance protection zones:

$$R_{Fp} = \frac{1}{KIMP} \cdot R1RINT \cdot 0.95 = 59.5ohm$$

(Equation 68)

This resistive reach satisfies in most practical cases for the resistive covering of the distance protection zones one and two. Factor 0.95 in equation 68 is considered as a safety factor. In this way we can keep the setting of the first transition timer to tP1 = 45ms.

Setting of the tP2 timer

The tP2 timer serves the detection of (generally faster) consecutive slips. Its setting is calculated according to equation 63 and the specified value of the maximum expected slip frequency:

$$tP2 = \frac{\delta_{int} - \delta_{ext}}{360^{\circ} \cdot f_{sm}} = 14ms$$

(Equation 69)

The required value is well over the minimum suggested value of 10ms. The maximum detectable slip frequency with setting of the tP2 timer equal to $tP2_{min}$ = 10ms and with unchanged settings of the impedance oscillation detection boundaries is equal to:

$$f_{smax} = \frac{\delta_{int} - \delta_{ext}}{360^{\circ} \cdot tP2_{min}} = 11.25Hz$$

(Equation 70)

This is a very high value, which usually does not appear in a real power system.

Settings of the reverse oscillation detection resistive boundaries

It has been mentioned that the similar pole slip protection device is intended to be used at the remote line end. The maximum load in reverse direction is also much smaller than in forward direction. The system requirements require this way only the operation for the pole slips with their electrical center in forward direction. The reverse (left side) resistive reach of the oscillation detection characteristics can be for this reason equal to the one in forward direction:

$$R1LEXT = R1REXT = 42.87 ohm$$

(Equation 71)

$$R1LINT = R1RINT = 20.69 ohm$$

(Equation 72)

Setting of the right and left tripping characteristics

The necessary setting of the resistive reach for the right tripping characteristic is calculated according to equation 67 and equation 68:

$$Z1\dot{R}TR = \frac{1}{2} \cdot \dot{Z}_S \cdot \left[1 - \frac{j}{\tan\left(\frac{\delta_{trR}}{2}\right)}\right] - \dot{Z}_{SA} = (18.72 + j9.38) ohm$$

(Equation 73)

$$R1RTR = Re\langle Z1\dot{R}TR\rangle - Im(Z1\dot{R}TR) \cdot \tan(90^{\circ} - \varphi_S)$$

(Equation 74)

$$R1RTR = 17.68\ ohm$$

(Equation 75)

The condition R1RTR<R1RINT is in this way fulfilled.

Necessary setting of the resistive reach for the left tripping characteristic is calculated according to equations.

$$\dot{Z1LTR} = \frac{1}{2} \cdot \dot{Z}_S \cdot \left[1 + \frac{j}{\tan\left\langle 180^\circ - \frac{\delta_{trL}}{2} \right\rangle} \right] - \dot{Z}_{SA}$$

(Equation 76)

$$\dot{Z1LTR} = (18.72 + j9.38)ohm$$

(Equation 77)

$$R1LTR = Re(\dot{Z1LTR}) + Im(\dot{Z1LTR}) \cdot \tan(90^\circ - \varphi_S)$$

(Equation 78)

$$R1LTR = 19.76ohm$$

(Equation 79)

The condition R1RTR<R1RINT is in this way fulfilled.

Setting of the reactive tripping characteristics

The reactive operating characteristics are presented in “Application”, figure 1, and marked by 5 for the operation in forward direction and by 6 for the operation in reverse direction.

Since it is required to operate only for the pole slip situation with centers of slips in forward direction, and because a similar device will be used at the remote line terminal, only the operation for the transition from forward to reverse direction (FwRv) is required. This kind of operation does not require any reverse reach. It is recommended for this reason to set the corresponding setting parameters to their minimum values.

$$R1PSLRv = 0.1ohm$$

(Equation 80)

$$X1PSLRv = 0.1ohm$$

(Equation 81)

The tripping characteristic in forward direction should cover the slips with their electrical center on the protected power line. 10% of safety margin is sufficient in order not to overreach for the slips with their centers on the adjacent power lines. The necessary settings are equal to:

$$R1PSLFw = 0.9 \cdot Re(\dot{Z}_L) = 3.18 ohm$$

(Equation 82)

$$X1PSLFw = 0.9 \cdot Im(\dot{Z}_L) = 22.45 ohm$$

(Equation 83)

Setting of the reactive reach of the oscillation detection characteristics

The reactive reach of the oscillation detection characteristic should cover in forward and in reverse direction with sufficient margin (10 to 15%) the power lines and other elements, for which the pole slip protection should provide also the back up protection for the slips with remote centers of the oscillations. System studies should determine the necessary reach as well as the number of permitted remote slips more in details.

We assume in this example that the pole slip protection should also block the operation of the distance protection zones one and two. Zone two must be set to at least 120% of the protected line. The necessary reactive reach of the internal boundary in the forward direction is this way equal to:

$$X1FINT = 1.15 \cdot 1.2 \cdot Im(\dot{Z}_L) = 34.43\ ohm$$

(Equation 84)

Reactive reach of the external oscillation detection boundary should permit the same speed of detected slips as the one determined in the resistive direction. We can even provide some additional margin (5%).

$$X1FEXT = 1.05 \cdot (R1REXT - R1RINT) + X1FINT$$

(Equation 85)

$$X1FEXT = 57.73 ohm$$

(Equation 86)

Setting of the reactive reach in the reverse direction depends on the system conditions. In our case we do not need to cover any special distance protection zone. It is also not necessary to operate for the slips with their center in the reverse direction, since the remote end pole slip protection takes care of such cases.

It is anyway suggested to set the reactive reach in reverse direction to at least 10% of the one in forward direction. The impedance difference between the internal and the internal boundary should also in this case permit detection of the same slip frequency as in the forward direction. The necessary values are:

$$X1RINT = 0.1 \cdot X1FINT = 3.44\,ohm$$

(Equation 87)

$$X1REXT = 1.05 \cdot (R1REXT - R1RINT) + X1RINT$$

(Equation 88)

$$X1REXT = 26.75 ohm$$

(Equation 89)

Setting of the tW waiting timer

Setting of the waiting timer influences the detection of the consecutive slips. The tW timer must be set higher than the time the measured impedance needs after leaving the impedance detection area and entering it again on the other side of the impedance plain. It is necessary to consider the minimum possible speed of the oscillations, which might occur in the system. The time necessary for the impedance to move from the internal left impedance boundary (after the FwRv transition has been completed) to the external right impedance boundary (to start the detection of the new oscillation) is calculated according to the equation:

$$tW = 1.3 \cdot \frac{\delta_{Rext} + (360^{\circ} - \delta_{L\,int})}{360^{\circ} \cdot f_{smin}} = 1.79\,s$$

(Equation 90)

Where:

δ_{Rext}	Corresponding load angle at the right external resistive boundary (in our case they equal to 61.9 deg)
δ_{Lint}	Corresponding load angle at the left internal resistive boundary (in our case equal to 298.1 deg)
f_{smin}	Minimum expected slip frequency in a system (should not be considered less than 0.2 Hz)

Factor 1.3 is a safety factor, which could be considered also in most other cases, when the exact technical characteristics of the system are not known.

Setting of the tripping modes and the transition counters

The pole slip protection should according to the system requirements operate only for the slips with their electrical center on the protected power line and for the transitions from the forward to the reverse direction. It is for this reason necessary to set the parameters related to the reverse to forward (RvFw) transition to the following values:

- TrRvFw = Off
- TrIncRvFw = Off
- TrOutRvFw = Off
- TrFastRvFw = Off
- TrDelRvFw = Off
- nFastRvFw = 10
- nDelRvFw = 10

According to the results of the system studies the following settings are applicable for the transitions detected from forward to the reverse direction:

- TrFwRv = On
- TrIncFwRv = On
- TrOutFwRv = Off
- TrFastFwRv = On
- TrDelFwRv = On
- nFastFwRv = 1
- nDelFwRv = 3

Additional timers in the oscillation detection circuits

Timers tR1, tR2, tEF, and tHZ are used in the oscillation detection logic (see figure in "Design") to suit the oscillation detection to different system conditions. Their settings must be co-ordinated with the time delays set on different protection devices, like distance protection, directional or non directional residual overcurrent protection, dead time of the single pole autoreclosing, etc.

tHz hold timer

The tHz hold timer prolongs the duration of the PSP--START signal, which can be used for blocking the distance protection zones. Its setting should be with a certain margin (10 to 15%) longer than the time required for the detection of the consecutive slips with fastest slip frequency in a system. In our case the required value is equal to:

$$tHZ = 1.15 \cdot \frac{1}{f_{sm}} = 144ms$$

(Equation 91)

tR1 inhibit timer

The tR1 inhibit timer delays the influence of the detected residual current $3 \cdot I_0$ on the inhibit criteria for the PSP function. It prevents the operation of the function for short transients in the residual current as measured by the terminal. The time delay of 50 ms is suggested as default, when the residual current criteria is used.

tR2 inhibit timer

The tR2 inhibit timer disables the output PSP--START signal, if the measured impedance remains within the impedance detection area for more than the set time. This time delay is generally set to 2 seconds, when used in the protection.

tEF timer

The setting of the tEF timer must cover with sufficient margin the opening time of the associated circuit breaker and the dead time of the single pole autoreclosing together with the circuit breaker closing time.

Chapter 5 Current

About this chapter

This chapter describes the current protection functions.

1 Instantaneous overcurrent protection (IOC)

1.1 Application

unbalanceLong transmission lines often transfer great quantities of electrical power from production to consumption areas. The unbalance of the produced and consumed electrical power at each end of the transmission line is very large. This means that a fault on the line can easily endanger the stability of a complete system.

The transient stability of a power system depends mostly on three parameters (at constant amount of transmitted electrical power):

- The type of the fault. Three-phase faults are the most dangerous, because no power can be transmitted through the fault point during fault conditions.
- The magnitude of the fault current. A high fault current indicates that the decrease of transmitted power is high.
- The total fault clearing time. The phase angles between the EMFs of the generators on both sides of the transmission line increase over the permitted stability limits if the total fault clearing time, which consists of the protection operating time and the breaker opening time, is too long.

The fault current on long transmission lines depends mostly on the fault position and decreases with the distance from the generation point. For this reason the protection must operate very quickly for faults very close to the generation (and relay) point, for which very high fault currents are characteristic.

For this reason instantaneous, non-directional, phase-segregated, overcurrent protection (IOC), which can operate in 15 ms (50 Hz nominal system frequency) for faults characterized by very high currents, is included in some of the REx 5xx terminals. Refer to the ordering information for more details.

The conventional distance protection can manage the fault clearance of earth-faults in most of the cases. In some applications, especially applications with long lines, the clearance can be improved by use of an instantaneous earth-fault protection. Those are for instance:

- In the case of high infeed of fault current from the opposite end of the line, this might increase the fault resistance seen by the distance relay to such a value that the instantaneous step of the distance protection will not operate.
- In applications with series compensated lines, where the capacitor is located at the end of the line and very strong infeed of fault current from that end, will result in a difficult problem for the distance protection to perform a selective fault clearance. This due to the voltage reversal that might occur.

The use of instantaneous overcurrent earth-fault protection is most suitable for long lines in meshed transmission systems. It can also be used for radial lines with low fault current infeed from the opposite end of the line.

The instantaneous residual overcurrent function is very suitable as back-up protection for phase to earth faults close to the terminal. This enables a short back-up faults clearance time for the phase to earth faults with high fault current.

The instantaneous, non-directional, earth-fault overcurrent protection (IOC), which can operate in 15 ms (50 Hz nominal system frequency) for faults characterized by very high currents, is included in some of the REx 5xx terminals. Refer to the ordering information for more details.

1.2 Functionality

The current-measuring elements within one of the built-in digital signal processors continuously measure the current in all three phases, and compare them with the IP>> set value. The logical value of each phase current signal on the output of the digital signal processor (STIL1, STIL2 and STIL3 respectively) is equal to 1 if the measured phase current exceeds the preset value.

The measuring technic is based on measuring of the incoming residual current to the terminal.

The current-measuring elements within one of the built-in digital signal processors continuously measure the zero sequence current, and compare it with the IN>> set value. A recursive Fourier filter filters the current signals, and a separate trip counter prevents high overreaching of the measuring elements. The logical value of the signal on the output of the digital signal processor (IOC--STIN) is equal to 1 if the measured zero sequence current exceeds the pre-set value.

1.3 Design

The simplified logic diagram of the instantaneous phase overcurrent function is shown in figure 49.

The overcurrent function is disabled if:

- The terminal is in TEST mode (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockIOC=Yes)
- The input signal IOC--BLOCK is high.

The IOC--BLOCK signal is a blocking signal of the instantaneous phase overcurrent function. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through OR gate it can be connected to both binary inputs and internal function outputs. The IOC--BLOCK signal blocks also the instantaneous residual overcurrent function, if this is installed in the terminal.

When the instantaneous phase overcurrent function is enabled, the output tripping signals IOC--TRL1, IOC--TRL2, IOC--TRL3, IOC--TRP and IOC--TRIP can operate. The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just a little above the set operating value.

The single phase trip signals IOC--TRL1, IOC--TRL2, and IOC--TRL3 are related to L1, L2, and L3 phases and therefore also suitable for the single phase tripping with single-phase auto-reclosing.

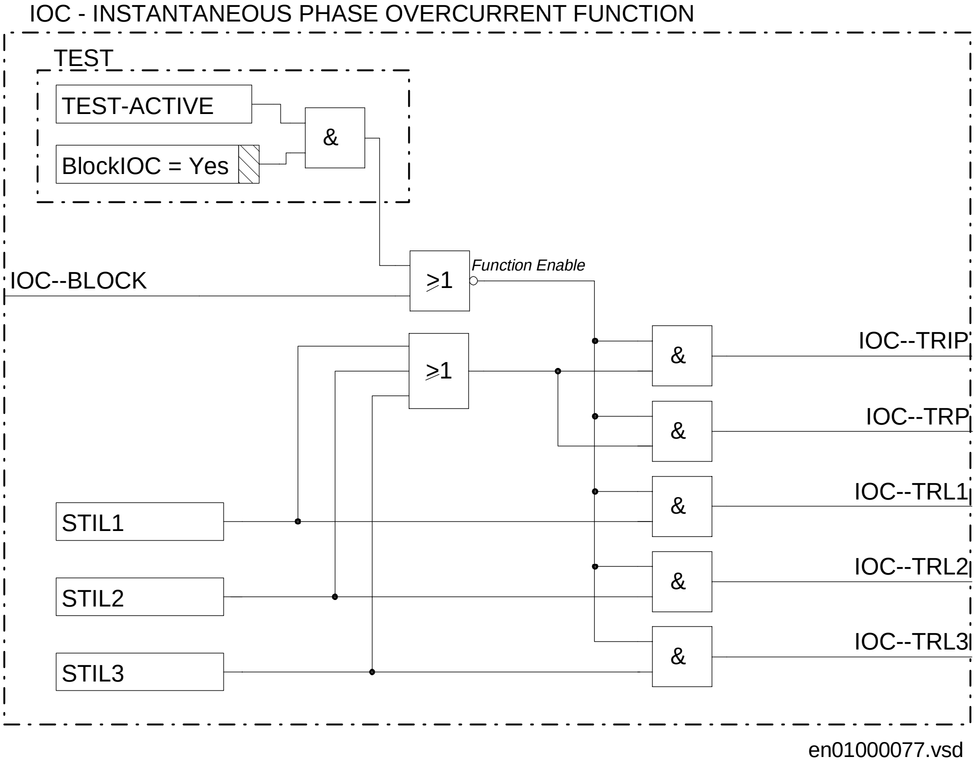


Figure 49: Simplified logic diagram of instantaneous overcurrent protection

The signal IOC--TRP is the logic OR of the three single phase trips. It can be used to trip the circuit breaker if only three phase operation is desired.

The IOC--TRIP output signal behaves as general instantaneous overcurrent trip when in the REx 5xx terminal also the instantaneous residual overcurrent function is implemented; i.e. this signal will be activated in case of any single phase overcurrent or residual overcurrent detection. If only the instantaneous phase overcurrent function is installed in the terminal, then this signal behaves exactly as the signal IOC--TRP and can be used for signalization.

The simplified logic diagram of the instantaneous phase overcurrent function is shown in figure 50.

The overcurrent function is disabled if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockIOC=Yes)
- The input signal IOC--BLOCK is high.

The IOC--BLOCK signal is a blocking signal of the overcurrent function. It can be connected to a binary input in order to receive a block command from external devices or it can be configured (software connection) to other internal functions within the terminal itself, in order to receive a block command from internal functions. Through OR gates it can be connected to both binary inputs and internal function outputs.

When the overcurrent function is enabled, the output tripping signals IOC--TRN and IOC--TRIP can operate. The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just beyond the set operating value.

The IOC--TRN signal is related to the residual overcurrent trip.

The IOC--TRIP output signal behaves as general instantaneous overcurrent trip when in the REx 5xx terminal also the instantaneous phase overcurrent function is implemented. I.e. this signal will be activated in case of residual overcurrent detection or in case of any single-phase overcurrent detection (IOC--STIL_: IOC--STIL1 or IOC--STIL2 or IOC--STIL3). If only the residual overcurrent function is implemented in the terminal, then this signal behaves exactly as the signal IOC--TRN and can be used for signalising.

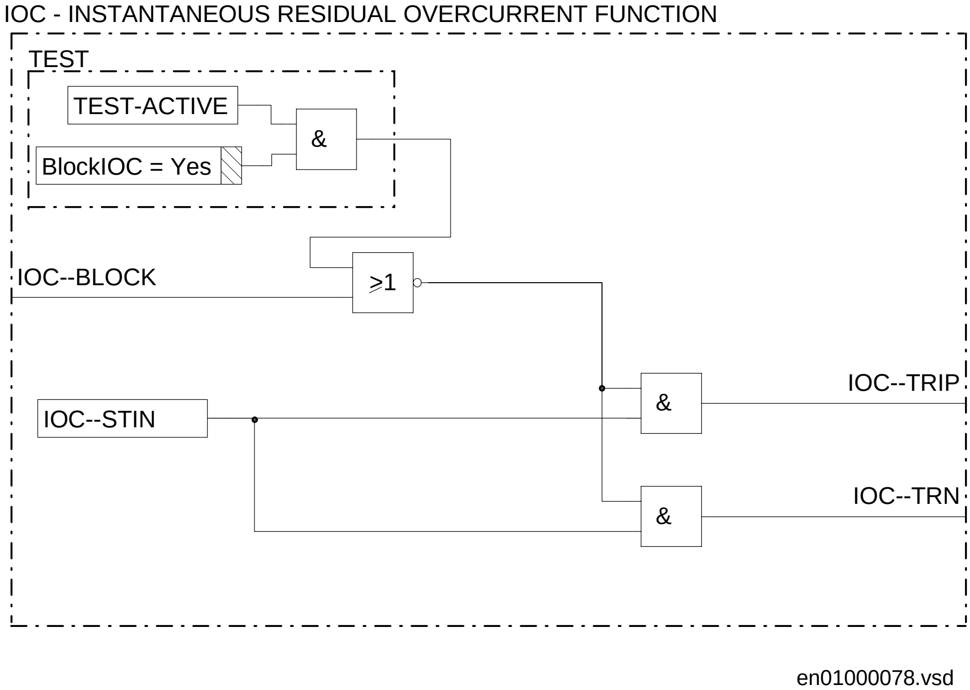


Figure 50: Simplified logic diagram of instantaneous residual overcurrent protection.

1.4 Calculations

1.4.1 Setting instructions

This protection function must operate only in a selective way. So check all system and transient conditions that could cause its unwanted operation.

Only detailed network studies can determine the operating conditions under which the highest possible fault current is expected on the line. In most cases, this current appears during three-phase fault conditions. But also examine single-phase-to-earth and two-phase-to-earth conditions.

Also study transients that could cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when connected to the network and can thus also cause the operation of the built-in, instantaneous, overcurrent protection.

Meshed network without parallel line

The following fault calculations have to be done for three-phase, single-phase-to-earth and two-phase-to-earth faults. With reference to figure 51, apply a fault in B and then calculate the relay through fault phase current I_{fB}. The calculation should be done using the minimum source impedance values for Z_A and the maximum source impedance values for Z_B in order to get the maximum through fault current from A to B.

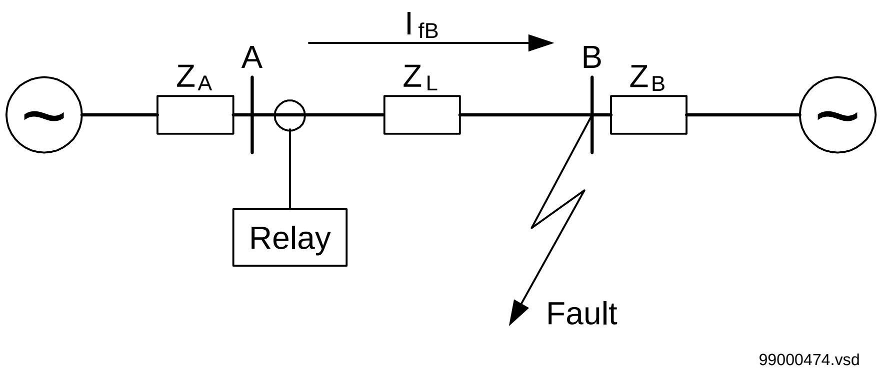


Figure 51: Through fault current from A to B: I_{fB}

Then a fault in A has to be applied and the through fault current I_{fA} has to be calculated (Figure 52). In order to get the maximum through fault current, the minimum value for Z_B and the maximum value for Z_A have to be considered.

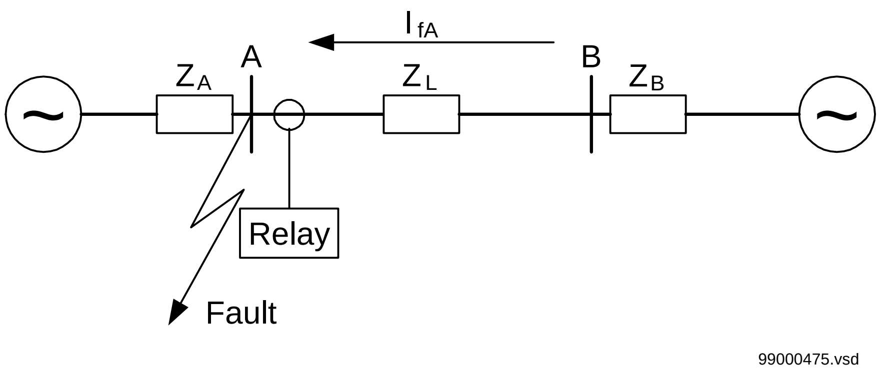


Figure 52: Through fault current from B to A: I_{fA}

The relay must not trip for any of the two trough fault currents. Hence the minimum theoretical current setting (Imin) will be:

$$Imin \geq MAX(I_{fA}, I_{fB})$$

(Equation 92)

A safety margin of 5% for the maximum protection static inaccuracy and a safety margin of 5% for the maximum possible transient overreach have to be introduced. An additional 20% is suggested due to the inaccuracy of the instrument transformers under transient conditions and inaccuracy in the system data.

The minimum primary setting (Is) for the instantaneous phase overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 93)

The protection function can be used for the specific application only if this setting value is equal to or less than the maximum fault current that the relay has to clear (I_F in figure 53).

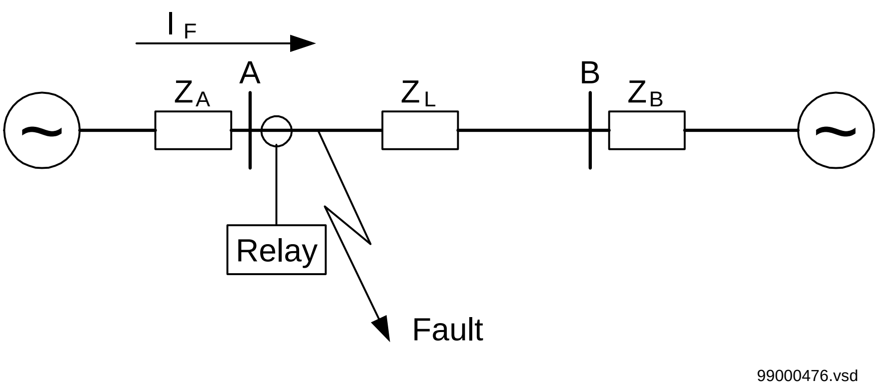


Figure 53: Fault current: I_F

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 94)

Where I_{SEC} is the secondary rated current of the main CT and I_{PRIM} is the primary rated current of the main CT.

The relay setting value IP>> is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. The value for IP>> is given from this formula:

$$IP>> = \frac{Is_{SEC}}{I_{1b}} \cdot 100$$

(Equation 95)

This is the value that has to be set in the terminal.

Set this value under the setting menu:

Settings
Functions
Group n
InstantOC

Meshed network with parallel line

In case of parallel lines, the influence of the induced current from the parallel line to the protected line has to be considered. One example is given in figure 54 where the two lines are connected to the same busbars. In this case the influence of the induced fault current from the faulty line (line 1) to the healthy line (line 2) is considered together with the two through fault currents I_{fA} and I_{fB} mentioned previously. The maximal influence from the parallel line for the relay in figure 54 will be with a fault at the C point with the C breaker open.

A fault in C has to be applied, and then the maximum current seen from the relay (I_M) on the healthy line (this applies for single-phase-to-earth and two-phase-to-earth faults) is calculated.

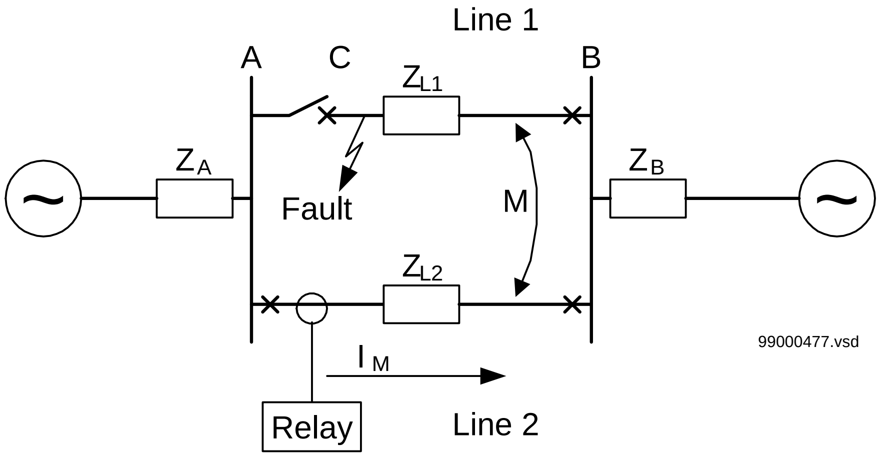


Figure 54: Two parallel lines. Influence from parallel line to the through fault current: I_M

The minimum theoretical current setting for the overcurrent protection function (Imin) will be:

$$Imin \geq MAX(I_{fA}, I_{fB}, I_M)$$

(Equation 96)

Where I_{fA} and I_{fB} have been described in the previous paragraph. Considering the safety margins mentioned previously, the minimum setting (Is) for the instantaneous phase overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 97)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum phase fault current that the relay has to clear.

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 98)

Where I_{SEC} is the secondary rated current of the main CT and I_{PRIM} is the primary secondary rated current of the main CT.

The relay setting value IP>> is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. The value for IP>> is given from this formula:

$$IP>> = \frac{Is_{SEC}}{I_{1b}} \cdot 100$$

(Equation 99)

This is the value that has to be set in the terminal.

Set this value under the setting menu:

Settings
Functions
Group n
InstantOC

1.4.2 Setting instructions

The residual overcurrent protection is very sensitive to the change of zero source impedance. Since it must operate only in a selective way, it is necessary to check all system and transient conditions that can cause unwanted operation.

Only detailed network studies can determine the operating conditions under which the highest possible fault current is expected on the line. In most cases, this current appears during single-phase fault conditions. But also examine two-phase-to-earth conditions, since this type of fault can be higher than single-phase to earth fault in some cases.

Also study transients that can cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when connected to the network and can thus also cause the operation of the built-in, instantaneous, earth-fault protection.

Meshed network without parallel line

The following fault calculations have to be done for single-phase-to-earth and two-phase-to-earth faults. With reference to figure 55, apply a fault in B and then calculate the relay through fault residual current I_{fB}. The calculation should be done using the minimum source impedance values for Z_A and the maximum source impedance values for Z_B in order to get the maximum through fault current from A to B. The zero sequence source impedances are of great importance.

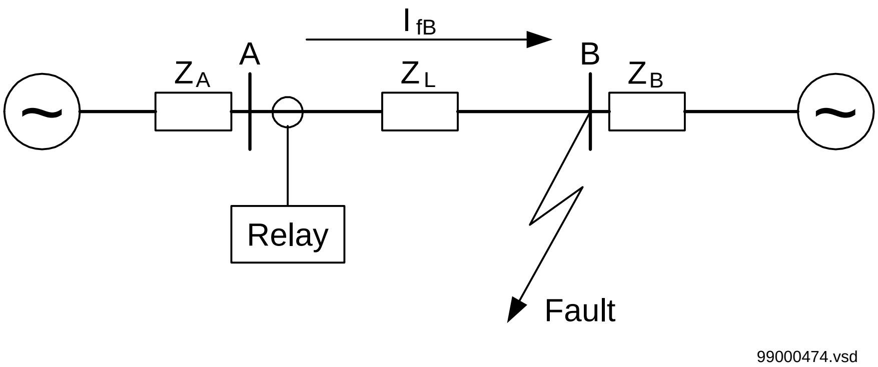


Figure 55: Through fault current from A to B: I_{fB}

Then a fault in A has to be applied and the through fault residual current I_{fA} has to be calculated (Figure 56). In order to get the maximum through fault current, the minimum value for Z_B and the maximum value for Z_A have to be considered.

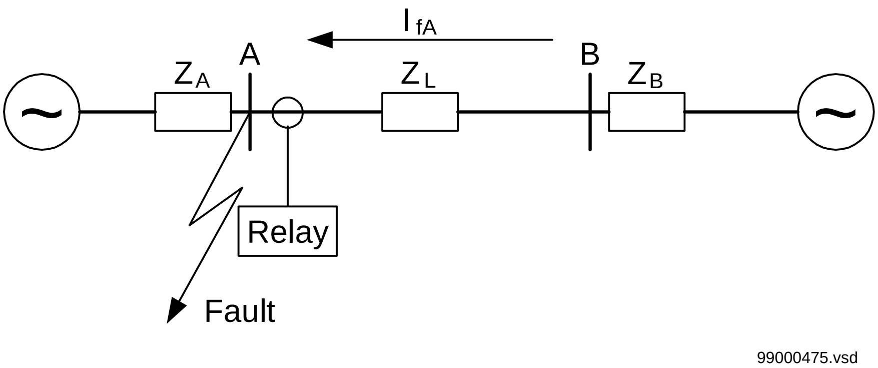


Figure 56: Through fault current from B to A: I_{fA}

The relay must not trip for any of the two trough fault currents. Hence the minimum theoretical current setting (*Imin*) will be:

$$Imin \geq MAX(I_{fA}, I_{fA})$$

(Equation 100)

A safety margin of 5% for the maximum protection static inaccuracy and a safety margin of 5% for the maximum possible transient overreach have to be introduced. An additional 20% is suggested due to the inaccuracy of the instrument transformers under transient conditions and inaccuracy in the system data.

The minimum setting (Is) for the instantaneous residual overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 101)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum fault current that the relay has to clear (I_F in Figure 57).

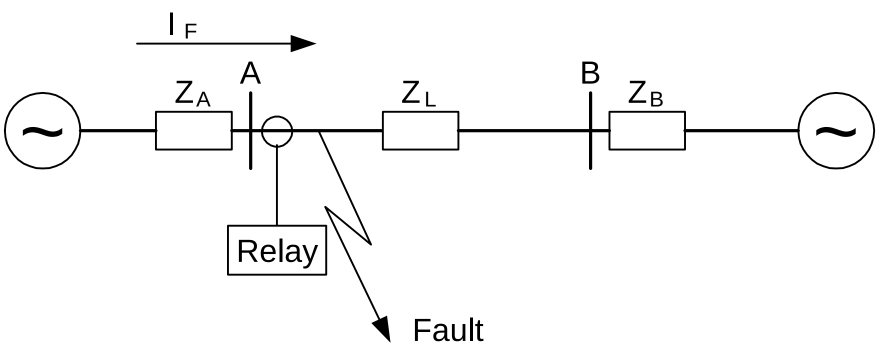


Figure 57: Fault current: I_F

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 102)

Set this value under the setting menu:

Settings
Functions
Group*n*
InstantOC

Note: *n*=1,2,3 or 4, depending on which group to set.

Meshed network with parallel line

In case of parallel lines, the influence of the induced current from the parallel line to the protected line has to be considered. One example is given in figure 58, where the two lines are connected to the same busbar. In this case the influence of the induced residual fault current from the faulty line (line 1) to the healthy line (line 2) is considered together with the two through fault currents I_{fA} and I_{fB} mentioned previously. The maximal influence from the parallel line for the relay in Figure 58 will be with a fault at the C point with the C breaker open.

A fault in C has to be applied, and then the maximum current seen from the relay (I_M) on the healthy line (this applies for single-phase-to-earth and two-phase-to-earth faults) is calculated.

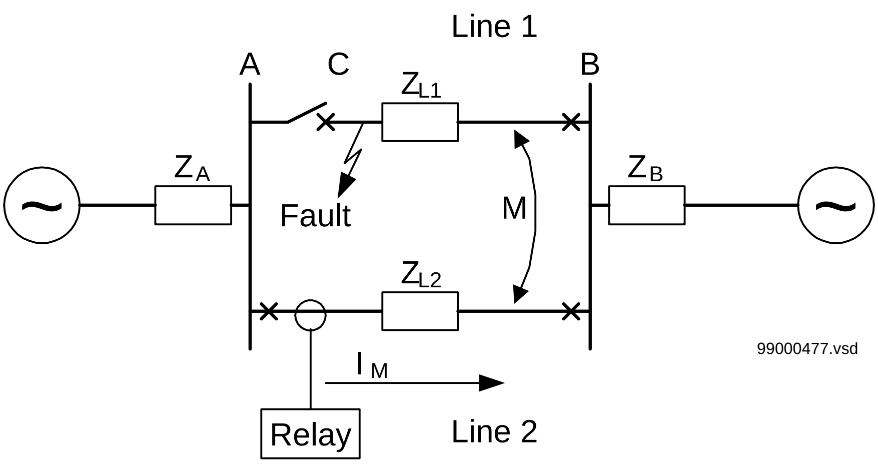


Figure 58: Two parallel lines. Influence from parallel line to the through fault current: I_M.

The minimum theoretical current setting for the residual overcurrent protection function (*Imin*) will be:

$$Imin \geq MAX(I_{fA}, I_{fB}, I_M)$$

(Equation 103)

Where I_{fA} and I_{fB} have been described in the previous paragraph. Considering the safety margins mentioned previously, the minimum setting (Is) for the instantaneous phase overcurrent protection is then:

$$Is \geq 1,3 \cdot Imin$$

(Equation 104)

The protection function can be used for the specific application only if this setting value is equal or less than the maximum residual fault current that the relay has to clear.

The current transformer secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 105)

Set this value under the setting menu:

Settings
Functions
Group*n*
InstantOC

Note: *n*=1,2,3 or 4, depending on which group to set.

2 Time delayed overcurrent protection (TOC)

2.1 Application

The time delayed phase overcurrent protection can be used as independent overcurrent protection, particularly for radially fed systems, or as back-up protection to the main distance or line differential protection functions. In the first case the protected zone of the time delayed overcurrent protection reaches upto the next overcurrent protection and works in its zone as back-up protection. The programmable time delay (definite time) of the function allows the time selectivity through an appropriate time grading among the overcurrent relays protecting the system.

Where the function acts as back-up for the main line protection, the trip from the overcurrent protection can be activated when the main protection function is blocked (e.g. by the fuse failure protection) or it can be active all the time.

In some cases, where it could be difficult to achieve a selective trip, the function can be used as a helpful overcurrent signallization for the post-fault analysis.

The time delayed residual overcurrent protection (TOC) which is an earth-fault protection, serves as a built-in local back-up function to the main protection function. In most cases, it is used as a back-up for the earth-fault measuring in distance protection.

The function is intended to be used in solidly earthed systems.

The time delay makes it possible to set the relay to detect high resistance faults and still perform selective trip.

The protection, which is non-directional, is included in some of the REx 5xx terminals. Refer to the ordering information for more details.

2.2 Functionality

The current-measuring elements within one of the built-in digital signal processors continuously measure the current in all three phases, and compare them with the IP> set value. A recursive Fourier filter filters the current signals, and a separate trip counter prevents high overreaching of the measuring elements. The logical value of each phase current signal on the output of the digital processor (STIL1, STIL2 and STIL3 respectively) is equal to 1 if the measured phase current exceeds the set value. These signals will instantaneously set their respective output starting signals (TOC--STL1, TOC--STL2, TOC--STL3), if the function is not blocked.

If any of the three phase currents exceeds the set value for a period longer than the set time tP, then a three phase trip is generated from the output signal TOC--TRP.

The current-measuring element within one of the built-in digital signal processors continuously measures the residual current (3I0), and compares it with the IN> set value. A recursive Fourier filter filters the current signal, and a separate trip counter prevents high overreaching of the measuring element. The logical value of the signal on the output of the digital signal processor (TOC--STIN) is equal to 1 if the measured residual current exceeds the pre-set value. This signal will instantaneously set the output start signal (TOC--STN), unless the function is blocked (see “Design”).

The function trip signal (TOC--TRN) can be delayed 0-60 s.

If the residual current exceeds the set value for a period longer than the set value, then a three phase trip is generated from the output signal TOC--TRN.

2.3 Design

The simplified logic diagram of the time delayed phase overcurrent function is shown in figure 59.

The function is disabled (blocked) if:

- The terminal is in TEST mode (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockTOC=Yes).
- The input signal TOC--BLOCK is high.

The TOC--BLOCK signal is a blocking signal of the time delayed phase overcurrent function. It prevents the activation of any trip or starting output signal. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through OR gate it can be connected to both binary inputs and internal function outputs. The TOC--BLOCK signal blocks also the time delayed residual overcurrent protection, if this is installed in the same REx 5xx terminal.

When the function is enabled, there is still the possibility to block the output trips only, without affecting the start signals, that will always be active. This can be obtained with the function input TOC--BLKTR. Similarly to the TOC--BLOCK signal, also the time delayed residual overcurrent protection, if present in the terminal, is blocked from TOC-BLKTR.

The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just a little above the set operating value.

The output trip signal TOC--TRP is a three phase trip. Single phase information is available from the starting signals, that are phase segregated.

The TOC--TRIP output signal behaves as general time delayed overcurrent trip when in the REx 5xx terminal also the time delayed residual overcurrent function is implemented; i.e. this signal will be activated in case of any time delayed overcurrent or time delayed residual overcurrent trip. If only the time delayed phase overcurrent function is installed in the terminal, then this signal behaves exactly as the signal TOC--TRP and can be used for signallization.

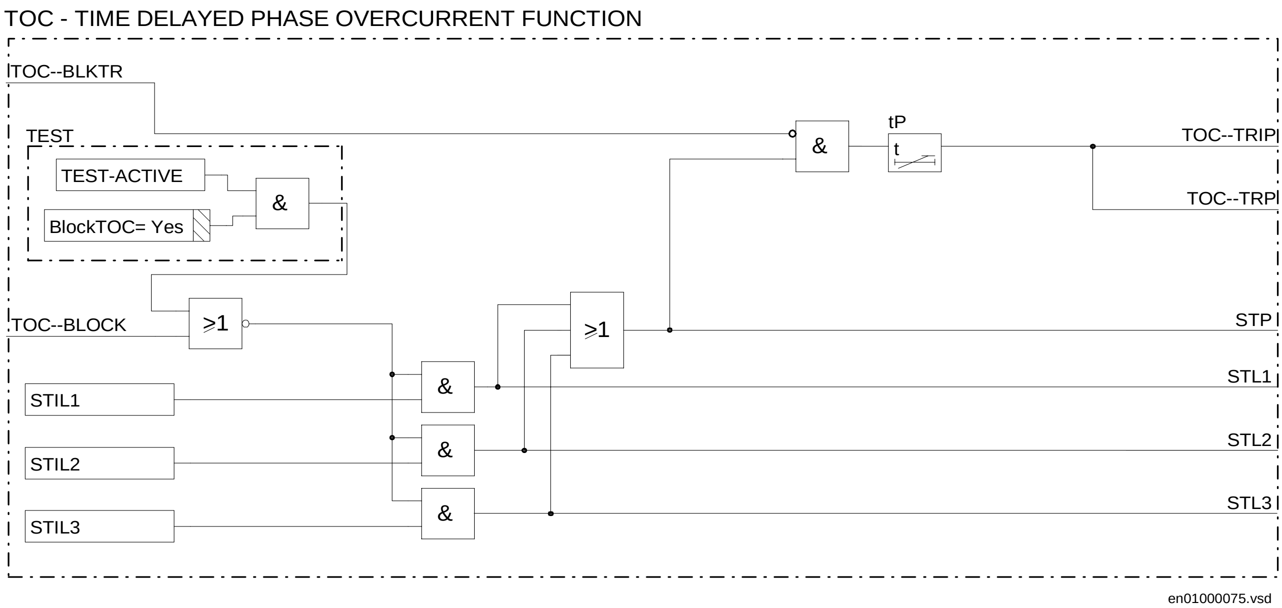


Figure 59: Simplified logic diagram of time delayed phase overcurrent protection

The simplified logic diagram of the time delayed earth-fault protection is shown in figure 60.

The time delayed residual function is disabled if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockTOC=Yes).
- The input signal TOC--BLOCK is high.

The TOC--BLOCK signal is a blocking signal of the earth-fault function. It blocks the whole function and prevents the activation of any trip or starting output signals.

It can be connected to a binary input in order to receive a block command from external devices or it can be configured (software connection) to other internal functions within the terminal itself, in order to receive a block command from internal functions. Through OR gates it can be connected to both binary inputs and internal function outputs.

When the residual overcurrent protection is enabled, there is still a possibility to block the trip output only, without affecting the start signals, which always will be active. The input which provides this function is TOC--BLKTR.

The duration of each output signal is at least 15 ms. This enables continuous output signals for currents, which go just a little beyond the set operating value.

The TOC--TRN signal is related to the residual overcurrent trip.

The TOC--TRIP output signal behaves as general time delayed overcurrent trip when in the REx 5xx terminal also the time delayed phase overcurrent function is implemented. I.e. this signal will be activated in case of delayed residual overcurrent trip or in case of time delayed phase overcurrent trip. If only the residual overcurrent function is implemented in the terminal, then this signal behaves exactly as the signal TOC--TRN and can be used for signalization.

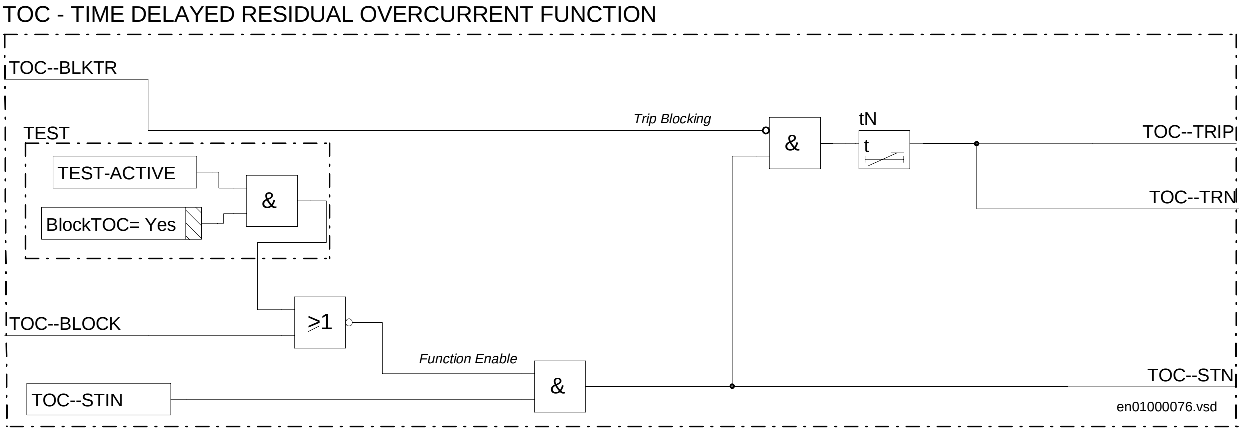


Figure 60: Simplified logic diagram of the TOC-- protection function.

2.4 Calculations

2.4.1 Setting instructions

The current setting value must be selected to permit the detection of the lowest short circuit current without having any unwanted tripping or starting of the function under normal load conditions. The following relation has to be considered for the setting of the primary operating current (Is) of the function:

$$1.2 \cdot \frac{ILmax}{K} < Is < 0.7 \cdot IFmin$$

(Equation 106)

Where:

ILmax	is the maximum permissible load current of the protected unit,
IFmin	is the minimum fault current that the relay has to clear. The values 1.2 and 0.7 are safety factors and
K	is the reset ratio of the overcurrent function: 0.95.

The settable time delay tP allows the time selectivity of the overcurrent function, according to the time grading plan of all the other overcurrent protections in the system. The time setting value should also consider transients that could cause a high increase of the line current for short times. A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when energized.

Where the time delayed overcurrent function is used as back-up of impedance protection, normally the time delay is set higher than the time delay of distance zone 2 (or 3) in order to avoid interferences with the impedance measuring system.

Setting of operating current IP>

If Is is the primary setting operating value of the function, than the secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 107)

Where:

I_{SEC}	is the secondary rated current of the main CT and
I_{PRIM}	is the primary rated current of the main CT.

The relay setting value IP> is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. The value for IP> is given from this formula:

$$IP> \;=\; \frac{Is_{SEC}}{I_{1b}} \cdot 100$$

(Equation 108)

This is the value that has to be set in the terminal.

Set this value under the setting menu:

Settings
Functions
Group n
TimeDelayOC

On the value IP>.

Setting of time delay tP

Set the time delay of the function, tP, under the setting menu:

Settings
Functions
Group n
TimeDelayOC

on the value tP.

2.4.2 Setting instructions

The residual overcurrent protection is very sensitive to the change of zero source impedance. Since it must operate only in a selective way, it is necessary to check all system and transient conditions that can cause unwanted operation.

The settings should be chosen in such a way that it can detect high resistance faults on the protected line and still be selective to other residual time delayed protections in both forward and reverse directions. The time setting value should also consider transients that can cause a high increase of the residual line current for short times.

A typical example is a transmission line with a power transformer at the remote end, which can cause high inrush current when being energised.

In well transposed system, the false earth-fault current is normally lower than 5% of the line current. For non transposed lines a considerably higher false residual current may be found.

In case of extremely short or not fully transposed parallel lines, the false residual current must be measured or calculated when maximum sensitivity is desired. Generally, 80 A is recommended as a minimum primary operation value for the residual overcurrent protection.

General criteria for the primary current setting value of the time delayed residual overcurrent protection is given in the formula below:

$$1.3 \cdot IRmax < Is < 0.7 \cdot IFmin$$

(Equation 109)

Where:

IRmax	is the maximum permissive residual current flowing in the protection unit during normal service conditions and
IFmin	is the minimum residual fault current that the relay has to clear.
1.3	and
0.7	are safety factor values.

Setting of operating current IN>

If Is is the primary setting operating value of the function, then the secondary setting current (Is_{SEC}) is:

$$Is_{SEC} = \frac{I_{SEC}}{I_{PRIM}} \cdot Is$$

(Equation 110)

where I_{SEC} is the secondary rated current of the main CT and I_{PRIM} is the primary rated current of the main CT.

The relay setting value IN> is given in percentage of the secondary base current value, I4b, associated to the current transformer on input I4. The value for IN> is given from the formula:

$$IN> = \frac{Is_{SEC}}{I4b} \cdot 100$$

(Equation 111)

and this is the value that has to be set in the relay.

Set the value under the setting menu:

Settings
Functions
Group n (n=1-4)
TimeDelayOC

For the parameter IN>.

Setting of time delay tN

Set the time delay of the function, tN, under the setting menu:

Settings
Functions
Group n (n=1-4)
TimeDelayOC

3 Two step time delayed phase overcurrent protection (TOC2)

3.1 Application

The time delayed phase overcurrent function is to be used as short-circuit protection in three phase networks operating at 50 or 60 Hz. It is intended to be used either as primary protection or back-up protection for differential functions or impedance measuring functions.

In radial networks it is often sufficient to use phase overcurrent relays as short circuit protection for lines, transformers and other equipment. The current time characteristic should be chosen according to common practice in the network. It is strongly recommended to use the same current time characteristic for all overcurrent relays in the network. This includes overcurrent protection for transformers and other equipment.

There is a possibility to use phase overcurrent protection in meshed systems as short circuit protection. It must however be realized that the setting of a phase overcurrent protection system in meshed networks, can be very complicated and a large number of fault current calculations are needed. There are situations where there is no possibility to have selectivity with a protection system based on overcurrent relays in a meshed system.

The measuring function contains one current measuring element for each phase, each of them with a low set and a high set measuring step. The low set step can have either definite time or inverse time characteristic. The characteristics available are extremely inverse, very inverse, normal inverse or RI inverse. The high set step has definite time delay.

The settings are common for all phases but both the low and high set step can be set On/Off individually and also have individual inputs for blocking.

3.2 Functionality

The time delayed overcurrent protection is used as short-circuit protection in power systems, either as the primary protection or as a back-up function for selective differential protection or impedance measuring protection.The protection function comprises of measuring circuits for the three phase currents, each with a low and high current setting. The low current setting has definite or inverse time-delay while the high current setting has only definite time-delay. The measuring circuits share common settings for all phases, however, both the low and high current settings can be blocked or enabled independent of the other setting.

Figure 61 shows a simplified logic diagram for the two step phase overcurrent protection.

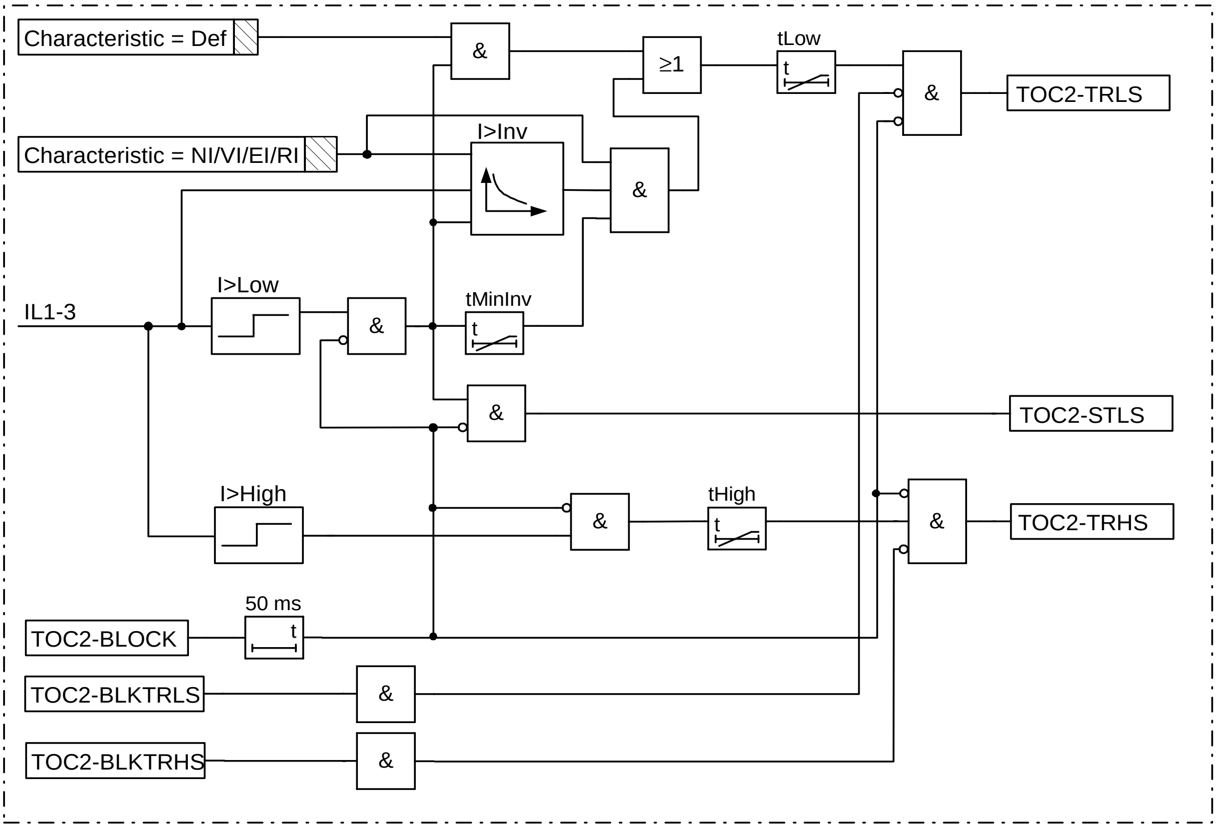


Figure 61: Two step time delayed phase overcurrent protection, simplified logic diagram

3.3 Calculations

3.3.1 Setting instructions

The phase overcurrent protection can be used in different applications. In most applications it is required that all short circuits within a protected zone shall be detected and cleared and the fault clearance shall be selective. As the protection can be used in several applications only some examples are discussed.

Line protection in radial network

The phase overcurrent protection is suitable to use in radial systems without any fault current infeed from the radial feeders.

The pick up current setting (inverse time relays) or the lowest current step (constant time relays) must be given a current setting so that the highest possible load current does not cause relay operation. Here consideration also has to be taken to the relay reset current, so that a short peak of overcurrent does not cause operation of the relay even when the overcurrent has ceased.

The lowest setting value can be written:

$$I_{pu} \geq 1.2 \cdot \frac{I_{max}}{k}$$

(Equation 112)

Where:

1.2	is a safety factor due to load estimation uncertainty etc.,
k	the resetting ratio of the relay (about 0.95) and
I_{max}	the maximum load current.

The maximum load current on the line has to be estimated. From operation statistics the load current up to the present situation can be found. Also emergency situations must be considered. The current setting must be valid also for some years ahead.

There is also a demand that all faults, within the zone that the protection shall cover, must be detected by the phase overcurrent relay. The minimum fault current Iscmin, to be detected by the relay, must be calculated. Taking this value as a base, the highest pick up current setting can be written:

$$I_{pu} \leq 0.7 \cdot I_{scmin}$$

(Equation 113)

Where:

0.7	is a safety factor, due to calculation uncertainty and
I_{scmin}	the smallest fault current to be detected by the overcurrent protection.

As a summary the pick up current shall be chosen within the interval:

$$1.2 \cdot \frac{I_{max}}{k} \leq I_{pu} \leq 0.7 \cdot I_{scmin}$$

(Equation 114)

The high current function of the overcurrent relay, which only has a short or no delay of the operation, must be given a current setting so that the relay is selective to other relays in the power system. It is desirable to have a rapid tripping of faults within as large portion as possible of the part of the power system to be protected by the relay (primary protected zone). A fault current calculation gives the largest current of faults, Iscmax, at the most remote part of the primary protected zone. Considerations have to be made to the risk of transient overreach, due to a possible DC component of the short circuit current. The lowest current setting of the most rapid stage, of the phase overcurrent relay, can be written:

$$I_{high} \geq 1.2 \cdot k_t \cdot I_{scmax}$$

(Equation 115)

Where:

1.2	is a safety factor, due to calculation uncertainty
k_t	is a factor that takes care of the transient overreach due to the DC component of the fault current. kt is less than 1.05 if the power system time constant is less than 100 ms.
I_{scmax}	is the largest fault current at a fault at the most remote point of the primary protection zone.

The operate times of the phase-overcurrent protection have to be chosen so that the fault time is so short that equipment will not be damaged due to thermal overload, at the same time selectivity is assured. For overcurrent protection, in a radial fed network, the time setting can be chosen in a graphical way. This is mostly used in the case of inverse time overcurrent protections.

Line protection in meshed network

The current setting can be made in the same way as for radial networks.

If inverse time characteristics are used with equal current and time setting for all phase current protections in the system the selectivity is assured as long as there are more than two bays carrying fault current to each substation. Sometimes this is however impossible due to the fault current distribution between the different lines.

If definite time characteristic is used the co-ordination between the different phase overcurrent line protections is done by means of current setting.

As the phase overcurrent protection often is used as a back-up protection of lines, where a distance protection is the main protection, relatively long operation times are acceptable for the phase overcurrent protection.

Setting characteristics

Following formulas are valid for the inverse time characteristic:

Table 6: Formulas for the inverse time characteristic

Characteristic:	Time delay(s):
Normal inverse	$t = \frac{0,14}{I^{0,02} - 1} \cdot k$ (Equation 116)
Very inverse	$t = \frac{13,5}{I - 1} \cdot k$ (Equation 117)
Extremely inverse	$t = \frac{80}{I^2 - 1} \cdot k$ (Equation 118)
RI inverse	$t = \frac{1}{0,339 - \langle (0,236) / I \rangle} \cdot k$ (Equation 119)

Where:

I	denotes (measured current)/ I>Inv and
k	is a time multiplier with setting range 0,05 - 1,10.

The decisive factors for the setting of inverse time characteristic are the allowable time for disconnection of fault at minimum fault current that the function shall operate for together with selectivity at maximum fault current.

The settings are given in Setting table. Setting of parameters are found in the menu under:

Settings
Functions
Group n (n=1-4)
InvTDelay

4 Two step time delayed directional phase overcurrent protection (TOC3)

4.1 Application

The time delayed phase overcurrent function is to be used as short-circuit protection in three phase networks operating at 50 or 60 Hz. It is intended to be used either as primary protection or back-up protection for differential functions or impedance measuring functions.

In radial networks it is often sufficient to use phase overcurrent relays as short circuit protection for lines, transformers and other equipment. The current time characteristic should be chosen according to common practice in the network. It is strongly recommended to use the same current time characteristic for all overcurrent relays in the network. This includes overcurrent protection for transformers and other equipment.

There is a possibility to use phase overcurrent protection in meshed systems, as short circuit protection. It must however be realized that the setting of a phase overcurrent protection system in meshed networks, can be very complicated and a large number of fault current calculations are needed. There are situations where there is no possibility to have selectivity with a protection system based on overcurrent relays in a meshed system.

In some applications the possibility of obtaining selectivity can be improved significantly if a directional phase overcurrent function is used. This can be the case in meshed networks and in radial networks with generation connected remote in the system, thus giving fault current infeed in “reverse” direction.

The measuring function contains one current measuring element for each phase, each of them with a low set and a high set measuring step. The low set step can have either definite time or inverse time characteristic. The characteristics available are extremely inverse, very inverse, normal inverse or RI inverse. The high set step has definite time delay.

The settings are common for all phases but both the low and high set step can be set On/Off individually and also got individual inputs for blocking.

4.2 Functionality

4.2.1 Theory of operation and design

Current measuring element

The current measuring element continuously measures the current in all phases and compares it to the set operating values for the two steps. If the current is above set value the corresponding output signal will be set. If the current is above both the setting I>Low and I>Inv the inverse time evaluation according to choosen characteristic starts and the INV signal sets after corresponding time. A filter ensures immunity to disturbances and DC-components and minimizes the transient overreach. A simplified block diagram is found in figure 62. The function is true phase segregated. This means that there are identical measuring elements in each phase.

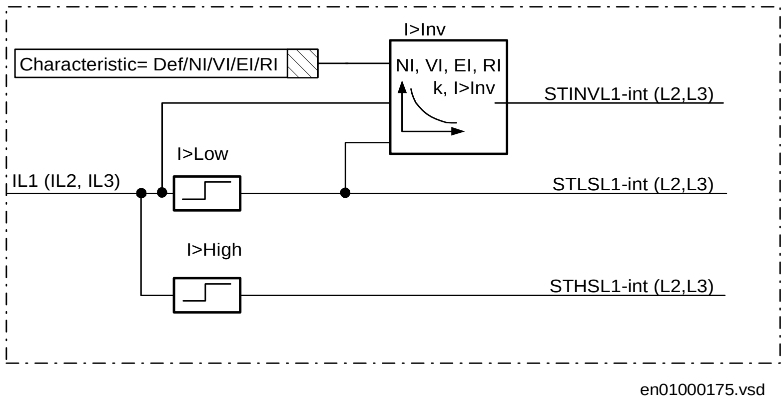


Figure 62: Simplified block diagram for definite and inverse time delayed phase overcurrent function

The inverse time delay can be set for different characteristics by the setting Characteristic = x, the x is choosen from the following:

1. Def (Definite time)
2. NI (Normal inverse)
3. VI (Very inverse)
4. EI (Extremely inverse)
5. RI (Inverse time corresponding to relays of type RI)

With setting Characteristic = Def the signal INV will be set to zero.

The different inverse time characteristics are defined in the “Technical reference manual”.

Directional overcurrent function

The directional overcurrent function uses the information from the current measuring elements as described in "Current measuring element" and the directional impedance measuring element as described for the distance protection function, to create the directional overcurrent function.

Directional phase selection

In order to use correct directional information during all types of faults the function is provided with a simple phase selection. The phase selection is assigned to distinguish between phase to earth faults and phase to phase faults.

The criteria for the two indications that are regarded in the function are:

Phase to earth fault (PE FAULT):

$$3 \cdot I_0 \geq 0.5 \cdot IMinOp$$

(Equation 120)

and

$$3 \cdot I_0 \geq INReleasePE / 100 \cdot I_{phmax}$$

(Equation 121)

Phase to phase fault (PP FAULT):

$$3 \cdot I_0 < 0.2 \cdot I_r$$

(Equation 122)

OR

$$3 \cdot I_0 < INBlockPP / 100 \cdot I_{phmax}$$

(Equation 123)

If the criteria for PE FAULT are fulfilled the phase to earth directional indications are used and if the criteria for PP FAULT are fulfilled the phase to phase directional indications are used. If all criteria are met, then only the directional indications for phase to phase are released. The aim is to preserve the phase to phase measurement also during two-phase to ground faults with high residual current (at least as long as the criteria allows, see equations above). However, the directional indications will appear also for healthy phases and in the phase to phase case the indications would overlap in an unwanted manner because the overcurrent evaluation is performed per phase only (both forward and reverse can be indicated for one phase, simultaneously). So in order to establish a complete directional phase selection the one and only faulty loop must be singled out. This is done by means of releasing the directional indication with the corresponding overcurrent indications (overcurrent in two phases is required, see figure 63).

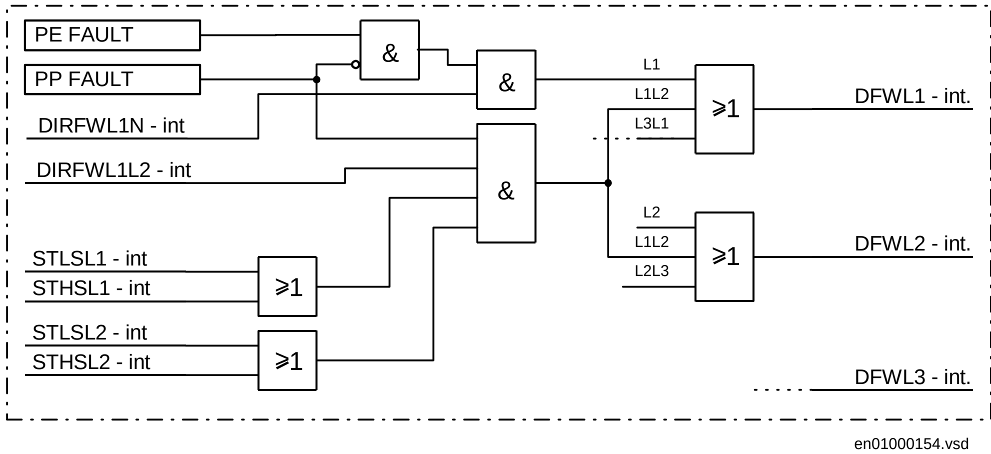


Figure 63: Excerpt from directional phase selection

Consider the case where a reverse fault is cleared and the prefault forward load conditions are retrieved. So, in order not to issue a false trip if the reversal indication is deactivated (or the forward indication becomes active) before the overcurrent indication drops, the reversal of direction is actually held back during 50 ms according to the logic of figure 64. Each phase and each set stage is provided with an individual logic circuit (six circuits in all) to allow operation during simultaneous earth faults (one forward, one reverse).

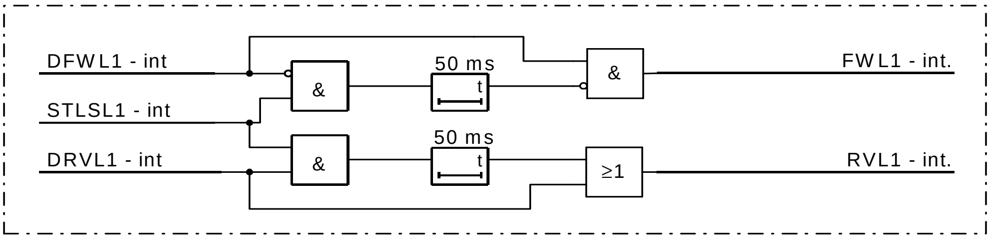


Figure 64: Current reversal logic for one phase and one set step

General overcurrent operating principles

The low and high set steps can individually be set directional or non-directional. If set in non-directional mode the overcurrent function only uses the signals from the current measuring elements as seen from figure 62. In directional mode there are two modes of operation, forward release and reverse block denoted ForwRelease and RevBlock respectively. The principles of these three modes of operation are illustrated in figure 65, below.

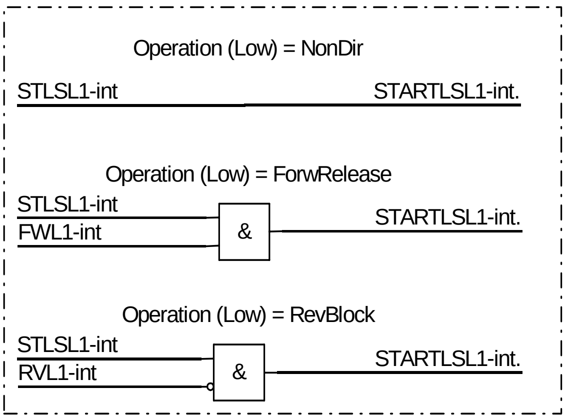


Figure 65: Directional operation modes of TOC3

In forward release operation mode a criteria that indicates that the fault is in forward direction is needed for tripping. Since the directional function needs voltage for the directional check it will not be able to operate when switching in a line against a persistent close-up three phase fault if voltage is measured on the line side of the breaker. A solution to this might be to use the SOTF function for the distance protection, with output TOC3-STND as acceleration signal.

In reverse block operation mode a criteria that indicates that the fault is in reverse direction is used for blocking the function. In this case there is no problem switching in a line against a persistent close-up three phase fault even if voltage is measured on the line side of the breaker since the directional function will not issue any reverse signal.

The general principles of time delay for the two steps of the overcurrent function is displayed in the following figure 66.

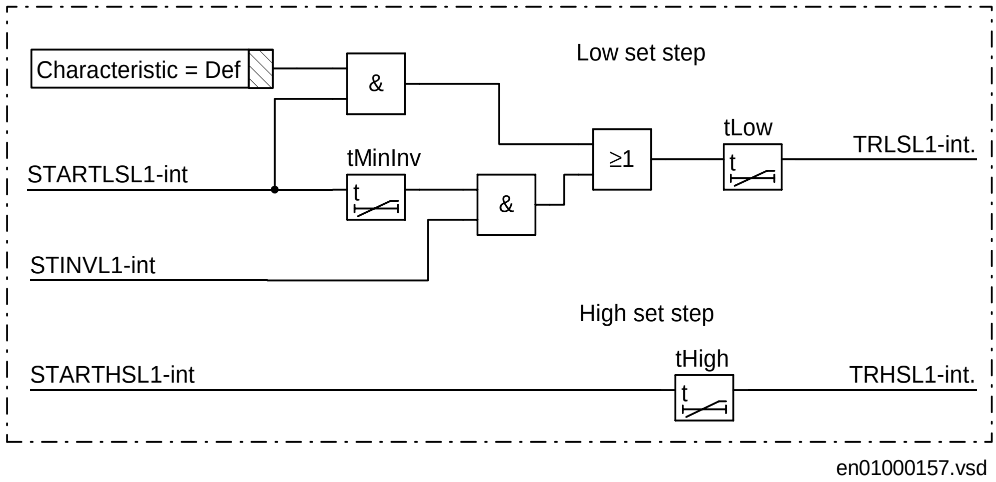


Figure 66: Delayed time operation for low set step and general time delay

General trip signals are derived from the phase segregated starts according to figure 67.

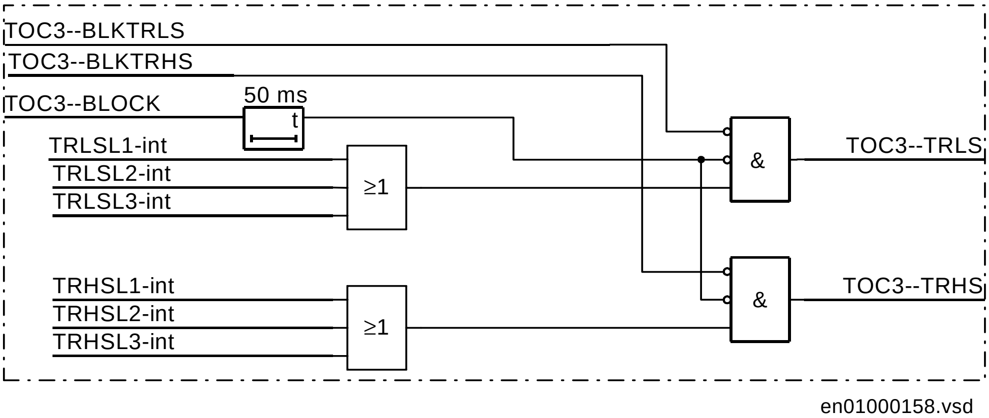


Figure 67: General trip

With setting Characteristic = Def (figure 66) the signal TOC3-TRLS will be active if, at least, one of the phase currents exceeds the set value I>Low for the low set step, and if the directional criterion is fulfilled for a longer time than the set delay tLow.

With setting Characteristic = NI/VI/EI or RI (figure 66) we have the following: If, at least one of the phase currents exceeds the set value I>Low, the timer circuit tMinInv is activated together with the inverse time measuring circuit (figure 62) in order to calculate the operating time. The operating time is determined by the magnitude of the current, characteristic choosen, set characteristic current I>Inv and time multiplier k. When both the inverse time and tMinInv have elapsed the timer tLow will be activated and after its time is elapsed the signal TOC3-TRLS is activated. It must be observed that the time delay of operation, if inverse time characteristics is used, will be the sum of the inverse time delay and the tLow setting.

The timer circuit tMinInv (figure 66) can be used to achieve a defined minimum operating time at high fault currents. The timer circuit tLow can be used for adding an additional time delay to the inverse time characteristic.

The signal TOC3-TRHS will be active if one of the phase currents exceeds the set value I>High for a longer time than the set delay tHigh at the same time as TOC--BLKTRSH and TOC--BLOCK are not present.

An external signal connected to TOC3_BLKTRLS will block tripping from low set step. The step can also be blocked with the setting Operation Low= Off.

An external signal connected to TOC3_BLKTRHS will block tripping from high set step. The step can also be blocked with the setting Operation High= Off.

An external signal connected to TOC3_BLOCK will block both low and high set steps.

Figure 68 illustrates how the start signals are formed.

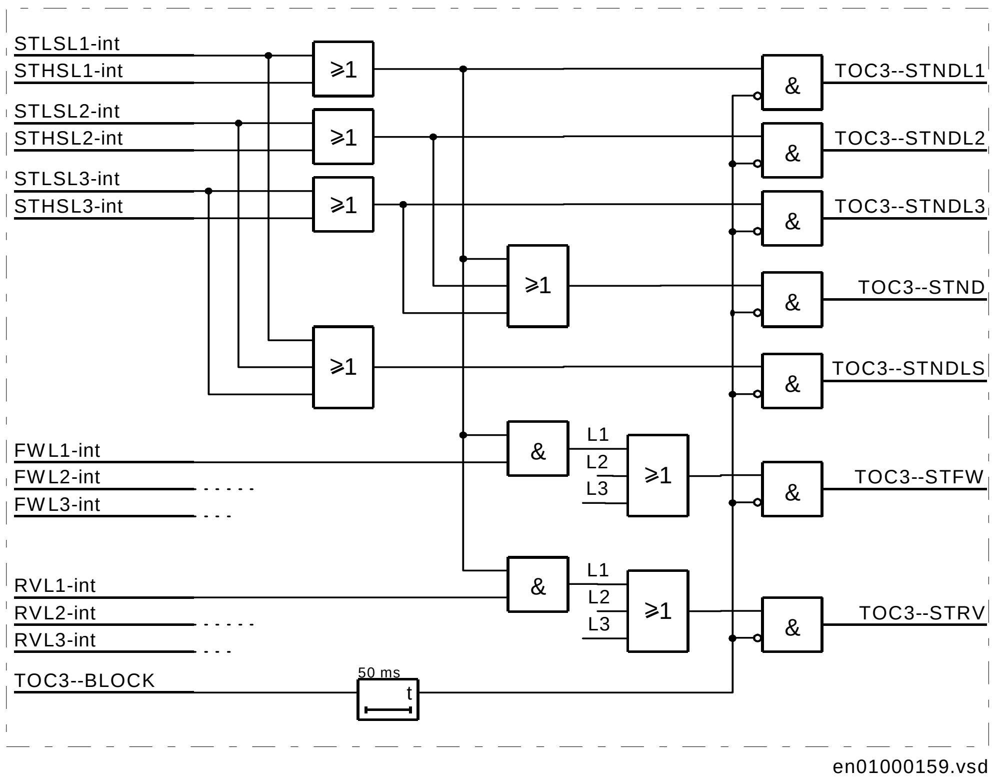


Figure 68: Start signals

As the phase segregated start signals are non directional, and used for indication only, there is no possibility to use a phase segregated transfer trip scheme. A three-phase transfer trip scheme will be applicable using the output TOC3-STFW or TOC3-STRV, keeping in mind the performance expected during simultaneous faults on parallel lines.

4.3 Calculations

4.3.1 Setting instructions

The directional phase overcurrent protection can be used in different applications. In most applications it is required that all short circuits within a protected zone shall be detected and cleared and the fault clearance shall be selective. As the protection can be used in several applications only some examples are discussed.

Line protection in a radial network

The directional phase overcurrent protection is suitable to use in radial systems with generation connected out in the system. In such a network the fault current can be fed both in the forward and reverse direction. Normally the protection will detect and trip faults in the forward direction.

The pick up current setting (inverse time functions) or the lowest current step (constant time functions) must be given a current setting so that the highest possible load current does not cause operation of the function. The reset ratio of the function has to be taken into consideration, so that a short peak of overcurrent does not cause operation of the protection even when the overcurrent has ceased.

The lowest setting value can be written:

$$I_{pu} \geq 1.2 \cdot \frac{I_{max}}{k}$$

(Equation 124)

Where:

1.2	is a safety factor due to load estimation uncertainty etc.,
k	the resetting ratio of the relay (about 0.95) and
I_{max}	the maximum load current.

The maximum load current on the line has to be estimated. From operation statistics the load current up to the present situation can be found. Also emergency situations must be considered. The current setting must be valid also for some years ahead.

There is also a demand that all faults, within the zone that the protection shall cover, must be detected by the phase overcurrent relay. The minimum fault current Iscmin, to be detected by the relay, must be calculated. Taking this value as a base, the highest pick up current setting can be written:

$$I_{pu} \leq 0.7 \cdot I_{scmin}$$

(Equation 125)

Where:

0.7 is a safety factor, due to calculation unsertainty and

I_{scmin} the smallest fault current to be detected by the overcurrent protection.

As a summary the pick up current shall be chosen within the interval:

$$1.2 \cdot \frac{I_{max}}{k} \le I_{pu} \le 0.7 \cdot I_{scmin}$$

(Equation 126)

The high current function of the overcurrent protection, which only has a short or no delay of the operation, must be given a current setting so that the protection is selective to other protections in the power system. It is desirable to have a rapid tripping of faults within as large portion as possible of the part of the power system to be protected by the relay (primary protected zone). A fault current calculation gives the largest current of faults, Iscmax, at the most remote part of the primary protected zone. The risk of transient overreach, due to a possible DC component of the short circuit current has to be taken into consideration. The lowest current setting of the most rapid stage, of the phase overcurrent relay, can be written:

$$I_{high} \ge 1.2 \cdot k_t \cdot I_{scmax}$$

(Equation 127)

Where:

1.2 is a safety factor, due to calculation unsertainty

k_t is a factor that takes care of the transient overreach due to the DC component of the fault current. kt is less than 1.05 if the power system time constant is less than 100 ms.

I_{scmax} is the largest fault current at a fault at the most remote point of the primary protection zone.

The operate times of the phase overcurrent relay have to be chosen so that the fault time is so short that equipment will not be damaged due to thermal overload, at the same time selectivity is assured. For overcurrent protection in a radial fed network, the time setting can be chosen in a graphical way. This is mostly used in the case of inverse time overcurrent protection.

Line protection in meshed network

The current setting can be made in the same way as for radial networks.

If inverse time characteristics are used with equal current and time setting for all phase current protections in the system the selectivity is assured as long as there are more than two bays carrying fault current to each substation. Sometimes this is however impossible due to the fault current distribution between the different lines.

If definite time characteristic is used the coordination between the different phase overcurrent line protections are done by means of current setting.

As the phase overcurrent protection often is used as a back-up protection of lines, where a distance protection is the main protection, relatively long operation times are acceptable for the phase overcurrent protection.

Setting characteristics

The setting parameters and ranges are shown in the setting table.

Following formulas are valid for the inverse time characteristic:

Table 7: Formulas for the inverse time characteristic

Characteristic:	Time delay(s):
Normal inverse	$t = \frac{0,14}{I^{0,02} - 1} \cdot k$ (Equation 128)
Very inverse	$t = \frac{13,5}{I - 1} \cdot k$ (Equation 129)
Extremely inverse	$t = \frac{80}{I^2 - 1} \cdot k$ (Equation 130)
RI inverse	$t = \frac{1}{0,339 - \langle (0,236)/I \rangle} \cdot k$ (Equation 131)

Where:

I	denotes (measured current)/ I>Inv and
k	is a time multiplier with setting range 0,05 - 1,10.

The decisive factors for the setting of inverse time characteristic are the allowable time for disconnection of fault at minimum fault current that the function shall operate for together with selectivity at maximum fault current.

The settings are given in Setting table. Setting of parameters are found in the menu under:

Settings
Functions
Group n (n=1-4)
DirInvTDelay

5 Definite and inverse time-delayed residual overcurrent protection (TEF)

5.1 Application

This earth-fault overcurrent protection is intended for solidly earthed networks.

Earth-fault overcurrent protection

In case of single-phase earth-faults, the primary fault resistance varies with the network conditions, the type of fault and location of the fault. In many cases, the fault resistance is much higher than the resistance that can be covered by an impedance-measuring distance protections. This can be the case with a phase to earth fault to a tower with large tower footing resistance.

Earth-faults with high fault resistances can be detected by measuring the residual current ($3I_0$).

The inrush current can cause unwanted tripping of the earth-fault overcurrent relay when energizing a directly earthed power transformer. The earth-fault overcurrent protection is therefore provided with second harmonic restraint, which blocks the operation if the residual current ($3I_0$) contains 20% or more of the second harmonic component.

In some cases, it is possible to improve the selectivity by adding a settable minimum operate current (IMin) and a minimum operate time (tMin) to the inverse characteristic. These functions are included in the earth-fault protection modules.

To minimize the operate time, in case of closing the circuit breaker to a fault, the residual overcurrent protection module is provided with a switch-onto-fault logic, which can be activated at breaker closure. The tripping time will temporarily be reduced to 300 ms.

In order to achieve the most sensitive earth fault protection the non-directional function can be used. As the residual current is normally very small during normal operation the setting value can be set very low. In case of small residual currents, due to high resistance phase to earth faults or serial faults, the residual voltage in the system can be very low. A serial fault can be caused by broken phase conductor(s) with no contact to earth, or pole discrepancy in a circuit breaker or a disconnector. The most common type of serial fault is pole discrepancy at breaker maneuvers.

As the residual voltage is often very small at high resistance earth faults and serial faults, any directional element can not be used.

The function can have different types of time-current characteristics; definite time delay or different types of inverse time delay. By using the inverse time delay characteristics some degree of selectivity between non-directional residual protection can be achieved.

Directional earth-fault protection is obtained by measuring the residual current and the angle between this current and the zero-sequence voltage ($3U_0$).

It is possible to obtain the polarizing voltage ($-3U_0$) from an open delta winding in the voltage transformer or via summation of the three phase voltages supplied to the terminal.

The $3I_0$ current lags the polarizing voltage ($-3U_0$) by a phase angle equal to the angle of the zero-sequence source impedance. In solidly earthed networks, this angle is in the range of 40° to nearly 90°. The high value refers to stations with directly earthed transformers with delta winding. To obtain maximum sensitivity at all conditions, the forward measuring element should have a characteristic angle of 65°.

As a general rule, it is easier to obtain selectivity by using directional instead of non-directional earth-fault overcurrent protection, but sufficient polarizing voltage must be available.

It is not possible to measure the distance to the fault by using the zero-sequence components of the current and voltage, because the zero-sequence voltage is a product of the zero-sequence components of current and source impedance. It is possible to obtain selectivity by the use of a directional comparison scheme, which uses communication between the line ends.

If a communication scheme can not be used, the best selectivity is generally obtained by using inverse time delay. All relays, in the network, must have the same type of inverse characteristic. An earth-fault on a line is selectively tripped if the difference between the residual current ($3I_0$) out on the faulted line and the residual current ($3I_0$) out on the other lines gives a time difference of 0.3-0.4 seconds. A logarithmic characteristic is generally the most suitable for this purpose, because the time difference is constant for a given ratio between the currents.

Directional comparison logic function

In the directional comparison scheme, information of the fault current direction must be transmitted to the other line end. A short operate time enables auto-reclosing after the fault. During a single-phase reclosing cycle, the auto-reclosing device must block the directional comparison earth-fault scheme.

A communication logic block for residual overcurrent protection can be included in the REx 5xx terminal to provide this feature. The function contains circuits for blocking overreach and permissive overreach schemes. See the section *“Communication logic for residual overcurrent protection”*.

Also an additional communication logic block for the communication can be included. It contains logic for the weak-end-infeed and current-reversal functions, which are used only in the permissive overreach scheme. See the section *“Current reversal and weak end infeed logic for residual overcurrent protection*.

5.2 Functionality

5.2.1 Theory of operation

Directional earth-fault overcurrent protection

This protection measures the residual current ($3I_0$) and the residual voltage ($3U_0$). Figure 69 shows the current measuring, time delay and logic circuits (both with and without directional check) of this protection function.

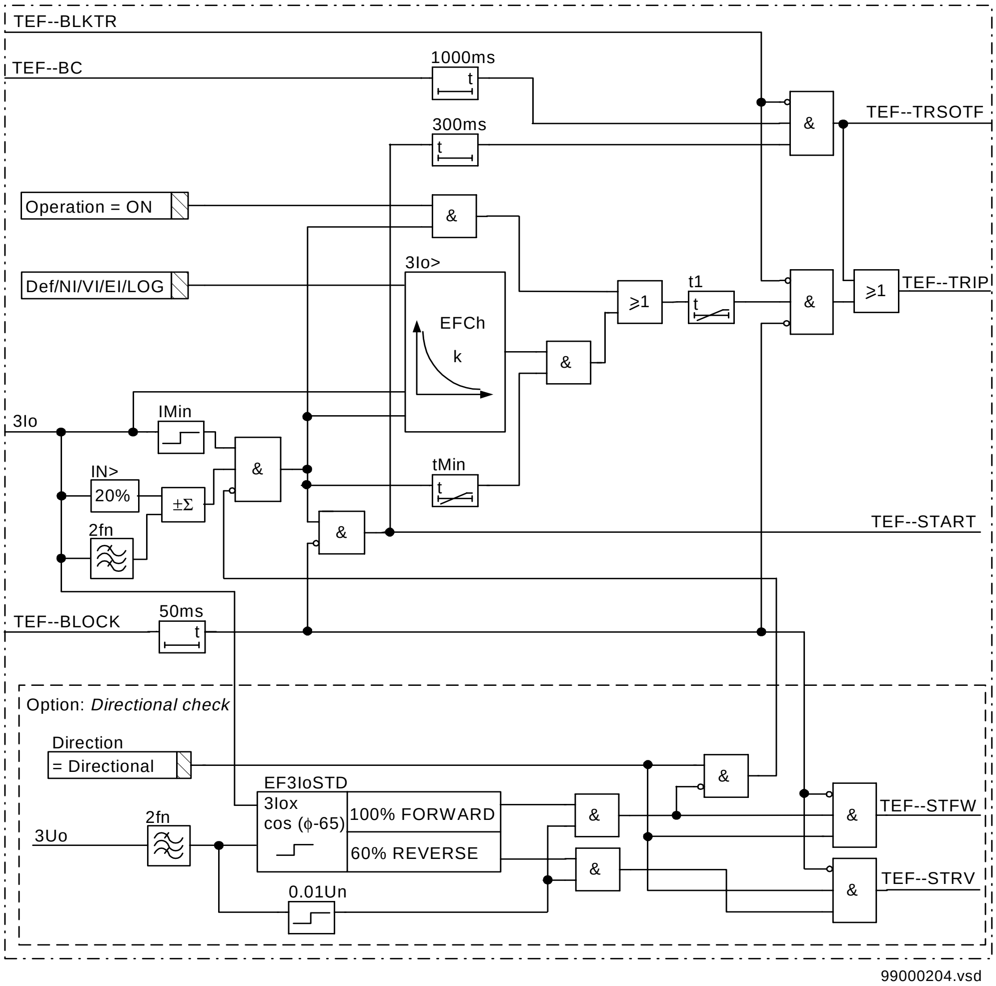


Figure 69: Simplified logic diagram for the residual overcurrent protection

Activate the independent time-delay function by setting *Characteristic*= Def (or inverse time delay according to the setting table). The t1 timer starts when both the definite/inverse time characteristic and the tMin timer operate. The tMin timer starts when the $3I_0$ current to the relay is equal to or higher than the set operate value for IMin and the content of the second harmonic in $3I_0$ is less than 20%.

The inverse time calculation starts when $3I_0$ is equal to or higher than the set operate value for IMin and the content of the second harmonic in $3I_0$ is less than 20%. The inverse time delay is determined by the selection of the characteristic (NI, VI etc.) in the Characteristic setting and the setting of the characteristic IN> current.

The t1 timer is normally set to zero. Use it to add a constant time to the inverse time delay. Figure 70 shows the effect of the IMin and tMin settings on the inverse characteristic.

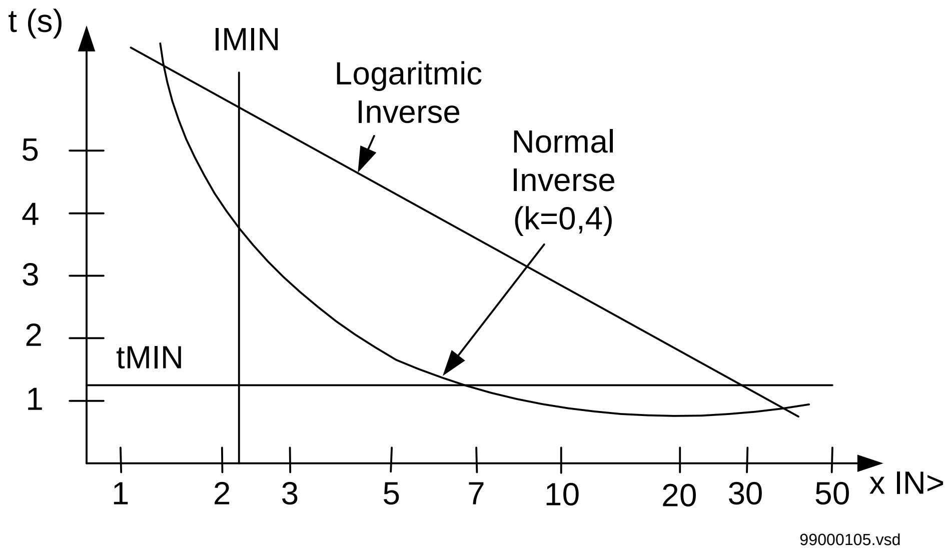


Figure 70: Normal inverse and logarithmic inverse time characteristics.

The switch-onto-fault function is used to minimise the operate time in case of pole discrepancy at breaker closing and in cased of closing on to a fault. The function is released by activating the TEF--BC binary input. The function is activated for 1 second after the reset of the TEF--BC binary input.

The function is blocked by activating the TEF--BLOCK binary input.

Activating the TEF--BLKTR blocks the definite/inverse delay trip outputs TEF--TRIP and the switch-on-to-fault trip TEF-TRSOTF.

The $3I_0$ current lags the polarising voltage ($3U_0$) by a phase angle equal to the angle of the zero-sequence source impedance. The forward measuring element operates when:

$$3I_0 \cdot \cos(\varphi - 65°) \geq IN{>}Dir$$

(Equation 132)

Where:

φ	is the angle between $3I_0$ and $3U_0$ (positive if $3I_0$ lags $3U_0$)
IN>Dir	is the set operate value

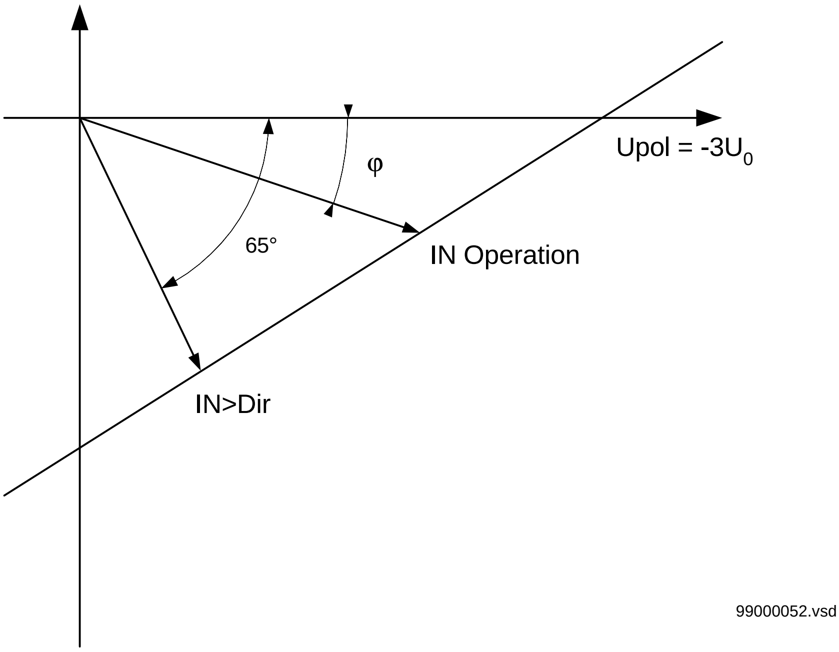


Figure 71: Measuring characteristic of the directional element

The change in operate value is small when the phase angle deviates moderately from 65°. A deviation of 20° increases the operate value by only 6.5%.

The polarising voltage, normally obtained from the broken delta windings of the VTs, can have a high content of harmonics relative to the fundamental frequency when the output voltage is low, particularly when capacitive VTs are used. To secure a correct measurement, the directional function must have an effective bandpass filtering of the voltage. In the module, the filtering secures a correct function for fundamental frequency polarising voltages down to 1% of the rated voltage.

In case of an external fault, the capacitive current generated on the line decreases the current to the earth-fault relay situated at the line end towards the fault. So the reverse direction comparator must have an increased sensitivity to secure reliable blocking in case of external faults when a directional comparison or a blocking communication scheme is used. The operate current of the reverse direction measuring element in the module is, as a fixed ratio, set at 0.6 IN> Dir.

5.3 Calculations

5.3.1 Setting instructions

To detect high resistive earth-faults, a low operate current is required. On the other hand, a low setting increases the risk for unwanted operation due to imbalance in the network and the current transformer circuits. Set the minimum operate current (IN> *IMin) of the earth-fault overcurrent protection higher than the maximum false earth-fault current. If the directional function is chosen, set the start level of the directional function (IN> Dir) higher than the maximum false earth-fault current.

The imbalance in the network that causes false earth-fault currents is caused mainly by untransposed or not fully transposed parallel lines with strong zero-sequence mutual coupling. There might also be high imbalance currents for non-transposed single circuit lines if the zero sequence source impedance is low at both line ends. This false earth-fault current is directly proportional to the load current.

In a well-transposed system, the false earth-fault current is normally lower than 5% of the line current.

In case of not fully transposed parallel lines, measure or calculate the false earth-fault current at maximum load.

The choice of time delay characteristics - definite time, normal inverse, very inverse, extremely inverse or logarithmic inverse - depends on the network. To achieve optimum selectivity, use the same type of characteristic for all earth-fault overcurrent protections in the network. This means that in networks already equipped with earth-fault overcurrent relays, the best selectivity is normally achieved by using the same type of characteristic as in the existing relays.

The following formulas for the operate time (in seconds) apply to the characteristic used within the REx 5xx terminal with line protection, see table 8.

Table 8: Operate time formulas

Characteristics	**Operate time (s)**
Normal inverse	$t = \frac{0.14}{I^{0.02} - 1} \cdot k$ (Equation 133)
Very inverse	$t = \frac{13.5}{I - 1} \cdot k$ (Equation 134)
Extremely inverse	$t = \frac{80}{I^2 - 1} \cdot k$ (Equation 135)
Logarithmic inverse	$t = 5.8 - (1.35 \cdot \ln I)$ (Equation 136)

Where:

I is a multiple of set current $3I_0>$

k is a time multiplying factor, settable in the range of 0.05 to 1.10

All inverse time characteristic settings are a compromise between short fault clearing time and selective operation in a large current range. The main determining factors are the maximum allowed fault-clearing time at the maximum fault resistance to be covered and the selectivity at maximum fault current.

Set the minimum operate current (IMin) of the earth-fault overcurrent protection to one to four times the set characteristic quantity (IN>) of the inverse time delay. So an inverse characteristic with a low set IN> set to get a short operate time at minimum fault current can be combined with a higher set IMin minimum operate current, to avoid unwanted operation due to false earth-fault currents.

Set the minimum operate time independent of the inverse time characteristic. Normally, set this time longer than the time delay of distance zone 2 in REx 5xx to avoid interference with the impedance measuring system in case of earth-faults with moderate fault resistance within zone 2.

When a solidly earthed, power transformer is energized, an inrush current normally flows in the neutral-to-earth connection of the transformer. This current is divided among other earthed transformers and lines connected to the same bus, inversely proportional to their zero-sequence impedance. The amplitude and time duration of this current can be sufficiently large to cause the unwanted operation of a sensitive earth-fault overcurrent protection.

The earth-fault overcurrent protection has a built-in second harmonic current stabilization, which prevents unwanted operation if the inrush current has a second harmonic content of 20% or more. This is normally the case. On rare occasions, it may be necessary to increase the setting of the operate value for the residual earth-fault overcurrent protection to avoid unwanted operation due to transformer inrush current.

When single-phase auto-reclosing is used, the minimum time of the inverse time delayed residual overcurrent protection (tMin) should be set to be longer than the time from the occurrence of the fault to the reclosing of the breaker at both line terminals. An alternative method is to block the earth fault protection by the autorecloser during the dead time. This avoids unwanted three-phase tripping during a single-phase auto-reclosing cycle controlled by the distance protection.

The polarizing voltage for directional earth-fault overcurrent protection is normally obtained from the broken delta windings of instrument voltage transformers or by internal calculation. The voltage contains a certain amount of harmonics, especially when the protection is connected to CVTs.

Due to the bandpass filtering a polarizing voltage down to 1 percent of the rated voltage will provide correct directional functionality. This is also valid when the protection is connected to CVTs.

The minimum polarizing voltage to the protection (Umin) is calculated from the formula:

$$U_{min} = I_{F\ min} \cdot Z_{0\ min} \cdot \frac{U_{sec}}{U_{prim}}$$

(Equation 137)

Where:

I_{Fmin}	is the minimum primary operate fault current
Z_{0min}	is the minimum zero-sequence impedance seen from the relay
U_{sec}, U_{prim}	are the rated phase voltages of the broken delta connected CVTs (VTs)

Observe that when a blocking scheme or a permissive scheme with current reversal or weak-end-infeed logic is used, IFmin represents the primary operate current of the reverse-looking directional element which is 60% of the forward element.

To even secure operation in unfavorable cases, Umin must be equal to at least 1 volt plus the maximum network frequency false voltage, due to measuring errors in the VT circuits.

If not blocked, the directional comparator operates during the dead time in case of a single-phase auto-reclosure. So the TEF--BLOCK blocking input must be activated during the single-phase auto-reclosing cycle.

6 Scheme communication logic for residual overcurrent protection (EFC)

6.1 Application

This communication logic is intended for residual overcurrent protections.

To achieve fast fault clearing for a fault on the part of the line not covered by the instantaneous zone 1, the directional residual overcurrent protection function can be supported with logic, that uses communication channels.

One communication channel in each direction, which can transmit an on/off signal is required. The performance and security of this function is directly related to the transmission channel speed and security against false or lost signals. So special channels are used for this purpose. When power line carrier is used for communication, these special channels are strongly recommended due to the communication disturbance caused by the primary fault.

In the directional comparison scheme, information of the fault current direction must be transmitted to the other line end.

With directional comparison, an operate time of 50-60 ms, including a channel transmission time of 20 ms, can be achieved. This short operate time enables rapid automatic reclosing function after the fault.

During a single-phase reclosing cycle, the auto-reclosing device must block the directional comparison earth-fault scheme.

The communication logic module for the REx 5xx terminal contains circuits for blocking overreach and permissive overreach schemes. The module also contains logic for the weak-end-infeed and current-reversal functions, which are used only in the permissive overreach scheme.

6.2 Functionality

6.2.1 Theory of operation

Directional comparison logic function

The directional comparison function contains logic for blocking overreach and permissive overreach schemes.

The circuits for the permissive overreach scheme contain logic for current reversal and weak-end-infeed functions. These functions are not required for the blocking overreach scheme.

Use the independent or inverse time functions in the directional earth-fault protection module to get back-up tripping in case the communication equipment malfunctions and prevents operation of the directional comparison logic.

Connect the necessary signal from the auto-recloser for blocking of the directional comparison scheme, during a single-phase auto-reclosing cycle, to the EFC--BLOCK input of the directional comparison module.

Blocking scheme

In the blocking overreach scheme, a signal is sent to the other line end if the directional element detects a fault in the reverse direction. When the forward directional element operates, it trips the line after a short time delay if no blocking signal is received from the other line end. The time delay, normally 30-40 ms, depends on the communication transmission time and the chosen safety margin.

One advantage of the blocking scheme is that only one channel (carrier frequency) is needed and the channel can be shared with the impedance-measuring system, if that also works in the blocking mode. The communication signal is also transmitted on a healthy line and no signal attenuation will occur due to the fault.

Blocking schemes are particularly favourable for three-terminal applications if there is no zero-sequence current outfeed from the tapping. The blocking scheme is immune to current reversals because the received carrier signal is maintained long enough to avoid unwanted operation due to current reversal. There is neither any need for weak-end-infeed logic, because the strong end trips for an internal fault when no blocking signal is received from the weak end. But the fault clearing time is generally longer for a blocking scheme than for a permissive one.

If the fault is on the line, the forward direction measuring element operates. If no blocking signal comes from the other line end via the EFC--CR binary input (carrier receive) the EFC--TRIP output is activated after the tCoord set time delay.

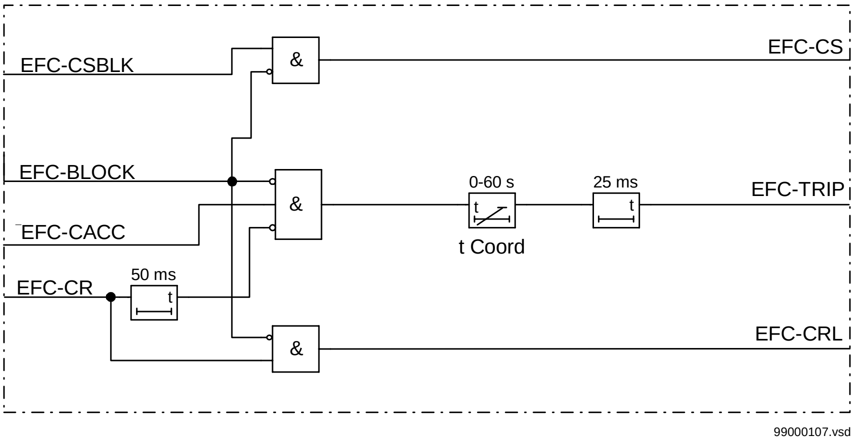


Figure 72: Simplified logic diagram, Scheme type = blocking

Permissive overreach scheme

In the permissive scheme, the forward directed measuring element sends a permissive signal to the other line end if a fault is detected in the forward direction. The directional element at the other line end must wait for a permissive signal before giving a trip signal. Independent channels (frequencies) must be available for the communication in each direction.

An impedance-measuring relay which works in an underreach permissive mode with one channel in each direction can share the channels with the earth-fault overcurrent protection. If the impedance measuring relay works in the permissive overreach mode, common channels can be used in single-line applications. In case of double lines connected to a common bus at both ends, use common channels only if the ratio Z_{1S} / Z_{0S} (positive through zero-sequence source impedance) is about equal at both line ends. If the ratio is different, the impedance measuring and the directional earth-fault current system of the healthy line may detect a fault in different directions, which could result in unwanted tripping.

Common channels can not be used when the weak-end-infeed function is used in the distance or earth-fault protection.

In case of an internal fault, the forward directed measuring element operates and sends a permissive signal to the remote end via the EFC--CS output (carrier send). Local tripping is permitted when the forward direction measuring element operates and a permissive signal is received via the EFC--CR binary input (carrier receive).

The total operate-time for the system is the sum of the Pick-up time (of the measuring element) and the Transmission time (of the permissive signal)

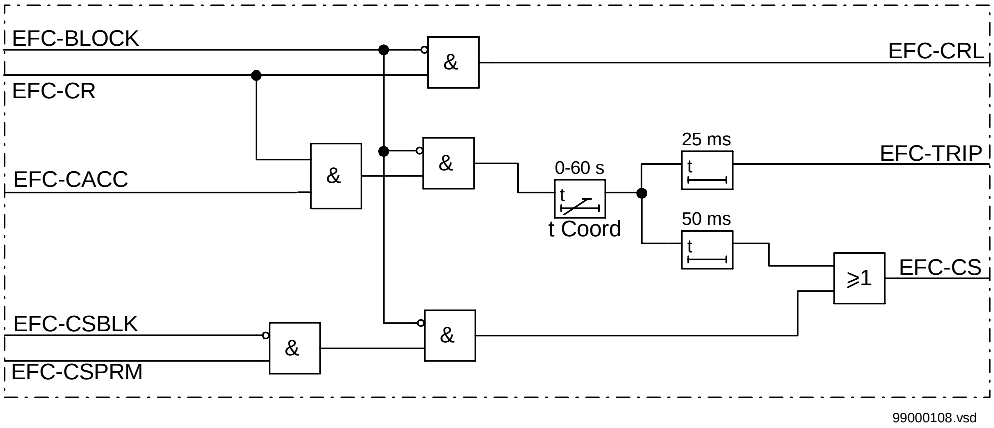


Figure 73: Simplified logic diagram, Scheme type = permissive

6.3 Design

Blocking scheme

In the blocking scheme, a signal is sent to the other line end if the directional element in TEF function, connected to the EFC--CSBLK input signal, detects a fault in the reverse direction. When the forward directional element operates, it trips the line after a short time delay if no blocking signal is received from the other line end. The time delay, normally 30-40 ms, depends on the communication transmission time and the chosen safety margin.

Permissive overreaching scheme

In the permissive scheme, the forward direction measuring element in TEF function, connected to the EFC--CSPRM input, sends a permissive signal to the other line end if a fault is detected in the forward direction. The directional element at the other line end must wait for a permissive signal before giving a trip signal. Independent channels (frequencies) must be available for the communication in each direction.

6.4 Calculations

6.4.1 Setting

The settings are done from the local HMI under the menu:

Settings
Functions
Group n (n = 1.4)
Earth Fault
EFCom

Blocking scheme

In the blocking scheme, set the tCoord timer to the channel transmission time during disturbance conditions. Add a margin of 20-30 ms. Two times the nominal value of the channel transmission time is recommended when a power line carrier is used.

Permissive communication scheme

In the permissive communication scheme, the security against unwanted operation caused by spurious carrier receive signals can be increased by delaying the tripping output with the tCoord timer. Set the timer in the range of 0.000 to 60.000 s. In most cases, a time delay of 30 ms is sufficient.

7 Current reversal and weak end infeed logic for residual overcurrent protection (EFCA)

7.1 Application

This additional communication logic is intended for the Communication logic for residual overcurrent protections.

To achieve fast fault clearing for a fault on the part of the line not covered by the instantaneous zone 1, the earth-fault protection functions can be supported with logic, that uses communication channels. REx 5xx terminals have for this reason available a scheme communication logic. Different system conditions require in many cases additional special logic circuits, like current reversal logic and weak-end-infeed logic. Both functions are available within the additional communication logic for earth-fault protection.

Current reversal logic

If parallel lines are connected to common buses at both terminals, overreaching permissive communication schemes can trip unselectively due to fault current reversal. This unwanted tripping affects the healthy line when a fault is cleared on the other line. This lack of security can result in a total loss of interconnection between the two buses.

To avoid this type of disturbance, a fault current-reversal logic (transient blocking logic) can be used.

Weak end infeed logic

Permissive communication schemes can basically operate only when the protection in the remote terminal can detect the fault. The detection requires a sufficient minimum fault current. The fault current can be too low due to an opened breaker or low short-circuit power of the source. To overcome these conditions, weak end infeed (WEI) echo logic is used.

The fault current can also be initially too low due to the fault current distribution. Here, the fault current increases when the breaker opens in the strong terminal and a sequential tripping is achieved. This requires a detection of the fault by an independent-tripping zone 1. To avoid sequential tripping as described and when zone 1 is not available, weak end infeed tripping logic is used.

7.2 Functionality

7.2.1 Theory of operation

Directional comparison logic function

The directional comparison function contains logic for blocking overreach and permissive overreach schemes.

The circuits for the permissive overreach scheme contain logic for current reversal and weak end infeed functions. These functions are not required for the blocking overreach scheme.

Use the independent or inverse time functions in the directional earth-fault protection module to get back-up tripping in case the communication equipment malfunctions and prevents operation of the directional comparison logic.

Figures 76, 77 and 78 shows the logic circuits.

Connect the necessary signal from the auto-recloser for blocking of the directional comparison scheme, during a single-phase auto-reclosing cycle, to the EFCA-BLOCK input of the directional comparison module.

Fault current reversal logic

Figures 74 and 75 show a typical system condition, which can result in a fault current reversal; note that the fault current is reversed in line L2 after the breaker opening. This can cause an unselectiv trip on line L2 if the current reversal logic does not block the permissive overreach scheme in the terminal at B:2.

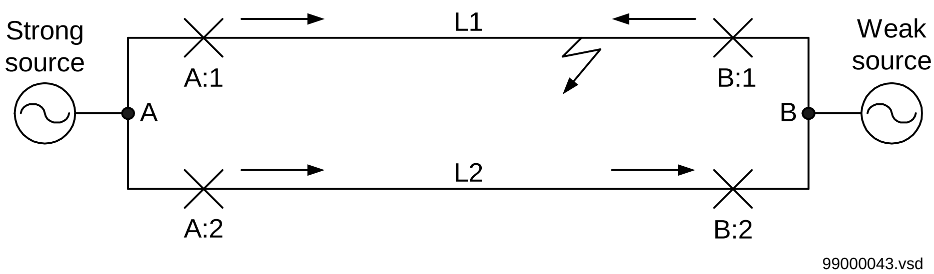


Figure 74: Initial condition

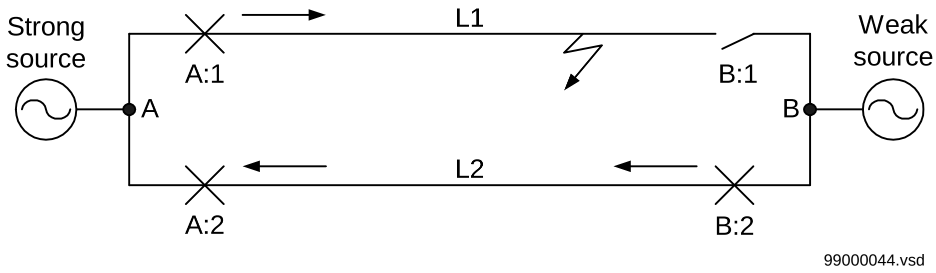


Figure 75: Current distribution after the breaker at B:1 is opened

The fault current reversal logic uses a reverse directed element, connected to EFCA-IRV, which in terminal at B:2 recognises the fault on the L1 line. See Figure 74. When the reverse direction element is activated during the tPickUp time, the EFCA-IRVL signal is activated, see figure 76. The logic is now ready to handle a current reversal without tripping. EFCA-IRVL will be connected to the block input on the permissive overreach scheme.

When breaker in B:1 operate, the fault current is reversed in line L2. The terminal at B:2 recognises now the fault in forward direction. Together with the remaining carrier received signal it will trip the breaker in B:2. To ensure that this does not occur, the permissive overreach function need to be blocked by EFCA-IRVL, until the carrier receive signal is reset.

When the fault current is reversed in line L2, EFCA-IRV is deactived and EFCA-IRVBLK is actived. The reset of EFCA-IRVL is delayed by the tDelay time, see figure 76. This ensures the reset of the carrier receive EFCA-CR signal in terminal B:2.

In terminal A:2, where the forward direction element was initially activated. This direction element must reset before the carrier send signal is initiated from B:2. The delayed reset of EFCA-IRVL also ensures the carrier send signal from terminal B:2 is held back until the forward direction element is reset in terminal A:2.

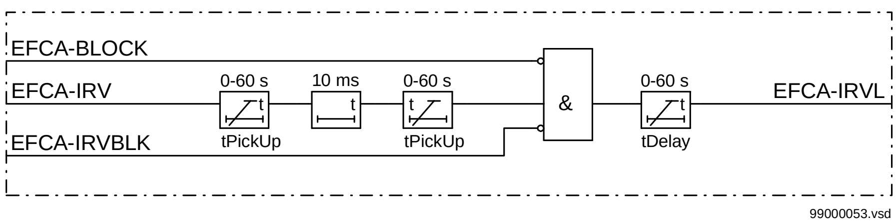


Figure 76: Simplified logic diagram, current reversal

Weak and infeed logic

Figure 77 shows a typical system condition, which can result in a missing operation; note that there is no fault current from node B. This cause that terminal at B cannot detect the fault and trip the breaker in B. To cope with this situation, a selectable weak end infeed logic is provided for the permissive overreach scheme.

The weak end infeed function can be set to send only an echo signal (WEI=Echo) or an echo signal and a trip signal (WEI=Trip). See figures 78 and 79.

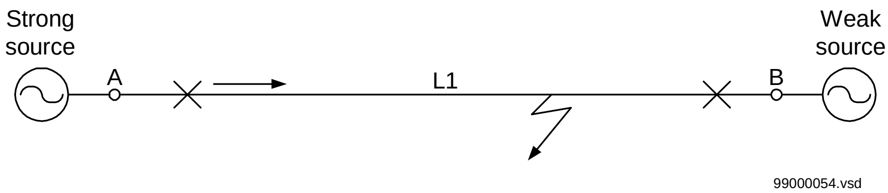


Figure 77: Initial condition

The weak end infeed logic uses normally a reverse and a forward direction element, connected to EFCA-WEIBLK via an OR-gate. See figure 78. If neither the forward nor the reverse directional measuring element is activated during the last 200 ms. The weak-end-infeed logic echoes back the received permissive signal. See figure 78.

If the forward or the reverse directional measuring element is activated during the last 200 ms, the fault current is sufficient for the terminal in B to detect the fault with the earth-fault function that is in operation.

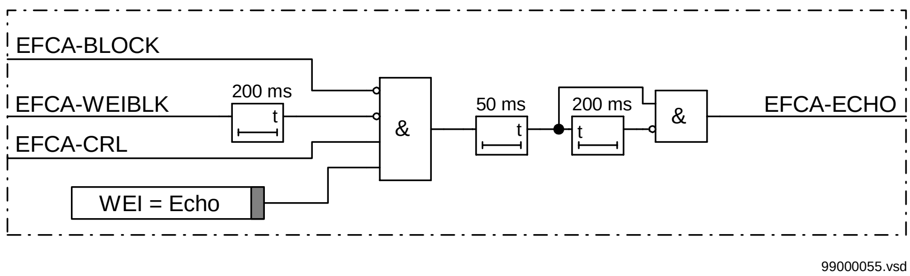


Figure 78: Simplified logic diagram, weak end infeed - echo.

With the Trip setting, the logic sends an echo according to above. Further, it activates the EFCA-TRWEI signal to trip the breaker if the echo conditions are fulfilled and the neutral point voltage is above the set operate value for $3U_0$.

The voltage signal that is used to calculate the zero sequence voltage is set in the earth-fault function that is in operation.

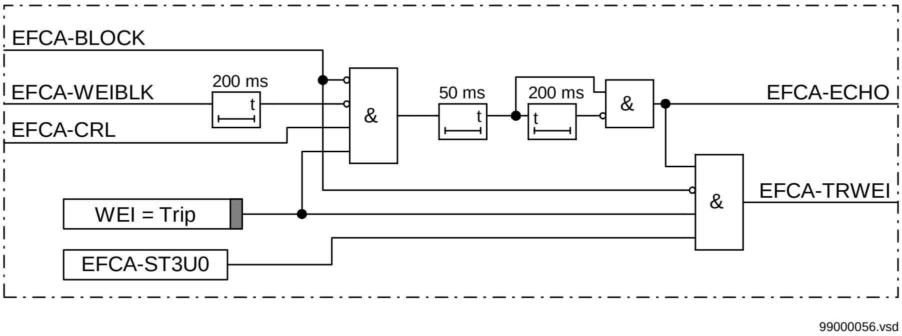


Figure 79: Simplified logic diagram, weak end infeed - Trip.

The weak end infeed echo sent to the strong line end has a maximum duration of 200 ms. When this time period has elapsed, the conditions that enable the echo signal to be sent are set to zero for a time period of 50 ms. This avoids ringing action if the weak end echo is selected for both line ends.

7.3 Design

The complete EFCA additional logic for the directional residual OC protection is consisting of two parts: Current reversal logic and weak end infeed logic. Each of them has its own setting parameters and possibility for its own configuration.

Figure 80 presents a simplified logic diagram for the current reversal function. The reverse directed signal from the TEF directional residual OC function should be connected to the EFCA-IRV functional input, to start the operation of a logic. The EFCA-IRVL signal will be activated, if the fault has been detected in reverse direction for more than the tPickUp time set on the corresponding timers.

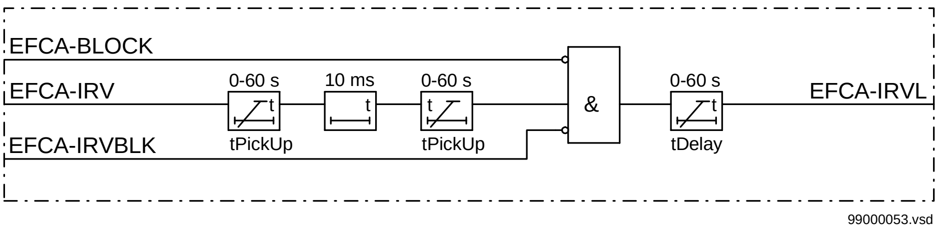


Figure 80: Simplified logic diagram, current reversal

The tDelay timer delays the reset of the output signal, when the current reversal occurs and the fault is detected in the forward direction. This prevents the TEF function to operates unnecessarily during the current reversal conditions.

The weak end infeed function can be set to send only an echo signal (WEI=Echo) or an echo signal and a trip signal (WEI=Trip). The function is released with either of the WEI=Echo or WEI=Trip settings in the menu.

The weak end infeed logic uses normally a reverse and a forward directional element, connected to EFCA-WEIBLK via an OR-gate. The weak-end-infeed logic echoes back the received permissive signal, if neither the forward nor the reverse directional measuring element is activated during the last 200 ms.

With the Trip setting, the logic sends an echo according to above. Further, it activates the EFCA-TRWEI signal to trip the breaker if the echo conditions are fulfilled and the residual voltage is above the set operate value for $3U_0$>.

7.4 Calculations

7.4.1 Setting

The settings are done from the local HMI under the menu:

Settings
Functions
Group n (n = 1..4)
Earth Fault
ComIRevWeiEF

Current reversal

The Current-reversal function is set on and off by setting the parameter CurrRev = On/Off. Time delays shall be set for the timers tPickUp and tDelay.

tPickUp is chosen shorter (<80%) than the breaker opening time, but minimum 20 ms.

tDelay is chosen at a minimum to the sum of protection reset time and the communication reset time. A minimum tDelay setting of 40 ms is recommended.

Weak end infeed

The weak end infeed can either be set off or to echo or trip by setting the parameter WEI = Off/Echo/Trip. (Echo = Echo, Trip = Echo + Trip). Operate zero sequence voltage for WEI trip is set with Ugr = xx % of Ub.

The zero sequence voltage for a fault at the remote line end and appropriate fault resistance is calculated.

To avoid unwanted trip from the weak end infeed logic (if spurious carrier signals should occur), set the operate value of the broken delta voltage level detector ($3U_0$) higher than the maximum false network frequency residual voltage that can occur during normal service conditions. The recommended minimum setting is two times the false zero-sequence voltage during normal service conditions.

8 Thermal overload protection (THOL)

8.1 Application

When the load currents exceed the permitted continuous current there is a risk that the conductor or the insulation will be subject to permanent damage due to overheating. Even moderate overloads under long time give appreciable temperature increase. For example, a current of 1.2 times rated load current gives a temperature rise of 1.2 x 1.2 = 1.44 times rated value.

The temperature rise as a function of time for a fixed load is determined by the so called thermal time constant τ of the element.Moderate overloads are normally not detected by current or impedance measuring relays. A current thermal overload protection can prevent damage caused by excessive temperature increase due to moderate or heavy current overloads.

Electrical cables which can be loaded up to the permissible load current should be provided with thermal protection. For cables surrounded by air, the thermal time constant τ can vary from some few minutes for 10 kV cables with small cross-sectional area to more than one hour for high voltage cables with large cross-sectional area. The shorter time constant valid for cables in air is decisive if some part of the cable is surrounded by air.

For overhead lines and cables placed in the air, the ambient temperature will normally vary considerably. Since the temperature of the element is the sum of the ambient temperature and the temperature rise, the thermal protection for heavily loaded lines should be provided with compensation for the ambient temperature.The heating effect of radiant power from the sun can also be appreciable in some areas.

8.2 Functionality

The function includes a memory that is continuously updated with the heat content of the line based on the RMS value of the line current and the ambient temperature. The current used in the function is the phase current having the highest RMS value out of the three phase currents. The function has two settable operating levels for temperature, one intended for alarm and one intended for tripping. For the tripping function a reset hysteresis is included that can be set between 5 and 30°C while for the alarm function it is fixed at 5°C hysteresis.

For the alarm there is an output denoted ALARM which is active as long as the temperature is above alarm level. For the tripping there are two outputs, one denoted TRIP which gives only a 50 ms pulse at operation and one denoted START which is active as long as the temperature is above tripping level.

The function also includes a possibility for ambient temperature compensation through a mA transducer input. The upper and lower value for the input range can be set between -25 and +25 mA and corresponding temperature between -1000 and + 1000°C. If transducer for ambient temperature is not available the function uses a +20°C reference value instead. This value will also be used if a fault is detected in the transducer circuits or mA input module.

8.3 Calculations

The settings for the THOL function, with exception of the settings for the ambient temperature compensation, can be made on the built-in HMI unit:

Settings
  Functions
    Group n (n=1...4)
      ThermOverLoad

The settings can also be made by aids of the SMS or PST setting tools.

For temperature compensation, input No. 1 on the MIM module No.1 is always used (fixed configuration). Necessary settings for the MIM module are On/Off for activation, time intervals for measuring of current, upper and lower value for the current input and temperatures corresponding to max. respectively min. current. These settings can only be made via the SMS or PST setting tools.

To make the correct settings, the following data are required for the protected object:

- Final temperature rise after continous load with specified load current
- Max. permissible continuous temperature and thermal time constant τ of the object
- Max. ambient temperature
- Max. temperature rise due to radiant power from the sun - if significant

The time constant can be found if a curve is available which shows the temperature rise as a function of time for a given load current. At load current Iload and final temperature rise Tfin the following is valid:

Time:	1 x τ	2 x τ	3 x τ	4 x τ	5 x τ
Temperature rise$^{1)}$:	63	86	95	98	99
1) in % of Tfin					

If different values of τ are calculated from the curve, select the lowest value of τ to obtain the best protection.

The time to function is calculated from the formula:

$$t = \tau \cdot \ln \frac{\left(\frac{I}{I_{base}}\right)^2 - p^2}{\left(\frac{I}{I_{base}}\right)^2 - \frac{T_{trip} - T_{amb}}{T_{base}}}$$

(Equation 138)

Where:

p	is Ip/I_{base}
Ip	is continuous load current before the current is icreased to I Tamb = ambiant temperature. If temperature compensation is not used, Tamb = 20°C as fixed value,
T_{amb}	is ambient temperature and
T_{amb}	is 20° C as a fixed value if temperature compensation is not used.

For other parameters: see description in the setting table in the Technical Reference Manual

Setting example

Assume the following data:

- I1b: 5 A
- Temperature increase of the conductor : 90°C at continuous load current 4.5 A.
- Max. permissible temperature of the conductor: 125°C
- Time constant τ = 20 min
- Max. ambient temperature: 30°C
- Max. temperature increase due to radiant power from the sun: 5°C

Example 1: THOL with no temperature compensation

I_{base} = 4.5 A = 4.5/5 x 100 = 90 % of I1b

T_{base} = 90°C, τ = 20 min

The thermal function assumes 20°C ambient temperature as a fixed value instead of the actual value 30°C. Also, the 5°C temperature increase due to the sun radiant power is not included in the calculated temperature increase. Hence, the function calculates continous conductor temperature 20 + 90 = 110°C at 4.5 A whereas the max. value is 30 + 90 +5 = 125°C. Hence the setting should be TTrip = 125 - (125 - 110) = 110°C.

Example 2: THOL with temperature compensation

Assume temperature measuring elements with output 4 mA at -20°C and 20 mA at 100°C. Settings of Ibase, T_{base} and τ same as above

.MI11-I-Max= 20.00mA MI11-I-MaxValue = +100°C

CMI11-I-Min= 4.00mA MI11-I-MinValue = -20°C

The influence of the ambient temperature is included in the calculated values. The 5°C temperature increase due to the sun radiant power, however, is not included. Hence the setting should be T_{trip} = 125 - 5 = 120°C.

9 Breaker failure protection (BFP)

9.1 Application

This function issues a back-up trip command to trip adjacent circuit breakers in case of a tripping failure of the circuit breaker (CB), and clears the fault as requested by the object protection.

The breaker-failure function is started by a protection trip command, from the line and busbar protection through the breaker-related trip relays. The start can be single-phase or three-phase. Correct fault current clearing or failure is detected by a current check in each phase. The current level can be set at 0,05 to 2 times the rated current.

Retrip of the faulty CB can be done with or without current check. A delay, 0-60 s, can be set for the retrip.

The use of retrip, limits the impact on the power system if the breaker-failure protection function (BFP) is started by mistake during testing or other maintenance work.

A second time step is used for the back-up trip command. It should be connected to trip the adjacent breakers, to clear the busbar section and intertrip the remote end, if so required. The time setting range is 0-60 s.

By using separate timers for each phase, correct operation at evolving faults is ensured.

The timer setting should be selected with a certain margin to allow variation in the normal fault clearing time. The properties of the BFP function allow the use of a small margin.

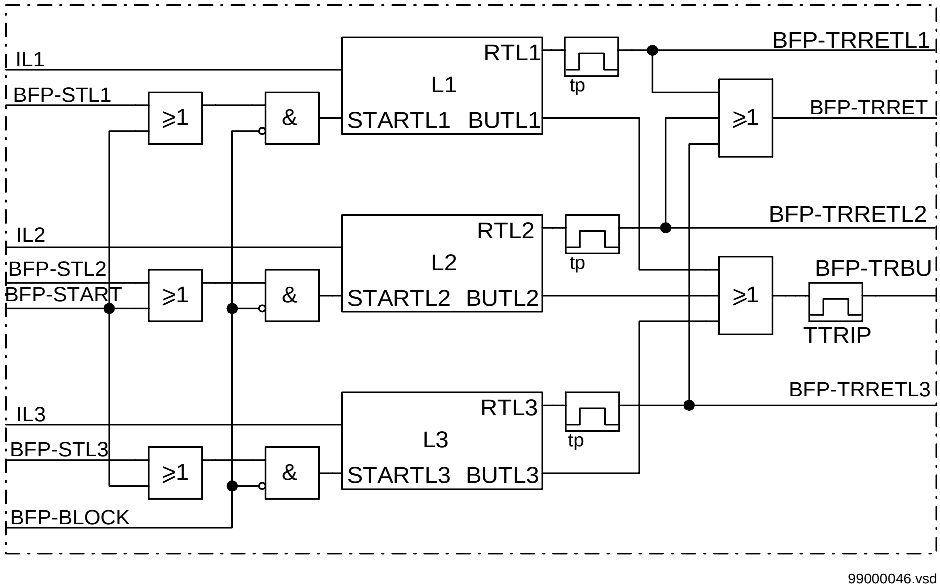


Figure 81: Simplified logic diagram - Start and trip functions

The application functions of the protection are:

- Individual phase-current detection
- Two time steps, one for retrip of the related circuit breaker and one for the back-up trip of the adjacent circuit breakers
- Selection of current controlled or unconditional retrip
- Phase separated timers gives correct operation at an evolving fault
- Accurate timers and current elements reset in 10 ms, allowing the use of short back-up trip time

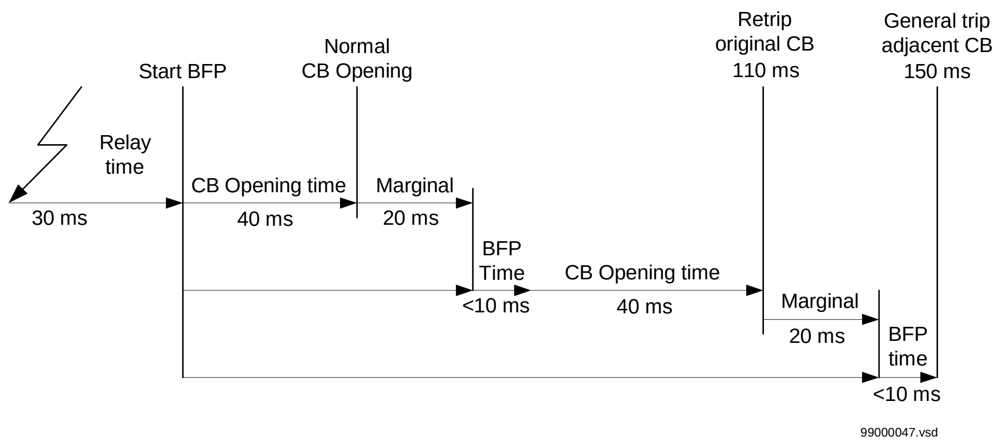


Figure 82: Time sequence

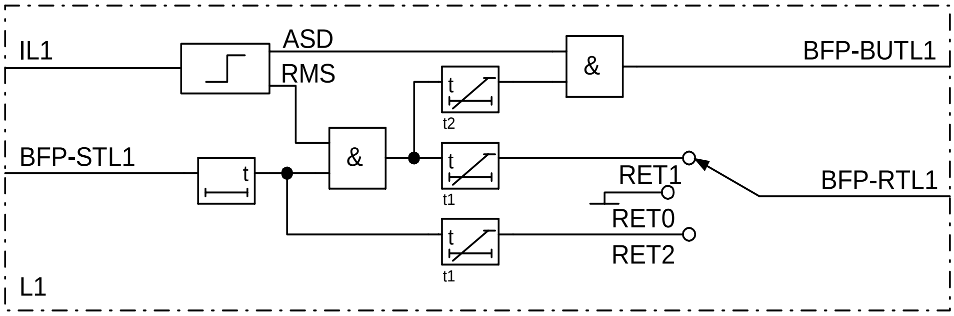
9.2 Functionality

The breaker-failure protection starts on a single-phase or three-phase condition, either from an external protection, or internally from a protection trip signal in the terminal.

The breaker receiving the original protection trip command can be retripped from the BFP. The retrip can be controlled by a current check, or carried out as a direct retrip without any current check. The direct retrip can be used, because the breaker-to-trip has already received a tripping command, and the direct retrip does not cause any unselective tripping

The use of retrip, limits the extent of unwanted power disconnection in case of an accidental start of the BFP at work in the initiating circuits, with the primary circuit in service and the load above the set current level.

The back-up trip is sent to the adjacent circuit breakers in order to clear the fault and disconnect the failing circuit breaker.



RET0 : No retrip
RET1 : Retrip with current check
RET2 : Unconditional retrip

Figure 83: Logic diagram of breaker-failure protection, phase L1

Input and output signals

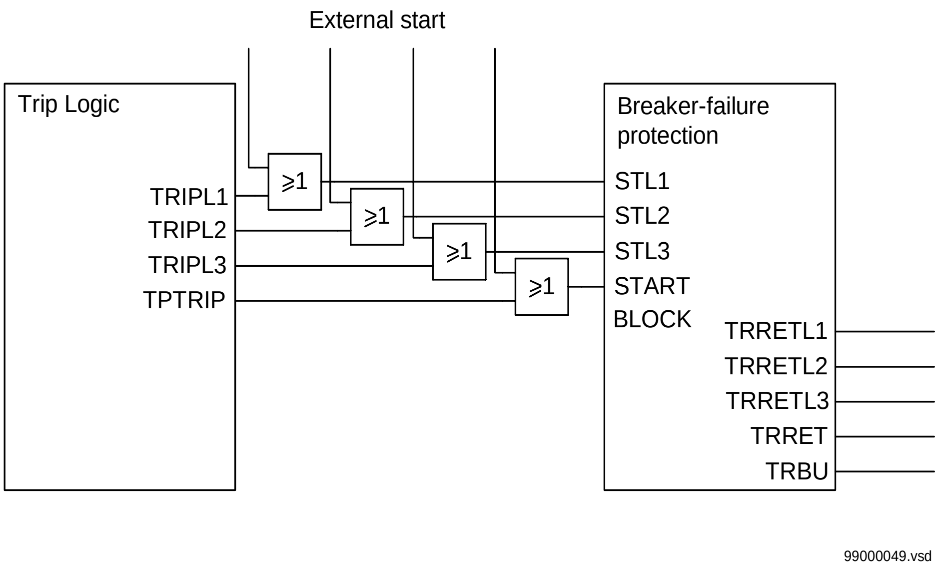


Figure 84: Input and output signals

The connectable inputs are connectable by configuration to the binary inputs of the terminal or to other internal functions’ outputs. The outputs are connectable by configuration to the binary output relays. “Connectables” and “outputs” can be connected to the free-logic functions of the unit, OR gates, and in that way add connection links

Start functions

The breaker-failure protection can be started either internally or externally. The start pulse is sealed-in as long as the current exceeds the preset current level, to prevent a restart of the BFP timers in case of a chattering starting contact. The preset current level may be set to (0.05 - 2.0) · Ir where Ir is 1 or 5 A.

Measuring principles

The current is filtered through a specially designed high-pass filter to obtain the required suppression of the dc components.

High-pass filtering is performed basically for two reasons, i.e. to remove the:

- dc component caused by saturated current transformers with a decaying current due to de-energizing of the secondary circuit. This is done to achieve a more correct representation of the real current in the line.
- dc component that is a part of the fault current. This is done to achieve a correct base for both ASD and RMS calculations.

The frequency limit of the filter is very close to the service frequency, to obtain a maximum suppression of the above dc components.

The intention of the adaptive signal detection (ASD) concept is to achieve independence from the absolute filtering requirement, when dealing with extremely high fault currents in combination with low preset values. This is obtained by creating a new stabilizing signal to compare the current with.

The ASD works continuously, regardless of if the BFP was started. Its result is however considered only when the BFP has started and the pre-set time has elapsed.

As the current exceeds the previously stabilized sample, it adapts the value of the current and when it does not, it decays. This adaptive behaviour makes it possible to rapidly and securely detect a breaker failure situation after the pre-set time has elapsed. Continuously and in parallel, the RMS value of the post-filtered signal is calculated and compared with a preset current level. As the RMS value decreases below the preset current level, the breaker-failure function is momentarily reset.

At normal operation of the circuit breaker, the stabilizing signal exceeds the post-filtered signal for a consecutive period of maximum 10 ms before it is reset. Resetting occurs before the back-up trip timer t2 has timed out.

At a breaker failure situation, the post-filtered current exceeds the stabilizing signal, resulting in a trip from the breaker-failure function within 10 ms after the trip timer t2 has elapsed.

The breaker-failure protection works with all three phases totally separated. But a possibility exists to start all three phases simultaneously. The back-up trip is always three-phase.

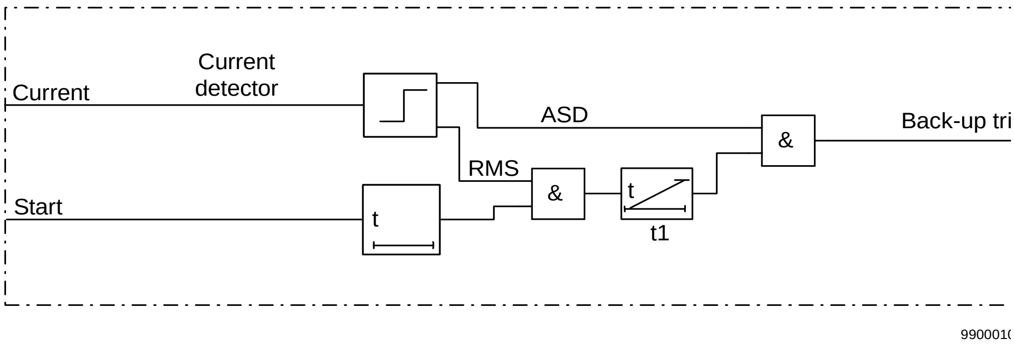


Figure 85: Breaker-failure protection

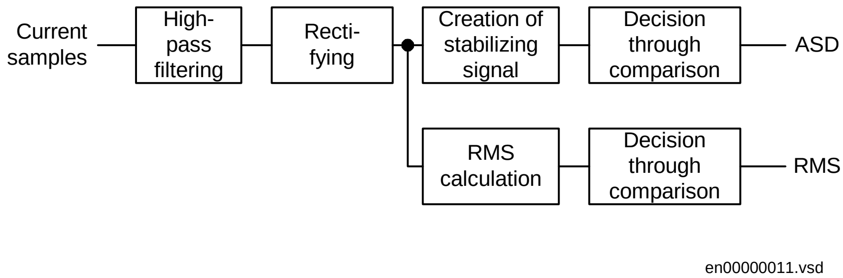


Figure 86: Current detector, ASD and RMS measurement

Retrip functions

The retrip function of the original circuit breaker is set at one of three options:

Setting:	The retrip;
Off	function is not executed.
I> check	occurs with a current check.
No I> check	occurs without a current check.

The retrip timer t1 can be set from 0 to 60 s.

A trip pulse, tp, is generated with a length of 150 ms.

Back-up trip

The back-up trip delay timer t2 can be set between 0 and 60 s.

A trip pulse, tp, is generated with a length of 150 ms.

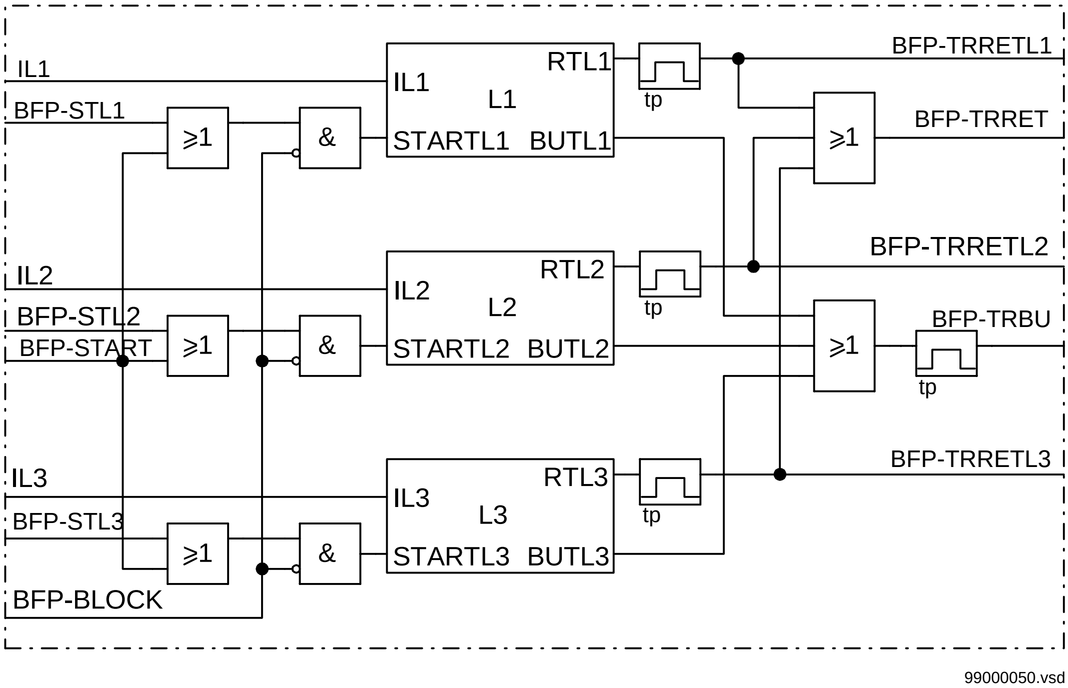


Figure 87: Breaker-failure protection

9.3 Design

The breaker failure protection is initiated by the trip commands from the protection functions, either internal to the terminal or from external commands through binary inputs. The start can be single-phase or three-phase.

The operating values of the three current measuring elements are settable within a wide setting range. The measuring is stabilised against the dc-transient that can cause unwanted operation at saturated current transformers and correct breaker operation. Time measurement is individual for each phase. Two independent timers are available, T1 for repeated tripping of “own” breaker and T2 which operates trip logic for adjacent breakers.

9.4 Calculations

9.4.1 Setting

Human-machine interface (HMI)

The configuration of alternatives or settings to the functions is made on the built-in HMI:

Settings
Functions
Group n
Breaker Failure

The breaker-failure protection can be controlled from the human-machine interface (HMI) by an “Operation” parameter, to be set between alternatives Off/On.

When “Operation” is set to Off, the function becomes inoperative.

The configuration of input and output signals to the function is made on the built-in HMI:

Configuration
Function Inputs
Breaker Failure

The inputs and the outputs to and from the breaker-failure protection are presented in the signal list.

Fixed values	
Trip pulse, tp	150 ms, fixed

The breaker failure protection shall be set by means of a current limit for detection of a breaker failure. The current setting shall be chosen in relation to the protection functions, initiating the breaker failure protection. Normally the current setting should be equal to or lower than the most sensitive setting of a residual overcurrent protection.

If the retrip function is used a time delay before retrip has to be set. In most cases this time delay can be set to zero.

The time delay of the back-up trip function shall be chosen so that selectivity is maintained. Consider the following:

t1: Set retrip time delay

t_{br}: Circuit breaker opening time

BFR reset time

The back-up trip delay t2 shall be set:

$$t2 \geq t1 + t_{br} + margin$$

(Equation 139)

At the same time it is desired that the back-up trip is done so fast that remote protections will not trip.

10 Unbalance protection for capacitor banks (TOCC)

10.1 Application

Capacitor banks are made up of individual units which are series and parallel connected. Each unit contains a number of series and parallel connected elements. The individual elements in a capacitor can be separately fused.

If one element is damaged, it will be disconnected by its fuse and the rest of the elements can continue to operate. However, the load on the healthy elements will increase. When a certain number of elements are out of service, the load on the remaining elements becomes so high that the remaining elements will quickly be destroyed.The purpose of the unbalance protection is to detect the damage and disconnect the capacitor bank from the network before the the healthy units are overloaded.

The protection is connected to a current transformer which measures the current flowing between two normally balanced parts of the capacitor battery. Under normal conditions, no fundamental frequency current flows in the interconnection. A low set current stage gives alarm when elements are damaged and current flows in the interconnection. The trip stage is set to disconnect the battery before healthy elements become overloaded and quickly damaged.

Three-phase capacitor banks are often made up of two identical Y-connected groups. The neutral points are then interconnected via a current transformer which feeds the unbalance protection.

10.2 Functionality

The current measuring element continuously measures the unbalance current (via analog input I5) and compares it to the set operate value for the two current stages. A recursive Fourier filter ensures immunity to disturbances and harmonic currents. When applied between the neutral points of two identical Y-connected capacitor groups, no false unbalance currents will flow, even for high contents of harmonics in the voltage. The output relay for the low current (alarm) stage operates if the current becomes higher than the set operate value ILow during a time exceeding the set time delay tLow. If the current becomes higher than the set operate value IHigh during a time exceeding the set delay tHigh, the output relay for the high current stage operates.

The input signal TOCC-BLOCK blocks both the low set and the high set function.The stages may also be blocked individually by setting Operation Low = Off respectively Operation High = Off. The setting BlockTOCC = Yes will block the function, during testing.

10.3 Calculations

The settings for the TOCC function can be made on the built-in HMI unit:

Settings
Functions
Group n (n=1...4)
CapUnbalance

The settings can also be made by aids of the SMS or PST setting tools.

The current stage I>High is normally set to trip the capacitor battery before any unit is subjected to a voltage increase of 10 % above rated value. The delay tHigh should be set longer than the operate time of the ground fault protection if the primary operate current of stage IHigh is low compared to the ground fault current in the system. The current stage I>Low is normally set to give alarm at 50 % of the set operate current of stage I>High.

The calculation of settings for the unbalance protection function must take into consideration how the capacitor bank is built up and it is often made by aids of a computer program.

Chapter 6 Voltage

About this chapter

This chapter describes the voltage protection functions.

1 Time delayed undervoltage protection (TUV)

1.1 Application

Undervoltage protection prevents the sensitive elements from running under conditions that could cause their overheating and thus shorten their life expectancy below the economical limits. In many cases, it is a useful tool in circuits for local or remote automation processes in the power system.

1.2 Design

The voltage measuring elements within one of the built-in digital signal processors continuously measure the phase-to-neutral voltages in all three phases. Recursive Fourier filter filters the input voltage signals and a separate trip counter prevents high overreaching or underreaching of the measuring elements.

1.3 Calculations

The parameters for the undervoltage protection are set on the local HMI under the menu:

Settings
  Functions
    Group n (n = 1...4)
      TimeDelayUV

All the voltage conditions in the system where the undervoltage protection performs its functions should be considered. The same also applies to the associated equipment, its voltage and time characteristic.

2 Time delayed overvoltage protection (TOV)

2.1 Application

The application areas of the overvoltage protection functions are different in distribution and transmission networks.

The overvoltage protection is used to protect the equipment and its insulation against overvoltage. In this way it prevents damage to the equipment in the power system and shortening of their life time.

The residual overvoltage protection function is mainly used in distribution networks, primarily as a back-up protection for the residual overcurrent protection in the line feeders. This to secure disconnection of earth-faults.

2.2 Functionality

The phase overvoltage protection function continuously measures the three phase voltages and initiates the corresponding output signals if the measured phase voltages exceed the preset value (starting) and remain high longer than the time delay setting on the timers (trip). This function also detects the phases which caused the operation.

The residual overvoltage protection function calculates the residual voltage (3U0) from the measuring three phase voltages and initiates the corresponding output signals if the residual voltage is larger than the preset value (starting) and remains high longer than the time delay setting (trip).

2.3 Design

Figure 88 shows a simplified logic diagram of the overvoltage protection function. The time delayed residual overvoltage protection and the time delayed overvoltage protection share some input signals and logical elements. For this reason and for the sake of better overview both the protections are shown in the figure.

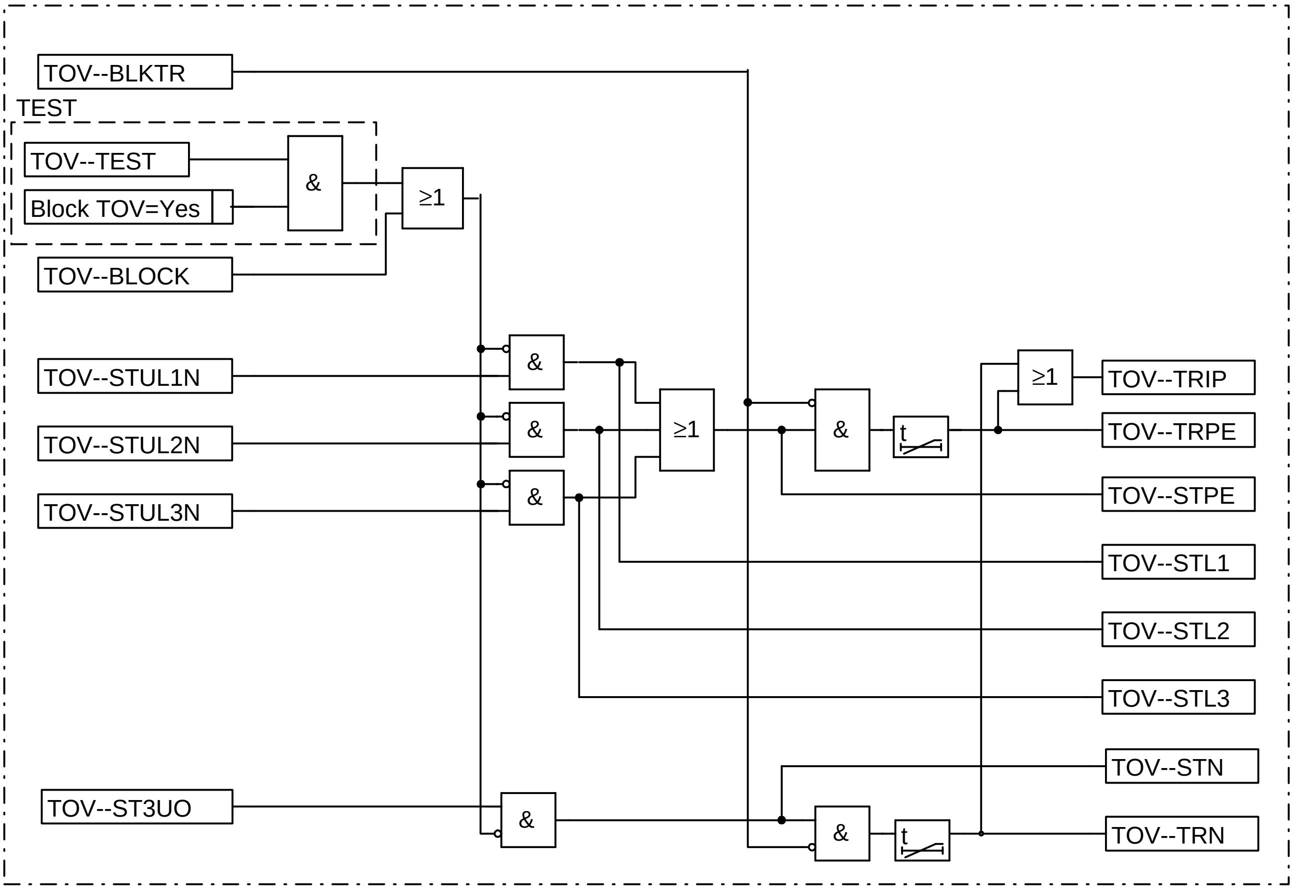


Figure 88: Time delayed overvoltage protection - simplified logic diagram

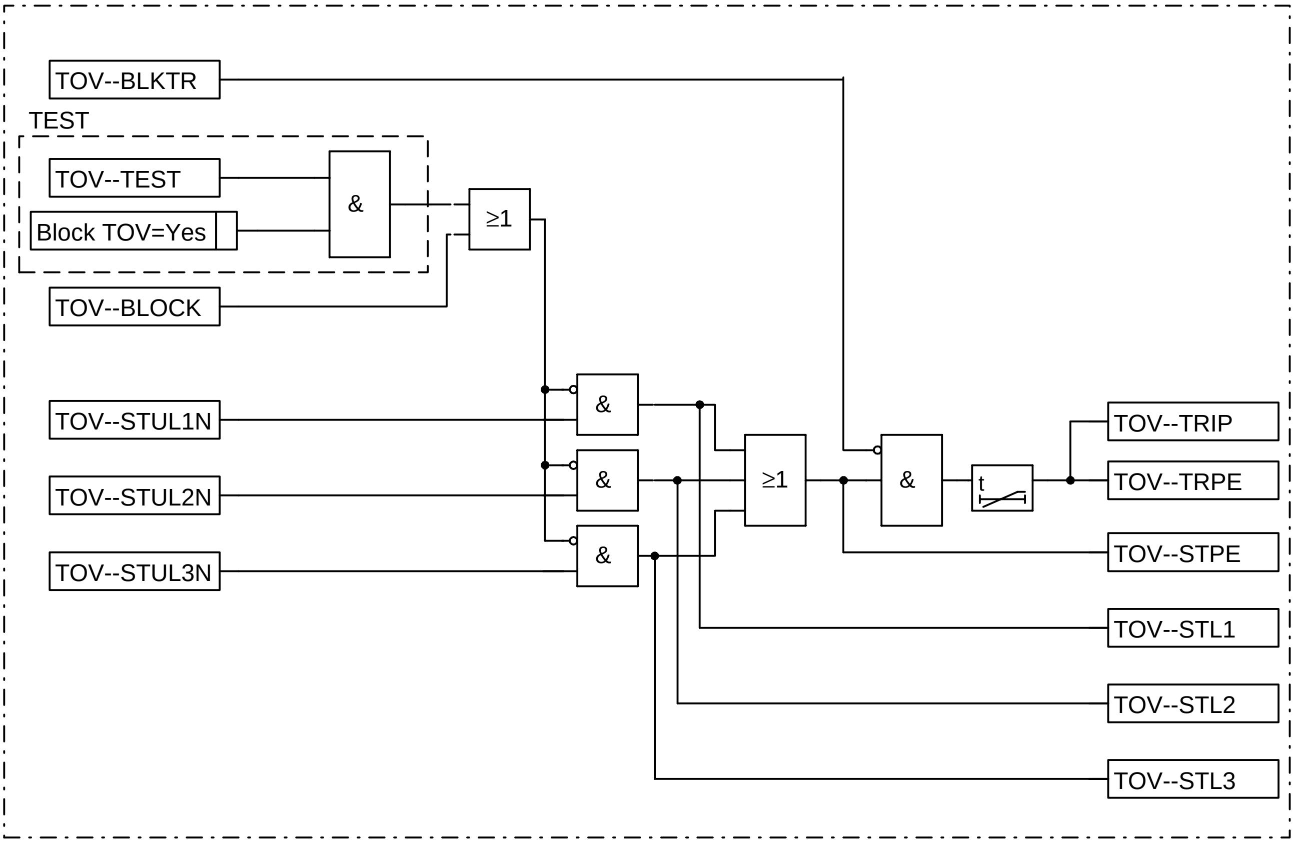


Figure 89: Logic diagram, time delayed overvoltage protection, phase wise

The TOV--TRIP and TOV--TRPE output signals changes from logical 0 to logical 1 if at least one of the logical signals TOV--STUL1N, TOV--STUL2N, TOV--STUL3N remains equal to logical 1 for a time longer than the set value on the corresponding timer. The signal TOV--TRPE will be high, to indicate that the overvoltage protection caused the trip

Any signal connected to the TOV--BLOCK input blocks the operation of the time delayed overvoltage protection. Similarly any signal connected to TOV--BLKTR will block the trip output from the time delayed overvoltage protection.

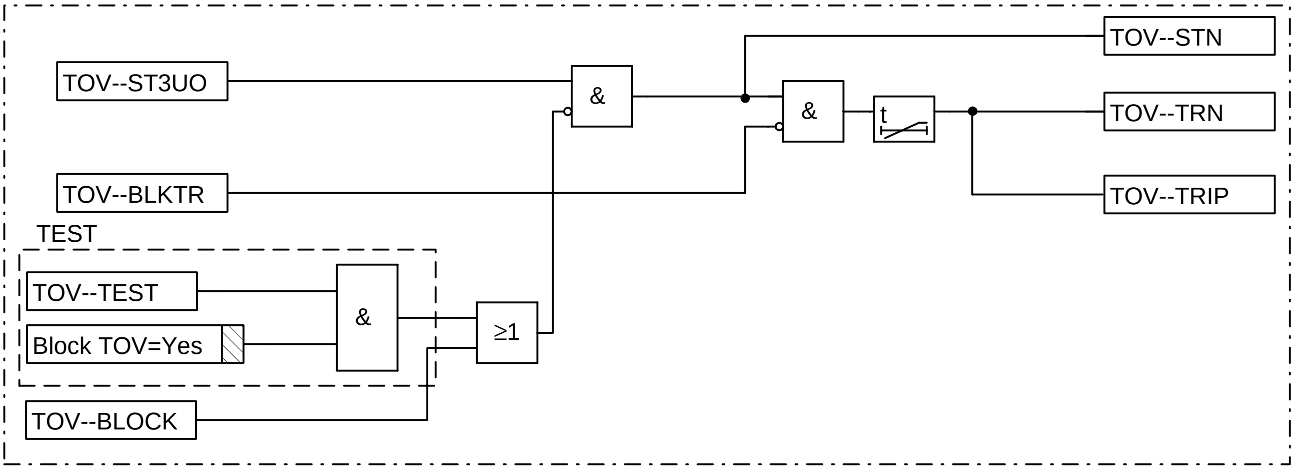


Figure 90: Logic diagram, time delayed overvoltage protection, residual

The TOV--TRIP and TOV--TRN output signal changes from logical 0 to logical 1 if TOV--ST3U0 remains equal to logical 1 for a time longer than the set value on the corresponding timer. The signal TOV--TRN will be high, to indicate that the residual overvoltage protection caused the trip.

Any signal connected to the TOV--BLOCK input blocks the operation of the time delayed residual overvoltage protection. Similarly any signal connected to TOV--BLKTR will block the trip output from the time delayed residual overvoltage protection.

2.4 Calculations

2.4.1 Setting

The time delayed overvoltage protection parameters can be set on the local HMI under the menu:

Settings
Functions
Group n (n = 1...4)
TimeDelayOV

All the voltage conditions in the system where the overvoltage protection performs its functions must be considered. The same also applies to the associated equipment, its voltage-time characteristic.

The overvoltage protection should be set higher than the expected maximum system operate voltage that is in a particular part of a network. A safety margin of at least 10% should also be considered due to the inaccuracies in the instrument transformers, calculation methods, and the inaccuracy of the measuring elements in the terminal.

The residual overvoltage protection should be set higher than the expected maximum system operate voltage that is in a particular part of a network. A safety margin of at least 10% should also be considered due to the inaccuracies in the instrument transformers, calculation methods, and the inaccuracy of the measuring elements in the terminal.

3 Intercircuit bridging protection (TOVI)

3.1 Application

If a conductor in the 50 Hz system comes into contact with the conductor of a 16 2/3 Hz system with higher nominal voltage, the 16 2/3 Hz voltage must quickly be disconnected to avoid damage on the power transformer and other components in the 50 Hz system. The protection is connected to measure the phase-to-earth voltage of the 50 Hz conductor. The operate voltage must, with margin, be set higher than the 16 2/3 Hz voltage injected in the conductor.

3.2 Functionality

The voltage measuring element continuously measures the 16 2/3 Hz voltage component from U4 and compares it to the set operate value U>. A second order band-pass filter (center frequency 16 2/3 Hz) ensures immunity to disturbances and harmonic voltages and reduces the influence of the 50 Hz voltage component with a factor > 10.The output trip relay operates if the voltage becomes higher than the set operate value U> under a time exceeding the set definite time delay t.

An extenal signal connected to the input TOVI-BLOCK may block the function. It is also possible to block the function during testing, by setting Block TOVI = Yes.

3.3 Calculations

The settings for the TOVI function can be made on the built-in HMI unit:

Settings
 Functions
  Group n (n=1...4)
   IntCircBridge

The settings can also be made by aids of the SMS or PST setting tools.

The operate voltage must be set higher than the highest 16 2/3 Hz voltage injected in the conductor. A safety margin of at least 10 % in addition to the inaccuracies of the voltage transformer and the measuring function is recommended.

Chapter 7 Power system supervision

About this chapter

This chapter describes the power system supervision functions.

1 Loss of voltage check (LOV)

1.1 Application

The trip of the circuit breaker at a prolonged loss of voltage at all the three phases is normally used in automatic restoration systems to facilitate the system restoration after a major blackout. The loss of voltage check function gives a trip signal only if the voltage in all the three phases is low for more then 7 seconds. If the trip to the circuit breaker is not required, then the function can be used for signallization through an output contact or through the event recording function.

1.2 Functionality

The voltage-measuring elements continuously measure the three phase-to-earth voltages, and compare them with the set values. Fourier recursive filter filters the voltage signals.

The logical values of the following signals become equal to 1, if the related phase measured voltage decrease under the pre-set value:

- STUL1N for U_{L1N} voltage
- STUL2N for U_{L2N} voltage
- STUL3N for U_{L3N} voltage

The 150 ms output trip pulse is issued if all the three phase voltages are below the setting value for more than 7s. The function can be blocked from the fuse failure supervision function intervention and when the main circuit breaker is open.

1.3 Design

The simplified logic diagram of the loss of voltage check function is shown in figure 91.

The function is disabled (blocked) if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockLOV=Yes)
- The input signal LOV--BLOCK is high

The LOV--BLOCK signal is a general purpose blocking signal of the loss of voltage check function. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through an OR gate it can be connected to both binary inputs and internal function outputs.

The function has a particular internal latched enable logic that:

- enables the function (signal latched enable in figure 91 is set to 1) when the line is restored; i.e. at least one of the three voltages is high for more then 3 seconds (signal set enable in figure 91).
- disables the function (signal latched enable in figure is set to 0) if the signal reset enable in figure 91 is set to 1 (reset of latced enable signal).

The latched enable signal is reset (i.e. the function is blocked) if:

- the main circuit breaker is opened. This is achieved by connecting a N.C. contact of the main circuit breaker to a terminal binary input connected to the function input LOV--BC
- the fuse failure supervision function has tripped. This is achieved by connecting the output signal of the fuse failure supervision, FUSE-VTSU, to the function input LOV--VTSU
- not all the three phase voltages are low for more then 10 s (only one or two phase voltages are low).

The output trip signal of the voltage check function is LOV--TRIP.

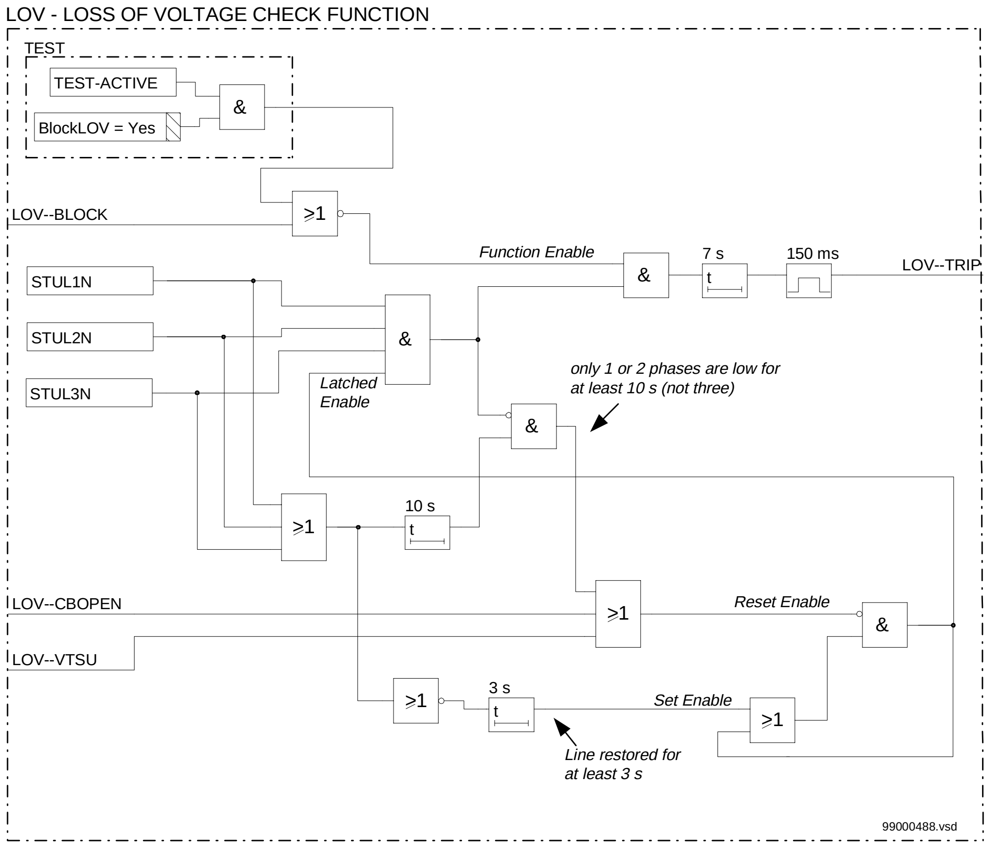


Figure 91: Simplified logic diagram of loss of voltage check protection function

1.4 Calculations

1.4.1 Setting instructions

The setting parameters are accessible through the HMI. The parameters for the loss of voltage function are found in the HMI-tree under:

Settings
Functions
Group 1,2,3 and 4
LossOfVoltage

For the parameter list and their setting ranges, please see “Setting parameters” in the “Technical reference manual”.

The low voltage primary setting should be lower than the minimum system operating voltage. A reasonable setting will probably be 20-50% of system nominal voltage.

For a primary set value Us_{PRIM} the secondary setting value Us_{SEC} is:

$$Us_{SEC} = \frac{U_{SEC}}{U_{PRIM}} \cdot Us_{PRIM}$$

(Equation 140)

Where:

U_{SEC}	is the secondary rated voltage of the main VT and
U_{PRIM}	is the primary rated voltage of the main VT

The relay setting value UPE< is given in percentage of the secondary base voltage value, U_{1b}, associated to the voltage transformer input. The value for UPE< is given from this formula:

$$UPE< = \frac{Us_{SEC}}{U_{1b}} \cdot 100$$

(Equation 141)

and this is the value that has to be set in the terminal.

2 Dead line detection (DLD)

2.1 Application

The dead-line detection function (DLD) detects the disconnected phase(s) of a protected object. The output information serves as an input condition for some other measuring functions within the REx 5xx terminals. Typical examples of such functions are:

- Fuse failure supervision function (FUSE)
- Switch-onto-fault function (SOTF)

For this reason, always configure the DLD--START output signal to the corresponding inputs of the above functions.

2.2 Design

Figure 92 presents a simplified logic diagram of the function. Phase L1, L2 and L3 currents and voltages are measured by one of the built-in digital signal processors. Logical signals STMILn become logical one, if the measured current in the corresponding phase (n = 1..3) decreases under the set operating level.

Logical signals STULnN become logical one, if the measured voltage in the corresponding phase (n = 1..3) decreases under the set operating level.

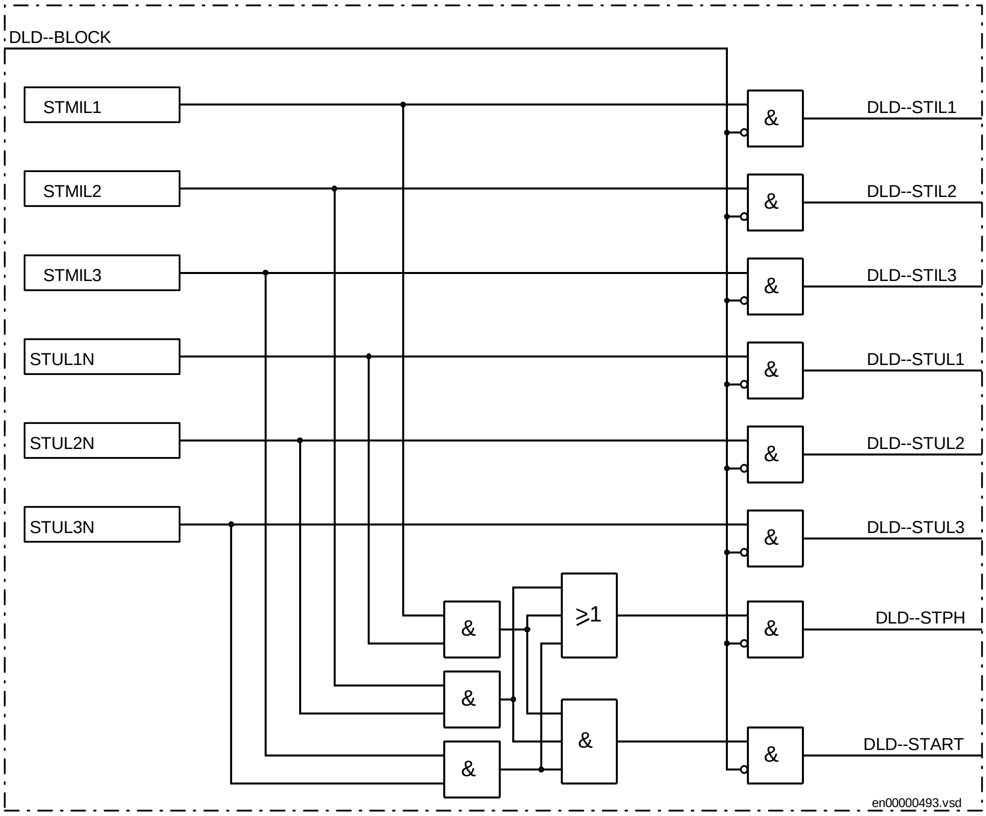


Figure 92: DLD - simplified logic diagram of the dead line detection function

Corresponding phase starting output signals DLD--STILn and DLD--STULn become in this case logical one, if the function is not blocked by the logical one on DLD--BLOCK functional input.

Simultaneous operation of current and voltage measuring elements in one phase is a necessary condition for the determination of a “dead-phase” condition. This condition is presented by the activation of a DLD--STPH output signal.

A complete line is determined as a “dead-line”, when the voltages and the currents in all three phases decrease under the set operate values. A DLD--START output informs about this operating condition.

2.3 Calculations

2.3.1 Setting instructions

The setting parameters are accessible through the HMI. The parameters for the dead line detection function are found in the HMI-tree under:

Settings
Functions
Group n (n=1-4)
DeadLineDet

Set the minimum operate voltage UP< (phase value) with a sufficient margin (at least 15%) under the minimum expected system operate voltage.

Set the minimum operate current with sufficient margin (15 - 20%) under the minimum expected load current. In many cases the minimum load current of a line is close to 0 or even 0. In such cases a setting must be chosen so that signals DLD-STILn are given during normal operation. The operate value must however acceed the maximum charging current of an overhead line, when only one phase is disconnected (mutual coupling to the other phases).

Chapter 8 Secondary system supervision

About this chapter

This chapter describes the secondary system supervision functions.

1 Fuse failure supervision (FUSE)

1.1 Application

Different protection functions within the REx 5xx protection, control and monitoring terminals operate on the basis of the measured voltage in the relay point. Examples are: distance protection function, undervoltage measuring function and voltage check for the weak infeed logic.

These functions can operate unnecessarily if a fault occurs in the secondary circuits between the voltage instrument transformers and the terminal.

It is possible to use different measures to prevent such unwanted operations. Miniature circuit breakers in the voltage measuring circuits, located as close as possible to the voltage instrument transformers, are one of them. Separate fuse-failure monitoring relays or elements within the protection and monitoring devices are another possibilities. These solutions are combined to get the best possible effect in the fuse failure supervision function (FUSE) of REx 5xx terminals.

The fuse-failure supervision function as built into the REx 5xx terminals can operate on the basis of external binary signals from the miniature circuit breaker or from the line disconnector. The first case influences the operation of all voltage-dependent functions while the second one does not affect the impedance measuring functions.

The negative sequence detection algorithm, based on the negative-sequence measuring quantities, a high value of voltage $3 \cdot U_2$ without the presence of the negative-sequence current $3 \cdot I_2$, is recommended for terminals used in isolated or high-impedance earthed networks.

The zero sequence detection algorithm, based on the zero sequence measuring quantities, a high value of voltage $3 \cdot U_0$ without the presence of the residual current $3 \cdot I_0$, is recommended for terminals used in directly or low impedance earthed networks.

A criterion based on delta current and delta voltage measurements can be added to the FUSE function in order to detect a three phase fuse failure, which in practice is more associated with voltage transformer switching during station operations.

1.2 Functionality

Negative sequence

The current and voltage measuring elements within one of the built-in digital signal processors continuously measure the currents and voltages in all three phases and calculate:

- The negative-sequence current 3I2
- The negative-sequence voltage 3U2

comparing them with their respective set values 3I2< and 3U2> .

Fourier's recursive filter filters the current and voltage signals, and a separate trip counter prevents high overreaching of the measuring elements. The signal STNEG is set to 1, if the negative sequence measured voltage exceeds its set value 3U2> and if the negative sequence measured current does not exceed its pre-set value 3I2<.

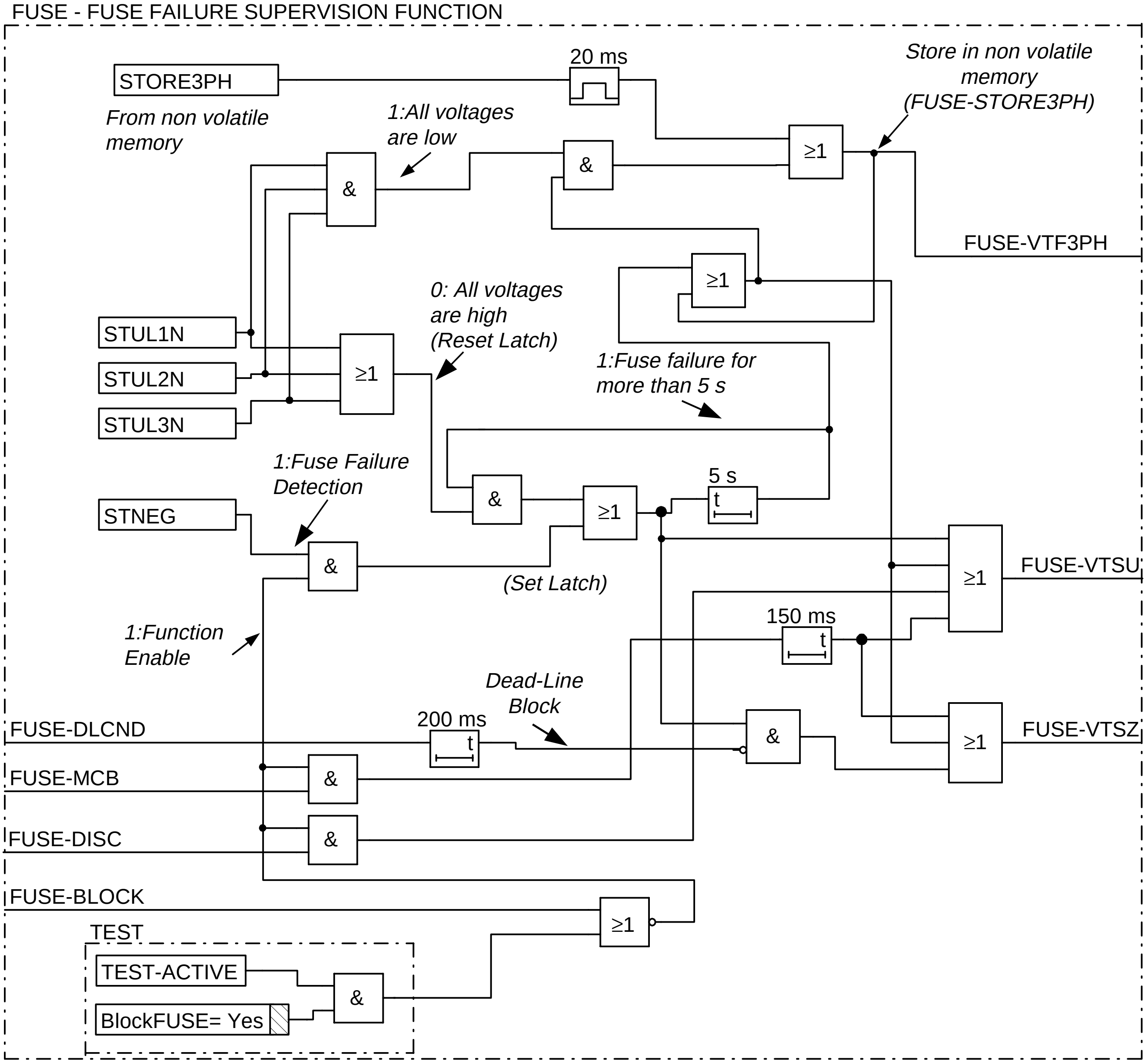


Figure 93: Simplified logic diagram for the fuse failure supervision function, negative sequence based.

Zero sequence

The current and voltage measuring elements within one of the built-in digital signal processors continuously measure the currents and voltages in all three phases and calculate:

- The zero-sequence current $3 \cdot I0$
- The zero-sequence voltage $3 \cdot U0$

comparing them with their respective set values 3I0< and 3U0>.

Fourier’s recursive filter filters the current and voltage signals, and a separate trip counter prevents high overreaching of the measuring elements. The signal STZERO is set to 1, if the zero sequence measured voltage exceeds its set value 3U0> and if the zero sequence measured current does not exceed its pre-set value 3I0<.

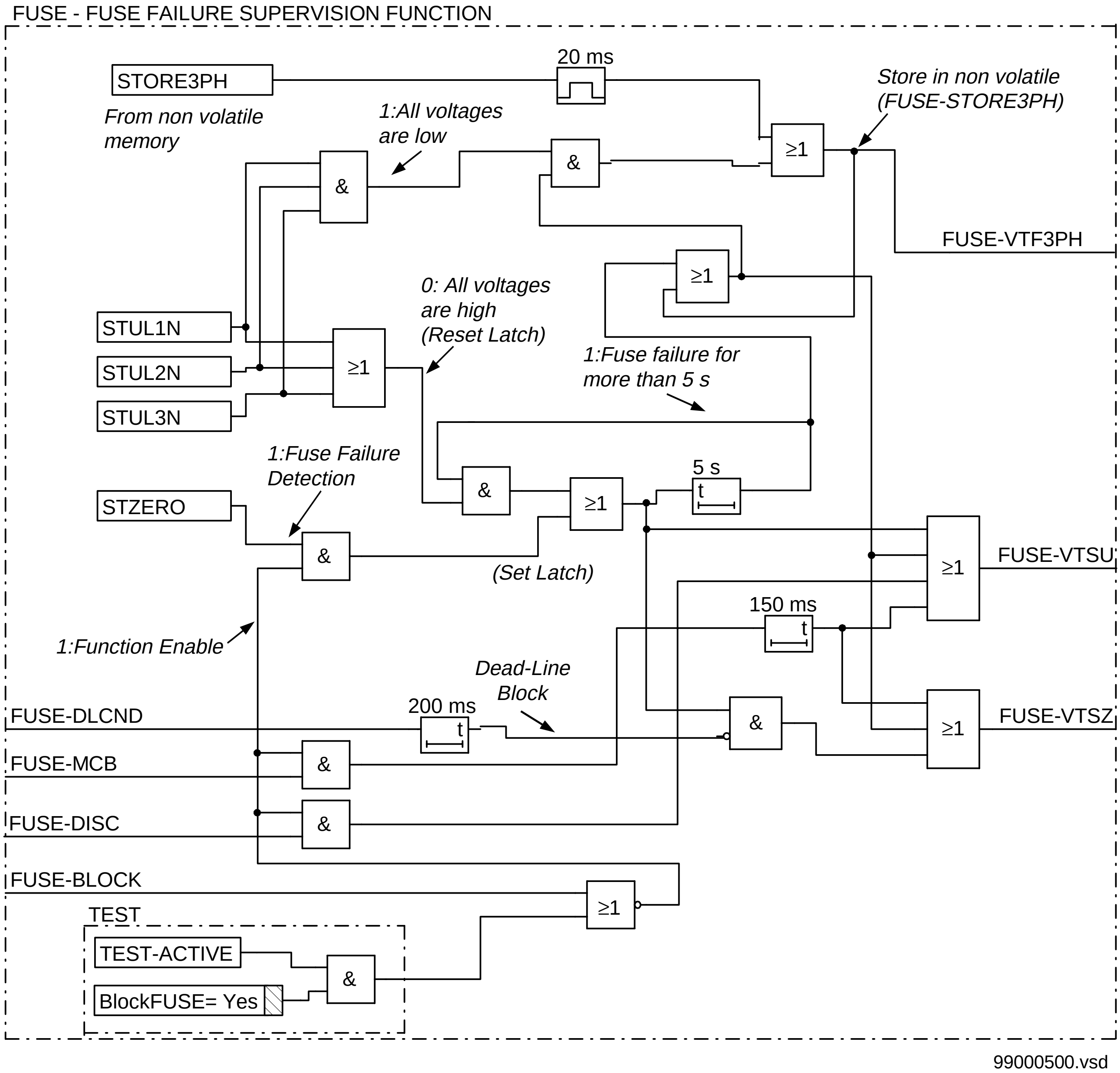


Figure 94: Simplified logic diagram for fuse failure supervisione function, zero sequence based

du/dt, di/dt

The current and voltage measuring elements within one of the built-in digital signal processors continuously measure the currents and voltages in all three phases and calculate:

- The change of current ΔI/Δt
- The change of voltage ΔU/Δt

comparing them with their respective set values ΔI< and ΔU>.

The delta current and delta voltage algorithm, detects a fuse failure if a sufficient negative change in voltage amplitude without a sufficient change in current amplitude is detected in each phase separately. This check is performed if the circuit breaker is closed. Information about the circuit breaker position is brought to the function input CBCLOSED through a binary input of the terminal.

The signal STDUDI is set to 1, if the measured voltage change exceeds its set value DU> and if the measured current change does not exceed its pre-set value DI<. If the voltage is low in any phase (STUL1N, STUL2N or STUL3N=1), the STDUDI signal is sealed in.

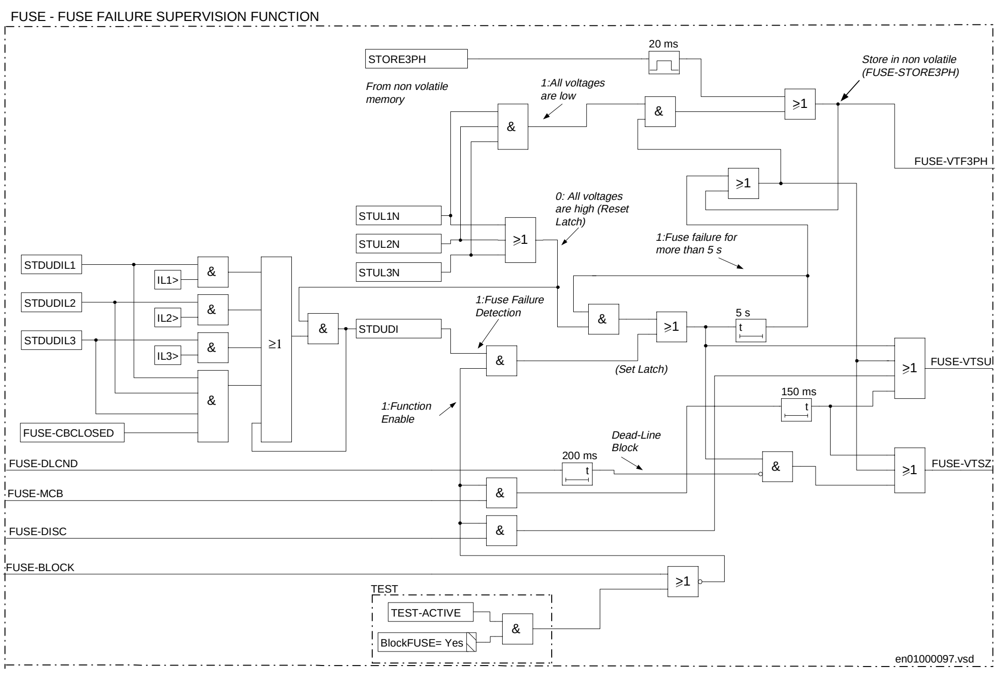


Figure 95: Simplified logic diagram for fuse failure supervision function, du/dt based.

Logic

Signals STUL1N, STUL2N and STUL3N are related to phase to earth voltages and become 1 when the respective phase voltage is lower than the set value. The set value (U<) is chosen in the dead line detection function, that is always present in the terminal when the fuse failure supervision is present.

The fuse failure supervision function is disabled (blocked) if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockFUSE=Yes)
- The input signal FUSE-BLOCK is high

The FUSE-BLOCK signal is a general purpose blocking signal of the fuse failure supervision function. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through OR gate it can be connected to both binary inputs and internal function outputs.

Function input signal FUSE-MCB is to be connected via a terminal binary input to the N.C. auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit.

Function input signal FUSE-DISC is to be connected via a terminal binary input to the N.C. auxiliary contact of the line disconnector.

The function output FUSE-VTSU can be used for blocking the voltage related measuring functions (undervoltage protection, synchrocheck etc.) except for the impedance protection.

Function output FUSE-VTSZ can be used for blocking the impedance protection function.

The FUSE-MCB signal sets the output signals FUSE-VTSU and FUSE-VTSZ in order to block all the voltage related functions when the MCB is open. The additional drop-off timer of 150 ms prolongs the presence of FUSE-MCB signal to prevent the unwanted operation of voltage dependent function due to non simultaneous closing of the main contacts of the miniature circuit breaker.

The FUSE-DISC signal sets the output signal FUSE-VTSU in order to block the voltage related functions when the line disconnector is open. The impedance protection function is not affected by the position of the line disconnector.

The function input signal FUSE-DLCND is related to the dead line condition detection. It has to be connected to the output signal of the dead line condition function DLD-STPH (dead phase condition detected). This signal is activated from the dead line condition function when the voltage and the current in at least one phase are below their respective setting values. It prevents the blocking of the impedance protection by a fuse failure detection during dead line condition (that occurs also during single pole autoreclosing). The 200 ms drop-off timer prolongs the dead line condition after the line-energization in order to prevent the blocking of the impedance protection for unequal pole closing.

If a fuse failure condition is detected, the signal FUSE-VTSU is turned high, and if there is no dead line condition also FUSE-VTSZ is high. If the fuse failure condition remains for more then five seconds and at least one of the phases has a low phase to earth voltage, then the fuse failure condition is latched.

The output signal FUSE-VTF3PH is high if the fuse failure condition is detected for 5 seconds and all the three measured voltages are low (STUL1N = STUL2N = STUL3N = 1).

Fuse failure condition is unlatched when the normal voltage conditions are restored (STUL1N = STUL2N = STUL3N = 0).

Fuse failure condition is stored in the non volatile memory of the terminal. In the new start-up procedure the terminal checks the VTF3PH (STORE3PH) value in its non volatile memory and establishes the corresponding starting conditions.

1.3 Calculations

The operating value for the voltage check function (signals STUL1N, STUL2N, STUL3N) is the same as the operating value of the dead line detection function. The setting of the voltage minimum operating value U< occurs under the submenu:

Settings
Functions
Group n
DeadLineDet

Negative sequence function

The negative sequence voltages and currents always exist due to different non-symmetries in the primary system and differences in the current and voltage instrument transformers. The minimum value for the operation of the current and voltage measuring elements must always be set with a safety margin of 10 to 15%, depending on the system operating conditions.

Pay special attention to the dissymmetry of the measuring quantities when the function is used on longer untransposed lines, on multi circuit lines and so on.

Setting of negative sequence voltage 3U2>

The relay setting value 3U2> is given in percentage of the secondary base voltage value, U_{1b}, associated to the voltage transformer input U1. If Us_{SEC} is the secondary setting value of the relay, then the value for 3U2> is given from equation 142.

$$3U2> = \frac{US_{SEC}}{U_{1b}} \cdot 100$$

(Equation 142)

Set this value under the setting menu:

Settings
Functions
Group n
FuseFailure

on the value 3U2>.

Setting of negative sequence current 3I2<

The relay setting value 3I2< is given in percentage of the secondary base current value, I_{1b}, associated to the current transformer input I1. If Is_{SEC} is the secondary setting value of the relay, then the value for 3I2< is given from equation 143.

$$3I2< \; = \; \frac{IS_{SEC}}{I_{1b}} \cdot 100$$

(Equation 143)

Set this value under the setting menu:

Settings
Functions
Group n
FuseFailure

on the value 3I2<.

Zero sequence function

The zero sequence voltages and currents always exist due to different non-symmetries in the primary system and differences in the current and voltage instrument transformers. The minimum value for the operation of the current and voltage measuring elements must always be set with a safety margin of 10 to 15%, depending on the system operating conditions.

Pay special attention to the dissymmetry of the measuring quantities when the function is used on longer untransposed lines, on multi circuit lines and so on.

Setting of zero sequence voltage 3U0>

The relay setting value 3U0> is given in percentage of the secondary base voltage value, U1b, associated to the voltage transformer input U1. If Us_{SEC} is the secondary setting value of the relay, then the value for 3U0> is given from equation 144.

$$3U0> \; = \; \frac{Us_{SEC}}{U1b} \cdot 100$$

(Equation 144)

Set this value under the setting menu:

Settings
Functions
Group n
FuseFailure

on the value 3U0>.

Setting of zero sequence current 3I0<

The relay setting value 3I0< is given in percentage of the secondary base current value, I1b, associated to the current transformer input I1. If Is_{SEC} is the secondary setting value of the relay, then the value for 3I0< is given from equation 145.

$$3I0< = \frac{Is_{SEC}}{I1b} \cdot 100$$

(Equation 145)

Set this value under the setting menu:

Settings
Functions
Group n
FuseFailure

on the value 3I0<.

Setting of voltage change DU>

The relay setting value DU> is given in percentage of the secondary base voltage value, U1b, associated to the voltage transformer input U1. If Us_{SEC} is the secondary setting value of the relay, the value for DU> is given from equation 146.

$$DU> = \frac{US_{SEC}}{U1b} \cdot 100$$

(Equation 146)

Set this value under the setting menu:

Settings
Functions
Group n
FuseFailure

on the value DU>.

Setting of current change DI<

The relay setting value DI< is given in percentage of the secondary base current value, I1b, associated to the current transformer input I1. If Is_{SEC} is the secondary setting value of the relay, the value for DI< is given from equation 147.

$$DI< = \frac{IS_{SEC}}{I1b} \cdot 100$$

(Equation 147)

Set this value under the setting menu:

Settings
Functions
Group n
FuseFailure

on the value DI<.

2 Voltage transformer supervision (TCT)

2.1 Application

If a capacitor element in a capacitive voltage transformer breaks down, that is the element is short circuited or interrupted an unbalance appears. This unbalance occurs as a “false” residual voltage on the capacitive voltage transformer terminals. If the capacitor element is interrupted the corresponding phase voltage will be undefined, and if the capacitor element is short circuited the corresponding phase voltage is increased. This “false” voltage change might affect different functions, such as distance protection, under voltage, overvoltage and voltage check for weak infeed logic.

After a settable time delay, the voltage transformer supervision function activates the TCT_START signal, if the residual voltage exceeds the set value. This signal can be used as an alarm to the operator that the capacitive voltage transformer is not in a good condition and/or as a blocking signal for certain relays that rely on any phase voltage or the residual voltage.

To ensure that the function is not activated while the protected object is out of operation, it is required that at least one of the phase to phase voltages exceeds 80% of nominal voltage.

Fuse failure supervision is a related function, but is activated only when a secondary voltage totally disappears, i.e. goes to approximately zero. The TCT function can act on smaller residual voltages.

2.2 Functionality

Abbreviations and definitions

Table 9: Abbreviations and definitions

TCT	Voltage transformer supervision
UL1	Phase L1
UPP	Phase-to-phase voltage
STUPP	Start phase-to-phase voltage
UR	Residual voltage
STUR	Start residual voltage

Description of operation

Algorithm

The algorithm of the Voltage transformer supervision function is rather straightforward. The phase voltages pass a fourier filter. The magnitude of phase-to-phase voltage, UPP is measured. An indicator signal STUPP will be issued when the magnitude of phase-to-phase voltage passes the set value of nominal phase-to-phase voltage. See figure 96.

Residual voltage pass a frequency adjusted fourier filter. The magnitude of residual voltage, UR is measured. An indicator signal STUR will be issued when the magnitude of residual voltage passes the set value of residual voltage.

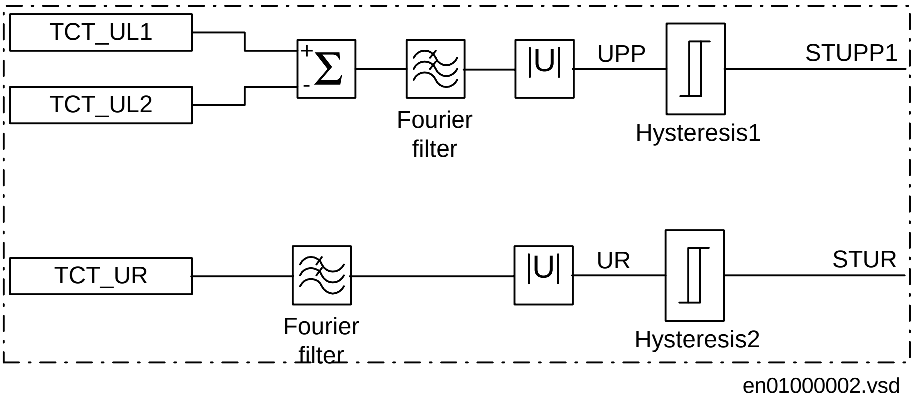


Figure 96: Phase-to-phase voltage and residual voltage measurement

Logic

Following modules for the TCT are described:

- Start logic
- Block and VTSU logic

The logic consists of two different functions, one for detection of lower limit phase-to-phase voltage and one for detection of over limit residual voltage.

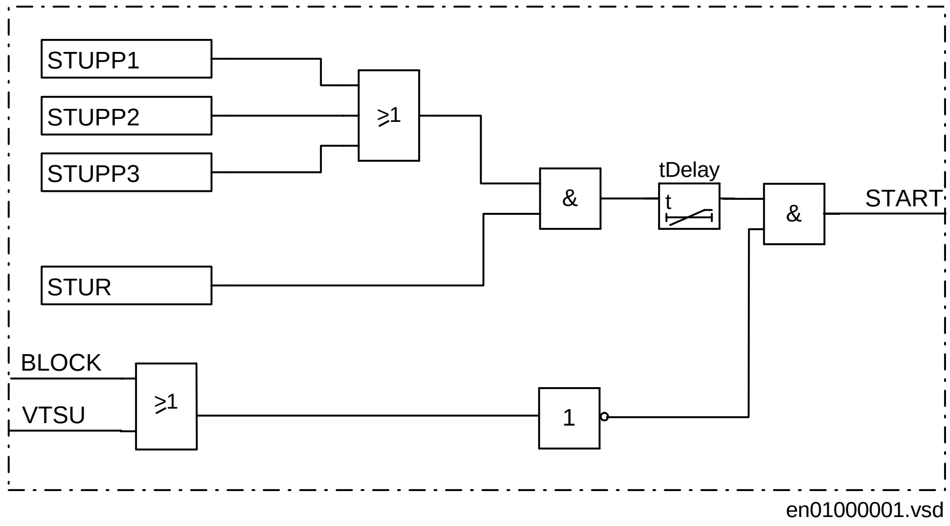


Figure 97: TCT logic

Start logic

The START signal shall be issued when all the conditions below are fulfilled:

- Residual voltage 3U0 passing the set value for residual voltage limit UN>. At least one of the phase-to-phase voltage is higher than 80% of the rated voltage phase-to-phase, see figure 97.
- Time delay tDelay has elapsed.

The START signal shall be reset when at least one of the conditions below is fulfilled:

- Residual voltage is lower than the set value for residual voltage limit UN>.
- All of the phase-to-phase voltages are lower than 40% of the rated voltage phase to phase.

Block logic

All binary outputs shall be reset when the input BLOCK or VTSU is set.

Note that the BLOCK or VTSU only blocks outputs. All measuring functions are still executing. Disabling the input BLOCK or VTSU can trip the TCT instantaneously.

2.3 Calculations

There are only two parameters to set for the TCT function: the residual overvoltage limit, and the time delay.

The capacitive voltage transformer is schematically shown in figure 98, the voltage increase in a phase voltage, after the insulation break-down in one capacitor element, is shown i figure 99 and can be calculated as:

$$\Delta V_a = V'_a - V_a = \frac{1}{(n-1)+1}V_A - \frac{1}{n+1}V_A = \frac{1}{n(n+1)}V_A = \frac{1}{n}V_a$$

(Equation 148)

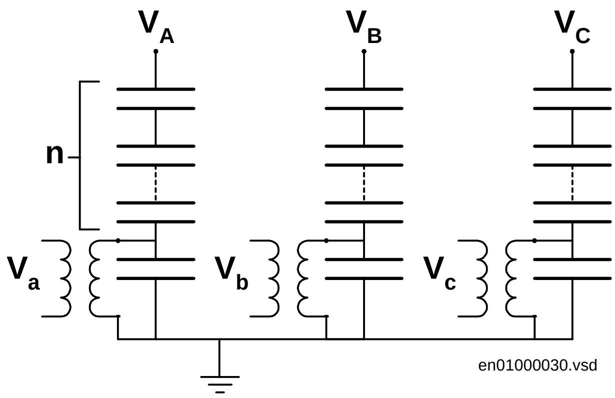


Figure 98: Capacitive voltage transformer

The corresponding vector diagram is shown in figure 99, where also the residual voltage is shown. The residual voltage will be equal to the voltage increase in the phase with the broken capacitor element.

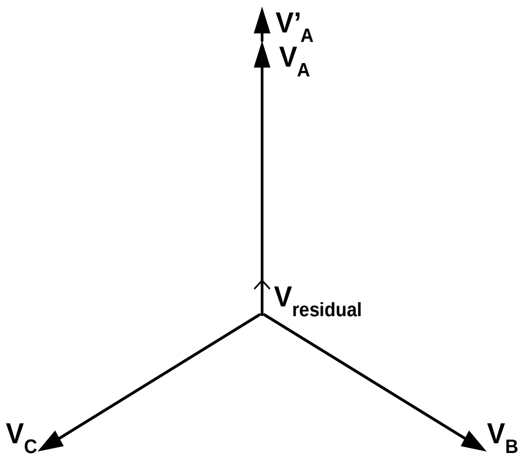


Figure 99: The residual voltage will be equal to the voltage increase in the phase with the broken capacitor element.

With a security margin of about 15% the suitable setting for the residual overvoltage limit should be:

$$UN> = 0.85 \cdot 1/n$$

(Equation 149)

Where:

(n+1) is the total number of capacitor elements in one phase of the capacitive voltage transformer, having one element feeding the magnetic voltage transformer.

The time delay is set in such a way that high speed protective functions, not sensitive to the residual voltage caused by the insulation break-down of one capacitor element, are not affected. Sensitive delayed protective functions, that are sensitive to this change in residual voltage could be blocked by this voltage transformer supervision function.

Chapter 9 Control

About this chapter

This chapter describes the control functions.

1 Synchrocheck (SYN)

1.1 Application

Synchrocheck, general

The synchrocheck function is used for controlled closing of a circuit in an interconnected network. When used, the function gives an enable signal at satisfied voltage conditions across the breaker to be closed. When there is a parallel circuit established, the frequency is normally the same at the two sides of the open breaker. At power swings, e.g. after a line fault, an oscillating difference can appear. Across the open breaker, there can be a phase angle and a voltage amplitude difference due to voltage drop across the parallel circuit or circuits. The synchro-check function measures the difference between the U-line and the U-bus, regarding voltage (UDiff), phase angle (PhaseDiff), and frequency (FreqDiff). It operates and permits closing of the circuit breaker when the following conditions are simultaneously fulfilled:

- The voltages U-line and U-bus are higher than the set value for UHigh of the base voltage U1b.
- The differences in the voltage and phase angles are smaller than the set values of UDiff and PhaseDiff.
- The difference in frequency is less than the set value of FreqDiff. The bus frequency must also be within a range of +/-5 Hz from the rated frequency.

Note!

Phase-phase volage (100 V or 220 V) can not be connected directly to an individual input voltage transformer. The individual transformer is designed for phase-neutral voltage (U_r = 63.5 V or U_r = 127 V.

The function can be used as a condition to be fulfilled before the breaker is closed at manual closing and/or together with the auto-recloser function.

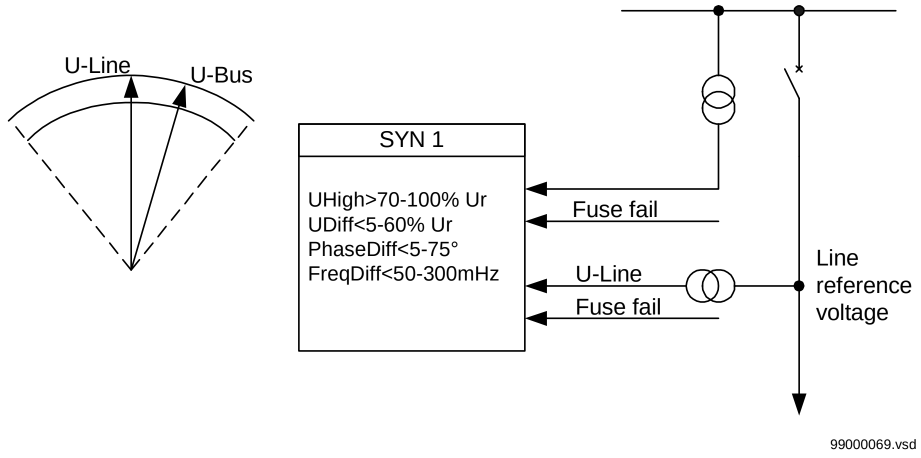


Figure 100: Synchrocheck.

Synchrocheck, single circuit breaker

The voltage circuits are arranged differently depending on the number of synchrocheck functions that are included in the terminal.

In terminals intended for one bay the U-line voltage reference phase is selected on the human-machine interface (HMI). The reference voltage can be phase-neutral L1, L2, L3 or phase-phase voltage L1-L2, L2-L3, L3-L1. The U-bus voltage must then be connected to the same phase or phases as are chosen on the HMI. Figure 101 shows the voltage connection.

In terminals intended for several bays, all voltage inputs are single phase circuits. The voltage can be selected for single phase or phase-to-phase measurement on the HMI. All voltage inputs must be connected to the same phase or phases.

The circuit breaker can be closed when the conditions for FreqDiff, PhaseDiff, and UDiff are fulfilled with the UHigh condition.

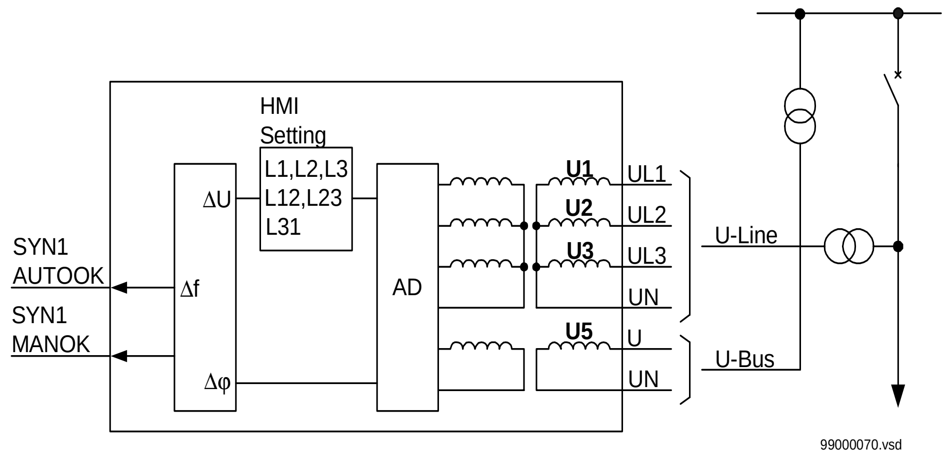


Figure 101: Connection of the synchrocheck function for one bay.

Energizing check, general

The energizing check is made when a disconnected line is to be connected to an energized section of a network, see figure 102. The check can also be set to allow energization of the busbar or in both directions.

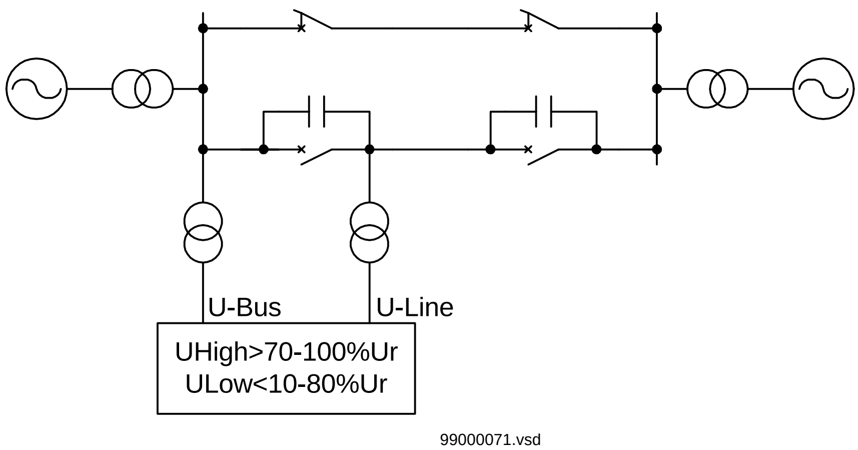


Figure 102: Principle for energizing check.

The voltage level considered to be a non-energized bus or line is set on the HMI. An energizing can occur — depending on:

- the set direction of the energizing function
- the set limit for energized (live - UHigh) condition
- the set limit for non-energized (dead - Ulow) condition

The equipment is considered energized if the voltage is above the set value UHigh (e.g. 80% of the base voltage), and non-energized if it is below the set value, ULow (e.g. 30% of the base voltage). The user can set the UHigh condition between 70-100% U1b and the ULow condition between 10-80% U1b.

A disconnected line can have a considerable potential due to, for instance, induction from a line running in parallel, or by being fed via the extinguishing capacitors in the circuit breakers. This voltage can be as high as 30% or more of the rated voltage of the line.

The energizing operation can be set to operate in either direction over the circuit breaker, or it can be permitted to operate in both directions. Use the AutoEnerg and ManEnerg HMI setting to select the energizing operation in:

- Both directions (Both)
- Dead line live bus (DLLB)
- Dead bus live line (DBLL)

The voltage check can also be set Off. A closing impulse is issued to the circuit breaker if one of the U-line or U-bus voltages is High and the other is Low, that is, when only one side is energized. The user can set AutoEnerg and ManEnerg to enable different conditions during automatic and manual closing of the circuit breaker.

In the manual mode it is also possible to allow closing when both sides of the breaker are dead. This is done by setting the parameter ManDBDL = “On” and ManEnerg to “DLLB”, “DBLL” or “Both”.

Voltage selection, single circuit breaker

The voltage selection function is used for the synchrocheck and energizing check functions. When the terminal is used in a double bus, the voltage that should be selected depends on the status of the breakers and/or disconnectors. By checking the status of the disconnectors and/or breakers auxiliary contacts, the terminal can select the right voltage for the synchrocheck and energizing check functions. Select the type of voltage selection from the synchrocheck, Uselection, SingleBus or DbleBus on the HMI. When using voltage selection, some extra binary inputs are required.

The configuration of internal signal inputs and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the terminal.

Voltage connection for a single bus and single bay

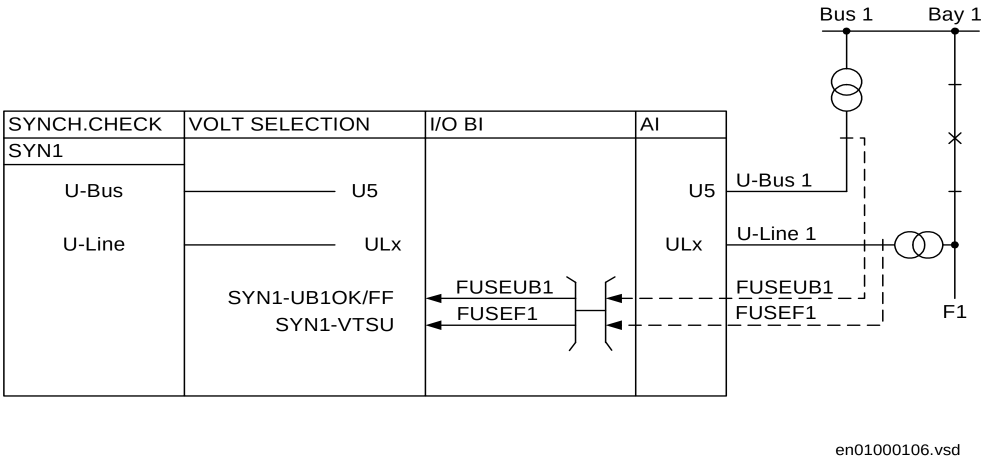


Figure 103: Voltage connection in a single busbar arrangement.

Single bus is selected on the HMI. Figure 103 shows the principle for the connection arrangement. One terminal unit is used for one bay. For the synchrocheck (SYN1) and energizing check function, there is one voltage transformer at each side of the circuit breaker. The voltage transformer circuit connections are straight forward, no special voltage selection is needed.

For the synchrocheck and energizing check, the voltage from Bus 1 (U-Bus 1) is connected to the single phase analogue input (U5) on the terminal unit.

The line voltage (U-line 1) is connected as a three-phase voltage to the analog inputs UL1, UL2, UL3 (ULx).

Fuse failure and Voltage OK signals, single bus and single bay

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs that are configured to inputs of the synchrocheck functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1-UB1OK and SYN1-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYN1-VTSU input is related to the line voltage.

The user can use the FUSE-VTSU signal from the built-in optional fuse-failure function as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line-check) is blocked via the inputs (SYN1-UB1OK/FF or SYN1-VTSU).

Voltage selection for a double bus and single bay

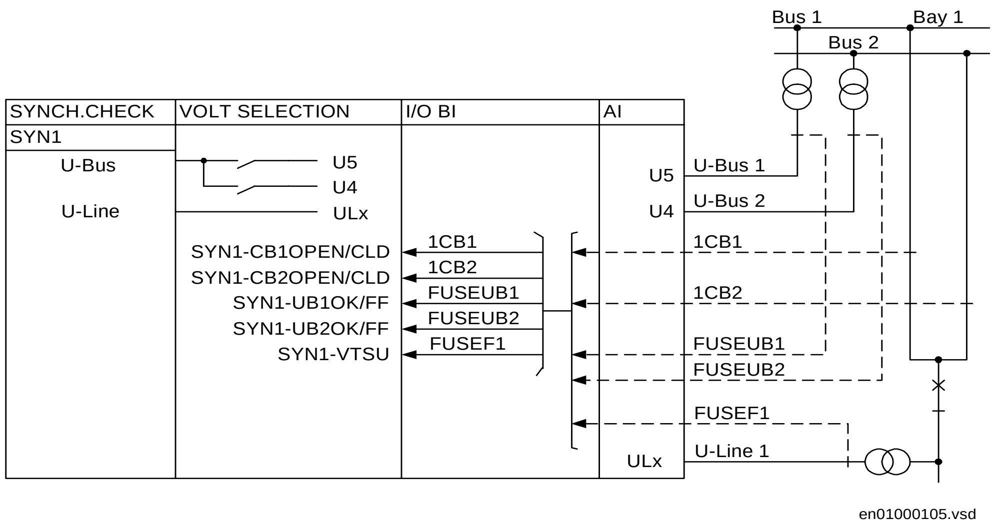


Figure 104: Voltage selection in a double bus arrangement.

Select DbleBus on the HMI. Figure 104 shows the principle for the connection arrangement. One terminal is used for one bay. For the synchrocheck (SYN1) and energizing check function, the voltages on the two busbars are selected by the voltage selection in the terminal unit. The bus voltage from Bus 1 is fed to the U5 analog single-phase input, and the bus voltage from Bus 2 is fed to the U4 analog single-phase input. The line voltage transformers are connected as a three-phase voltage UL1, UL2, UL3 (ULx) to the input U-line 1.

The selection of the bus voltage is made by checking the position of the disconnectors' auxiliary contacts connected via binary inputs of the voltage selection logic inputs, SYN1-CB1OPEN (Disconnector section 1 open), SYN1-CB1CLD (Disconnector section 1 closed) and SYN1-CB2OPEN (Disconnector section 2 open), SYN1-CB2CLD (Disconnector section 2 closed).

Fuse failure and Voltage OK signals, double bus and single bay

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1-UB1(2)OK and SYN1-UB1(2)FF inputs are related to each busbar voltage. The SYN1-VTSU input is related to the line voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar respectively the line voltage. Only the fuse failure of a selected voltage causes a blocking of the relevant energizing check unit.

The user can use the FUSE-VTSU signal from the built-in optional selectable fuse-failure function as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line-check) is blocked via the inputs (SYN1-UB1OK/FF, SYN1-UB2OK/FF or SYN1-VTSU).

Voltage selection for a single bus and several bays

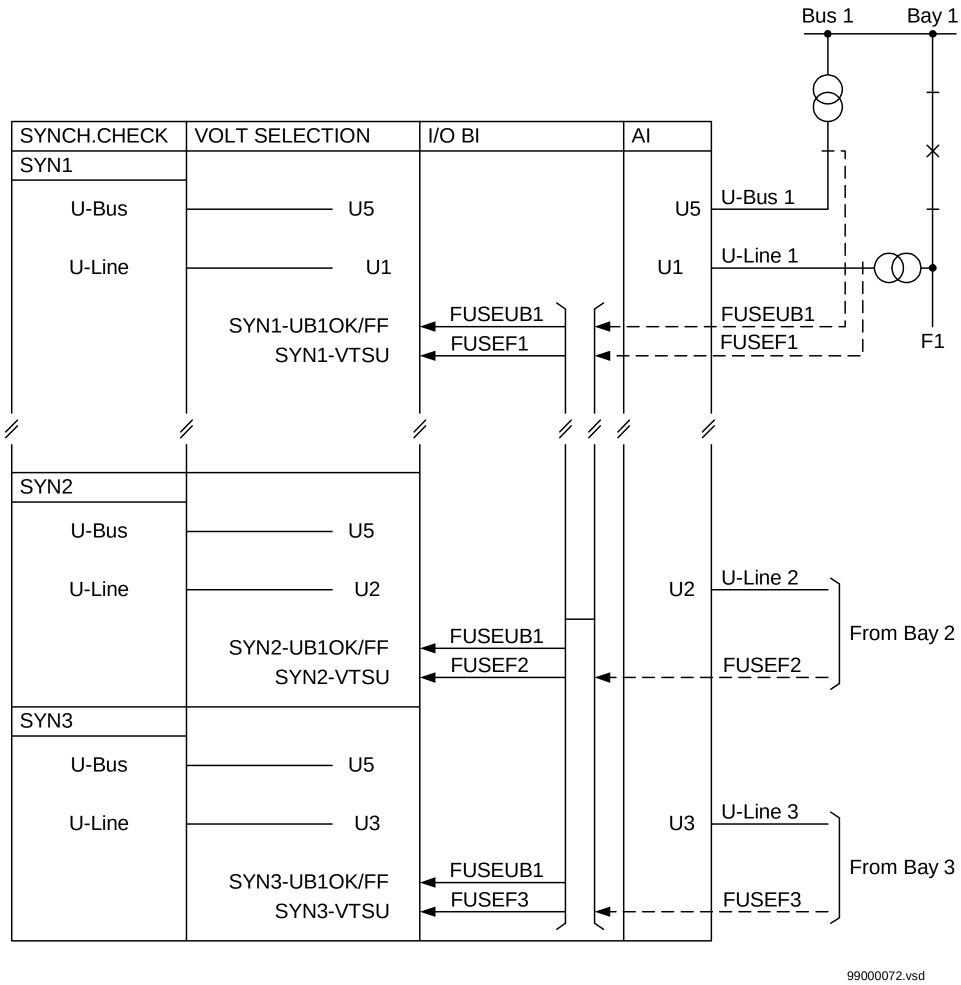


Figure 105: Voltage connection in a single busbar arrangement for up to three bays in one terminal.

Single bus is selected on the HMI. Figure 105 shows the principle for the connection arrangement. One terminal is used for up to three bays. For the synchrocheck (SYNx) and energizing check function, there is one voltage transformer at each side of the circuit breaker. The voltage transformer circuit connections are straight forward, no special voltage selection is needed.

For the synchrocheck and energizing check, the voltage from Bus 1 (U-Bus 1) is connected to the single phase analog input (U5) on the terminal unit.

For terminals intended for three bays, the line voltages are connected as three single-phase inputs, UL1 for Bay 1, UL2 for Bay 2, and UL3 for Bay 3.

Fuse failure and Voltage OK signals, single bus and several bays

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchrocheck functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYNx-UB1OK and SYNx-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYNx-VTSU input is related to the line voltage from each line.

In case of a fuse failure, the energizing check (dead line-check) is blocked via the inputs (SYNx-UB1OK/FF or SYNx-VTSU).

Voltage selection for a double bus and several bays

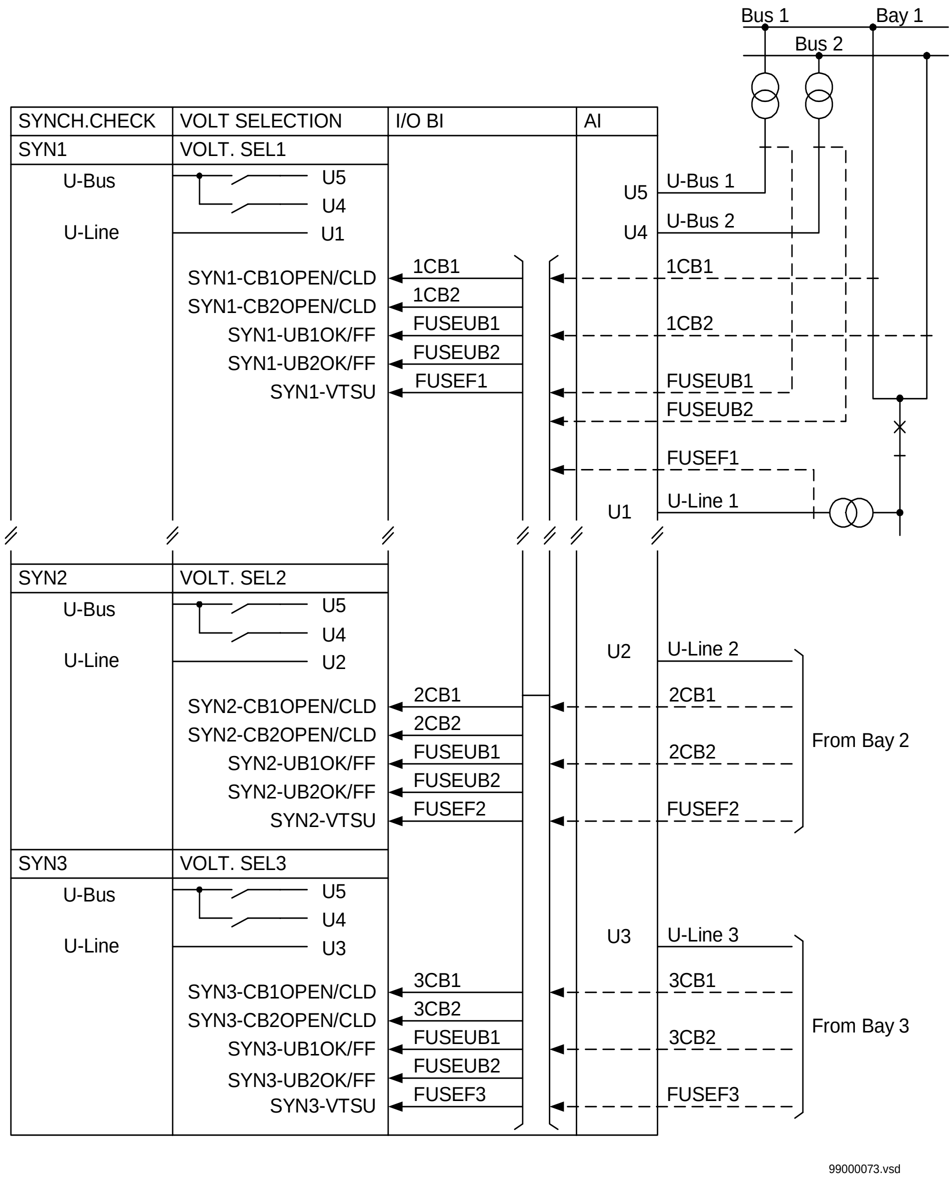


Figure 106: Voltage selection in a double bus arrangement for up to three bays in one terminal.

Select DbleBus on the HMI.Figure 106 shows the principle for the connection arrangement. One terminal unit is used for up to three bays. For the synchrocheck (SYNx) and energizing check function, the voltages on the two busbars are selected by the voltage selection in the terminal unit. The bus voltage from Bus 1 is fed to the U5 analog single-phase input, and the bus voltage from Bus 2 is fed to the U4 analog single-phase input. For terminals intended for three bays, the line voltages are connected as three, single-phase inputs, U1 for Bay1, U2 for Bay2 and U3 for Bay3.

The selection of the bus voltage is made by checking the position of the disconnectors' auxiliary contacts connected via binary inputs of the voltage selection logic inputs, SYNx-CB1OPEN (Disconnector section 1 open), SYNx-CB1CLD (Disconnector section 1 closed) and SYNx-CB2OPEN (Disconnector section 2 open), SYNx-CB2CLD (Disconnector section 2 closed).

Fuse failure and Voltage OK signals, double bus and several bays

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYNx-UB1(2)OK and SYNx-UB1(2)FF inputs are related to each busbar voltage. The SYNx-VTSU input is related to each line voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar respectively the line voltage. Only the fuse failure of a selected voltage causes a blocking of the relevant energizing check unit.

In case of a fuse failure, the energizing check (dead line-check) is blocked via the inputs (SYNx-UB1OK/FF, SYNx-UB2OK/FF or SYNx-VTSU).

Synchrocheck, double circuit breaker

The voltage circuits are arranged differently depending on the number of synchrocheck functions that are included in the terminal.

In terminals intended for one bay the U-line voltage reference phase is selected on the human-machine interface (HMI). The reference voltage can be phase-neutral L1, L2, L3 or phase-phase L1-L2, L2-L3, L3-L1. The U-bus voltage must then be connected to the same phase or phases as are chosen on the HMI. Figure 107 shows the voltage connection.

In terminals intended for several bays, all voltage inputs are single phase circuits. The voltage can be selected for phase-neutral or phase-to-phase measurement on the HMI. All voltage inputs must be connected to the same phase or phases.

The circuit breaker can be closed when the conditions for FreqDiff, PhaseDiff, and UDiff are fulfilled with the UHigh condition.

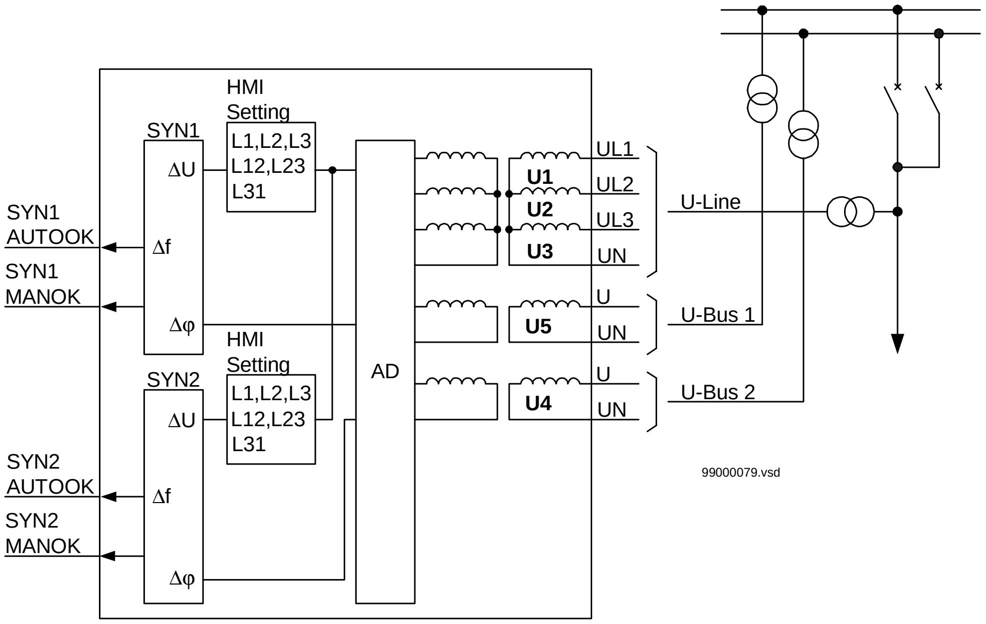


Figure 107: Connection of the synchrocheck function for one bay.

Voltage connection, double circuitbreaker and single bay

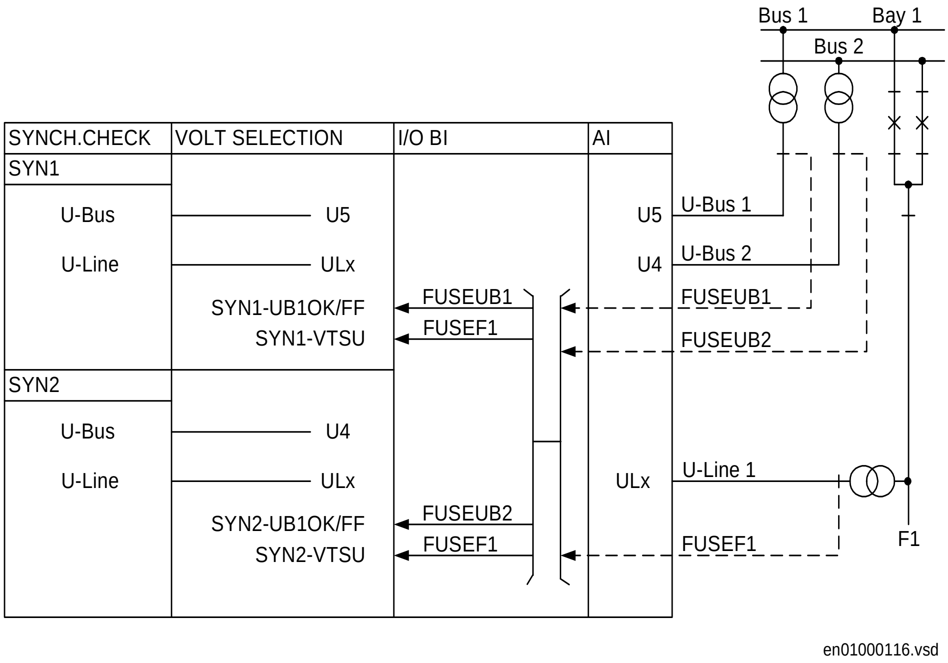


Figure 108: Voltage connection in a double breaker arrangement.

The principle for the connection arrangement is shown in figure 108. One terminal is used for the two circuit breakers in one bay. There is one voltage transformer at each side of the circuit breaker, and the voltage transformer circuit connections are straightforward, without any special voltage selection.

For the synchrocheck and energizing check, the voltage from Bus 1 (U-bus 1) is connected to the single-phase analog input (U5) on the terminal and the voltage from Bus 2 (U-bus 2) is connected to the single-phase analog input (U4).

The line voltage transformers are connected as a three-phase voltage to the analogue inputs UL1, UL2, UL3 (ULx).

The synchronism condition is set on the HMI of the terminal, and the voltage is taken from Bus 1 and the Line or from Bus 2 and the Line (U-line 1). This means that the two synchrocheck units are operating without any special voltage selection, but with the same line (U-line 1) voltage.

The configuration of internal signals, inputs, and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the terminal.

Fuse failure and Voltage OK signals, double circuit breaker and single bay

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1(2)-UB1OK and SYN1(2)-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYN1(2)-VTSU input is related to the line voltage from each line.

The user can use the FUSE-VTSU signal from the built-in optional selectable fuse-failure function as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line check) is blocked via the inputs (SYN1(2)-UB1OK/FF or SYN1(2)-VTSU).

Voltage connection, double circuit breaker and two bays

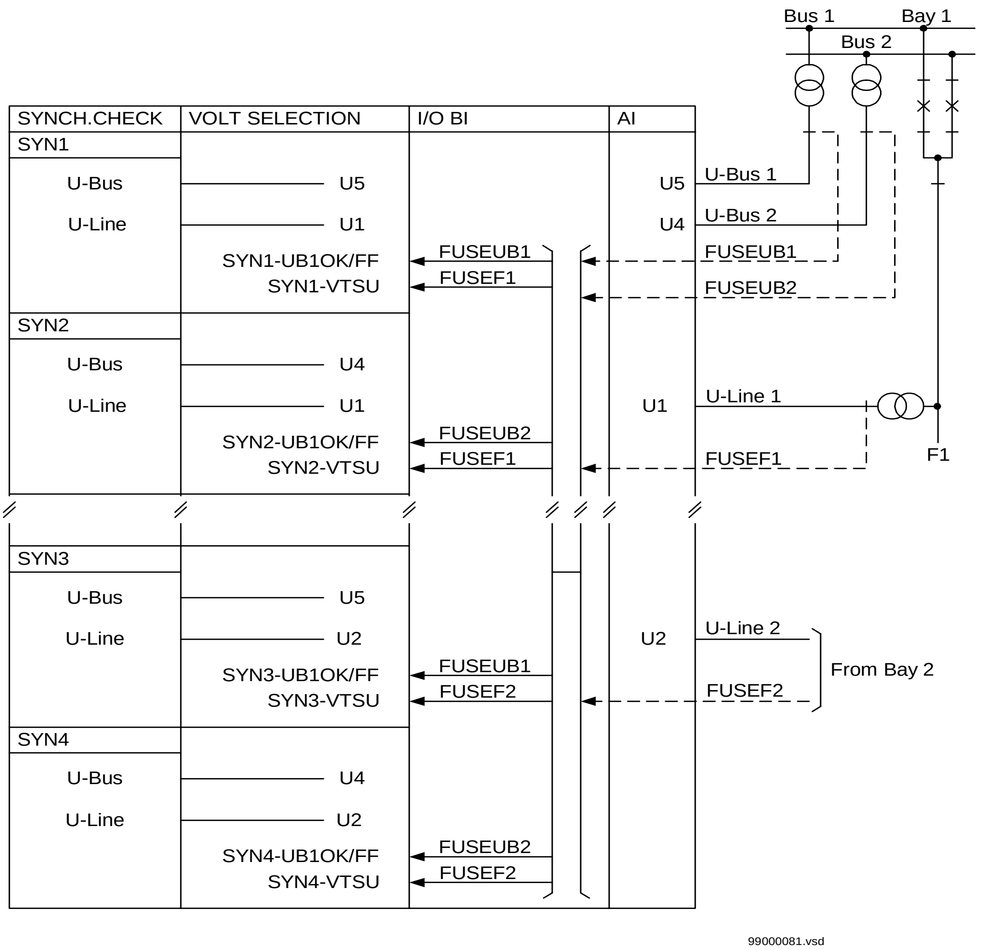


Figure 109: Voltage connection in a double breaker arrangement for up to two bays in one terminal.

The principle for the connection arrangement is shown in figure 109. One terminal is used for the two circuit breakers in each of up to two bays. There is one voltage transformer at each side of the circuit breaker, and the voltage transformer circuit connections are straightforward, without any special voltage selection.

For the synchrocheck and energizing check, the voltage from Bus 1 (U-bus 1) is connected to the single-phase analog input (U5) on the terminal and the voltage from Bus 2 (U-bus 2) is connected to the single-phase analog input (U4).

For the terminals intended for two bays the line voltages are connected as two single phase inputs, U1 for Bay 1 and U2 for Bay 2.

The synchronism condition is set on the HMI of the terminal, and the voltage is taken from Bus 1 and the Line or from Bus 2 and the Line (U-line 1(2)). This means that the two synchrocheck units in each bay are operating without any special voltage selection, but with the same line (U-line 1(2)) voltage.

The configuration of internal signals, inputs, and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the terminal.

Fuse failure and Voltage OK signals, double circuit breaker and two bays

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYNx-UB1OK and SYNx-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYNx-VTSU input is related to the line voltage from each line.

In case of a fuse failure, the energizing check (dead line check) is blocked via the inputs (SYNx-UB1OK/FF or SYNx-VTSU).

Phasing, general

The phasing function is used to close a circuit breaker when two asynchronous systems are going to be connected. The breaker close command is issued at the optimum time when conditions across the breaker are satisfied in order to avoid stress on the network and its components.

The systems are defined to be asynchronous when the frequency difference between bus and line is larger than an adjustable parameter. If the frequency difference is less than this threshold value the system is defined to have a parallel circuit and the synchro-check function is used.

The phasing function measures the difference between the U-line and the U-bus. It operates and enables a closing command to the circuit breaker when the calculated closing angle is equal to the measured phase angle and the following conditions are simultaneously fulfilled:

- The voltages U-line and U-bus are higher than the set value for UHigh of the base voltage U1b.
- The difference in the voltage is smaller than the set value of UDiff.
- The difference in frequency is less than the set value of FreqDiffSynch and larger than the set value of FreqDiff. If the frequency is less than FreqDiff the synchrocheck is used. The bus and line frequencies must also be within a range of +/-5 Hz from the rated frequency.
- The frequency rate of change is less than 0.21 Hz/s for both U-bus and U-line.
- The closing angle is less than approx. 60 degrees.

The phasing function compensates for measured slip frequency as well as the circuit breaker closing delay. The phase advance is calculated continuously by the following formula:

$$\text{Closing angle} = 360° \cdot \text{Meas. freq. diff.} \cdot \text{tBreaker}$$

(Equation 150)

Closing angle is the change in angle during breaker closing operate time.

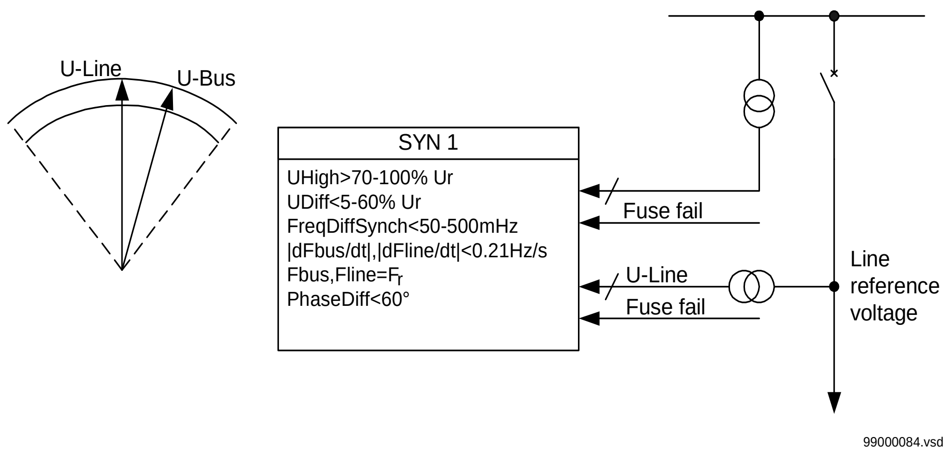


Figure 110: Phasing.

Phasing, single circuit breaker

The reference voltage can be phase-neutral L1, L2, L3 or phase-phase L1-L2, L2-L3, L3-L1. The U-bus voltage must then be connected to the same phase or phases as are chosen on the HMI. Figure 111 shows the voltage connection.

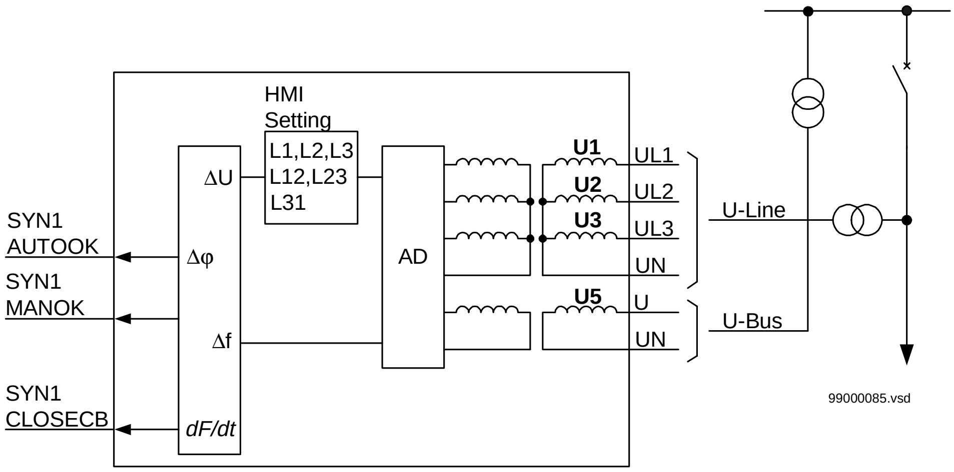


Figure 111: Connection of the phasing and synchrocheck function for one bay.

Voltage selection, single circuit breaker

The voltage selection function is used for the phasing and synchronism (SYN1) and energizing check functions. When the terminal is used in a double bus, the voltage that should be selected depends on the positions of the breakers and/or disconnectors. By checking the position of the disconnectors and/or breakers auxiliary contacts, the terminal can select the right voltage for the synchronism and energizing function. Select the type of voltage selection from the Synchro-check, Uselection, SingleBus or DbleBus on the HMI.

The configuration of internal signal inputs and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the terminal.

Voltage selection for a single bus and single bay

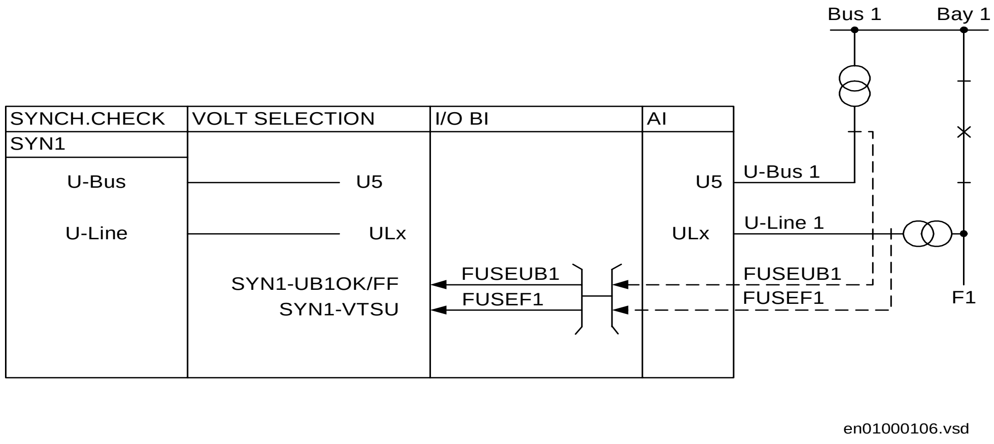


Figure 112: Voltage connection in a single busbar arrangement.

Single bus is selected on the HMI. Figure 112 shows the principle for the connection arrangement. For the phasing, synchrocheck (SYN1) and energizing check function, there is one voltage transformer at each side of the circuit breaker. The voltage transformer circuit connections are straight forward, no special voltage selection is needed.

For the phasing, synchrocheck and energizing check, the voltage from Bus 1 (U-Bus 1) is connected to the single phase analog input (U5) on the terminal.

The line voltage (U-line 1) is connected as a three-phase voltage to the analog inputs UL1, UL2, UL3 (ULx).

Fuse failure and Voltage OK signals, single bus and single bay

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchrocheck functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1-UB1OK and SYN1-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYN1-VTSU input is related to the line voltage.

The user can use the FUSE-VTSU signal from the built-in optional fuse-failure function as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line check) is blocked via the inputs (SYN1-UB1OK/FF or SYN1-VTSU).

Voltage selection for a double bus and single bay

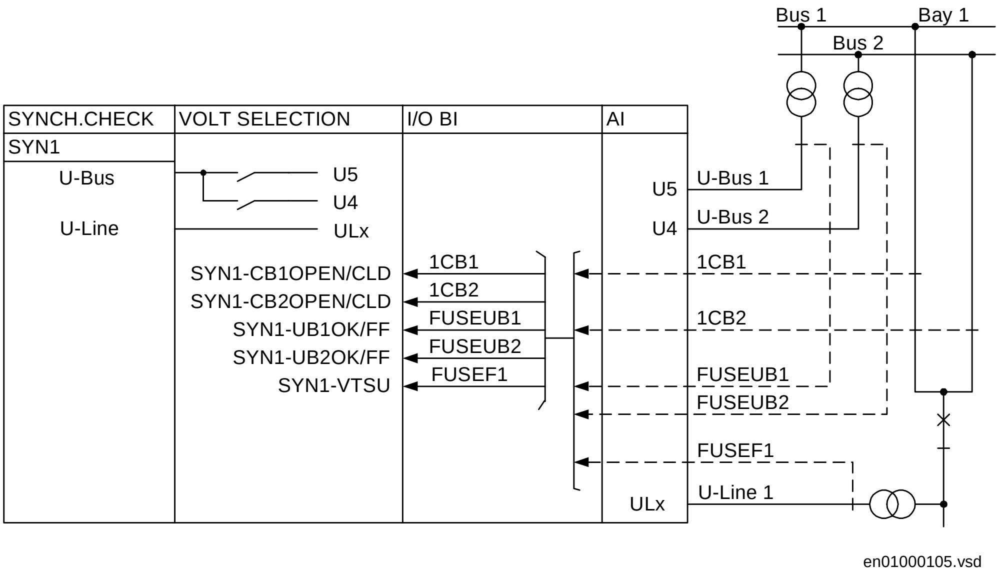


Figure 113: Voltage selection in a double bus arrangement.

Select DbleBus on the HMI. Figure 113 shows the principle for the connection arrangement. For the phasing and synchrocheck (SYN1) and energizing check function, the voltages on the two busbars are selected by the voltage selection in the terminal unit. The bus voltage from Bus 1 is fed to the U5 analog single-phase input, and the bus voltage from Bus 2 is fed to the U4 analog single-phase input. The line voltage transformers are connected as a three-phase voltage UL1, UL2, UL3 (ULx) to the input U-line 1.

The selection of the bus voltage is made by checking the position of the disconnectors' auxiliary contacts connected via binary inputs of the voltage selection logic inputs, SYN1-CB1OPEN (Disconnector section 1 open), SYN1-CB1CLD (Disconnector section 1 closed) and SYN1-CB2OPEN (Disconnector section 2 open), SYN1-CB2CLD (Disconnector section 2 closed).

Fuse failure and Voltage OK signals, double bus and single bay

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1-UB1(2)OK and SYN1-UB1(2)FF inputs are related to each busbar voltage. The SYN1-VTSU input is related to each line voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar respectively the line voltage. Only the fuse failure of a selected voltage causes a blocking of the relevant energizing check unit.

The user can use the FUSE-VTSU signal from the built-in optional selectable fuse-failure function as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line check) is blocked via the inputs (SYN1-UB1OK/FF, SYN1-UB2OK/FF or SYN1-VTSU).

Phasing, double circuit breaker

The reference voltage can be phase-neutral L1, L2, L3 or phase-phase L1-L2, L2-L3, L3-L1. The U-bus voltage must then be connected to the same phase or phases as are chosen on the HMI. Figure 114 shows the voltage connection.

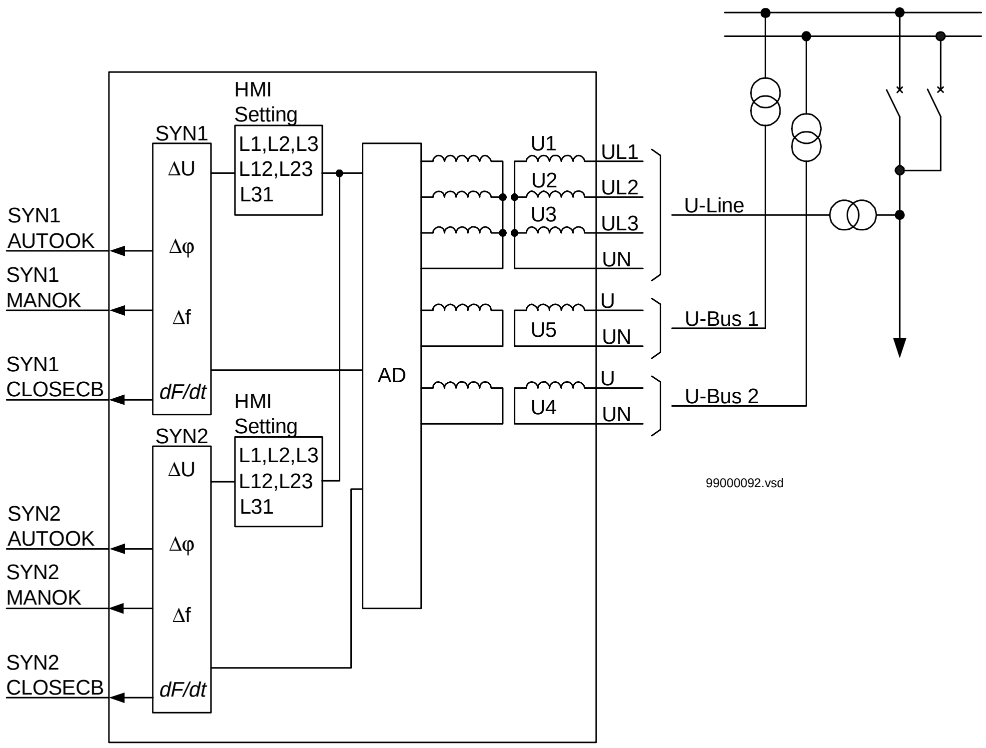


Figure 114: Connection of the phasing and synchrocheck function for one bay.

Voltage connection, double circuit breaker and single bay

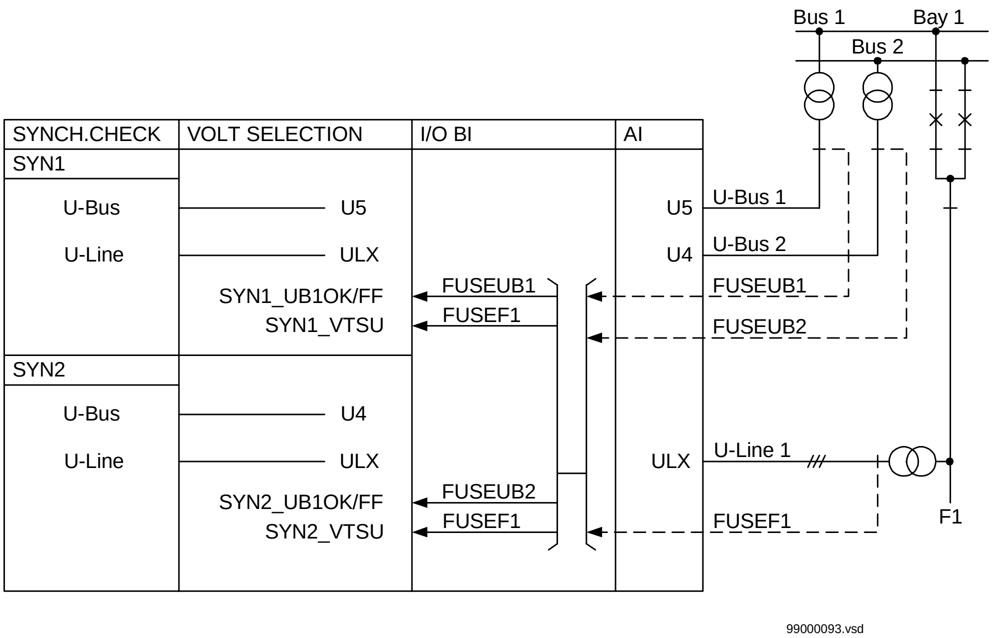


Figure 115: Voltage connection in a double breaker arrangement.

The principle for the connection arrangement is shown in figure 115. One terminal unit is used for the two circuit breakers in one bay. There is one voltage transformer at each side of the circuit breaker, and the voltage transformer circuit connections are straight forward, without any special voltage selection. For the synchrocheck and energizing check, the voltage from Bus 1 (U-bus 1) is connected to the single-phase analog input (U5) on the terminal and the voltage from Bus 2 (U-bus 2) is connected to the single-phase analog input (U4).

The line voltage transformers are connected as a three-phase voltage to the analog inputs UL1, UL2, UL3 (ULx).

The synchronism condition is set on the HMI of the terminal unit, and the voltage is taken from Bus 1 and the Line or from Bus 2 and the Line (U-line 1). This means that the two synchrocheck units are operating without any special voltage selection, but with the same line (U-line 1) voltage.

The configuration of internal signals, inputs, and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the terminal.

Fuse failure and Voltage OK signals, double circuit breaker and single bay

The external fuse-failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1(2)-UB1OK and SYN1(2)-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYN1(2)-VTSU input is related to the line voltage from each line.

The user can use the FUSE-VTSU signal from the built-in optional selectable fuse-failure function as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line- check) is blocked via the input (SYN1(2)-UB1OK/FF or SYN1(2)-VTSU).

Synchrocheck, 1 1/2 circuit breaker

The voltage circuits are arranged differently depending on the number of synchrocheck functions that are included in the terminal.

In terminals intended for one bay the U-line voltage reference phase is selected on the human-machine interface (HMI). The reference voltage can be phase-neutral L1, L2, L3 or phase-phase L1-L2, L2-L3, L3-L1. The U-bus voltage must then be connected to the same phase or phases as chosen on the HMI. Figure 116 shows the voltage connection.

In terminals intended for several bays or a 1 and 1/2 circuit breaker diameter, all voltage inputs are single-phase circuits. The voltage can be selected for phase-neutral or phase-to-phase measurement on the HMI. All voltage inputs must be connected to the same phase or phases.

The circuit breaker can be closed when the conditions for FreqDiff, PhaseDiff, and UDiff are fulfilled with the UHigh condition.

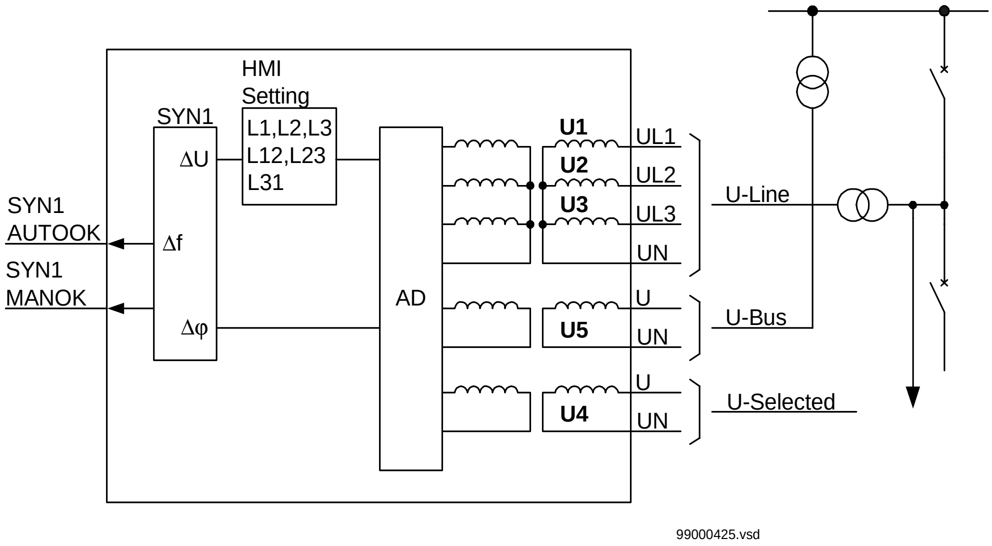


Figure 116: Connection of the synchrocheck function for one bay.

Voltage selection, 1 1/2 circuit breaker with one terminal per breaker

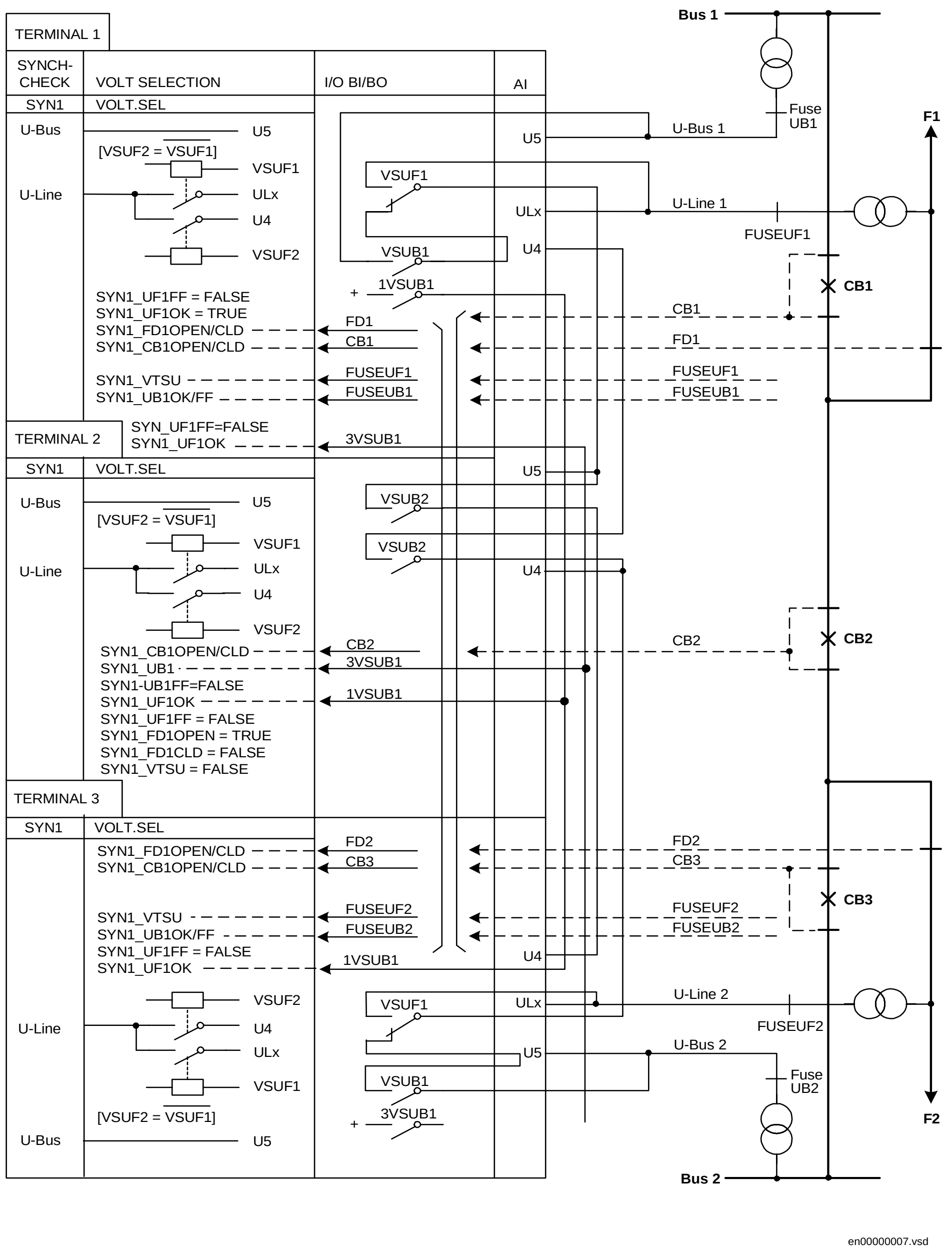


Figure 117: Connections in 1 1/2 circuit breaker arrangement with one terminal per breaker

The principle for the connection arrangement is shown in Figure 117. One terminal is used for the two circuit breakers in one or two bays dependent of selected option. There is one voltage transformer at each side of the circuit breaker, and the voltage transformer circuit connections are straight forward, without any special voltage selection.

For the synchrocheck and energizing check, the voltage from Bus 1 (SYN1(T1) - U-bus 1) is connected to the single-phase analog input (U5) on terminal 1 and the voltage from Bus 2 (SYN1(T3) - U-bus 2) is connected to the single-phase analog input (U4) on terminal 1.

Vice verse, the voltage from Bus 1 (SYN1(T1) - U-bus 1) is connected to the single-phase analog input (U4) on terminal 3 and the voltage from Bus 2 (SYN1(T3) - U-bus 2) is connected to the single-phase analog input (U5) on terminal 3.

For a terminal intended for one bay the line voltage transformers are connected as a three-phase voltage to the analog inputs UL1, UL2, UL3 (ULx) (SYN1(T2) - U-Line) voltage. For the version intended for two bays the line voltages are connected as two single-phase inputs, UL1 for Bay 1 and UL2 for Bay 2.

The synchronism condition is set on the local HMI of the terminal, and the voltage is taken from Bus 1 and the Line or from Bus 2 and the Line (U-line). This means that the two synchro-check units are operating without any special voltage selection, but with the same line (U-line) voltage.

The configuration of internal signals, inputs, and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the terminals.

Fuse failure and Voltage OK signals, 1 1/2 circuit breaker with one terminal per breaker

The external fuse-failure signals or signals from a tripped fuse switch/MCBs are connected to binary inputs configured to inputs of the synchro-check functions in the terminal. There are two alternative connection possibilities. Inputs named OK must be supplied if the voltage circuit is healthy. Inputs named FF must be supplied if the voltage circuit is faulty.

The SYN1-UB1OK and SYN1-UB1FF inputs are related to the busbar voltage. Configure them to the binary inputs that indicate the status of the external fuse failure of the busbar voltage. The SYN1-VTSU input is related to the line voltage from each line.

The FUSE-VTSU signal, from the built-in optional selectable fuse-failure function, can be used as an alternative to the external fuse-failure signals.

In case of a fuse failure, the energizing check (dead line - check) is blocked via the inputs (SYN1-UB1OK/FF or SYN1-VTSU).

Synchrocheck, 1 1/2 circuit breaker diameter

All voltage inputs are single phase circuits. The voltage can be selected for phase-neutral or phase-phase measurement on the HMI. If all voltage inputs aren’t connected to to the same phase or phases they can be corrected with the settings URatio and PhaseShift.

The circuit breaker can be closed when the conditions for FreqDiff, PhaseDiff and UDiff are fulfilled, together with the UHigh condition.

Voltage selection, 1 1/2 circuit breaker diameter

The principle for the connection arrangement is shown in figure 118. One control terminal is used for one diameter of 1 1/2 circuit breaker arrangement. This will utilize for sequential autoreclosing and synchronism with voltage selection for each circuit breaker. For the synchronism (SYN) and energizing check, the voltage on the two sides of the breaker which should be closed, is used. When the line voltage transformers (VTs) are on the line side of the line disconnectors, and not at the “Tee point”, a voltage selection is necessary.

All voltage inputs are single phase circuits and must be connected to the same phase or phases. For the circuit breaker CB1 the bus voltage is connected to input U5. The inputs UL1and UL2 is used for the voltage from Line 1respectively Line 2. For the circuit breaker CB3 the bus voltage is connected to input U4. The voltage inputs can be selected for single phase or phase to phase measurement

For the breaker connected to the busbar 1, e.g. CB1 in figure 118, (the same principle also applies to CB 3) the voltage at the “Tee point” can be connected to and energized from the line F1 or from the other side of the central breaker section, e.g. line F2 or busbar 2 (depending on the position of the line disconnector on F2). It may also be isolated both from line F1 and from the central circuit breaker.

When we consider the central circuit breaker, the upper “Tee point” can be energized from line F1 or busbar 1, or be isolated. The lower “Tee point” can be energized from line F2 or busbar 2, or be isolated. The control terminal is equipped with modules for analog input circuits including VT circuits (AI), and binary inputs. (I/O BI). Positions of the line disconnector and the breaker section (the breaker and the two disconnectors near it) are used to control the logic and thus the voltage selection. This information is connected to the binary input modules and configured to the relevant inputs of the voltage selection logic.

The configuration of internal signal inputs and outputs may be different for different busbar systems, and the actual configuration for the substation must be done during engineering of the control terminal.

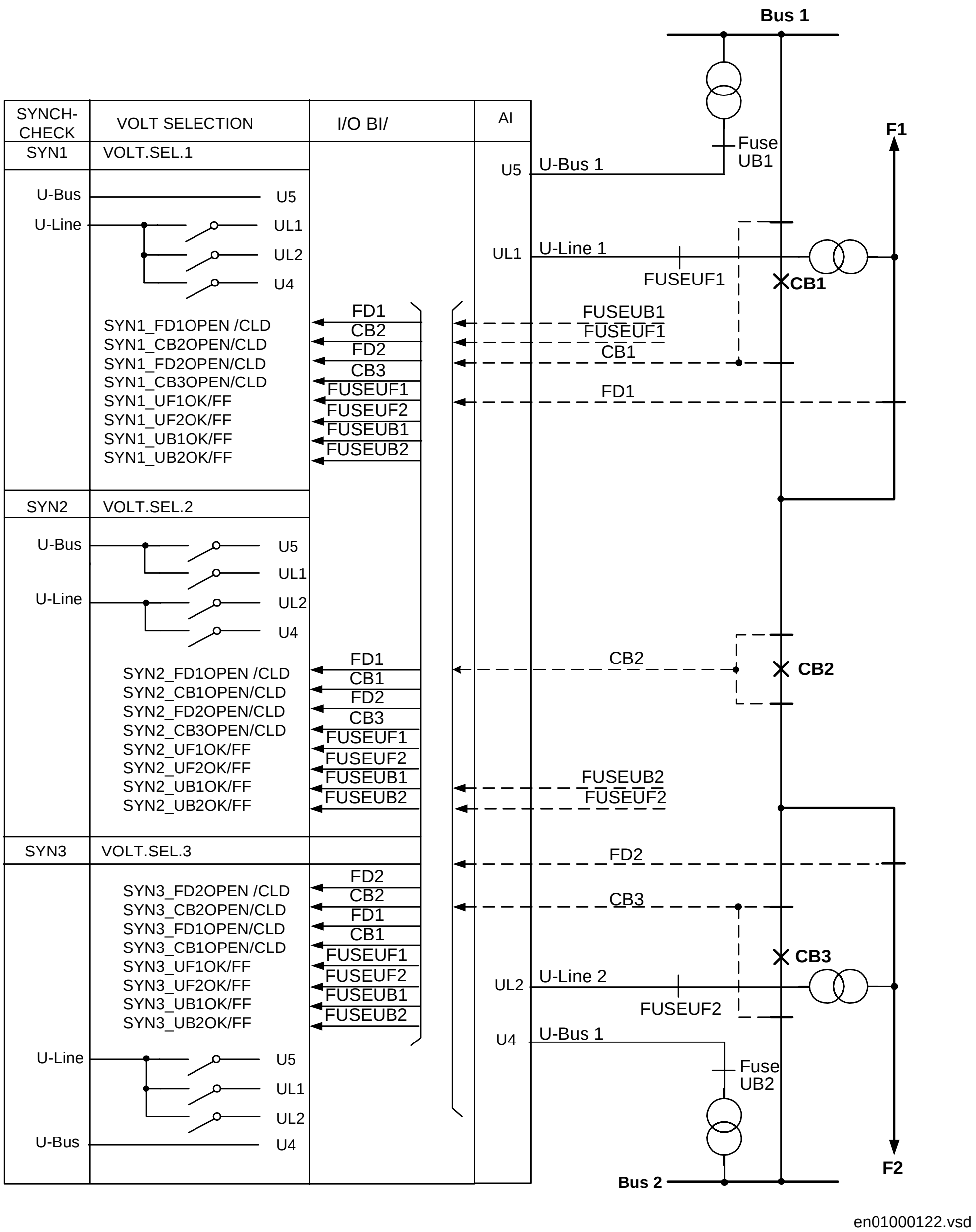


Figure 118: Voltage selection and configuration of binary inputs for a 1 1/2 circuit breaker diameter

Abbreviations:

SYN1 (2, 3)	Synchro check for CB1 (2, 3)
VOLT-SEL1(2, 3)	Voltage selection logic for CB 1 (2, 3)
I/O BI	Binary inputs
AI	Analoge inputs
UL1 (2)	Reference voltage from Line 1 (2)
U5	Reference voltage from busbar 1
U4	Reference voltage from busbar 2
F1 (2)	Line 1 (2)
CB1 (2, 3)	Circuit breaker 1(2, 3)
FD1(2)OPEN	Line 1(2) disconnector open (FD1,2)
FD1(2)CLD	Line 1(2) disconnector closed (FD1,2)
CB1(2, 3)OPEN	Breaker section 1 (2, 3) open (breakers and disconnectors)
CB1(2, 3)CLD	Breaker section 1 (2, 3) closed (breakers and disconnectors)
UF1(2)OK	Line 1(2) Healthy voltage circuit
UF1(2)FF	Line 1(2) Faulty voltage circuit
UB1(2)OK	Busbar 1(2) Healthy voltage circuit
UB1(2)FF	Busbar 1(2) Faulty voltage circuit

Voltage selection for synchro-check at CB1, 1 1/2 circuit breaker diameter

The busbar voltage U-bus 1 is fed to the analogue single-phase voltage input U5 (Reference voltage from busbar 1).

In the control terminal there is an internal selection (VOLT-SEL1) of the line voltage (U-Line) or the voltage on the other side of the central circuit breaker, UL1, to the synchronism function. If the line disconnector (FD1) is closed, the line voltage U-Line is used as reference. If the line disconnector (FD1) is open the voltage must be selected from the other side of the central circuit breaker, e.g. from the line (FD2) or from busbar 2 (Bus 2).

The position of the line disconnector is taken from auxiliary contacts via the binary inputs connected to FD1(2) CLD (Line disconnector closed) and FD1(2) OPEN (Line disconnector open). The position of each breaker section (the breaker and the two disconnectors near it) is checked via the binary inputs connected to CB2(3)OPEN (Breaker section 2 or 3 open) and CB2(3)CLD (Breaker section 2 or 3 closed).

Voltage selection for synchro-check at CB2, 1 1/2 circuit breaker diameter

From each side of the section (Bus 1 and Bus 2), a voltage is received via the voltage selection logic (VOLT-SEL2) in the control terminal. The second synchro-check module (SYN2) is dedicated to the central circuit breaker. The U-Bus voltage has been selected from the upper section, either from U-Bus1 (U5) or U-Line 1 (UL1). The U-Line voltage has been selected from the lower section, either from U-Bus 2 (U4) or U-Line 2 (UL2).

If the line disconnector (FD1) is closed, the line voltage is used and connected to the input U-Bus. If the line disconnector (FD1) is open and breaker section CB1 is closed the voltage is selected from busbar 1.

If the Line 1 disconnector (FD2) is closed, the line voltage is used and connected to the input U-Line. If the line 2 disconnector (FD2) is open and breaker section CB3 is closed the voltage is selected from busbar 2

The position of the line disconnector is taken from auxiliary contacts via the binary input FD1(2) CLD (Line disconnector closed) and FD1(2) OPEN (Line disconnector open). The position of each breaker section (the breaker and the two disconnectors near it) is checked via the binary inputs connected to CB1(3)OPEN (Breaker section 1 or 3 open) and CB1(3)CLD (Breaker section 2 or 3 closed).

Voltage selection for synchro-check at CB3, 1 1/2 circuit breaker diameter

The voltage selection principle of the synchro-check (SYN3) belonging to the lower circuit breaker is the same as described under upper circuit breaker CB1 above, with the difference that the selection of voltage is made either from busbar 2 or from line 2 (F2).

Fuse failure and Voltage OK signals, 1 1/2 circuit breaker diameter

The external fuse failure signals or signals from a tripped fuse switch/MCB are connected to binary inputs configured to inputs of the voltage selection logic in the control terminal. There are two alternatives of connection possibilities. Inputs named OK shall be supplied from a contact indicating a healthy voltage circuit or alternatively inputs named FF shall be supplied if the contact indicates a faulty voltage circuit.

The inputs UB1(2)OK and UB1(2)FF are related to respectively busbar voltage. The input UF1(2)OK and UF1(2)FF are related to respectively line voltage. The inputs are incorporated in the voltage selection logic and only the fuse failure of a selected voltage causes a blocking of the relevant energizing check unit by resetting the release signal UENERG1(2 or 3)OK.

1.2 Functionality

Single circuit breaker

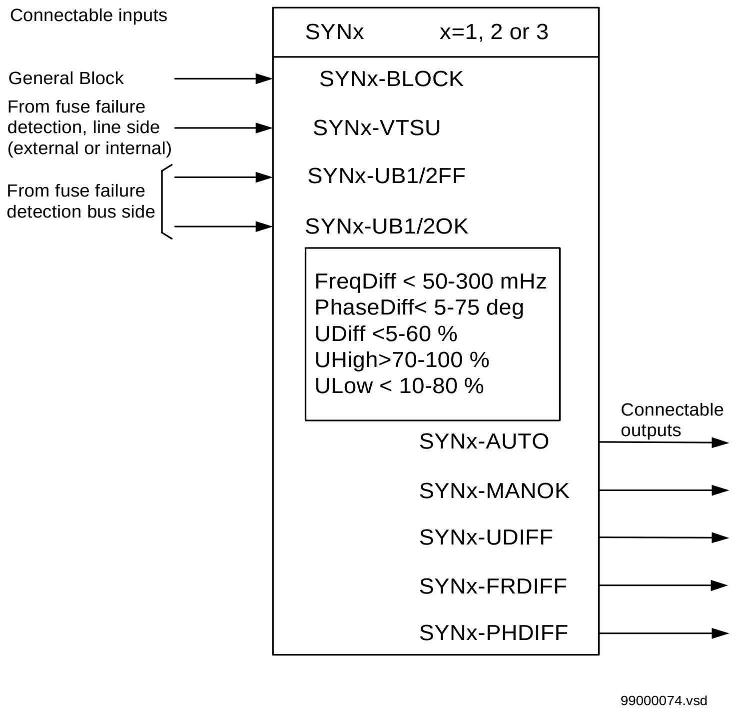


Figure 119: Input and output signals.

Synchrocheck

Description of input and output signals for the synchrocheck function.

Input signals	Description
SYNx-BLOCK	General block input from any external condition, that should block the synchrocheck.
SYNx-VTSU	The synchrocheck function cooperates with the FUSE-VTSU connected signal, which is the built-in optional fuse failure detection. It can also be connected to external condition for fuse failure. This is a blocking condition for the energizing function.
SYNx-UB1FF	External fuse failure input from busbar voltage Bus 1 (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure the energizing check is blocked.
SYNx-UB1OK	No external voltage fuse failure (U5). Inverted signal.
SYNx-UB2FF	External fuse failure input from busbar voltage Bus 2 (U4). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure the energizing check is blocked.
SYNx-UB2OK	No external voltage fuse failure (U4). Inverted signal.

Output signals	Description
SYNx-AUTOOK	Synchrocheck/energizing OK. The output signal is high when the synchrocheck conditions set on the HMI are fulfilled. It can also include the energizing condition, if selected. The signal can be used to release the auto-recloser before closing attempt of the circuit breaker. It can also be used as a free signal.
SYNx-MANOK	Same as above but with alternative settings of the direction for energizing to be used during manual closing of the circuit breaker.
SYNx-UDIFF	Difference in voltage is less than the set difference limit.
SYNx-FRDIFF	Difference in frequency is less than the set difference limit.
SYNx-PHDIFF	Difference in phase angle is less than the set difference limit.

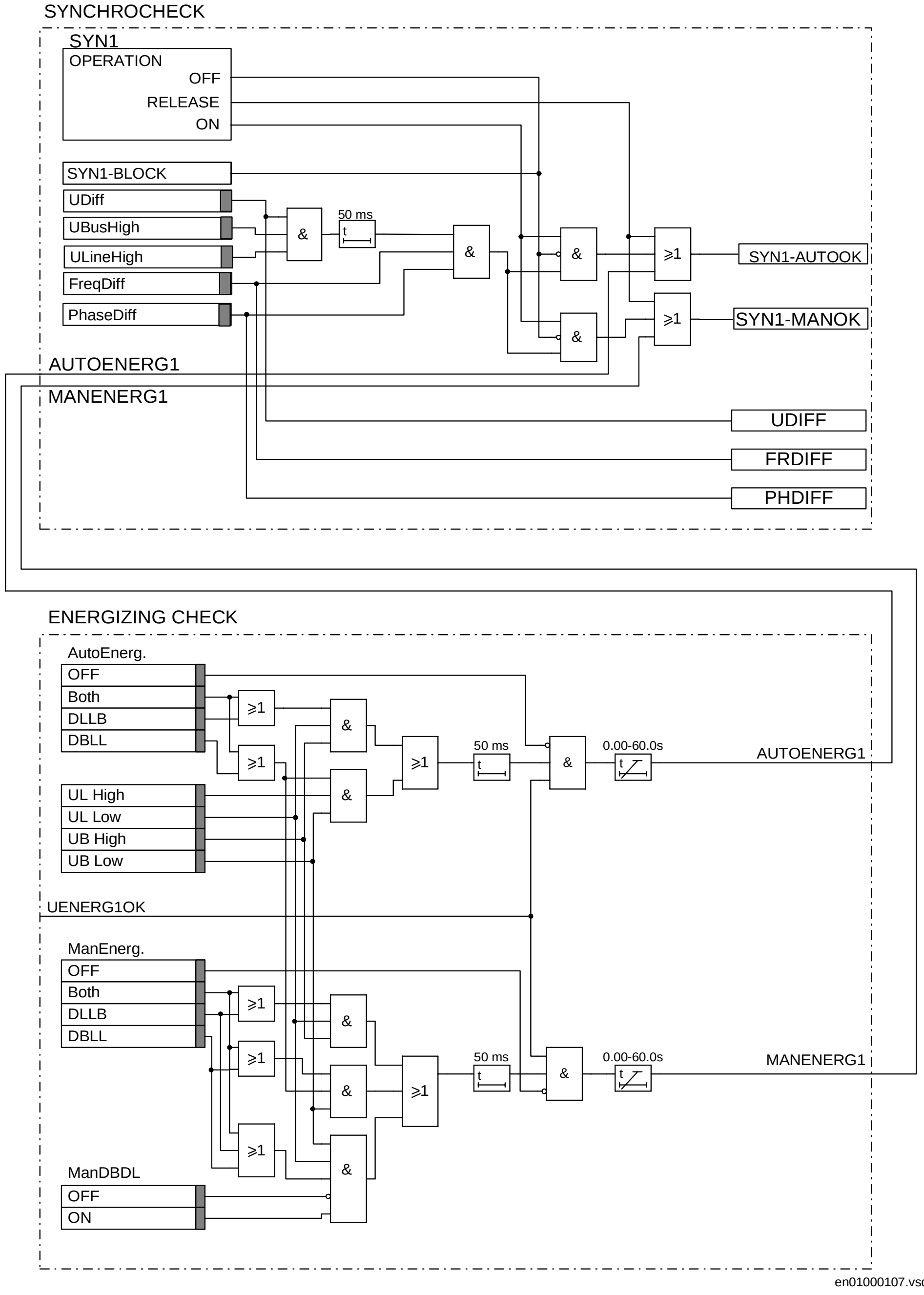


Figure 120: Simplified logic diagram - Synchrocheck and energizing check. The internal signal UENERG1OK refers to the voltage selection logic.

Voltage selection

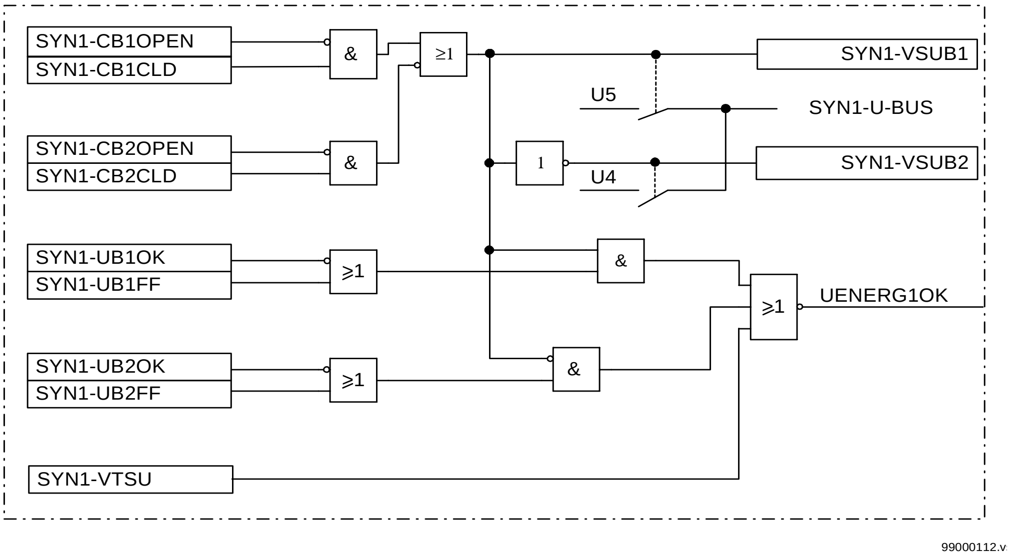


Figure 121: Voltage selection logic in a double bus, single breaker arrangement. In case of three bay arrangement the 1 in SYN1 and UENERG1OK are replaced by 2 and 3 in the logic.

Description of the input and output signals shown in the above simplified logic diagrams for voltage selection:

Input signal	Description
SYNx-CB1OPEN	Disconnector section of Bay x open. Connected to the auxiliary contacts of a disconnector section in a double-bus, single- breaker arrangement, to inform the voltage selection about the positions.
SYNx-CB1CLD	Disconnector section of Bay x closed. Connected to the auxiliary contacts of a disconnector section in a double-bus, single-breaker arrangement to inform the voltage selection about the positions.
SYNx-CB2OPEN	Same as above but for disconnector section 2.
SYNx-CB2CLD	Same as above but for disconnector section 2.
SYNx-UB1FF	External fuse failure input from busbar voltage Bus 1 (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure, the energizing check is blocked.

Input signal	Description
SYNx-UB1OK	No external voltage fuse failure (U5). Inverted signal.
SYNx-UB2FF	External fuse failure input from busbar voltage Bus 2 (U4). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of fuse failure, the energizing check is blocked.
SYNx-UB2OK	No external voltage fuse failure (U4). Inverted signal.
SYNx-VTSU	Internal fuse failure detection or configured to a binary input indicating external fuse failure of the UL1, UL2, UL3 line-side voltage. Blocks the energizing function.

Output signals	Description
SYNx-VSUB1	Signal for indication of voltage selection from Bus 1 voltage.
SYNx-VSUB2	Signal for indication of voltage selection from Bus 1 voltage.

Double circuit breaker

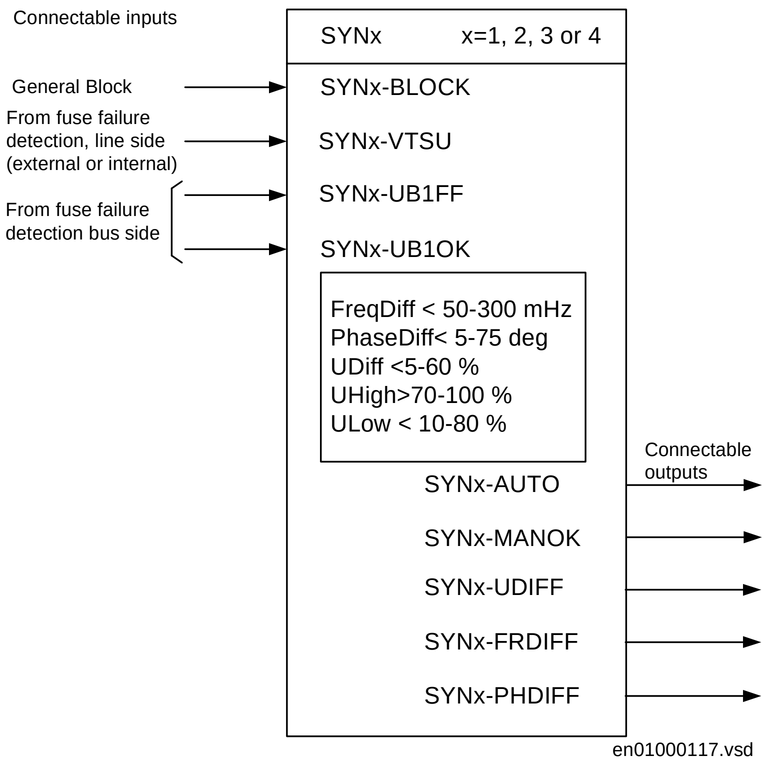


Figure 122: Input and output signals.

Synchrocheck

Description of input and output signals for the synchrocheck function.

Input signals	Description
SYNx-BLOCK	General block input from any external condition, that should block the synchrocheck.

Input signals	Description
SYNx-VTSU	The synchrocheck function cooperates with the FUSE-VTSU connected signal, which is the built-in optional fuse failure detection. It can also be connected to external condition for fuse failure. This is a blocking condition for the energizing function.
SYNx-UB1FF	External fuse failure input from busbar voltage Bus 1 (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure the energizing check is blocked.
SYNx-UB1OK	No external voltage fuse failure (U5). Inverted signal.

Output signals	Description
SYNx-AUTOOK	Synchrocheck/energizing OK. The output signal is high when the synchrocheck conditions set on the HMI are fulfilled. It can also include the energizing condition, if selected. The signal can be used to release the auto-recloser before closing attempt of the circuit breaker. It can also be used as a free signal.
SYNx-MANOK	Same as above but with alternative settings of the direction for energizing to be used during manual closing of the circuit breaker.
SYNx-UDIFF	Difference in voltage is less than the set difference limit.
SYNx-FRDIFF	Difference in frequency is less than the set difference limit.
SYNx-PHDIFF	Difference in phase angle is less than the set difference limit.

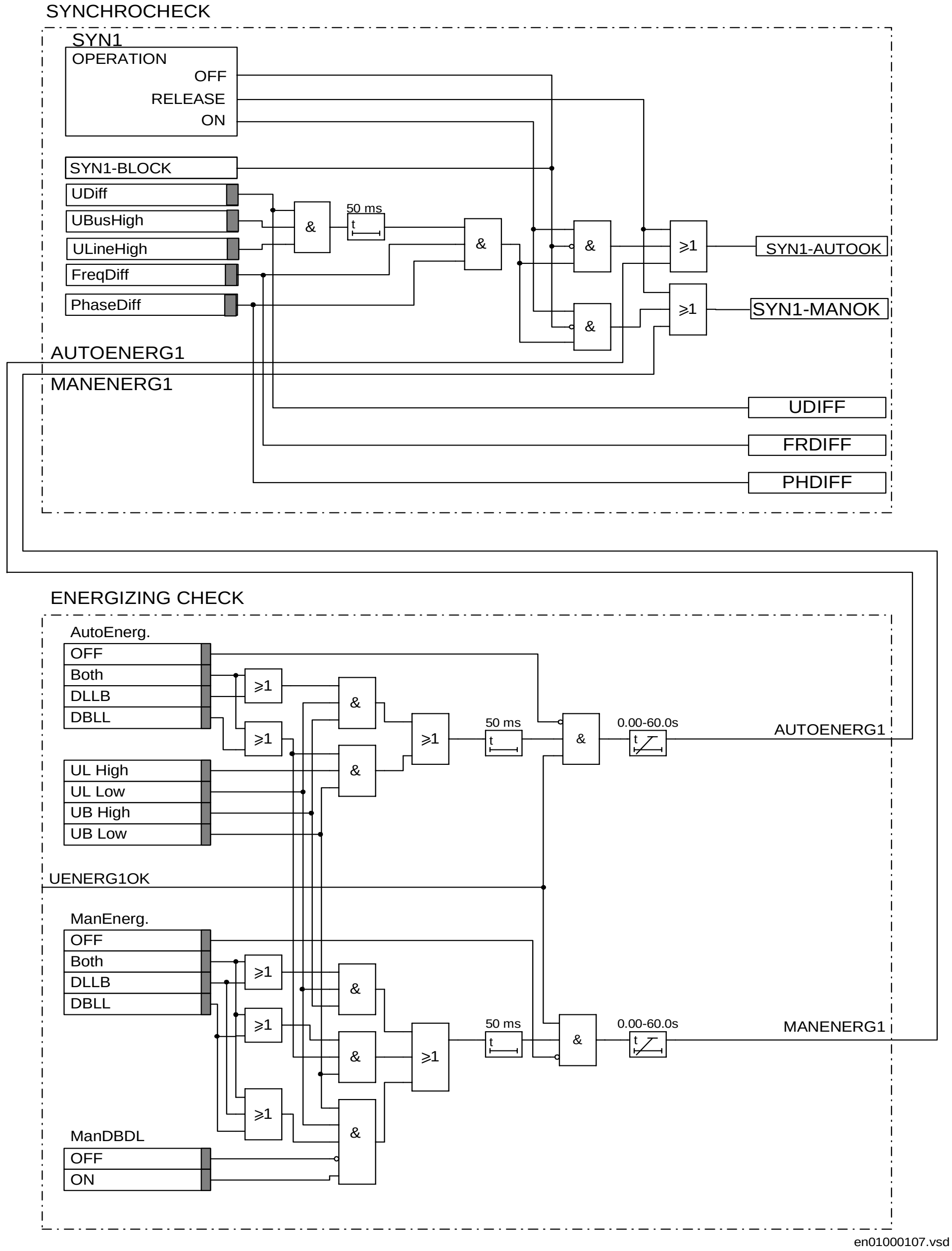


Figure 123: Simplified logic diagram - Synchrocheck and energizing check for one circuit breaker. The internal signal UENERG1OK derives from the external or internal fuse failure inputs SYN1-UB1OK/FF and SYN1-VTSU.

Phasing and synchrocheck, single circuit breaker

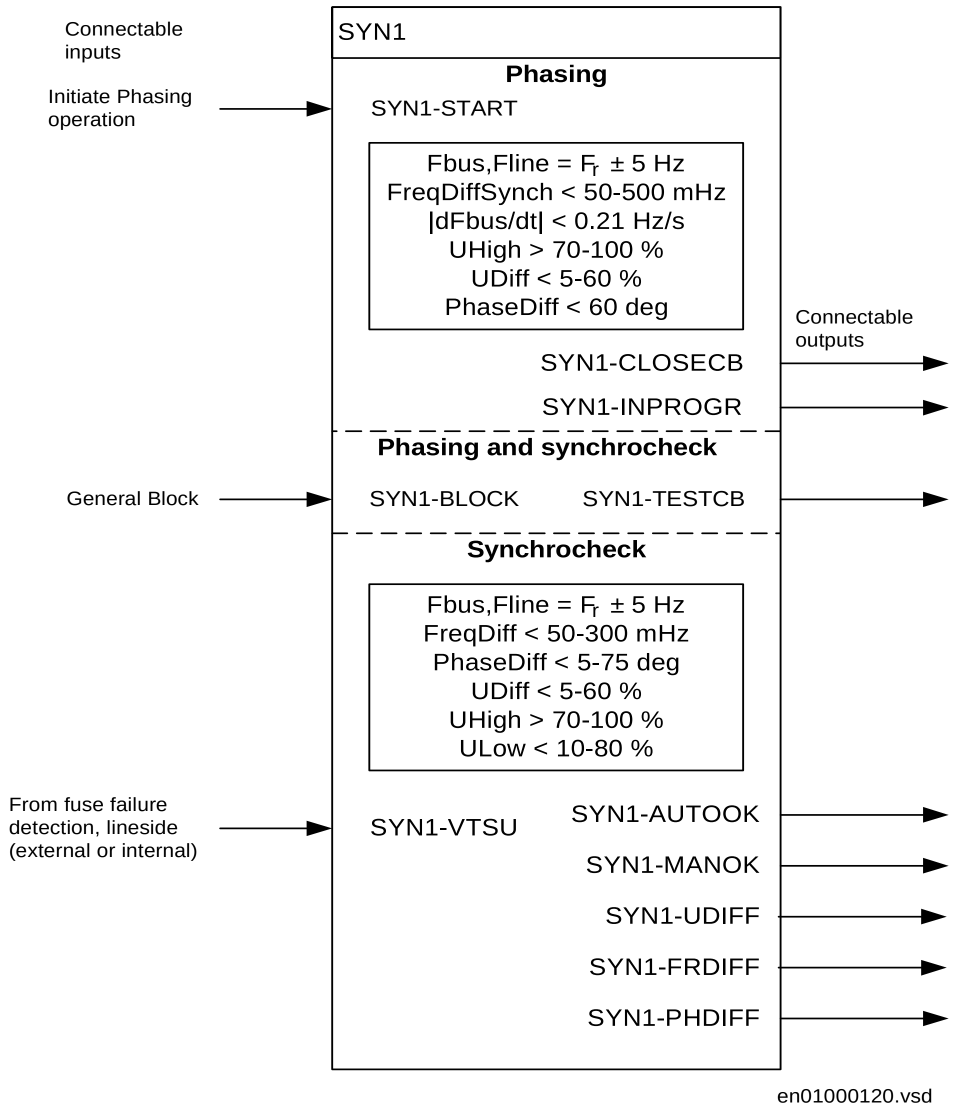


Figure 124: Input and output signals.

Phasing and synchrocheck

Description of input and output signals for the phasing and synchrocheck function.

Input signals	**Description**
SYN1-BLOCK	General block input from any external condition, that should block the phasing and the synchrocheck.
SYN1-VTSU	The SYNC function cooperates with the FUSE-VTSU connected signal, which is the built-in optional fuse failure detection. It can also be connected to external condition for fuse failure. This is a blocking condition for the energizing function
SYN1-START	The signal initiates the phasing operation. When initiated the function continues until the SYN1-CLOSECB pulse is submitted or it is stopped by the SYN1-BLOCK signal. In test mode (SYN1-TESTCB) ends the phasing operation.

Output signals	**Description**
SYN1-TESTCB	Output when the function is in test mode. In test mode a complete phasing sequence is performed except for closing of the circuit breaker. The output signal SYN1-TESTCB indicates when the SYN1-CLOSECB signal would have been submitted from the phasing function or when the conditions for paralleling are fulfilled, from the synchro-check function
SYN1-CLOSECB	Close breaker command from phasing. Used to the circuit breaker or to be connected to the auto-reclosing function.
SYN1-INPROGR	The signal is high when a phasing operation is in progress, i.e from the moment a SYN1-START is received until the operation is terminated. The operation is teminated when SYN1-CLOSECB or SYN1-TESTCB has been submitted or if a SYN1-BLOCK is received.
SYN1-AUTOOK	Synchrocheck/energizing OK. The output signal is high when the synchro-check conditions set on the HMI are fulfilled. It can also include the energizing condition, if selected. The signal can be used to release the autorecloser before closing attempt of the circuit breaker. It can also be used as a free signal.
SYN1-MANOK	Same as above but with alternative settings of the direction for energizing to be used during manual closing of the circuit breaker.
SYN1-UDIFF	Difference in voltage is less than the set difference limit.
SYN1-FRDIFF	Difference in frequency is less than the set difference limit.
SYN1-PHDIFF	Difference in phase angle is less than the set difference limit.

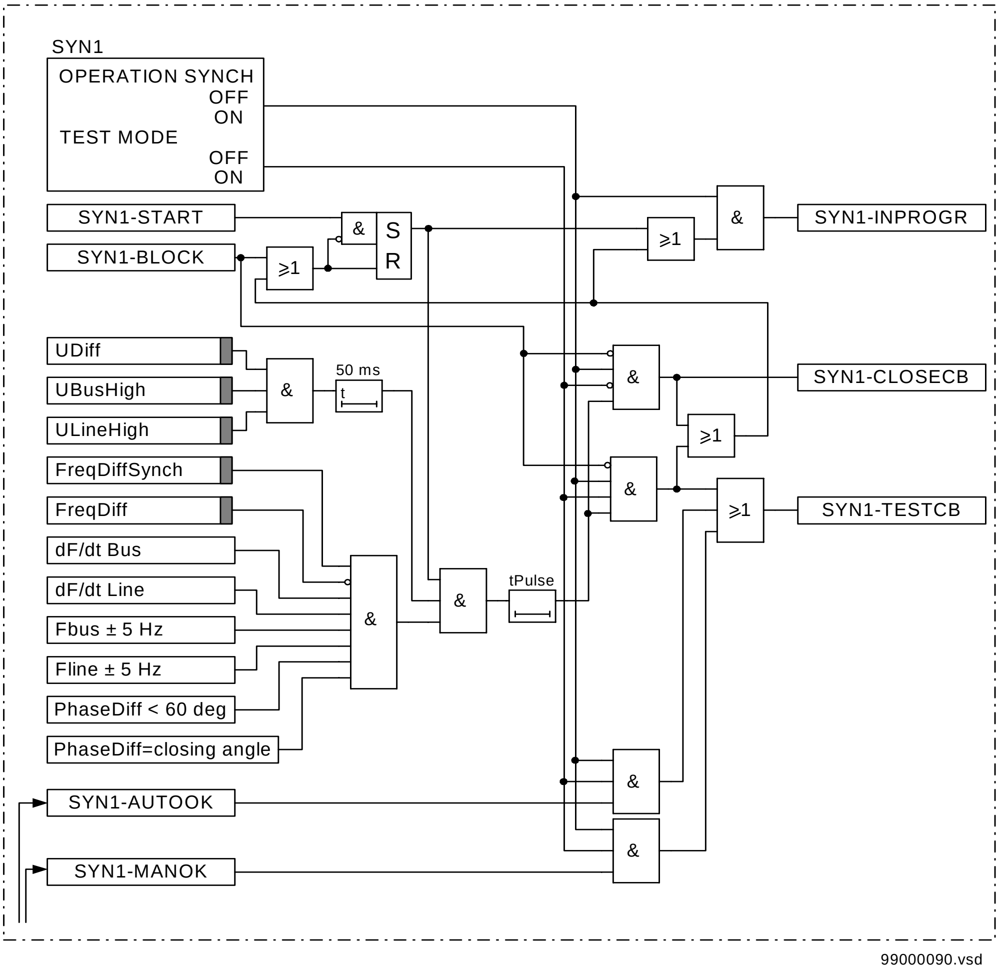


Figure 125: Simplified logic diagram - Phasing. The input signals SYN1-AUTOOK and SYN1-MANOK derive from the synchrocheck and energizing logic.

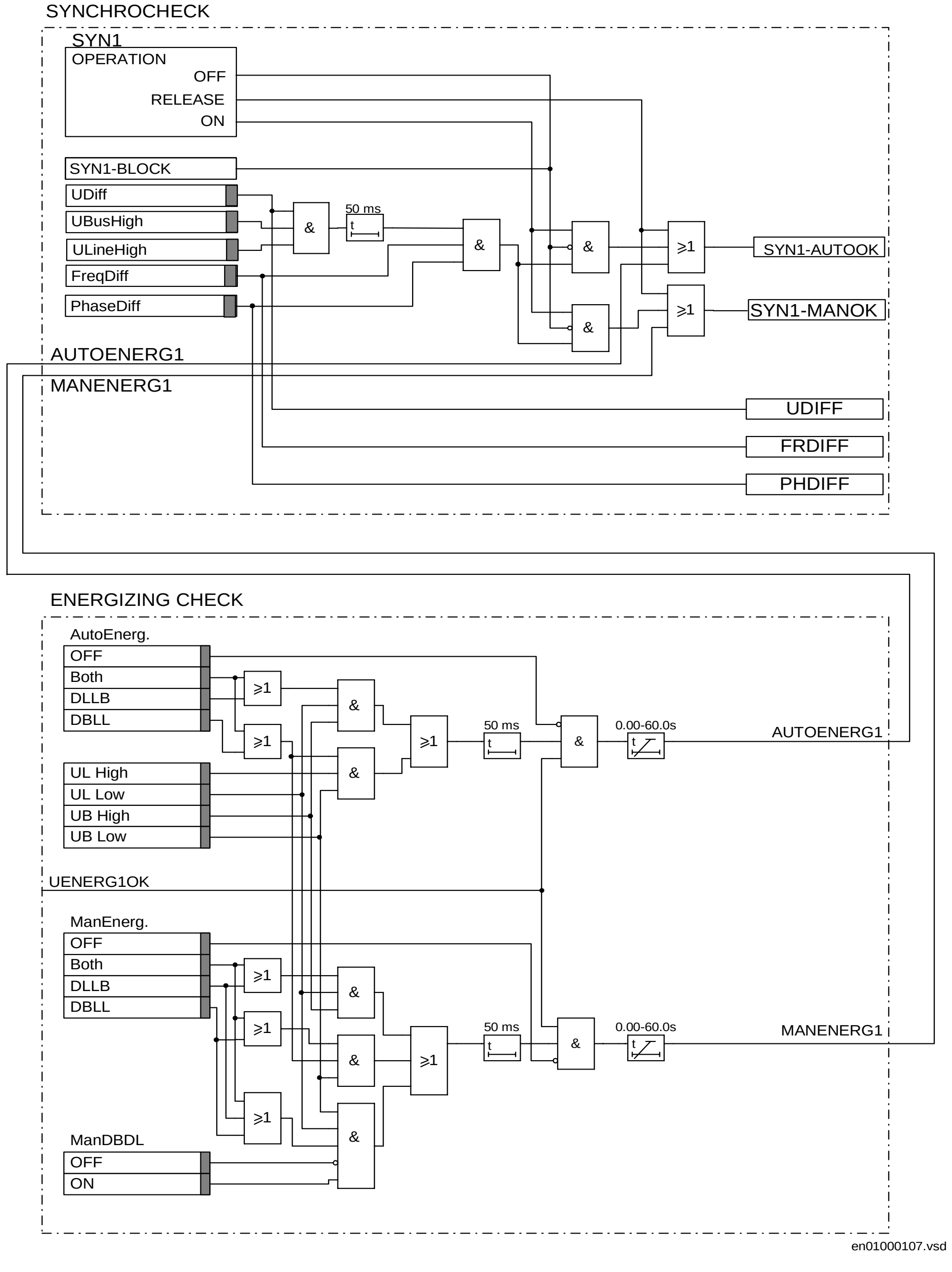


Figure 126: Simplified logic diagram - Synchrocheck and energizing check. The internal signal UENERG1OK refers to the voltage selection logic.

Voltage selection

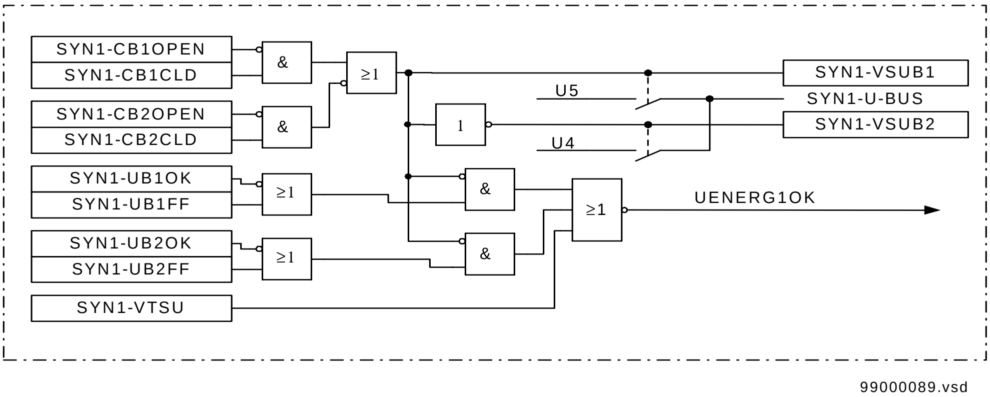


Figure 127: Simplified voltage selection logic in a double bus, single breaker arrangement.

Description of the input and output signals shown in the above simplified logic diagrams for voltage selection:

Input signal	**Description**
SYN1-CB1OPEN	Disconnector section 1 of Bay 1 open. Connected to the auxiliary contacts of a disconnector section in a double-bus, single breaker arrangement, to inform the voltage selection about the positions.
SYN1-CB1CLD	Disconnector section 1 of Bay 1 closed. Connected to the auxiliary contacts of a disconnector section in a double-bus, single breaker arrangement to inform the voltage selection about the positions.
SYN1-CB2OPEN	Same as above but for disconnector section 2.
SYN1-CB2CLD	Same as above but for disconnector section 2.
SYN1-UB1FF	External fuse failure input from busbar voltage Bus 1 (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure, the energizing check is blocked.
SYN1-UB1OK	No external voltage fuse failure (U5). Inverted signal.

Input signal	Description
SYN1-UB2FF	External fuse failure input from busbar voltage Bus 2 (U4). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of fuse failure, the energizing check is blocked.
SYN1-UB2OK	No external voltage fuse failure (U4). Inverted signal.
SYN1-VTSU	Internal fuse failure detection or configured to a binary input indicating external fuse failure of the UL1, UL2, UL3 line-side voltage. Blocks the energizing function.

Output signals	Description
SYN1-VSUB1	Signal for indication of voltage selection from Bus 1 voltage.
SYN1-VSUB2	Signal for indication of voltage selection from Bus 1 voltage.

Phasing and synchrocheck, double circuit breaker

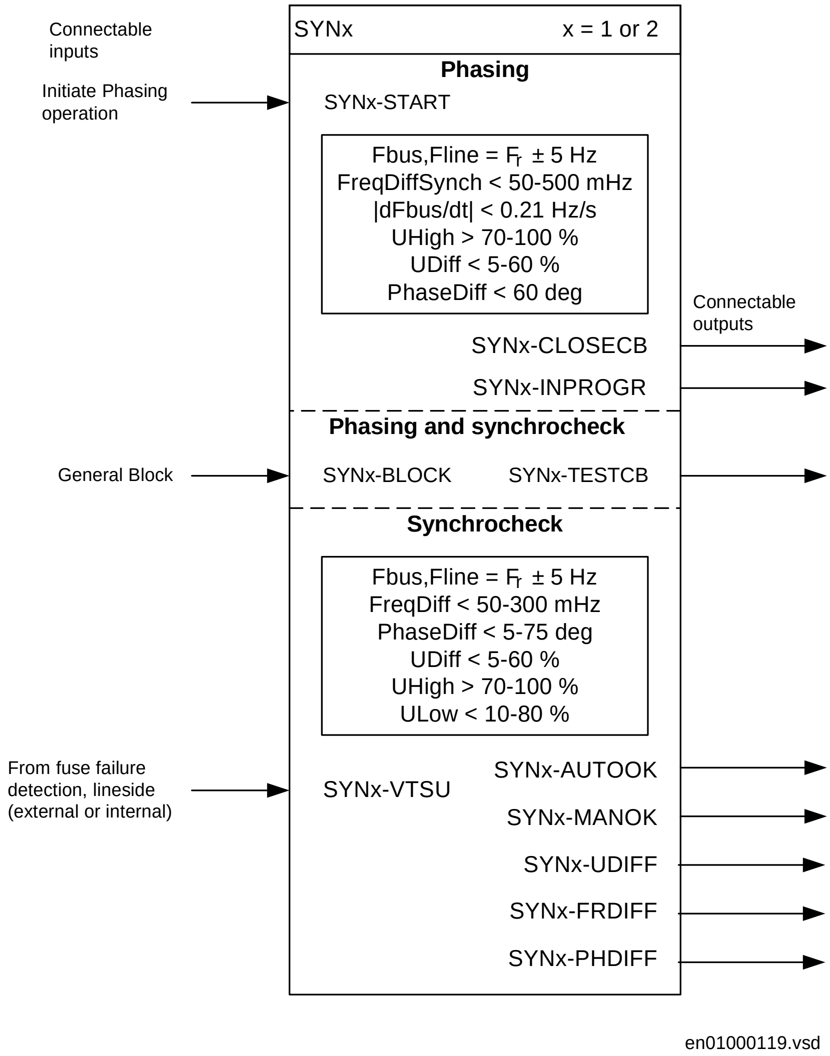


Figure 128: Input and output signals.

Phasing and synchrocheck

Description of input and output signals for the phasing and synchrocheck function.

Input signals	Description
SYNx-BLOCK	General block input from any external condition, that should block the phasing and the synchrocheck.
SYNx-VTSU	The SYNC function cooperates with the FUSE-VTSU connected signal, which is the built-in optional fuse failure detection. It can also be connected to external condition for fuse failure. This is a blocking condition for the energizing function.
SYNx-UB1FF	External fuse failure input from busbar voltage Bus 1 (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure the energizing check is blocked.
SYNx-UB1OK	No external voltage fuse failure (U5). Inverted signal.
SYNx-START	The signal initiates the phasing operation. When initiated the function continues until the SYNx-CLOSECB pulse is submitted or it is stopped by the SYNx-BLOCK signal. In test mode SYNx-TESTCB ends the phasing operation.

Output signals	Description
SYNx-TESTCB	Output when the function is in test mode. In test mode a complete phasing sequence is performed except for closing of the circuit breaker. The output signal SYNx-TESTCB indicates when the SYNx-CLOSECB signal would have been submitted from the phasing function or when the conditions for paralleling are fulfilled, from the synchro-check function.
SYNx-CLOSECB	Close breaker command from phasing. Used to control the circuit breaker or to be connected to the auto-reclosing function.
SYNx-INPROGR	The signal is high when a phasing operation is in progress, i.e from the moment a SYNx-START is received until the operation is terminated. The operation is teminated when SYNx-CLOSECB or SYNx-TESTCB has been submitted or if a SYNx-BLOCK is received.
SYNx-AUTOOK	Synchrocheck/energizing OK. The output signal is high when the synchrocheck conditions set on the HMI are fulfilled. It can also include the energizing condition, if selected. The signal can be used to release the autorecloser before closing attempt of the circuit breaker. It can also be used as a free signal.

Output signals	Description
SYNx-MANOK	Same as above but with alternative settings of the direction for energizing to be used during manual closing of the circuit breaker.
SYNx-UDIFF	Difference in voltage is less than the set difference limit.
SYNx-FRDIFF	Difference in frequency is less than the set difference limit.
SYNx-PHDIFF	Difference in phase angle is less than the set difference limit.

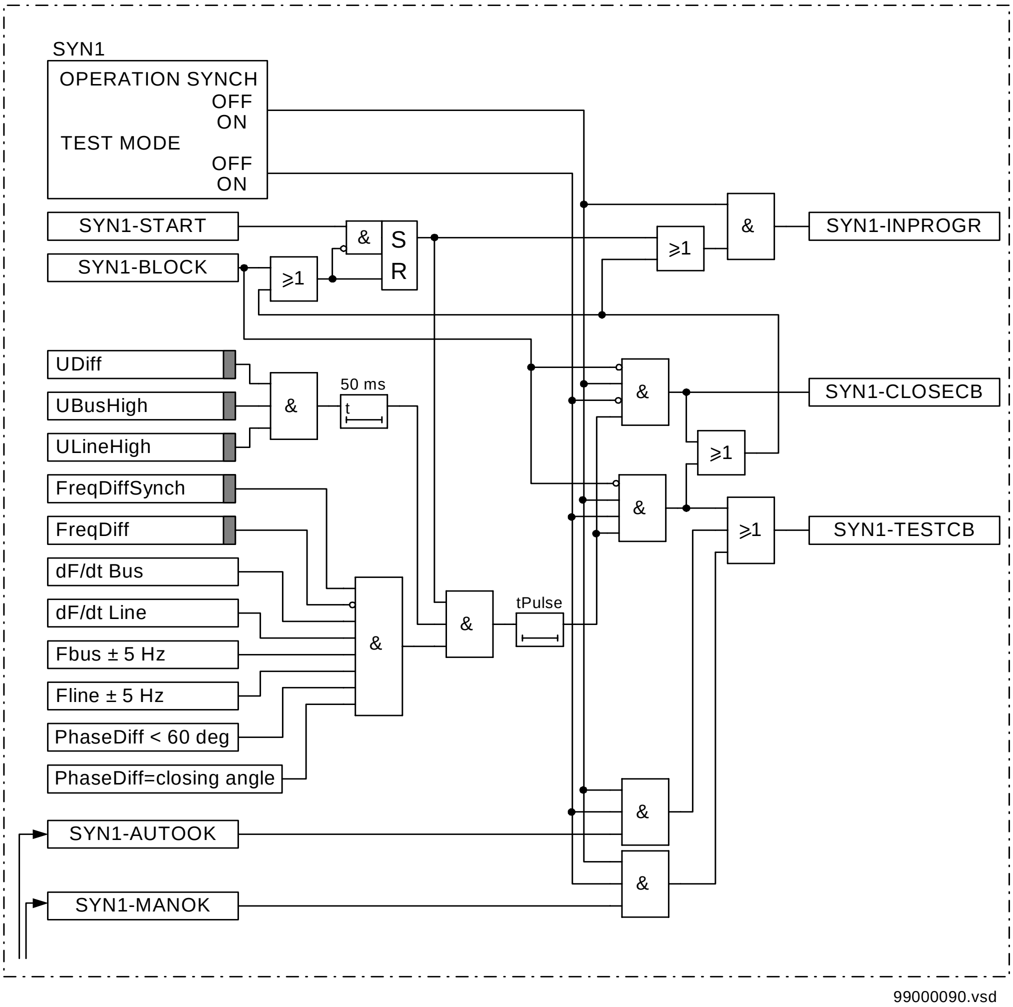


Figure 129: Simplified logic diagram - Phasing. The input signals SYN1-AUTOOK and SYN1-MANOK derive from the synchrocheck and energizing logic.

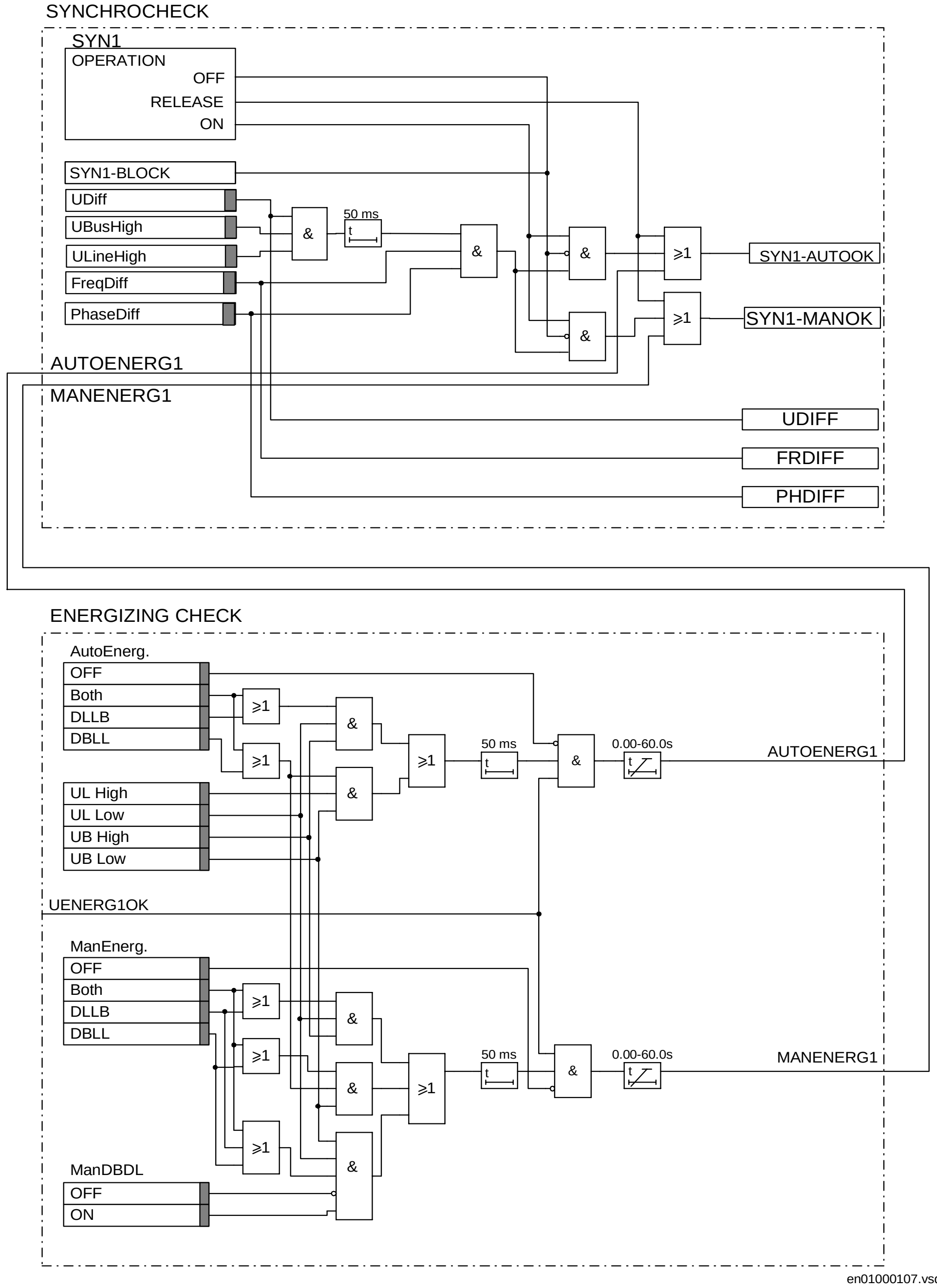


Figure 130: Simplified logic diagram - Synchrocheck and energizing check for one circuit breaker. The internal signal UENERG1OK derives from the external or internal fuse failure inputs SYN1-UB1OK/FF and SYN1-VTSU.

1 1/2 circuit breaker with one terminal per breaker

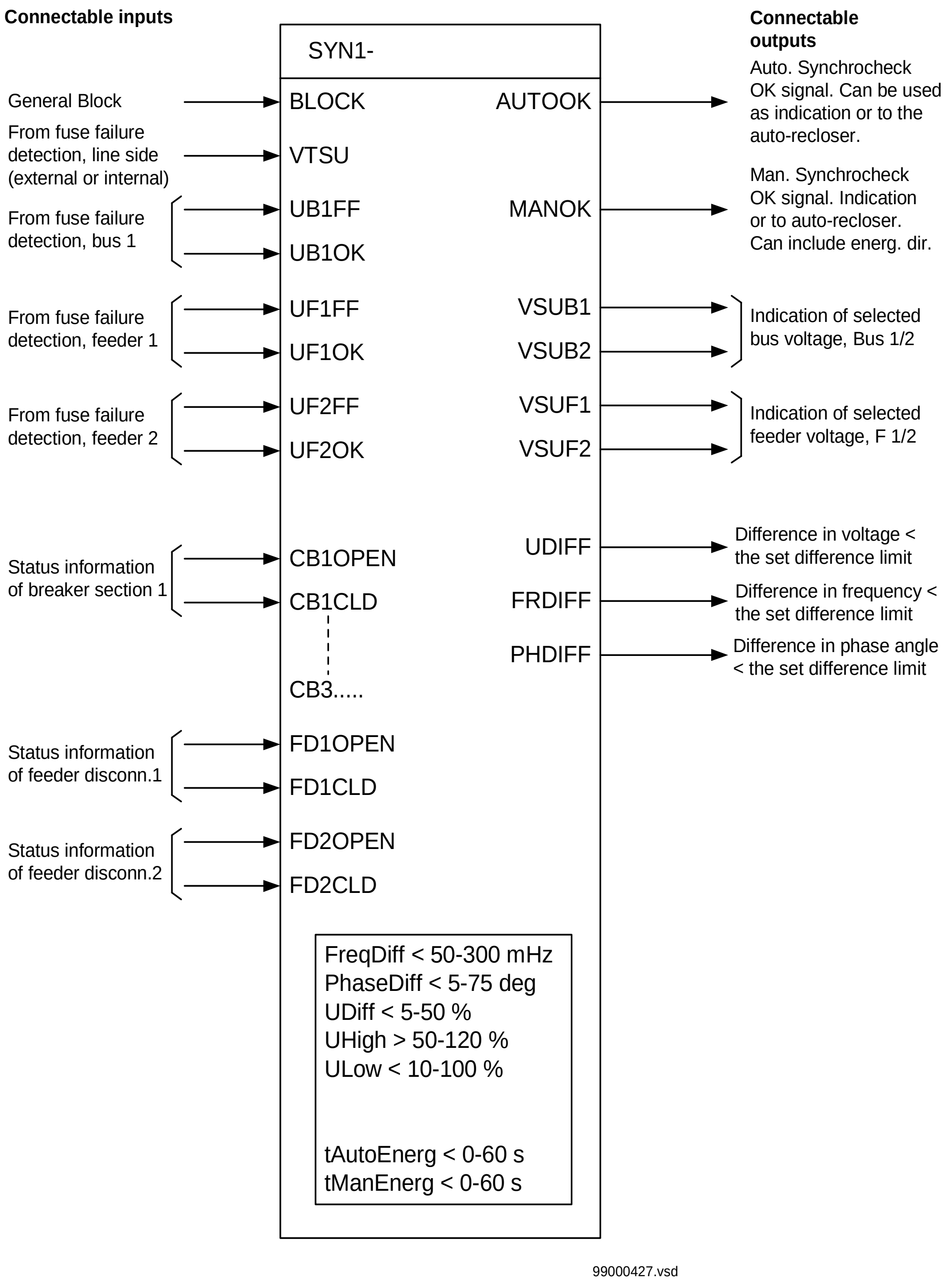


Figure 131: Input and output signals.

Synchrocheck

Figure 131 shows possible connections for the synchrocheck function and different parameters. A description of the input and output signals follows below.

Input signals	**Description**
SYN1-BLOCK	General block input from any external condition, that should block the synchrocheck.
SYN1-VTSU	The SYNC function cooperates with the FUSE-VTSU connected signal, which is the built-in optional fuse failure detection. It can also be connected to external condition for fuse failure. This is a blocking condition for the energizing function.
SYN1-UB1FF	External fuse failure input from busbar voltage Bus 1 or 2 resp. (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure the energizing check is blocked.
SYN1-UB1OK	No external voltage fuse failure (U5). Inverted signal.
SYN1-UFxFF	External fuse failure input from feeder voltage Feeder 1 or 2 resp. (U4). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure the energizing check is blocked.
SYN1-UFxOK	No external voltage fuse failure (U4). Inverted signal.
SYN1-CBnOPEN	Status signal of breaker section n (n=1..3), indicating *Open* breaker section.
SYN1-CBnCLD	Status signal of breaker section n, indicating *Closed* breaker section.
SYN1-FDmOPEN	Status signal of feeder disconnector m (m=1..2), indicating *Open* disconnector. Can be used for interlocking.
SYN1-FDmCLD	Status signal of feeder disconnector m, indicating *Closed* disconnector. Can be used as interlocking condition.

Output signals	Description
SYN1-AUTOOK	Synchro-/energizing check OK. The output signal is high when the synchrocheck conditions set on the HMI are fulfilled. It can also include the energizing condition, if selected. The signal can be used to release the autorecloser before closing attempt of the circuit breaker. It can also be used as a free signal.
SYN1-MANOK	Same as above but with alternative settings of the direction for energizing to be used during manual closing of the circuit breaker.
SYN1-VSUBx	Voltage Bus 1 (and Bus 2 respectively) selected for the synchro-check function.
SYN1-VSUFx	Voltage Feeder 1 (and Feeder 2 respectively) selected for the synchro-check function.
SYN1-UDIFF	Difference in voltage is less than the set difference limit.
SYN1-FRDIFF	Difference in frequency is less than the set difference limit.
SYN1-PHDIFF	Difference in phase angle is less than the set difference limit.

Figure 132 is a simplified logic diagram of the internal voltage selection function. All input signals can be find above. The voltage selection function requires an extra I/O-module.

The internal resulting signal UENERG1OK is further used by the internal energizing check function as a condition to release an AUTOENERG 1 or MANENERG 1 output. See Figure 133 for a simplified logic diagram of the synchrocheck and energizing check.

The output signals, AUTOENERG 1 and MANENERG 1, from the energizing check is dependent of the actual parameter settings. These signals are further connected to the main synchro-check.

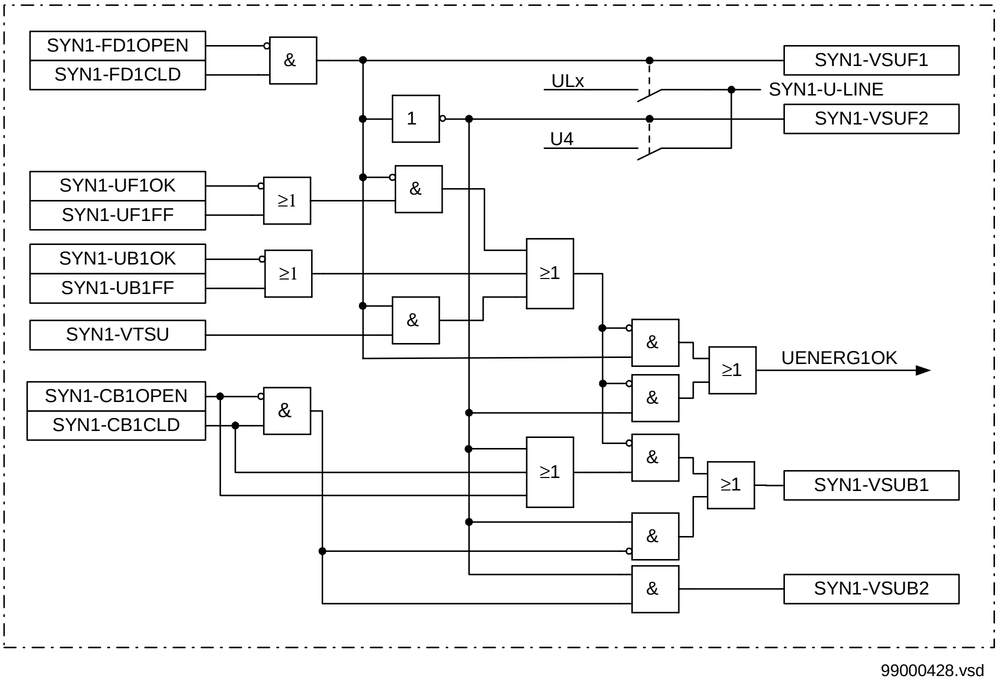


Figure 132: Simplified logic diagram - Voltage selection

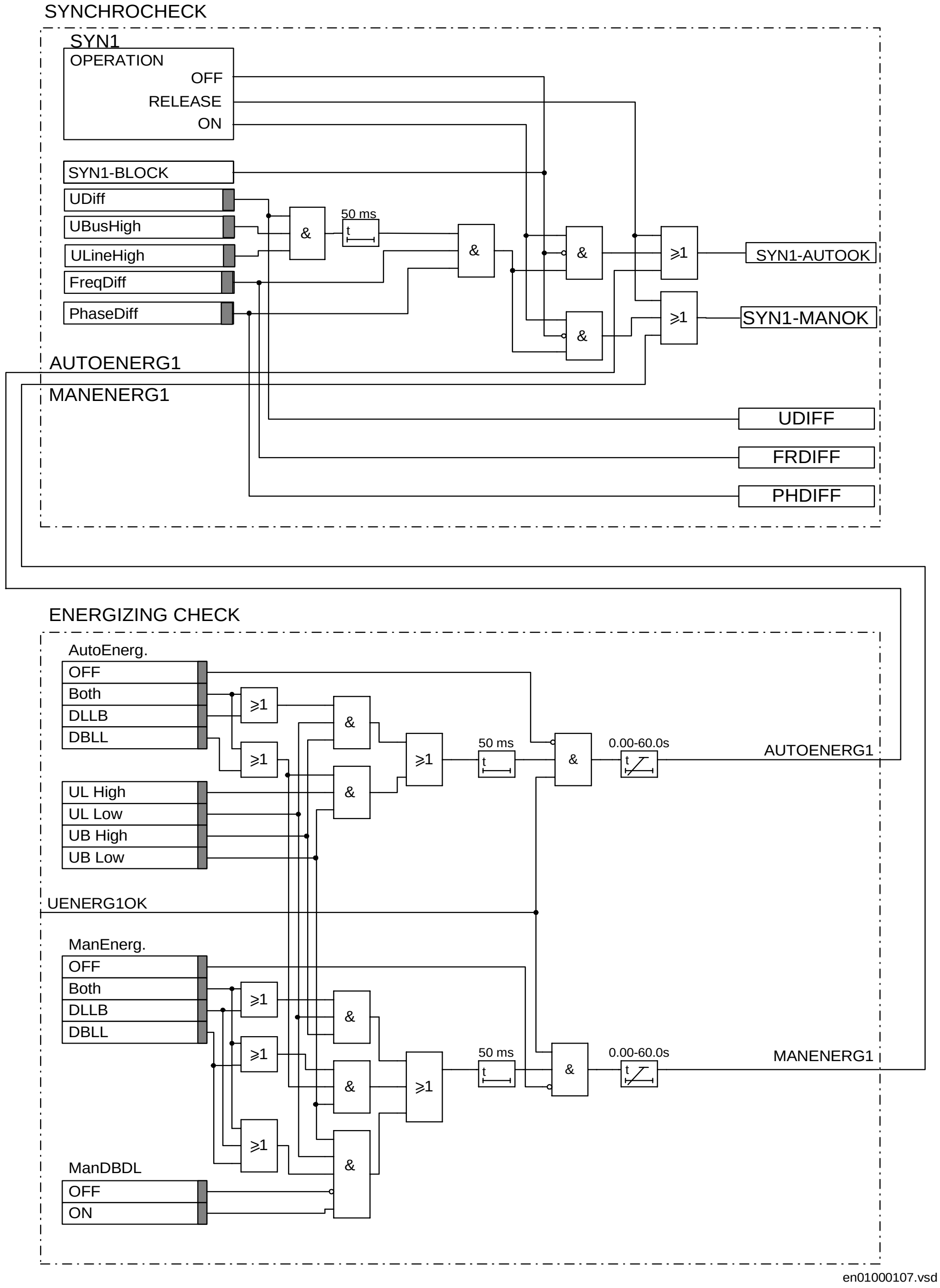


Figure 133: Simplified logic diagram - Synchrocheck and energizing check for one circuit breaker. The internal signal UENERG1OK refers to the voltage selection logic.

1 1/2 circuit breaker diameter

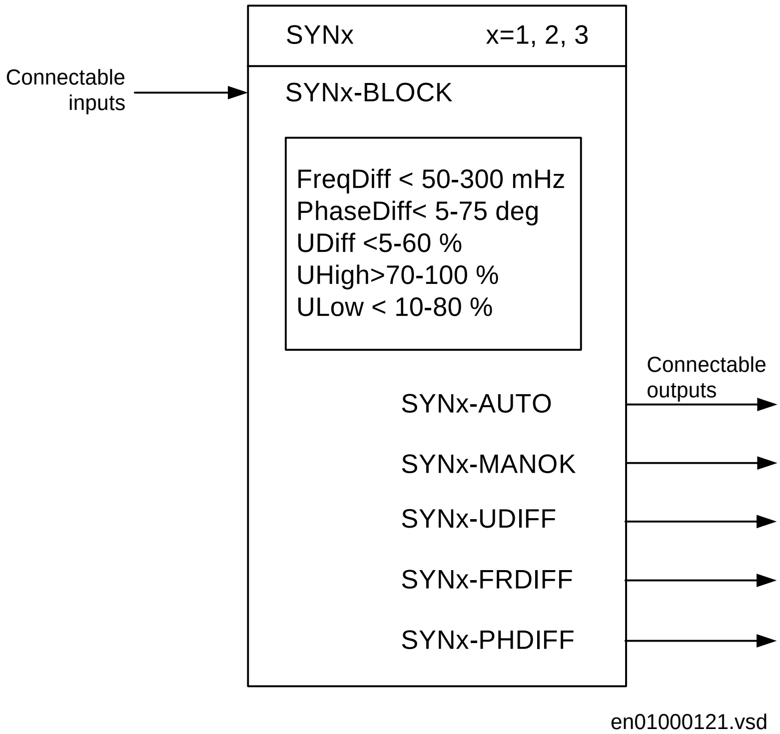


Figure 134: Input and output signals.

Synchrocheck

Description of input and output signals for the synchrocheck function.

Input signals	Description
SYNx-BLOCK	General block input from any external condition, that should block the synchro-check.

Output signals	Description
SYNx-AUTOOK	Synchro-check/Energizing OK. The output signal is high when the synchro-check conditions set on the MMI are fulfilled. It can also include the energizing condition, if selected. The signal can be used to release the autorecloser before a closing attempt of the circuit breaker. It can also be used as a free signal.
SYNx-MANOK	Same as above but with an alternative settings of the direction for energizing at manual closing of the circuit breaker.
SYNx-CB3CLD	Difference in voltage is less than the set difference limit.
SYNx-FRDIFF	Difference in frequency is less than the set difference limit.
SYNx-PHDIFF	Difference in phase angle is less than the set difference limit.

Voltage selection

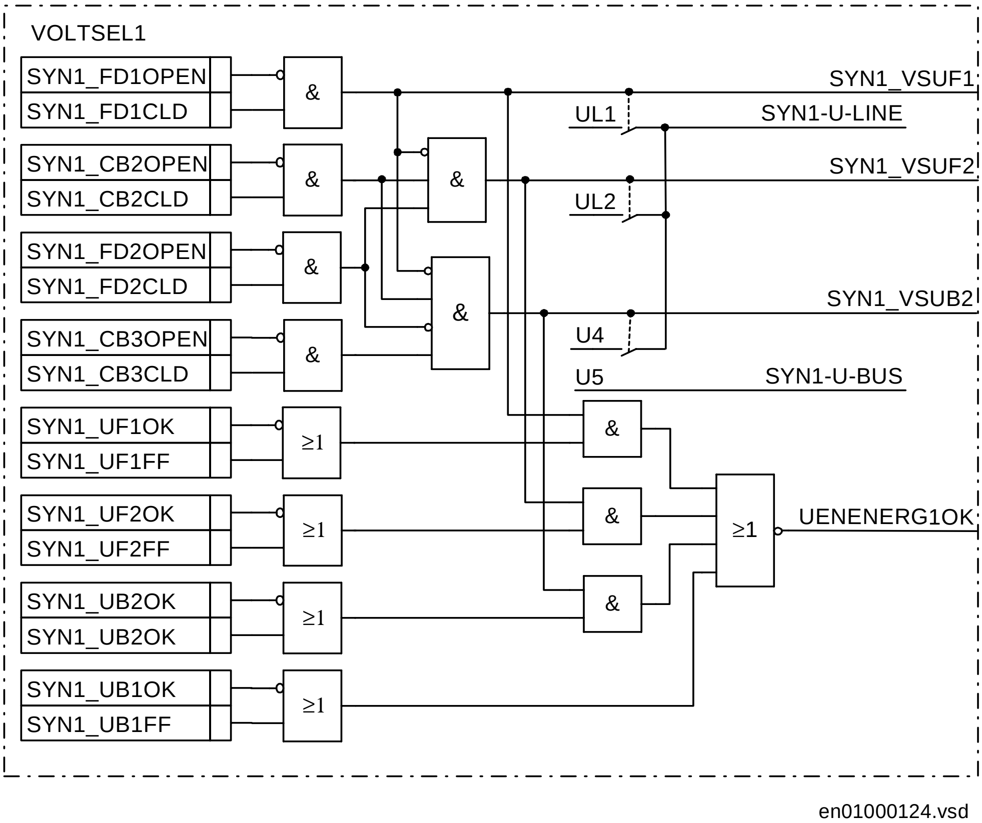


Figure 135: Voltage selection for CB1

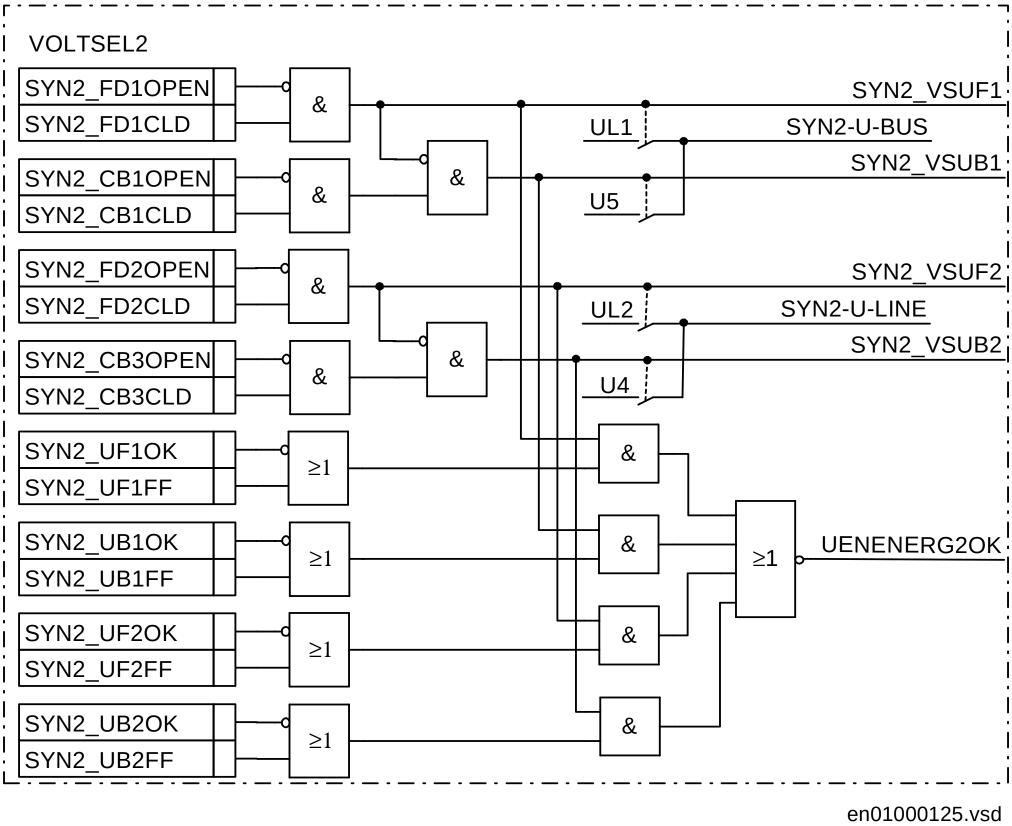


Figure 136: Voltage selection for CB2

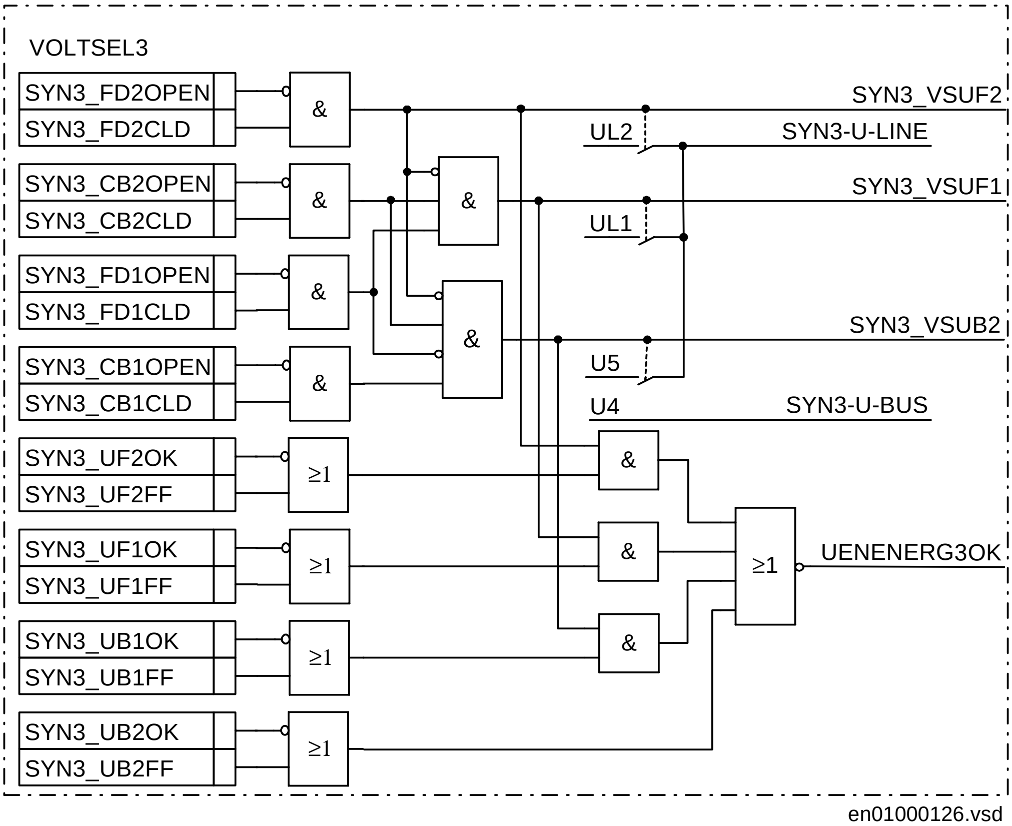


Figure 137: Voltage selection for CB3

A logic diagram of the voltage selection for a 1 1/2 circuit breaker arrangement is shown in the above, figure 135, figure 136 and figure 137. The signal UENERG1(2, 3)OK release the relevant synchronism and energizing check function.

Description of the input and output signals shown in the above logic diagrams for voltage selection:

Input signals	**Description**
SYNx-CB1OPEN	Breaker section of CB1 open. Connected to the auxiliary contacts of a breaker section (CB and disconnector).
SYNx-CB1CLD	Breaker section of CB1 closed. Connected to the auxiliary contacts of a breaker section (CB and disconnector).
SYNx-CB2OPEN	Breaker section of CB2 open. Connected to the auxiliary contacts of a breaker section (CB and disconnector).
SYNx-CB2CLD	Breaker section of CB2 closed. Connected to the auxiliary contacts of a breaker section (CB and disconnector).
SYNx-CB3OPEN	Breaker section of CB3 open. Connected to the auxiliary contacts of a breaker section (CB and disconnector).
SYNx-CB3CLD	Breaker section of CB3 closed. Connected to the auxiliary contacts of a breaker section (CB and disconnector).
SYNx-FD1OPEN	Line disconnector of Line 1 open. Connected to the auxiliary contacts of the Line disconnector.
SYNx-FD1CLD	Line disconnector of Line 1 closed. Connected to the auxiliary contacts of the Line disconnector
SYNx-FD2OPEN	Line disconnector of Line 2 open. Connected to the auxiliary contacts of the Line disconnector
SYNx-FD2CLD	Line disconnector of Line 2 closed. Connected to the auxiliary contacts of the Line disconnector.
SYNx-UB1FF	External fuse failure input from busbar voltage Bus 1 (U5). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure, the energizing check is blocked.
SYNx-UB1OK	No external voltage fuse failure (U5). Inverted signal.
SYNx-UB2FF	External fuse failure input from busbar voltage Bus 2 (U4). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of fuse failure, the energizing check is blocked.
SYNx-UB2OK	No external voltage fuse failure (U4). Inverted signal.
SYNx-UF1FF	External fuse failure input from line voltage Line 1 (UL1). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure, the energizing check is blocked.

Input signals	Description
SYNx-UF1OK	No external voltage fuse failure (UL1). Inverted signal.
SYNx-UF2FF	External fuse failure input from line voltage Line 2 (UL2). This signal can come from a tripped fuse switch (MCB) on the secondary side of the voltage transformer. In case of a fuse failure, the energizing check is blocked
SYNx-UF2OK	No external voltage fuse failure (UL2). Inverted signal.

Output signals	Description
SYNx-VSUB1	Signal for indication of voltage selection from Bus 1 voltage.
SYNx-VSUB2	Signal for indication of voltage selection from Bus 1 voltage.
SYNx-VSUF1	Signal for indication of voltage selection from Line 1 voltage.
SYNx-VSUF2	Signal for indication of voltage selection from Line 2 voltage

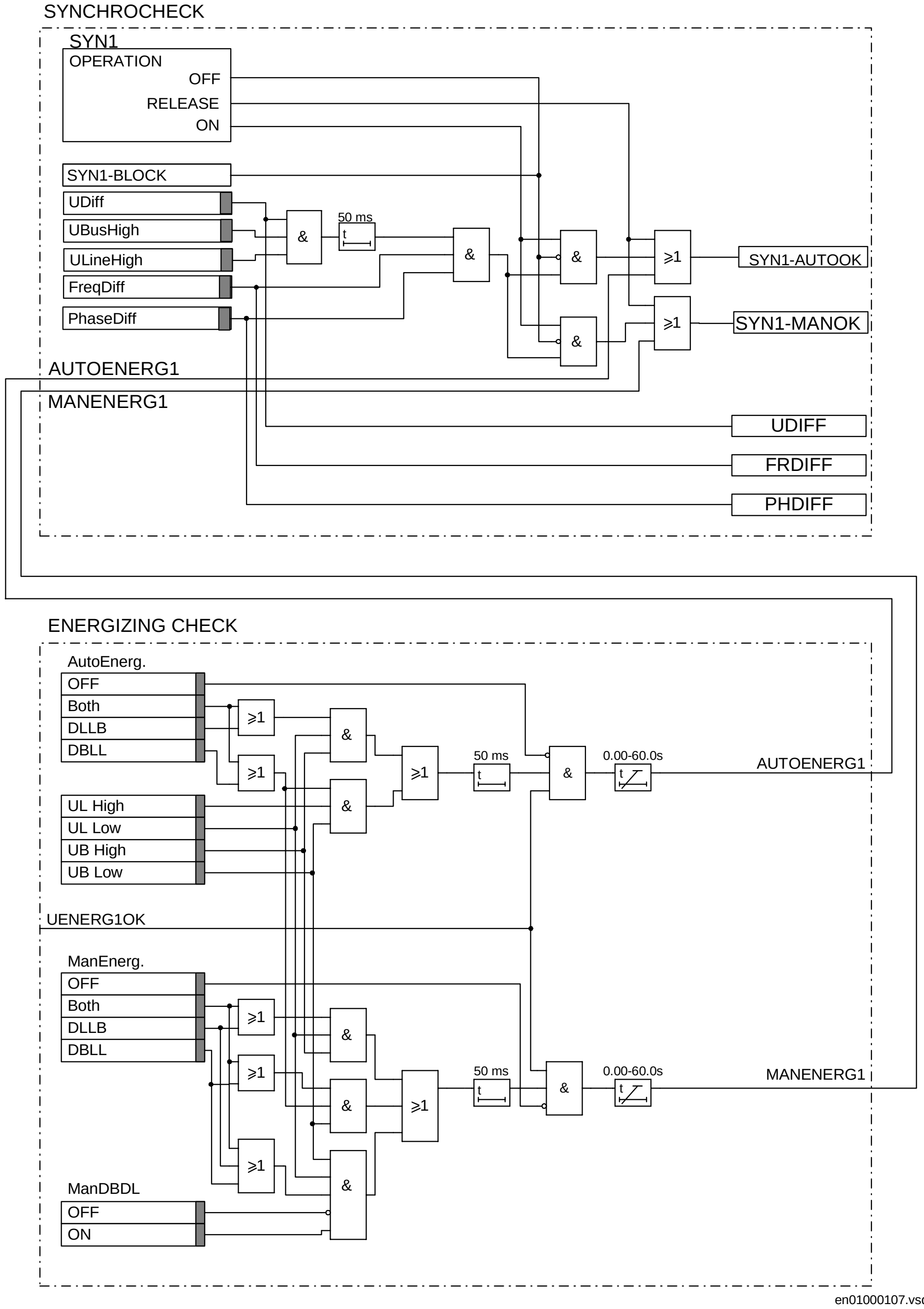


Figure 138: Simplified logic diagram - Synchrocheck and energizing check. The internal signal UENERG1OK refers to the voltage selection logic.

1.3 Calculations

The setting parameters are accessible through the HMI. The parameters for the synchrocheck function are found in the HMI tree under:

Settings
Functions
Group n
SynchroCheck
SynchroCheck n (n=1-3)

(The number of Synchro Check functions is dependent of the version)

Comments regarding settings.

Operation

Off/Release/On

Off	The synchrocheck function is disabled and the output is low.
Release	There are fixed, high output signals SYNx-AUTOOK = 1 and SYNx-MANOK = 1.
On	The function is in service and the output signal depends on the input conditions.

Input phase

The measuring phase of the UL1, UL2, UL3 line voltage, which can be of a single-phase (phase-neutral) or two-phases (phase-phase). (Only available in terminals intended for one bay).

UMeasure

Selection of single-phase (phase-neutral) or two-phase (phase-phase) measurement.(Only available in terminals intended for several bays).

PhaseShift

This setting is used to compensate for a phase shift caused by a line transformer between the two measurement points for UBus and ULine. The set value is added to the measured phase difference. The bus voltage is reference voltage.

URatio

The URatio is defined as URatio=UBus/ULine. A typical use of the setting is to compensate for the voltage difference caused if one wishes to connect the UBus phase-phase and ULine phase-neutral. The “Input phase”-setting should then be set to phase-phase and the “URatio”-setting to sqr3=1.732. This setting scales up the line voltage to equal level with the bus voltage.

USelection

Selection of single or double bus voltage-selection logic.

AutoEnerg and ManEnerg

Two different settings can be used for automatic and manual closing of the circuit breaker.

Off	The energizing function is disabled
DLLB	The line voltage U-line is low, below (10-80% U1b) and the bus voltage U-bus is high, above (70-100% U1b).
DBLL	The bus voltage U-bus is low, below (10-80% U1b) and the line voltage U-line is high, above (70-100% U1b).
Both	Energizing can be done in both directions, DLLB or DBLL.
tAutoEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-AUTOOK.
tManEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-MANOK.

ManDBDL

If the parameter is set to “On”, closing is enabled when Both U-Line and U-bus are below ULow and ManEnerg is set to “DLLB”, “DBLL” or “Both”.

The setting parameters are accessible through the HMI. The parameters for the synchrocheck function are found in the HMI tree under:

Settings
Functions
Group n
SynchroCheck
SynchroCheck n (n=1-4)

(The number of SynchroCheck settings is dependent of the version)

Comments regarding settings.

Operation

Off/Release/On

Off	The synchrocheck function is disabled and the output is low.
Release	There are fixed, high output signals SYN1-AUTOOK = 1 and SYN1-MANOK = 1.
On	The function is in service and the output signal depends on the input conditions.

Input phase

The measuring phase of the UL1, UL2, UL3 line voltage, which can be of a single-phase (phase-neutral) or two-phases (phase-phase). (Only available in terminals intended for one bay).

UMeasure

Selection of single-phase (phase-neutral) or two-phase (phase-phase) measurement. (Only available in terminals intended for several bays).

PhaseShift

This setting is used to compensate for a phase shift caused by a line transformer between the two measurement points for UBus and ULine. The set value is added to the measured phase difference. The bus voltage is reference voltage.

URatio

The URatio is defined as URatio=UBus/ULine. A typical use of the setting is to compensate for the voltage difference caused if one wishes to connect the UBus phase-phase and ULine phase-neutral. The “Input phase”-setting should then be set to phase-phase and the “URatio”-setting to sqr3=1.732. This setting scales up the line voltage to equal level with the bus voltage.

AutoEnerg and ManEnerg

Two different settings can be used for automatic and manual closing of the circuit breaker.

Off	The energizing function is disabled.
DLLB	The line voltage U-line is low, below (10-80% U1b) and the bus voltage U-bus is high, above (70-100% U1b).
DBLL	The bus voltage U-bus is low, below (10-80% U1b) and the line voltage U-line is high, above (70-100% U1b).
Both	Energizing can be done in both directions, DLLB or DBLL.
tAutoEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-AUTOOK.
tManEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-MANOK.

ManDBDL

If the parameter is set to “On”, closing is enabled when Both U-Line and U-bus are below ULow and ManEnerg is set to “DLLB”, “DBLL” or “Both”.

The setting parameters are accessible through the HMI. The parameters for the phasing and synchrocheck function are found in the MMI tree under:

Settings
  Functions
    Group n (n=1-4)
      SynchroCheck
        SynchroCheck1

Operation

Off	The synchrocheck function is disabled and the output is low.
Release	There are fixed, high output signals SYN1-AUTOOK = 1 and SYN1-MANOK = 1.
On	The synchro-check function is in service and the output signal depends on the input conditions.

Input phase

The measuring phase of the UL1, UL2, UL3 line voltage, which can be of a single-phase (phase-neutral) or two-phases (phase-phase).

PhaseShift

This setting is used to compensate for a phase shift caused by a line transformer between the two measurement points for UBus and ULine. The set value is added to the measured phase difference. The bus voltage is reference voltage.

URatio

The URatio is defined as URatio=UBus/ULine. A typical use of the setting is to compensate for the voltage difference caused if wished to connect the UBus phase-phase and ULine phase-neutral. The “Input phase”-setting should then be set to phase-phase and the “URatio”-setting to sqr3=1.732. This setting scales up the line voltage to equal level with the bus voltage.

USelection

Selection of single or double bus voltage-selection logic.

AutoEnerg and ManEnerg

Two different settings can be used for automatic and manual closing of the circuit breaker.

Off	The energizing condition is not used, only the synchro-check.
DLLB	The line voltage U-line is low, below (10-80% U1b) and the bus voltage U-bus is high, above (70-100% U1b).
DBLL	The bus voltage U-bus is low, below (10-80% U1b) and the line voltage U-line is high, above (70-100% U1b).
Both	Energizing can be done in both directions, DLLB or DBLL.
tAutoEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-AUTOOK.
tManEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-MANOK.

ManDBDL

If the parameter is set to “On”, closing is enabled when Both U-Line and U-bus are below ULow and ManEnerg is set to “DLLB”, “DBLL” or “Both”.

OperationSynch

Off	The phasing function is disabled and all outputs are low.
On	The phasing function is in service and the output signals depends on the input conditions.

ShortPulse

Off	The closing pulse issued to the circuit breaker will be of length=tPulse.
On	The closing pulse issued to the circuit breaker will be of length=one cycle time in the internal logic.

The setting parameters are accessible through the HMI. The parameters for the synchrocheck function are found in the MMI tree under:

Settings
Functions
Group n (n=1-4)
SynchroCheck
SynchroCheck1 (and 2)

Operation

Off	The function is disabled and the output is low.
Release	There are fixed, high output signals SYN1-AUTOOK = 1 and SYN1-MANOK = 1.
On	The function is in service and the output signal depends on the input conditions.

Input phase

The measuring phase of the UL1, UL2, UL3 line voltage, which can be of a single-phase (phase-neutral) or two-phases (phase-phase).

PhaseShift

This setting is used to compensate for a phase shift caused by a power transformer between the two measurement points for UBus and ULine. The set value is added to the measured phase difference. The bus voltage is reference voltage.

URatio

The URatio is defined as URatio=UBus/ULine. A typical use of the setting is to compensate for the voltage difference if UBus phase-phase and ULine phase-neutral is used. The “Input phase”-setting should then be set to phase-phase and the “URatio”-setting to sqr3=1.732. This setting scales up the line voltage to equal level with the bus voltage.

AutoEnerg and ManEnerg

Two different settings can be used for automatic and manual closing of the circuit breaker.

Off	The energizing condition is not used only the synchro-check.
DLLB	The line voltage U-line is low, below (10-80% U1b) and the bus voltage U-bus is high, above (70-100% U1b).
DBLL	The bus voltage U-bus is low, below (10-80% U1b) and the line voltage U-line is high, above (70-100% U1b).
Both	Energizing can be done in both directions, DLLB or DBLL.
tAutoEnerg	The required consecutive time of fulfilment of the energizing condition to achieve SYN1-AUTOOK.
tManEnerg	The required consecutive time of fulfilment of the energizing condition to achieve SYN1-MANOK.

ManDBDL

If the parameter is set to “On”, closing is enabled when Both U-Line and U-bus are below ULow and ManEnerg is set to “DLLB”, “DBLL” or “Both”.

OperationSynch

Off	The phasing function is disabled and all outputs are low.
On	The phasing function is in service and the output signals depends on the input conditions.

ShortPulse

Off	The closing pulse issued to the circuit breaker will be of length=tPulse.
On	The closing pulse issued to the circuit breaker will be of length=one cycle time in the internal logic.

The setting parameters are accessible through the local HMI. The parameters for the synchrocheck function are found in the HMI tree under:

Settings
Functions
Group n (n = 1..4)
SynchroCheck
SynchroCheck1

Comments regarding settings:

Operation

Off/Release/On	
Off	The synchrocheck function is disabled and the output is low.
Release	There are fixed, high output signals SYN1-AUTOOK = 1 and SYN1-MANOK = 1.
On	The function is in service and the output signal depends on the input conditions.

Input phase

The measuring phase of the UL1, UL2, UL3 line voltage, which can be single-phase (phase-neutral) or two-phase (phase-phase).

Note!

Only available in terminals intended for one bay.

UMeasure

Selection of single-phase (phase-neutral) or two-phase (phase-phase) measurement.

Note!

Only available in terminals intended for several bays.

PhaseShift

This setting is used to compensate for a phase shift caused by a line transformer between the two measurement points for UBus and ULine. The set value is added to the measured phase difference. The bus voltage is reference voltage.

URatio

The *URatio* is defined as URatio=UBus/ULine. A typical use of the setting, is to compensate for the voltage difference caused if desired to connect the UBus as phase-phase and the ULine as phase-neutral. The *Input phase* -setting should then be set to phase-phase and the *URatio*-setting to sqr(3) (=1.732). This setting scales up the line voltage to equal level with the bus voltage.

AutoEnerg and ManEnerg

Two different settings can be used for automatic and manual closing of the circuit breaker.

Off	The energizing function is disabled.
DLLB	The line voltage U-line is dead (low), below (10-80% U1b) and the bus voltage U-bus is live (high), above (70-100% U1b).
DBLL	The bus voltage U-bus is dead (low), below (10-80% U1b) and the line voltage U-line is live (high), above (70-100% U1b).
Both	Energizing can be done in both directions, DLLB or DBLL.
tAutoEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-AUTOOK.
tManEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-MANOK.

ManDBDL

If the parameter is set to *On*, closing is enabled when Both U-Line and U-bus are below ULow and ManEnerg is set to *DLLB*, *DBLL* or *Both*.

The setting parameters are accessible through the HMI. The parameters for the synchrocheck function are found in the HMI tree under:

Settings
Functions
Groupn
SynchroCheck 1,2 and 3

Comments regarding settings

Operation

Off/Release/On	
Off	The function is disabled and the output is low.
Release	There are fixed, high output signals SYN1-AUTOOK = 1 and SYN1-MANOK = 1.
On	The function is in service and the output signal depends on the input conditions.

UMeasure

Selection of single-phase (phase-neutral) or two-phase (phase-phase) measurement.

PhaseShift

This setting is used to compensate for a phase shift caused by a line transformer between the two measurement points for UBus and ULine. The setting can also be used to compensate for the phase difference when UBus and ULine are taken from different phases. The set value is added to the measured phase difference. The bus voltage is reference voltage. A phase difference of +30 deg should therefore be compensated with a setting of parameter PhaseShift=30 deg and a phase difference of -30 deg is compensated with a setting PhaseShift=330 deg.

URatio

The URatio is defined as URatio=UBus/ULine. A typical use of the setting is to compensate for the voltage difference caused if one wishes to connect the UBus phase-phase and ULine phase-neutral. The “Input phase”-setting should then be set to phase-phase and the “URatio”-setting to sqr3=1.732. This setting scales up the line voltage to equal level with the bus voltage. A mathematical representation would in this case be: ULine’=URatio * ULine, where ULine’ is the scaled internal representation of ULine.

In the reverse case when UBus is connected phase-neutral and ULine is connected phase-phase, the “Input phase”-setting should be set to phase-neutral and the “URatio”-setting should be 1/sqr3=0.577. This setting scales up the bus voltage to equal level with the line voltage. The formula is in this case: UBus’=1/URatio * UBus, where UBus’ is the scaled internal representation of UBus.

AutoEnerg and ManEnerg

Two different settings AutoEnerg and ManEnerg can be used for automatic respectiviely manual closing of the circuit breaker.

Off	The energizing condition is not used only the synchro-check.
DLLB	The line voltage U-line is low, below (10-80% U1b) and the bus voltage U-bus is high, above (70-100% U1b).
DBLL	The bus voltage U-bus is low, below (10-80% U1b)) and the line voltage U-line is high, above (70-100% U1b)).
Both	Energizing can be done in both directions, DLLB or DBLL.
tAutoEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-AUTOOK.
tManEnerg	The required consecutive time of fulfillment of the energizing condition to achieve SYN1-MANOK.

ManDBDL

If the parameter is set to “On”, closing is enabled when Both U-Line and U-bus are below ULow and ManEnerg is set to “DLLB”, “DBLL” or “Both”.

2 Automatic reclosing function (AR)

2.1 Application

Automatic reclosing (AR) is a well-established method to restore the service of a power line after a transient line fault. The majority of line faults are flashover arcs, which are transient by nature. When the power line is switched off by operation of line protection and line breakers, the arc de-ionises and recovers voltage withstand at a somewhat variable rate. So a certain line dead time is needed. But then line service can resume by the auto-reclosing of the line breakers. Select the length of the dead time to enable good probability of fault arc de-ionisation and successful reclosing.

For the individual line breakers and auto-reclosing equipment, the Auto-reclose open time (AR open time) expression is used. At simultaneous tripping and reclosing at the two line ends, Auto-reclose open time equals approximaltely the dead time of the line. Otherwise these two times may differ.

In case of a permanent fault, the line protection trips again at reclosing to clear the fault.

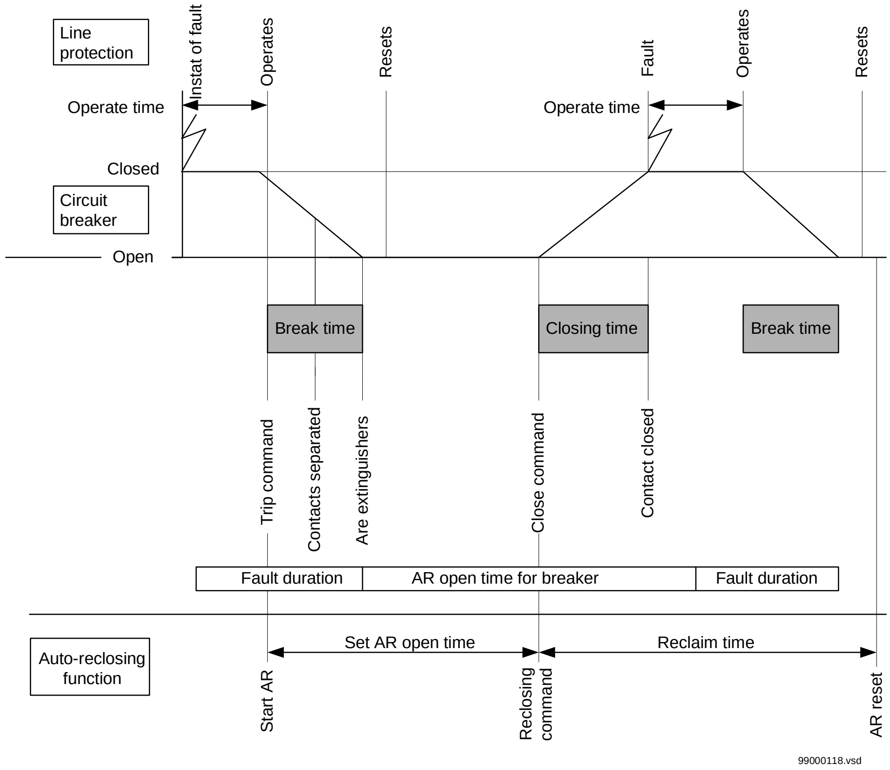


Figure 139: Single-shot auto-reclosing at a permanent fault

In a bay with one circuit breaker only one terminal is normally provided with one AR function.

Single-phase tripping and single-phase reclosing is a way to limit the effect of a single-phase line fault to system operation. Especially at higher voltages, the majority of line faults are of the single-phase type. The method is of particular value to maintain system stability in systems with limited meshing or parallel routing. It requires individual operation of each phase of the breakers, which is common at the higher transmission voltages.

A somewhat longer dead time may be required at single-phase reclosing compared to high-speed three-phase reclosing, due to influence on the fault arc from voltage and current of the non-tripped phases.

There is also a possibility to trip and reclose two of the circuit breaker poles, in case of faults when two out of the three phases are involved and parallel lines are in service. This type of faults is less common compared to single phase to earth faults, but more common than three phase faults.

In order to maximize the availability of the power system there is a possibility to chose single pole tripping and auto-reclosing at single phase faults, two pole tripping and auto-reclosing at faults involving two phases and three pole tripping and auto-reclosing at three phase faults.

During the single pole open time there will be an equivalent “series”-fault in the system. As a consequence there will be a flow of zero sequence current. Therefor the residual current protections must be co-ordinated with the single pole tripping and auto-reclosing.

The reclosing function can be selected to perform single-phase, two-phase and/or three-phase reclosing from six single-shot to multiple-shot reclosing programs. The three-phase auto-reclose open time can be set to give either high-speed auto-reclosing (HSAR) or delayed auto-reclosing (DAR). In the reclosing programs the delayed auto-reclosing (DAR) is always a three pole trip and reclosing, even if the first high-speed reclosing is a single pole action.

2.2 Functionality

The AR function is a logical function built up from logical elements. It operates in conjunction with the trip output signals from the line protection functions, the OK to close output signals from the synchrocheck and energizing check function, and binary input signals (for circuit breaker position/status, or from other external protection functions).

In the AR logic a number of parameters can be set to adjust the auto-reclosing function to the desired requirements. Examples are:

- Number of AR attempts
- AR programs
- Open times for different AR attempts

Start and control of the auto-reclosing

The automatic operation of the auto-reclosing function is controlled by the parameter *Operation* and the input signals as described above. When it is on, the AR01-SETON output is high (active). See Function block diagrams.

The auto-reclosing function is activated at a protection trip by the AR01-START input signal. At repeated trips, this signal is activated again to make the reclosing program continue.

There are a number of conditions for the start to be accepted and a new cycle started. After these checks, the start signal is latched in and the *Started* state signal is activated. It can be interrupted by certain events.

Extended AR open time, shot 1

The purpose of this function is to adapt the length of the AR Open time to the possibility of non-simultaneous tripping at the two line ends. If a permissive communication scheme is used and the permissive communication channel (for example, PLC, power-line carrier) is out of service at the fault, there is a risk of sequential non-simultaneous tripping. To ensure a sufficient line dead time, the AR open time is extended by 0.4 s. The input signal AR01-PLCLOST is checked at tripping. See Function block diagrams. Select this function (or not) by setting the Extended t1 parameter to On (or Off).

Long trip signal

During normal circumstances, the trip command resets quickly due to fault clearing. The user can set a maximum trip pulse duration by tTrip. At a longer trip signal, the AR open dead time is extended by Extend_t1. If the Extended t1 = Off, a long trip signal interrupts the reclosing sequence in the same way as AR01-INHIBIT.

Reclosing programs

The reclosing programs can be performed with up to maximum four reclosing attempts (shots), selectable with the NoOfReclosing parameter. The first program is used at pure 3-phase trips of breakers and the other programs are used at 1-, 2- or 3-phase trips of breakers.

3ph

3-phase reclosing, one to four attempts (NoOfReclosing parameter). The output AR01-P3P is always high (=1).

A trip operation is made as a three-phase trip at all types of fault. The reclosing is as a three-phase reclosing in program 1/2/3ph, described below.

1/2/3ph

1-phase, 2-phase or 3-phase reclosing in the first shot.

For the example, one-shot reclosing for 1-phase, 2-phase or 3-phase, see Figures in Function block diagrams. Here, the AR function is assumed to be On and Ready. The breaker is closed and the operation gear ready (manoeuvre spring charged etc.). Only the 1-phase and 3-phase cases are described.

AR01-START is received and sealed-in at operation of the line protection. The AR01-READY output is reset (Ready for a new AR cycle).

If AR01-TR2P (2-phase trip) is low and AR01-TR3P (3-phase trip) is:

low,	the timer for 1-phase reclosing open time t1 1Ph is started and the AR01-1PT1 output (auto-reclosing 1-phase, shot 1, in progress) is activated. It can be used to suppress Pole disagreement and Earth-fault protection during the 1-phase open interval.
high,	the timer for 3-phase AR open time, t1, is started (instead of t1 1Ph) and AR01-T1 is set (auto-reclosing 3-phase, shot 1, in progress). While either t1 1Ph or t1 is running, the output AR01-INPROGR is activated.

Immediately after the start-up of the reclosing and tripping of the breaker, the input (see Function block diagrams) AR01-CBCLOSED is low (possibly also AR01-CBREADY at type OCO). The AR Open-time timer, t1 1Ph or t1, keeps on running.

At the end of the set AR open time, t1 1Ph or t1, the respective SPTO or TPTO (single-phase or three-phase AR time-out, see Function block diagrams) is activated and goes on to the output module for further checks and to give a closing command to the circuit breaker.

At any kind of trip, the operation is as already described, program 1/2/3ph. If the first reclosing attempt fails, a 3-phase trip will be issued and 3-phase reclosings can follow, if selected. Maximum three additional attempts can be done (according to the NoOfReclosing parameter).

1/2ph

1-phase or 2-phase reclosing in the first shot.

At 1-phase or 2-phase trip, the operation is as in above described example, program **1/2/3ph**. If the first reclosing attempt fails, a 3-phase trip will be issued and 3-phase reclosings can follow, if selected. Maximum three additional attempts can be done (according to the NoOfReclosing parameter).

At 3-phase trip, TR2P low and TR3P high, the AR will be blocked and no reclosing takes place.

1ph + 1*2ph

1-phase or 2-phase reclosing in the first shot.

At 1-phase trip (TR2P low and TR3P low), the operation is as in above described example, program 1/2/3ph. If the first reclosing attempt fails, a 3-phase trip will be issued and 3-phase reclosings can follow, if selected. Maximum three additional attempts can be done (according to the NoOfReclosing parameter).

At 2-phase trip (TR2P high and TR3P low), the operation is similar as above. But, if the first reclosing attempt fails, a 3-phase trip will be issued and the AR will be blocked. No more attempts take place!

At 3-phase trip, TR2P low and TR3P high, the AR will be blocked and no reclosing takes place.

1/2ph + 1*3ph

1-phase, 2-phase or 3-phase reclosing in the first shot.

At 1-phase or 2-phase trip, the operation is as described above. If the first reclosing attempt fails, a 3-phase trip will be issued and 3-phase reclosings can follow, if selected. Maximum three additional attempts can be done (according to the NoOfReclosing parameter).

At 3-phase trip, the operation is similar as above. But, if the first reclosing attempt fails, a 3-phase trip will be issued and the AR will be blocked. No more attempts take place!

1ph + 1*2/3ph

1-phase, 2-phase or 3-phase reclosing in the first shot.

At 1-phase trip, the operation is as described above. If the first reclosing attempt fails, a 3-phase trip will be issued and 3-phase reclosings can follow, if selected. Maximum three additional attempts can be done (according to the NoOfReclosing parameter).

At 2-phase or 3-phase trip, the operation is similar as above. But, if the first reclosing attempt fails, a 3-phase trip will be issued and the AR will be blocked. No more attempts take place!

Table 10: Type of reclosing for different programs

Program	1st attempt	2-4th attempt
3ph	3ph	3ph
1/2/3ph	1ph	3ph
	2ph	3ph
	3ph	3ph
1/2ph	1ph	3ph

Program	1st attempt	2-4th attempt
	2ph	3ph
	No 3ph reclosing	No 3ph reclosing
1ph + 1*2ph	1ph	3ph
	2ph	No
	No 3ph reclosing	No 3ph reclosing
1/2ph + 1*3ph	1ph	3ph
	2ph	3ph
	3ph	No
1ph + 1*2/3ph	1ph	3ph
	2ph	No
	3ph	No

Blocking of a new reclosing cycle

A new start of a reclosing cycle is blocked for the reclaim time after the selected number of reclosing attempts are performed.

Reclosing checks and Reclaim timer

An AR open-time time-out signal is received from a program module. At three-phase reclosing, a synchro-check and/or energising check or voltage check can be used. It is possible to use an internal or an external synchro-check function, configured to AR01-SYNC. If a reclosing without check is preferred, configure the input AR01-SYNC to FIXD-ON (set to 1).

Another possibility is to set the output from the internal synchro-check function to a permanently active signal. Set Operation = Release in the synchro-check function. Then AR01-SYNC is configured to SYNx-AUTOOK.

At confirmation from the synchro-check or if the reclosing is of single-phase type, the signal passes on.

At AR01-CBREADY signal of the Close-Open (CO) type, it is checked that this signal is present to allow a reclosing.

The synchrocheck and energizing check must be fulfilled within a certain period of time, tSync. If it does not, or if the other conditions are not fulfilled, the reclosing is interrupted and blocked.

The Reclaim-timer defines a period from the issue of a reclosing command, after which the reclosing function is reset. Should a new trip occur within this time, it is treated as a continuation of the first fault. When a closing command is given (Pulse AR), the reclaim timer is started.

There is an AR State Control, see Function block diagrams, to track the actual state in the reclosing sequence.

Pulsing of CB closing command

The circuit breaker closing command, AR01-CLOSECB, is made as a pulse with a duration, set by the tPulse parameter. For circuit breakers without an anti-pumping function, the closing-pulse-cutting described below can be used. It is selected by means of the CutPulse parameter (set to On). In case of a new trip pulse, the closing pulse will be cut (interrupted). But the minimum length of the closing pulse is always 50 ms.

At the issue of a reclosing command, the associated reclosing operation counter is also incremented. There is a counter for each type of reclosing and one for the total number of reclosings. See Function block diagrams.

Transient fault

After the reclosing command, the reclaim timer keeps running for the set time. If no tripping occurs within this time, tReclaim, the auto-reclosing function will be reset. The circuit breaker remains closed and the operating gear ready (manoeuvre spring is recharged). AR01-CBCLOSED = 1 and AR01-CBREADY = 1.

After the reclaim time, the AR state control resets to original rest state, with AR01-SETON = 1, AR01-READY = 1 and AR01-P1P = 1 (depending on the selected program). The other AR01 outputs = 0.

Unsuccessful signal

Normally the signal AR01-UNSUC appears when a new start is received after the last reclosing attempt has been made. See Function block diagrams. It can be programmed to appear at any stage of a reclosing sequence by setting the parameter *UnsucMode* = On. The UNSUC signal is attained after the time tUnsuc.

Permanent fault

If a new trip takes place after a reclosing attempt and a new AR01-START or AR01-TRSOTF signal appears, the AR01-UNSUC (Reclosing unsuccessful) is activated. The timers for the first reclosing attempt (t1 1Ph, t1 2Ph and t1) cannot be started.

Depending on the PulseCut parameter setting, the closing command may be shortened at the second trip command.

After time-out of the reclaim timer, the auto reclosing function resets, but the circuit breaker remains open (AR01-CBCLOSED = 0, AR01-CBREADY = 1). Thus the reclosing function is not ready for a new reclosing cycle. See Function block diagrams and Sequence examples.

Automatic confirmation of programmed reclosing attempts

The auto-recloser can be programmed to continue with reclosing attempts two to four (if selected) even if the start signals are not received from the protection functions, but the breaker is still not closed. See figure in Function block diagrams. This is done by setting the parameter *AutoCont* = On and the wait time *tAutoWait* to desired length.

2.3 Calculations

2.3.1 Configuration and setting

The signals are configured in the CAP 531 configuration tool.

The parameters for the auto-reclosing function are set through the local HMI at:

Settings
  Functions
    Group n
      AutoRecloser
        AutoRecloser n

Recommendations for input signals

See figure 140 and the default configuration for examples.

AR01-START

Should be connected to the protection function trip output which shall start the auto-recloser. It can also be connected to a binary input for start from an external contact. A logical OR gate can be used to multiply the number of start sources.

AR01-ON and AR01-OFF

May be connected to binary inputs for external control.

AR01-INHIBIT

Can be connected to binary inputs, to block the AR from a certain protection, such as a line connected shunt reactor, transfer trip receive or back-up protection or breaker-failure protection.

AR01-CBCLOSED and AR01-CBREADY

Must be connected to binary inputs, for pick-up of the breaker signals. If the external signals are of Breaker-not-ready type, uncharged etc., an inverter can be configured before CBREADY.

AR01-SYNC

Is connected to the internal synchro-check function if required. It can also be connected to a binary input. If neither internal nor external synchronising or energising check (dead line check) is required, it can be connected to a permanent 1 (high), by connection to FIXD-ON.

AR01-PLCLOST

Can be connected to a binary input, when required.

AR01-TRSOTF

Can be connected to the internal line protection, distance protection, trip switch-onto-fault.

AR01-STTHOL

Start of thermal overload protection signal. Can be connected to OVLD-TRIP to block the AR at overload.

AR01-TR2P and AR01-TR3P

Are connected to the function block TRIP or to binary inputs. The protection functions that give two-phase or three-phase trips are supposed to be routed via that function.

Other

The other input signals can be connected as required.

Recommendations for output signals

See figure 140 and the default configuration for examples.

AR01-READY

Can be connected to the Zone extension of a line protection. It can also be used for indication, if required.

AR01-1PT1 and 2PT1

1-phase and 2-phase reclosing in progress is used to temporarily block an Earth-fault protection and/or a Pole disagreement function during the 1-phase or 2-phase open intervals.

AR01-CLOSECB

Connect to a binary output relay for circuit breaker closing command.

AR01-P3P

Prepare 3-phase trip: Connect to TRIP-P3PTR.

AR01-P1P

Permit 1-phase trip: Can be connected to a binary output for connection to external protection or trip relays. In case of total loss of auxiliary voltage, the output relay drops and does not allow 1-phase trip. If needed to invert the signal, it can be made by a breaking contact of the output relay.

Other

The other output signals can be connected for indication, disturbance recording etc., as required.

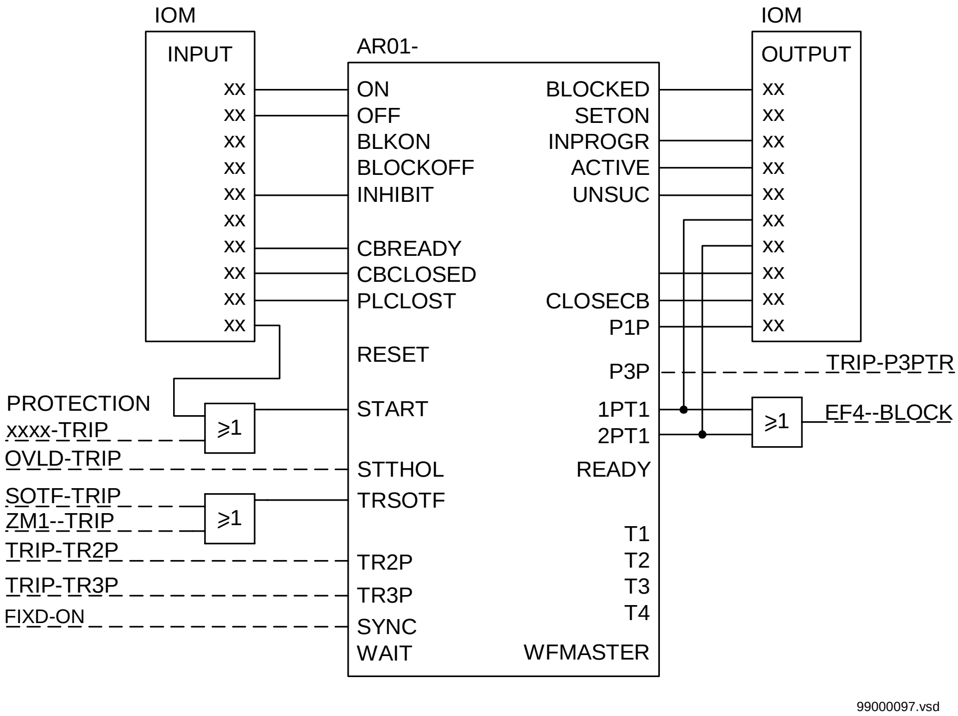


Figure 140: Recommendations for I/O-signal connections.

Recommendations for multi-breaker arrangement

Sequential reclosing at multi-breaker arrangement is achieved by giving the two line breakers different priorities. Refer to figure 141. At single breaker application, *Priority* is set to *No*, and this has no influence on the function. The signal *Started* is sent to the next function module. At double breaker and similar applications, *Priority* is set *High* for the Master terminal and *Priority* = *Low* for the Slave.

While reclosing is in progress in the master, it issues the signal -WFMASTER. A reset delay ensures that the -WAIT signal is kept high for the breaker closing time. After an unsuccessful reclosing, it is also maintained by the signal -UNSUC. For the slave terminal, the input signal -WAIT holds back a reclosing operation. A time *tWait* sets a maximum waiting time for the reset of the Wait signal. At time-out, it interrupts the reclosing cycle by a WM-INH, wait for master inhibit, signal.

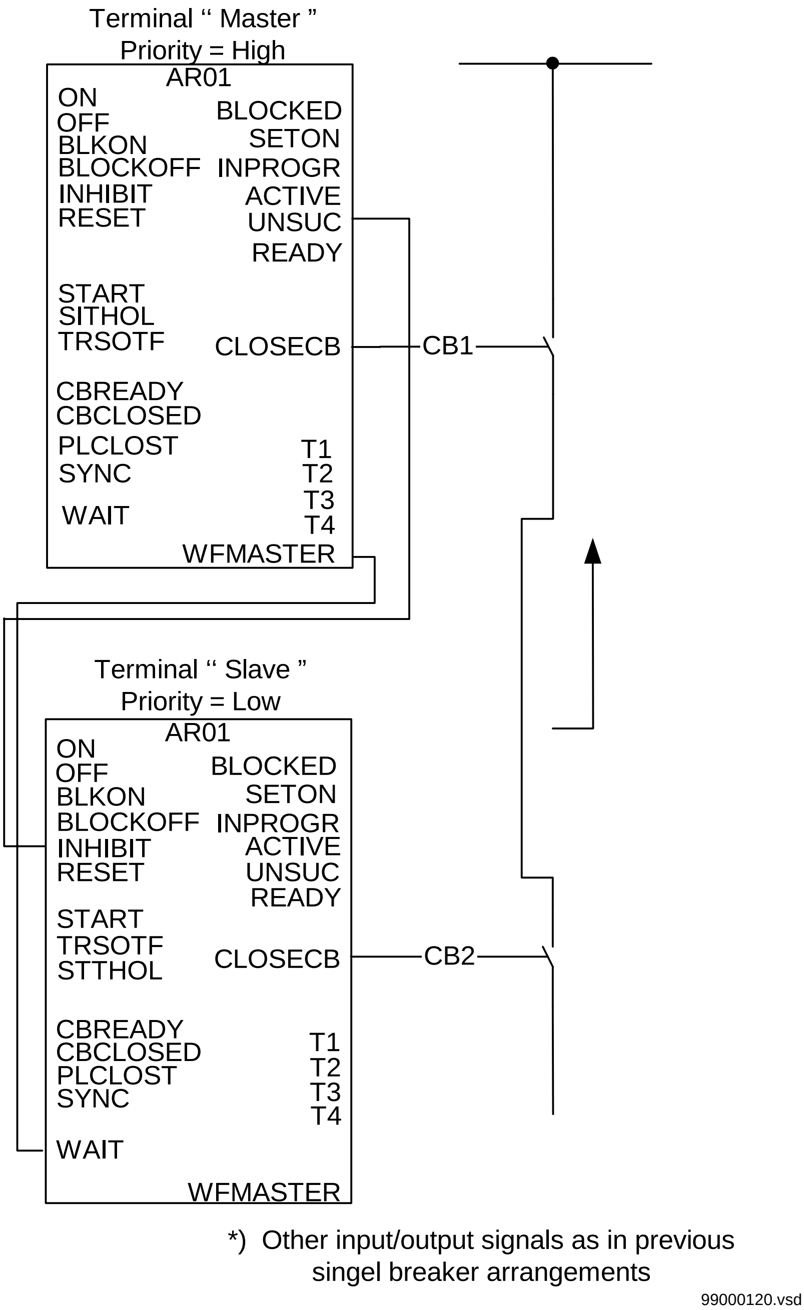


Figure 141: Additional input and output signals at multi breaker arrangement

Settings

Number of reclosing attempts: 1 to 4 attempts can be chosen. In most cases 1 attempt is sufficient as the majority of arcing faults will cease after the first reclosing shot. In power systems with many faults caused by other phenomena than lightning, for example wind, it can be motivated with more than one reclosing attempt.

There are six different possibilities in the selection of reclosing programs. What type of first shot reclosing shall be made, and for which types of faults? In completely meshed power systems it is often acceptable to use three pole auto-reclosing for all fault types, as first shot. In power systems with few parallel paths single pole auto-reclosing should be considered, in order to avoid reclosing in a phase opposition situation. In such systems auto-reclosing should be allowed for single phase faults only. It must be remembered that there will be zero sequence current flow in the power system during the single pole reclosing open time.

If a permissive channel is used between the line ends, and the availability of the communication channel is considered to be low, extended dead time in case of loss of the channel should be used.

Due to the secondary arc at single pole trip and auto-reclosing, the extinguishing time for the arc will be longer than for three pole trip and auto-reclosing. Typical required dead time for single pole trip and reclosing: 800 ms. Typical required dead time for three pole trip and reclosing: 400 ms. Different local phenomena, such as moisture, salt, pollution, etc. can influence the required dead time. Different open time for first auto-reclosing shot can be chosen for single pole (t1 1Ph), two pole (t1 2PH) and three pole (t1).

The open time for the three pole delayed auto-reclosing shots can be set individually (t2, t3 and t4). This setting can in some cases be restricted by national regulations.

In case of reclosing based on synchrocheck a maximum wait time (tSync) can be set. If the synchrocheck does not allow reclosing within this set time there will be no autoreclosing. This setting must be matched against the setting of the synchrocheck function. The operate time of the synchrocheck is mainly dependent on the setting angle difference. A typical operation time is about 200 ms. If the system will start to oscillate during the dead time, there can be some time before the synchronising quantities can be accepted for reclosing. This can be checked by means of dynamic simulations. As a base recommendation tSync can be set to 2.0 s.

The breaker closing pulse length (tPulse) can be chosen with some margin longer that the shortest allowed pulse for the breaker (see breaker data).

The tReclaim setting must be chosen so that all autoreclosing shots can be completed.

The setting tTrip is used for blocking of autoreclosing in case of long trip duration. This can be the consequence of an unwanted permanent trip signal or a breaker failure.

In case of two or more autoreclosing modules only one shall be chosen as maser (priority high). The others should have priority low. In case of one breaker only none priority is chosen.

3 Multiple command (CM)

3.1 Application

The terminals may be provided with a function to receive signals either from a substation automation system or from other terminals via the interbay bus. That receiving function block has 16 outputs that can be used, together with the configuration logic circuits, for control purposes within the terminal or via binary outputs. When it is used to communicate with other terminals, these terminals have a corresponding event function block to send the information.

3.2 Design

General

One multiple command function block CM01 with fast execution time also named *Binary signal interbay communication, high speed* and/or 79 multiple command function blocks CM02-CM80 with slower execution time are available in the REx 5xx terminals as options. For REC 561 the seventy-nine multiple command function blocks CM02-CM80 with slow execution time is included in basic.

The output signals can be of the types Off, Steady, or Pulse. The setting is done on the MODE input, common for the whole block, from the CAP 531 configuration tool.

- 0 = Off sets all outputs to 0, independent of the values sent from the station level, that is, the operator station or remote-control gateway.
- 1 = Steady sets the outputs to a steady signal 0 or 1, depending on the values sent from the station level.
- 2 = Pulse gives a pulse with one execution cycle duration, if a value sent from the station level is changed from 0 to 1. That means that the configured logic connected to the command function blocks may not have a cycle time longer than the execution cycle time for the command function block.

The multiple command function block has 16 outputs combined in one block, which can be controlled from the operator station or from other terminals. One common name for the block, with a maximum of 19 characters, is set from the configuration tool CAP 531.

The output signals, here OUT1 to OUT16, are then available for configuration to built-in functions or via the configuration logic circuits to the binary outputs of the terminal.

Binary signal interbay communication

The multiple command function block can also be used to receive information over the LON bus from other REx 5xx terminals. The most common use is to transfer interlocking information between different bays. That can be performed by an Event function block as the send block and with a multiple command function block as the receive block. The configuration for the communication between terminals is made by the LON Network Tool.

The MODE input is set to Steady at communication between terminals and then the data are mapped between the terminals.

The command function also has a supervision function, which sets the output VALID to 0 if the block did not receive data within an INTERVAL time, that could be set. This function is applicable only during communication between terminals over the LON bus. The INTERVAL input time is set a little bit longer than the interval time set on the Event function block (see the document Event function). If INTERVAL=0, then VALID will be 1, that is, not applicable.

3.3 Calculations

3.3.1 Settings

The setting parameters for the multiple command function are set from the CAP 531 configuration tool.

The multiple command function has a common name setting (CmdOut) for the block. The MODE input sets the outputs to be one of the types Off, Steady, or Pulse. INTERVAL is used for the supervision of the cyclical receiving of data.

4 Apparatus control

4.1 Application

The apparatus control function is supervising the operation of a set of high-voltage apparatuses within a bay. Apparatuses in the form of breakers, disconnectors, and earthing switches. Figure 142 gives an overview from what places the apparatus control function receive commands. Orders to operate an apparatus can come from the Control Centre (CC), the station HMI, or the local back-up panel (via the I/O).

When operating from the local back-up panel, the apparatus control function can be bypassed. The back-up panel is hard wired to the apparatuses for this purpose.

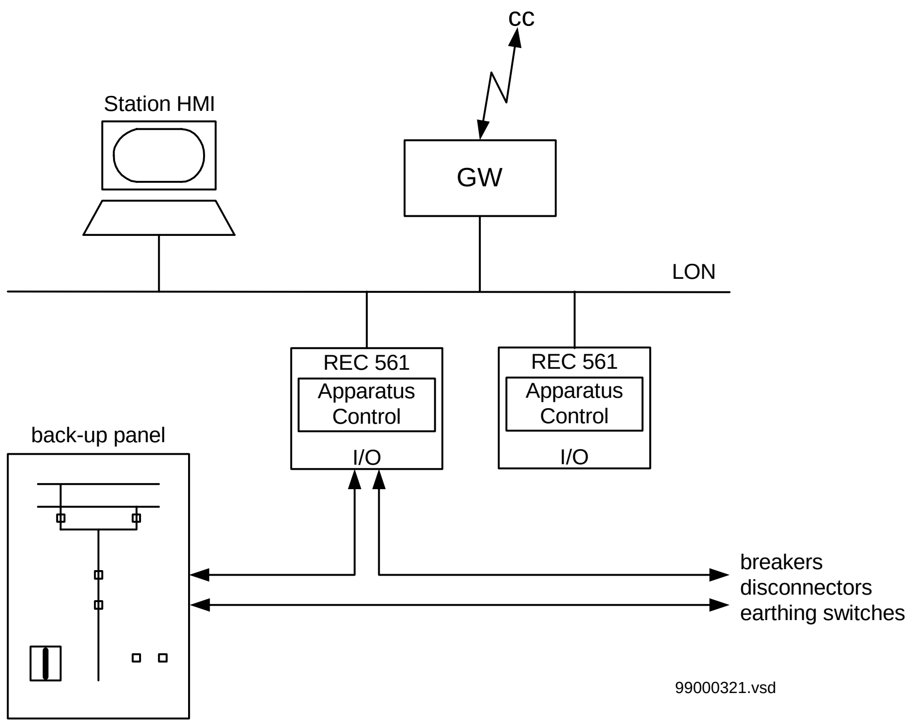


Figure 142: Overview of the apparatus control functions.

Features in the apparatus control function:

- Supervision of valid operator place (one operator place at a time)
- Each apparatus is prepared to be included in a sequence
- Each apparatus can be interlocked
- The breakers can be connected to synchrocheck/energizing check/phasing function
- Reservation of bays
- Supervision of status of primary apparatus

4.2 Functionality

4.2.1 General

A bay can handle, for examples a power line, a transformer, a reactor, or a capacitor bank. The different high-voltage apparatuses within the bay level can be controlled directly by the operator or indirectly by sequences. The different apparatuses can also be controlled automatically.

Because a high-voltage apparatus can be allocated to many functions within a Substation Automation system, the object-oriented approach with an internal module that handles the interaction and status of each process object ensures consistency in the process information used by higher-level control functions.

High-voltage apparatuses such as breakers and disconnectors are controlled and supervised by one software module each. Because the number and type of signals connected to a breaker and a disconnector are almost the same, the same software is used to handle these two types of apparatuses.

The software module is connected to the physical process unit in the switchyard by a number of digital inputs and outputs. Special function blocks were created for making bay and apparatus control programs as efficient as possible. Four types of function blocks are available to cover most of the control and supervision within the bay.

The different functions included in the apparatus control are described below.

4.2.2 Operator place

The apparatus can be controlled from three different operator places:

- Remote
- Station
- Local

The operator places have different priorities:

- Local (highest)
- Station
- Remote (lowest)

Normally, only one operator place is valid at a time. But the user can define that more than one operator place is valid at the same time.

The remote operator place is assigned by the station operator. When local operator place is deactivated (by the local operator) previous operator place becomes valid.

When the operator place is established, a selection of the apparatus can be made. This is possible in two different ways only, depending on the select/execute principle. Either there is one (close or open) selection input set, followed by simultaneous setting of the execute inputs.

Or if the other principle is used, setting of both selection inputs (close and open select) simultaneously followed by the direction (close or open) on the execute input. Any other combination causes a reset of the operation.

Because both select/execute principles are supported from the operator point of view, two selection and two execute inputs are implemented.

To inform operator(s) at the station HMI that the apparatus is selected from another operator place, there are indications for each apparatus from which operator place (remote, station or local) it is selected. This is to inform that the apparatus is already selected; so a selection from that operator place is not possible.

When a selection is made, the apparatus control goes back into idle state for one of these reasons:

- After a successful operation
- No open or close command within specified time
- When reservation failed
- When an interlock occurred
- In blocking state
- Cancelling of the operation

When the apparatus is in idle state, it is possible to make a new selection from the valid operator place.

The operator can override the interlocking and/or the reservation from the station HMI and from the local operator place.

Of course arbitrary orders can be sent to the control terminal, but only orders involved with the apparatus control are described below.

The apparatus control handles different kind of commands coming from different operator places. Interpret the local operator place as the back-up panel.

Remote

These commands are supported from remote operator place:

- Select, open/close
- Execute, open/close
- Cancel the selection

Station

These commands are supported from the station HMI:

- Select, open/close
- Execute, open/close
- Cancel the selection
- Block/deblock operation (per apparatus or bay)
- Override of reservation, interlocking and/or synchro-check/phasing
- Selection of operator place, station and/or remote
- Block/deblock updating of the position indications (per apparatus or bay)
- Setting of the position indication, open/close

Local

These commands are supported from the local HMI (back-up panel):

- Select, open/close
- Execute, open/close
- Override, reservation and/or interlocking
- Set operator place to local (switch on the back-up panel)

Automatic functions

An automatic program (placed in the control terminal or in external equipment) can be connected to the apparatus control. These signals can be connected to the apparatus control:

- Signals for select (open/close)
- Signals for execute (open/close)
- Cancel the selection
- Signal to reserve the apparatus for automatic functions. Used when the apparatus is included in a sequence

4.2.3 Selection and reservation

The purpose of the reservation and selection is to prevent double operation, either in the bay itself or in the complete station. For an operation in the bay, the reservation part always reserves the own bay. The engineer can include or exclude the part that reserves other bays.

The selection and reservation function consists of four parts:

1. Reservation of the own bay
2. Requesting reservation of other bays and handling of the acknowledgement signals
3. Replying to reservation requests
4. Permitting selection of apparatuses, depending on reservations

The selection and reservation function has two ways of starting. It starts when a request select signal is set in the own bay or when it receives a request for reservation from another bay.

The basic part of the reservation function is the reservation of the own bay. When the reservation is made, no acceptance of selections from other apparatuses can occur until all selection requests and reservations are cancelled.

Reservation of the other bays can also be made. A request for reservation is sent to these other bays. All bays should respond with an acknowledgement that they have reserved the own bay for operations. After reception of these signals, the reservation is considered successful and selection can proceed.

To prevent that a reservation is not reset when the reserve request becomes invalid, the reservation in the own bay and the acknowledgement to the other bays are cancelled when the cancel reservation timer has expired. The engineer should set this time to the operating time of the slowest not hand driven disconnector.

One timer supervises the reservation. If the time until a successful reservation is too long, the command sequence is stopped and an error message is generated.

It is possible to ignore failing reservation of other bays, if the operator wants to operate the apparatus. There is an override signal for this purpose.

Blocking of the reservation function is possible. With an override, the blocking of reservation on requests from inside the bay can be bypassed.

The reservation method is briefly explained in figure 143 and follows these steps:

1. Select close/open from the station HMI
2. Reservation signal from the bay, which is to be operated
3. Transfer of acknowledgement and actual position indications from the other bays
4. Performed selection is presented on the station HMI
5. Execution of the command from the station HMI
6. Release (cancel) of the reservation

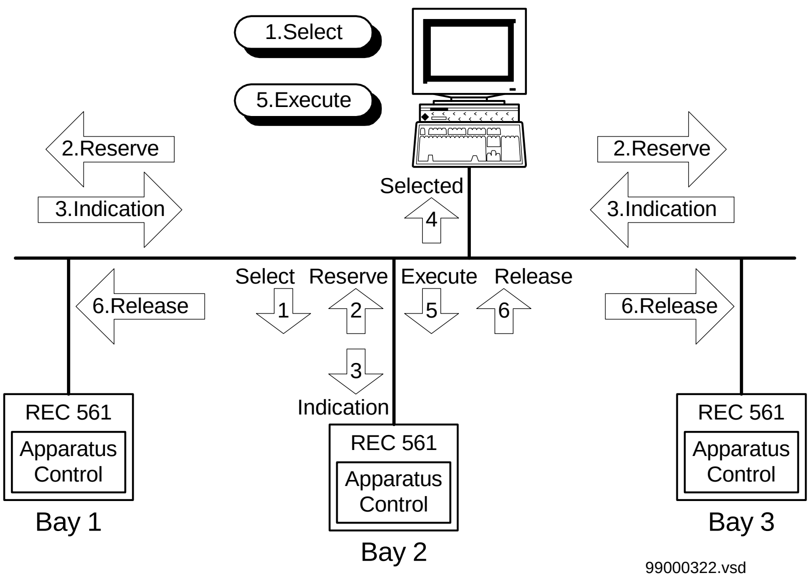


Figure 143: The reservation method.

4.2.4 Automatic functions

The apparatus control has inputs to be connected to automatic functions, for example, delayed autoreclosing. When an automatic operation program must take control of an apparatus, it must check if this is permitted. Automatic operations are permitted when these conditions are fulfilled:

- Operator place is not local
- The apparatus is not selected
- The apparatus is not reserved
- The concerned apparatus is not blocked for operation
- Position indications are not blocked

The function, which operates automatically, also first determines if automatic operation is permitted.

4.2.5 Manual updating of indications

The position indications can be set manually. This feature is only available from the station operator place.

There are two different independent functions given:

- Blocking of position updating from bay level (for all apparatuses in the bay) and apparatus level (for each separate apparatus)
- Setting the drive position indication to a defined position by the operator. This is mainly used in cases where the drive is in maintenance or is disturbed and a defined end position is required. This function should cause an automatic update blocking of the position indication.

It can be chosen if blocked position indications cause a blocking of operation.

The supervision of the positions of an apparatus is based on the indications from the program and not the process status. This is to be able to simulate the positions when operating. In most cases, the process and indication status are identical.

4.2.6 Blockings

There are two bay-oriented blocking functions:

- Blocking of operation
- Blocking of updating of the position indication

Both of these different blockings are applicable for each apparatus separately and for the complete bay.

Blocking of operations can be separately performed for open/close.

Commands for the above described blockings are executed from the station HMI. Of course, arbitrary signals can be used to cause a blocking. But the explicit orders come from the station HMI.

4.2.7 Command supervision

Supervision functions stops the program from hanging in the middle of a command sequence. When the operation time is too long there is an error indication, and the command sequence resets. Such functions are:

- Supervision of the time between the selection is made and the following execute command. Adjustable time.
- Supervision of the time between the request to override and the following selection. The same timer as above.
- Supervision of abnormal status between the select and execute signals. If select is given for one direction, it must be followed by execute for both directions. Or, if the other principle is used, both selection inputs are followed by execute for the desired direction.

4.2.8 Supervision of driving mechanism

The control part should check the start conditions (for example, if there is a select for open when the position is open) for a valid selection, the movement itself, and correct completion. The corresponding status signals are given. The operation depends on the interlocking and blocking signals.

The supervision of the command output is made by the microcontroller on the output board.

A timer supervises the start of the drive. If the drive does not succeed in starting within a specified time, the command sequence resets, and an error indication is generated.

A timer supervises the movement of the drive. The maximum time can be set between the start and until the new position is reached.

When three phase indications are included, the pole-discordance function is included.

If interlocking allows operation, the drive can be operated when the starting-point is in the intermediate position.

4.2.9 Synchrocheck with phasing

Synchrocheck and phasing conditions can be considered when manually closing a breaker. The closing command at synchrocheck is released via the apparatus control, as for ordinary operations with the synchrocheck function excluded.

A timer supervises the synchrocheck and phasing function. If the conditions are not fulfilled within a specified time (after a closing command is given), there is a failed synchronization.

The control terminal can use a built-in synchrocheck and phasing function (also called internal synchrocheck and phasing) or use an external synchrocheck and phasing equipment, which are separate devices outside the control terminal. Two solutions are supported. The explicit closing command can come from the apparatus control itself (activated by the synchrocheck) or from the external synchrocheck equipment (activated by the apparatus control).

4.3 Design

4.3.1 General

The apparatus control function contains several function blocks. These function blocks are interconnected to form a control program reflecting the switchyard configuration.

A control program contains four main types of function blocks. The total number used depends on the switchyard configuration. Beside the main types of function blocks the program contains simple logic like AND/OR gates.

These four main types are called BAYCON, COMCON, SWICON, and BLKCON.

BAYCON:

- BAY CONtrol, used for bay-oriented functions (one per bay) such as reservation, valid operator place, and supervision of select relays (when used).

COMCON:

- COMmand CONtrol, used for each apparatus. Supervises commands coming from the different operator places. The interface to the operator places.

SWICON:

- SWItching CONtrol, used for each apparatus. Supervises operating apparatuses. The interface to the process.

BLKCON:

- BLocK CONtrol, universal element used for different kinds of blockings. One per bay and one per apparatus.

Figure 144 shows how the modules are combined:

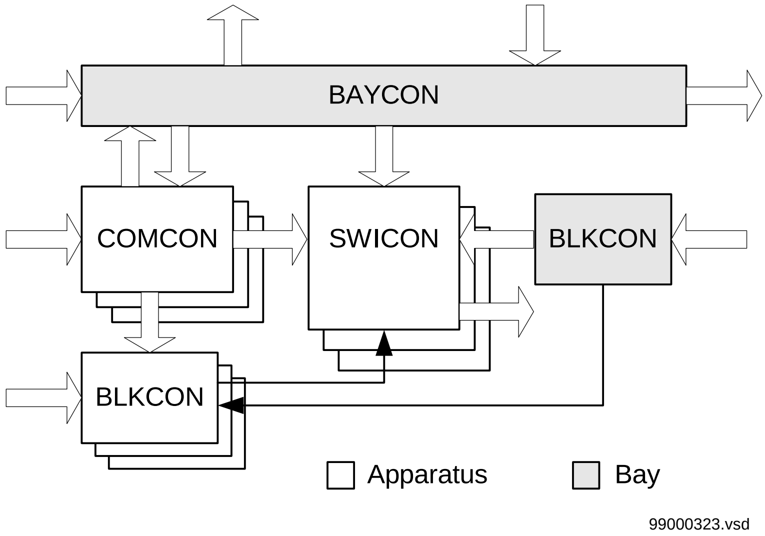


Figure 144: Overview of the interaction between the apparatus control modules

4.3.2 Standard modules

In the control terminal, several standard function blocks are available. Below the different standard modules are described. The chapter "Apparatus control" in the "Technical reference manual" describes input and output functions.

The BAYCON element consists of four variants:

BAYCONA: The normal version to be used.

BAYCONB: The same as A, but used when more than eight apparatuses are included in one bay, that is, when more than one BAYCON is used per bay.

BAYCONE: Is used if external selection relays with individual feedback signals are used.

BAYCONF: The same as E, but used when more than eight apparatuses are included in one bay, that is, when more than one BAYCON is used per bay.

COMCON consists of only one variant.

The SWICON element consists of three variants:

SWICONA: Used for internal synchro-check function and individual phase position indication. Normally used for circuit breakers.

SWICONB: Used for external synchro-check function and individual phase position indication. Normally used for circuit breakers.

SWICONC: Used for common position indication for all three phases. Normally used for disconnectors and earthing switches.

The BLKCON element consists of two variants:

BLKCONK: Normally used for the bays.

BLKCONL: Normally used for the apparatuses.

With control functions applicable for one bay or multiple bays, these standard modules are available:

Alternative for one bay and up to 14 apparatuses:

Normal use:

- 1 pcs BAYCONA or
- 2 pcs BAYCONB or

with external selection relays with individual feedback signals:

- 1 pcs BAYCONE or
- 2 pcs BAYCONF

and either

- 2 pcs SWICONA (internal synchro-check) or
- 2 pcs SWICONB (external synchro-check)

and

- 14 pcs SWICONC and
- 14 pcs COMCON and
- 14 pcs BLKCONL and
- 1 pcs BLKCONK

Alternative for up to three bays and up to 24 apparatuses:

Normal use:

- 3 pcs BAYCONA or
- 2 pcs BAYCONA and 3 BAYCONB or
- 1 pcs BAYCONA and 4 BAYCONB or

with external selection relays with individual feedback signals:

- 3 pcs BAYCONE or
- 2 pcs BAYCONE and 3 BAYCONF or
- 1 pcs BAYCONE and 4 BAYCONF

and either

- 4 pcs SWICONA (internal synchro-check) or
- 4 pcs SWICONB (external synchro-check)

and

- 24 pcs SWICONC and
- 24 pcs COMCON and
- 24 pcs BLKCONL and
- 3 pcs BLKCONK

Alternative for up to 12 bays and up to 24 apparatuses:

Normal use:

- 12 pcs BAYCONA or
- 11 pcs BAYCONA and 3 BAYCONB or
- 6 pcs BAYCONA and 4 BAYCONB or

with external selection relays with individual feedback signals:

- 12 pcs BAYCONE or
- 11 pcs BAYCONE and 3 BAYCONF or
- 6 pcs BAYCONE and 4 BAYCONF

and either

- 12 pcs SWICONA (internal synchro-check) or
- 12 pcs SWICONB (external synchro-check)

and

- 14 pcs SWICONC and
- 24 pcs COMCON and
- 24 pcs BLKCONL and
- 12 pcs BLKCONK

The selection of control alternative is made during manufacturing. The selection of standard modules within each control alternative in the control terminal is made by a Function Selector tool included in the CAP 531 Configuration tool.

4.4 BAYCON

4.4.1 Functionality

BAYCON handles bay control functions for operation of circuit breakers, disconnectors or earthing switches in a Substation Automation system. It contains functionality for operator place choice, selection and reservation, selection relay supervision and automatic functions. The total functionality depends on the variant of BAYCON. BAYCON handles maximum eight apparatuses. When a higher number is required, BAYCON can cooperate via information exchange with more BAYCON elements. “Apparatus control” in the “Technical reference manual” shows the function blocks for the different variants with the name of the input and outputs and describes these signals.

Operator place choice

The operator place has three possibilities:

- Remote for control via remote communication
- Station HMI
- Local for control from a local panel

With the inputs (S_R, S_S, L_L) that are obtained, the desired operator place can be selected. It has a built-in priority with Local as highest, Station as intermediate, and Remote as lowest priority. When two or more inputs are set at the same time, the higher priority prevails. The inputs S_R and S_S have pulse inputs, but the L_L requires a steady signal. Figure 145 shows the logic:

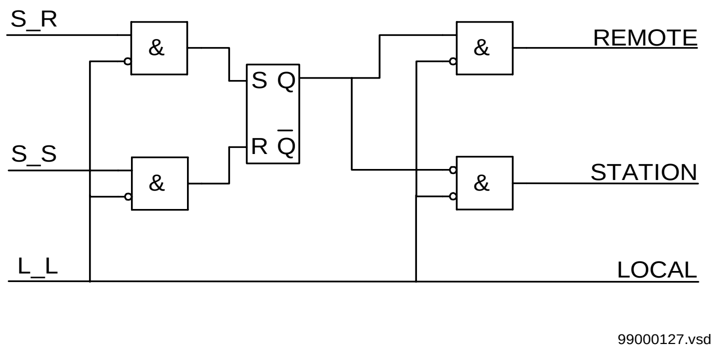


Figure 145: The operator place selection represented by logic

If the operator place selection is used without any priority and if the outputs REMOTE/STATION/LOCAL can be set independent of each other, the inputs REMOTE/STATION/LOCAL on COMCON can be used. See configuration example in the section of “Operator place selection” in “Configuration”.

Reservation and selection

The purpose of the reservation and selection function is primarily to transfer interlocking information in a safe way and to prevent double operation in a bay, switchgear, or complete substation. The section of “Reservation function” in “Configuration” describes the method and the meaning of the inputs and outputs of BAYCON.

Information exchange

The input EXCH_IN and output EXCH_OUT are used for information exchange between BAYCON elements, when more than eight apparatuses in the same bay are used for control. The inputs and outputs of these elements are connected to each other in a loop as shown in Figure 146.

The reservation and selection function has several bits available to request other BAYCONs to be reserved. These BAYCONs reply with an acknowledge through the same information exchange.

Only BAYCONB, and BAYCONF have this functionality.

Figure 146 shows the information exchange connections for one bay with up to 24 apparatuses.

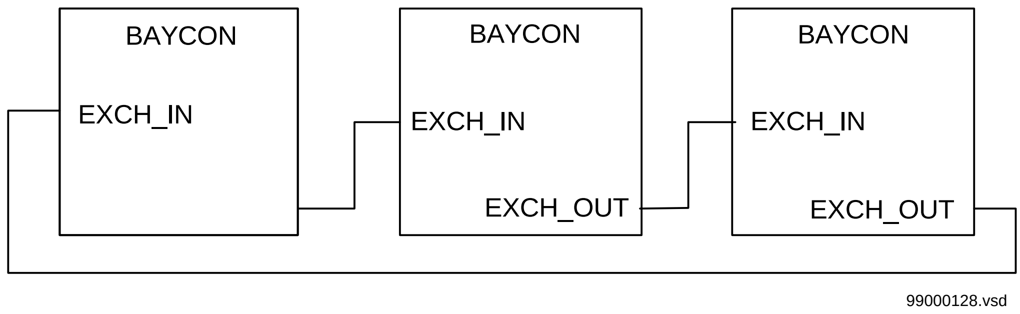


Figure 146: Connections between three BAYCONs intended to control up to 24 apparatuses

Selection relay supervision

The normal use of the command output module (BOM) does not require any external relays. The supervision of the command relays on the output module is performed on the circuit board. The output module is normally connected directly to the switchyard without any extra relays.

To meet requirements of supervision of external selection relays, it is possible to connect these relays and supervise them by BAYCONE or BAYCONF with individual feedback signals shown in figure 147.

The auxiliary contacts of the relays are wired to two inputs SEL_CH1 and SEL_CH2. A series connection of NC contacts connected to SEL_CH1 indicates that no relay is energized. A parallel connection of NO contacts connected to SEL_CH2 indicates that a relay is energized. BAYCON can now determine two types of errors. It can indicate that there is an error most probably at the system inputs with the BINPERR. BOUTERR indicates that the error is more likely to be found at the system outputs. BAYCON also checks the selection relays separately with a feedback signal from the energized selection relay. It can then determine if wrong relay is energized. It indicates this with the BRLYERR output. When an error occurs, BAYCON cancels all operations. It lets the reservation go into a fail state, which causes resetting of the selection or acknowledgement.

When BAYCON has a valid reservation for a selection request and no error occurs, the selection relay supervision also sets an output to the requesting apparatus. This is a feedback selection (FDB_SELx), which indicates that the energizing of the relay was correct. Now other software parts can give a close or open command.

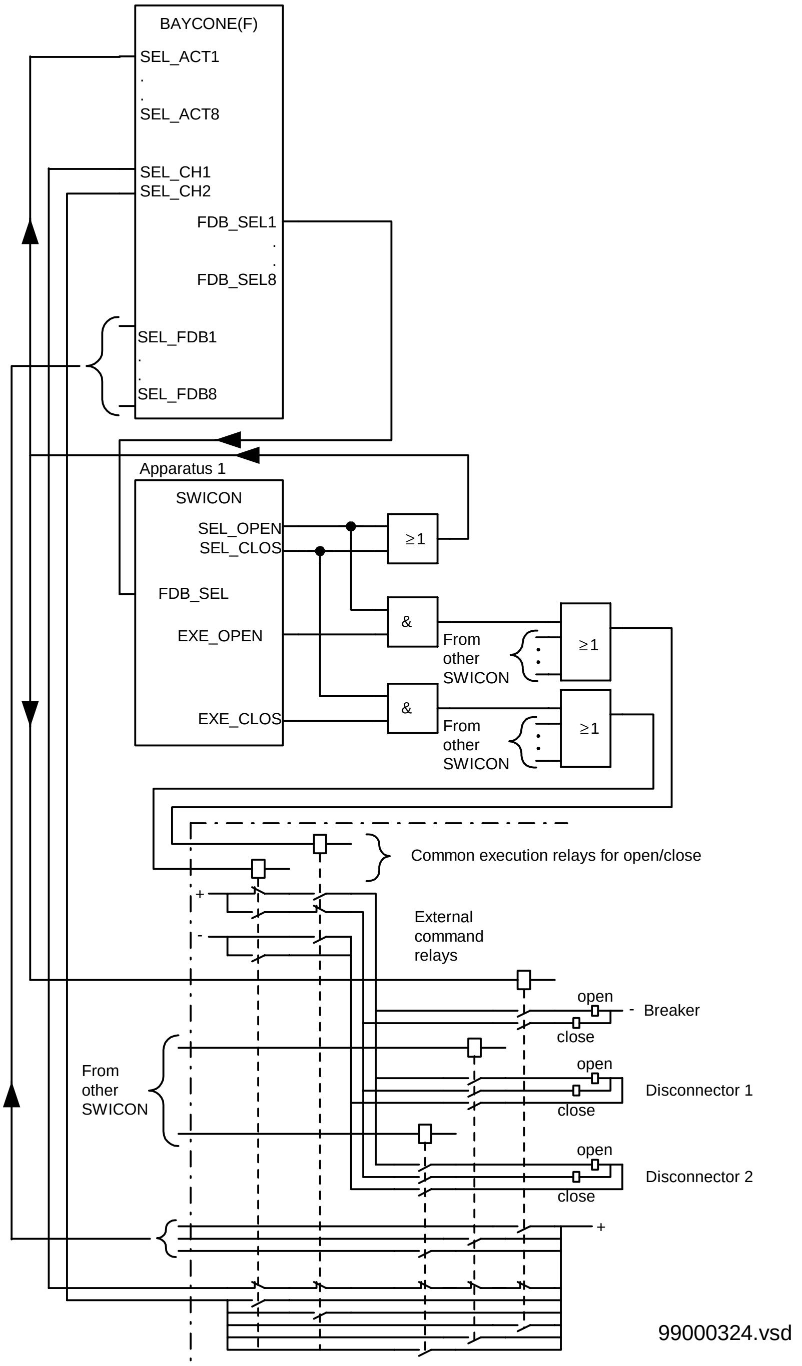


Figure 147: External selection relays with individual feedback signals.

Automatic operation check

BAYCON has an amount of information that concerns the permission for automatic operation. This information is made available at the AU_OP_Vx outputs. Other elements can combine this information to a signal to an automatic function indicating permission for operation.

Parameters

T_CAN_RE

Time-out when the reset of the reservation acknowledgement is not done by the requesting bays, for example, because of communication error.

4.5 COMCON

4.5.1 Functionality

COMCON acts as an interface between the possible operator places and the bay and the apparatus-control program. The validity of operator places is indicated on the REMOTE, STATION and LOCAL inputs. Only the signals from the operator place(s) that are valid are executed. When a change occurs, COMCON checks validity and forwards the commands to the outputs, if they are correct.

From station level, COMCON supports two ways of command executions:

1. From station HMI.
2. From remote gateway.

In the first way, that is normally used as standard from the station HMI (see item 1 in figure 148), only one selection input is activated, S_SEL_O or S_SEL_C. COMCON sets the RQ_SEL and the concerning direction output, OPEN or CLOSE. After the SELECT input is set by BAYCON, it allows the execute command S_OPEN and S_CLOSE to pass through. These execution inputs can be set at the same time or before SELECT is activated. Then the EXECUTE output is also activated.

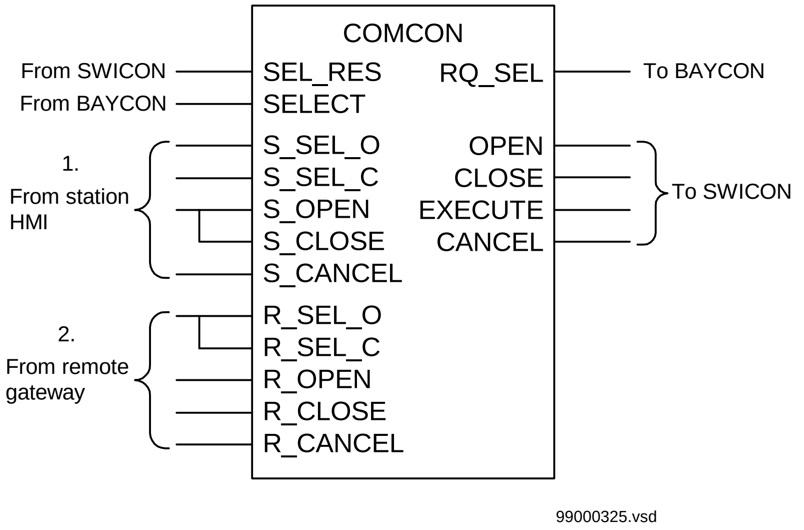


Figure 148: Example of different ways to connect the select and execute signals in COMCON

In the other way to select that is normally used as standard from remote gateway (see item 2 in figure 148), both selection inputs R_SEL_O and R_SEL_C are set at the same time. It sets only the RQ_SEL output. At reception of the SELECT, it allows the execute command R_OPEN or R_CLOSE to pass through. But now only one execute command R_OPEN or R_CLOSE can be given and COMCON passes the EXECUTE command with the OPEN/CLOSE directions.

The operation from a local operator place works in the same way as both alternatives from station HMI and remote gateway and can consequently be connected in a corresponding way.

When the operation has ended or failed, COMCON receives an input indication SEL_RES from SWICON. On reception of this input, it resets the stored commands and outputs.

An operation, which has already started with a selection, can be cancelled. The R/S_CANCEL inputs handle this. The output CANCEL is connected to the CANCEL input on SWICON to reset the started selection. COMCON also has an S/L_IR_OVR override input for station and local and an OVERRIDE output, which overrides the selection and reservation in other program parts.

COMCON also supports commands for blocking of operation and commands for manual position updating. These signals can come from station only and are being sent through to the rest of the program.

Besides from the three operator places, commands can also come from automatic functions. These inputs are handled in the same way as the normal operator place signals. For sequence switching, the apparatus can be reserved with the SEL_SEQ input.

For command supervision, COMCON has two time parameters. The supervision checks the time between select and execute signals and checks the response on a request for selection including reservation of other bays. When any of them is incorrect, COMCON indicates this with the LO_OP_T and RES_ERR outputs. Also, the CANCEL output gives a signal (pulse) to reset the selected command in SWICON.

Parameters

T_LO_OP

Maximum time between a select and the execute command coming from the operator. Also the maximum time between the request to override and the following select.

T_RES

Allowed time (for BAYCON) to make the reservation.

4.6 SWICON

4.6.1 Functionality

SWICON handles basically two functions, indication and supervision of operation. The indication inputs can either be individual per phase including the pole discordance check (SWICONA and SWICONB) or common for all three phases (SWICONC). The indication part checks the position indication information and gives indications (OX, CX) on the results. The POSIND_V input is used at external evaluations of the positions or at printed circuit board error. POSIND_V = True means valid positions. The result of (OX, CX) is (0, 0) (for intermediate position or when POSIND_V = False). It also includes the function for manual position updating. The position indication can be set manually, and the updating from the process is stopped. Manual updating is indicated by MA_UPD_P.

The indication part has two timer parameters. The POS_ERR is activated momentary at the intermediate position (1, 1) but is delayed the T_POSERR time at the position (0, 0). The POL_DISC output is activated when a pole discordance is detected and the T_POL timer expires.

SWICON has inputs and outputs for selection and execution. In case the SWICON assumes the select-open or -close-before-execute principle (that is, either OPEN or CLOSE is set), the SELx (SELECT) signal from BAYCON energizes the selection outputs of a given direction, SEL_OPEN or SEL_CLOS. After it has received the FDB_SEL signal, it proceeds with an EXECUTE command, which activates both EXE_OPEN and EXE_CLOS.

In case of the select-before-execute-open or -close principle, SWICON receives only a SELECT signal (that is, without the OPEN and CLOSE directions). Now it activates both the SEL_OPEN and SEL_CLOS selection outputs. After receiving a FDB_SEL feedback select, it waits for the EXECUTE command. This must now come together with the OPEN or CLOSE direction to activate either EXE_OPEN or EXE_CLOS. The connections between SWICON and the output board are shown in figure 149.

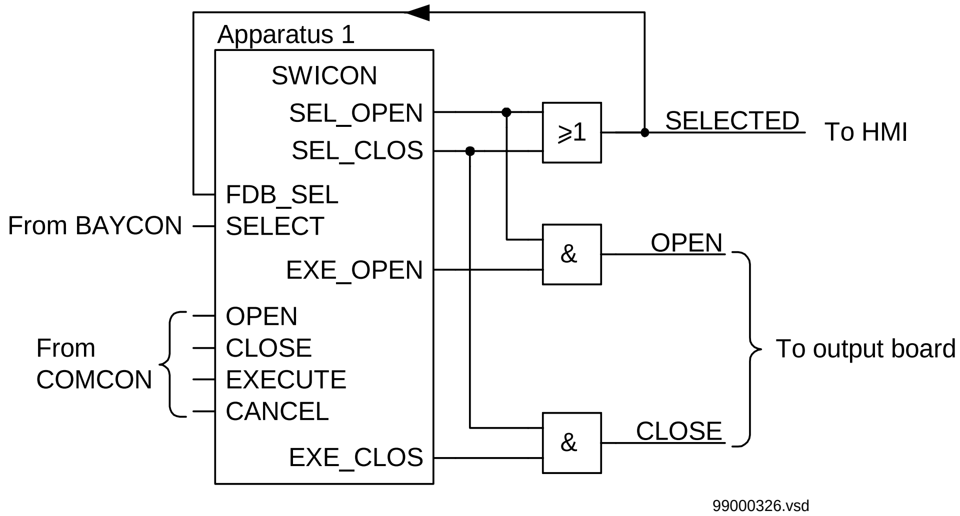


Figure 149: Connection of select and execute signals to the command output board from SWICON.

Before a selection output is activated, SWICON checks the blocking (BLK_OPEN/CLOS) and interlocking (INT_LOCK) inputs. After activation of the selection outputs, the selection timer (T_SEL) starts. When the feedback select signal does not come in time, SWICON sets the SEL_ERR output. After the execute outputs are activated, it sets the CMD_ERR if the position indication does not indicate a start in the position change, before the time T_START has elapsed.

Automatic operation is included in SWICON. It has an input for bay information concerning permission for automatic operation (AU_OP_V). It also has an output that indicates permission per apparatus (AU_OP_P).

For synchrocheck, SWICON has two versions. One version (SWICONA) is for a synchrocheck relay that checks the synchronization condition continuously and gives a signal on SY_OK if there is synchronism, see figure in “Synchrocheck with phasing” in “Configurations”. This is the normal application when the internal synchrocheck function is used. To close the breaker, SWICON can activate the EXE_CLOS output at the activation of the SY_OK signal, when the CLOSE and EXECUTE inputs are already set and also when the SEL_CLOS output is set. The SY_RUN input is set to FIXD-ON. If not the SY_OK input is used, it also must be set to FIXD-ON.

The other version (SWICONB) is used for an external synchrocheck or synchronization relay. The close command from this relay is normally handled outside the control terminal, see figure in “Synchrocheck with phasing” in “Configurations”. At the close command from the operator, COMCON activates the EXECUTE output and SWICONB the SEL_CLOS and EXE_CLOS outputs. SWICONB has two inputs SY_RUN and SY_FAIL, which need the status information of the synchronization sequence. The SY_RUN signal can be connected from the synchronization relay, so it will be activated when the synchronization relay is in progress and waiting for its close command. This signal stops the command supervision given by the T_START time, so that the command output can be activated until the synchronization relay gives its command to close the breaker. Also other timers in SWICONB are stopped when SY_RUN is activated. If not the SY_RUN input is used, it must be set to FIXD-OFF.

The SY_FAIL must be activated if the synchrocheck/phasing does not reach synchronism within a certain time. SY_FAIL resets the complete operation sequence.

The autoreclose function closes the breaker via an OR logic (OR with the same cyclicity as the autoreclose function) with the normal close order from SWICON. For high-speed autoreclose function used with external selection relays, the AR_SEL input is used to select the apparatus without any checks of the selection conditions. To block the autoreclose function at the moment the apparatus is under operation, SWICON gives a BLK_AR output.

Parameters

T_POSERR

Allowed time for middle position. Supervises the time for position change from 01 -> 10 or 10 -> 01.

T_POL

Time parameter for pole discordance. Allowed time to have discrepancy between the poles.

T_SEL

Allowed time from selection to feedback select.

T_START

Allowed time from execute to position indication change. Supervises the time for position change from 01 -> 00 or 10 -> 00.

T_PULSE

Time parameter for command output pulse length. T_PULSE = 0 gives a steady command output signal.

4.7 BLKCON

4.7.1 Functionality

BLKCON is used for blocking of functions in a bay and in an apparatus control program. BLKCONL (x=1) contains one blocking function and BLKCONK (x=1, 2 and 3) contains three blocking functions. The blocking function can be controlled by both steady and pulse signals. The functionality can be represented by logic as in Figure 150 below.

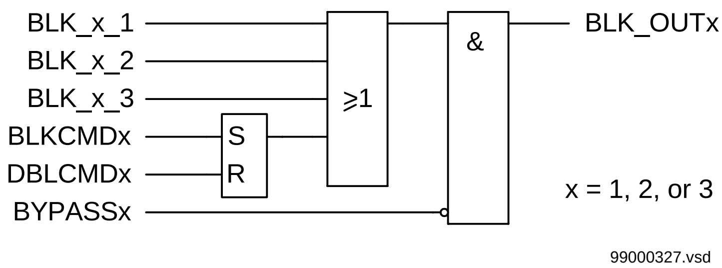


Figure 150: The function of BLKCON represented by logic.

4.8 Configuration

4.8.1 General

This part describes type solutions for connection to other application functions. All functions are described in separate chapters. A standard configuration for a single-breaker bay with double busbars including five high-voltage apparatusës can be found in an “Example configuration”. Figure 151 shows an overview of a circuit breaker module that includes breaker-related optional functions. Note that the OR gates for the open and close signals must have the same ex§ecution cyclicity as related protection function, that is, the breaker failure protection and autoreclosing functions.

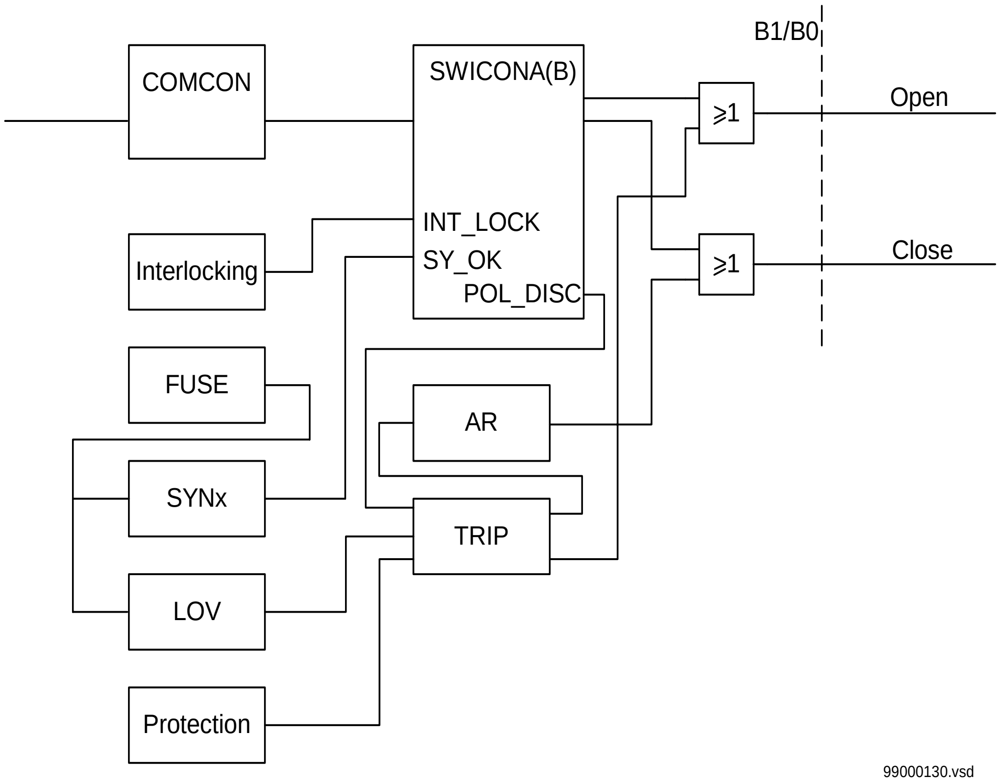


Figure 151: Example of a breaker configuration including optional functions within a control terminal.

Figure 152 shows an overview of a disconnector/earthing switch module.

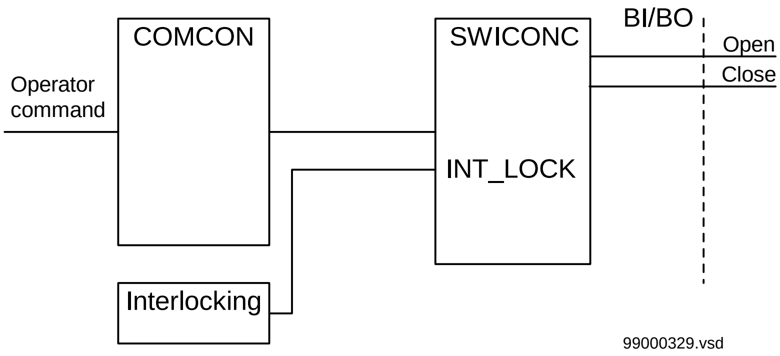


Figure 152: Overview of a disconnector/earthing switch configuration.

4.8.2 Communication between modules

Figure 153 is used as starting-point when explaining the signal flow between the different function block in the apparatus-control function. The control program in figure 153 handles one bay, which includes two apparatuses.

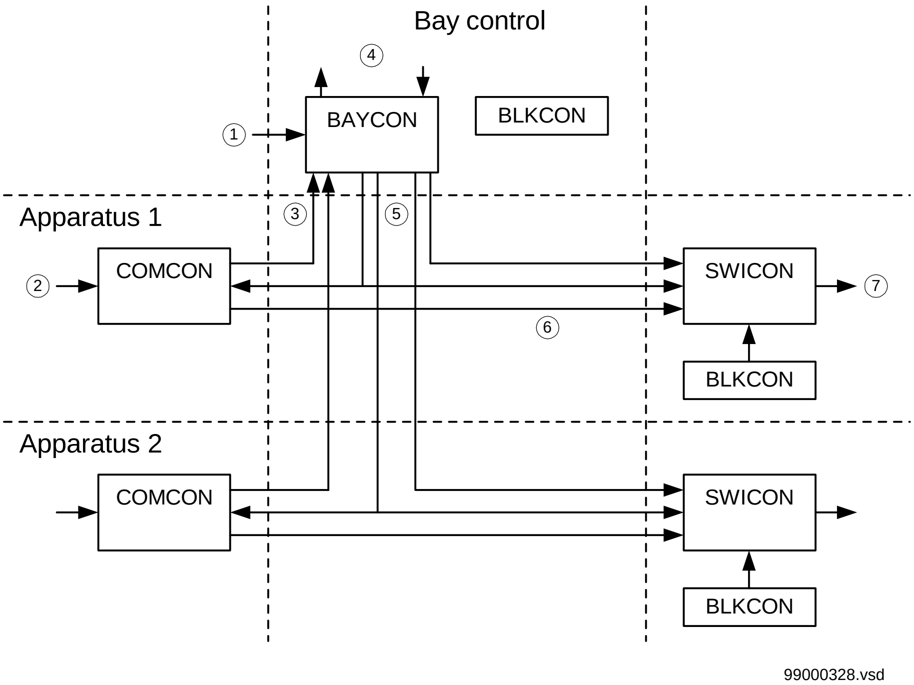


Figure 153: The signal flow between different modules in a bay.

When operating apparatus 1, the general procedure is as follow:

1. Command to set valid operator place for the complete bay. This command can come from station HMI or the local back-up panel. The command is given when there is need to change the operator place only.
2. COMCON receives commands to operate the apparatus. Only commands from the valid operator place are accepted. The first command is a request to select the apparatus.
3. The BAYCON element receives the request from COMCON.
4. The BAYCON element sends a signal to other control programs to reserve their bays (if necessary). That is, no operation is allowed there. Acknowledgement signals should be received. Other control programs can be placed in the same control terminal or in other control terminals (bay-bay communication).
5. If everything is OK, the select signal is passed through to the SWICON element and is displayed on the station HMI.
6. The program is now prepared to receive the execute command from the operator.
7. The closing or opening command is sent to the selected apparatus.

Different kinds of errors can be detected.

Operator related errors, if too long time between:

- The select and the execute commands
- A request to override (reservation and/or interlocking) and the following select command

Apparatus-related errors, if too long time between:

- The apparatus starts to move
- The apparatus reaches the new position

Other apparatus-related errors:

- Pole discordance
- Command error (for example, when the apparatus is blocked or interlocked)

Other errors:

- Reservation failure
- Binary output board error

4.8.3 Reservation function

The reservation function is primarily a method to transfer interlocking information from other bays in a safe way.

To reserve other bays, the BAYCON bay control module needs interaction with the bays that must be reserved. Note that only bays that must be reserved or need to reserve other bays must have these connections.

The question of which bays that should be reserved by this bay is delivery specific. In general there are three ways:

- Only the bays that influence the interlocking conditions must be reserved.
- The whole voltage level must be reserved. All other bays on this busbar voltage level must be blocked.
- The whole station must be reserved. All other bays in the station must be blocked.

The connections to reserve the apparatuses within the own bay are shown in figure 154. The timing diagram is shown in figure 155. The reservation function follows the steps below:

1. The op_SEL_O selection signal or op_SEL_C selection signal (op=operator place R/S/L) in COMCON is activated when an apparatus is selected for operation. COMCON sets the RQ_SEL output.
2. The signal RQ_SEL activates the RE_BAYS output via RQ_SELx in BAYCON for reserving other bays. After successful acknowledgement from other bays, the select output (SELx) is set to inform other elements that it has reached a reserved state. In this state, it will not accept other requests, which ensures that no other operations are possible in this bay.
3. After acknowledgement from all bays, the select output (SELx) from BAYCON activates the SELECT in COMCON and allows the execute command to pass through.
4. When SELECT in SWICON is activated, SWICON with the signals OPEN/CLOSE/EXECUTE from COMCON gives an execution signal (open/close) using the output signals SEL_OPEN/CLOS and EXE_OPEN/CLOS.
5. The signal SEL_RES resets the selection request (RQ_SEL) after successful operation (that is, new position reached) or command error. SEL_RES is active until SELECT is reset.

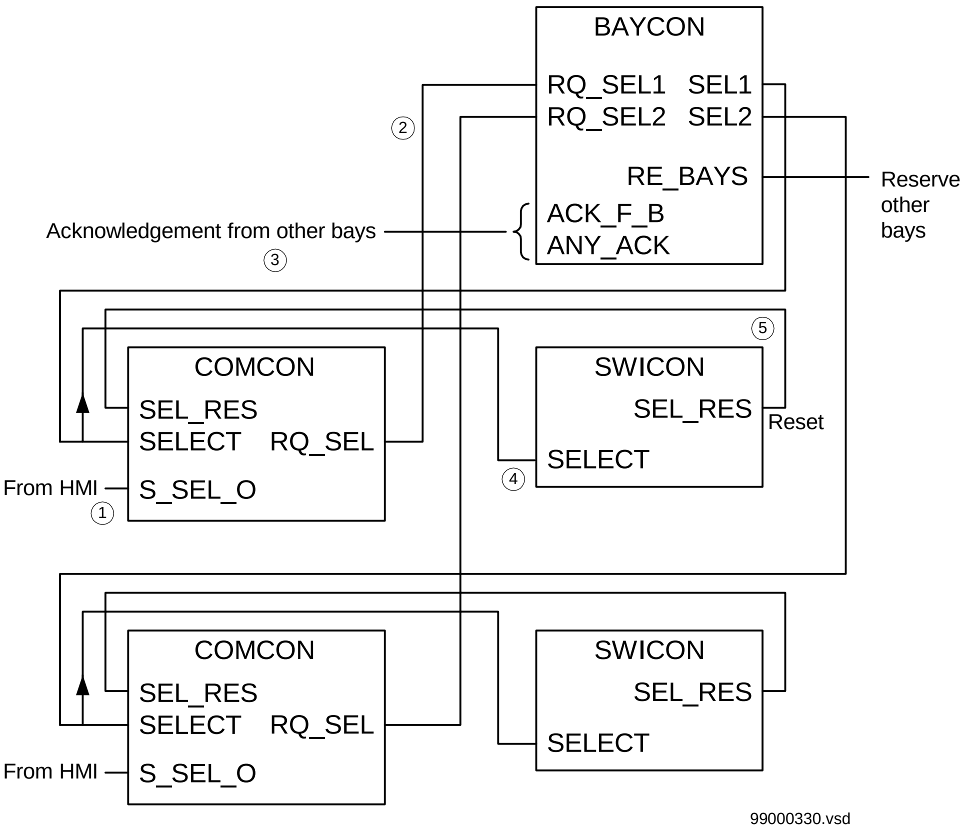


Figure 154: The reservation function within the own bay.

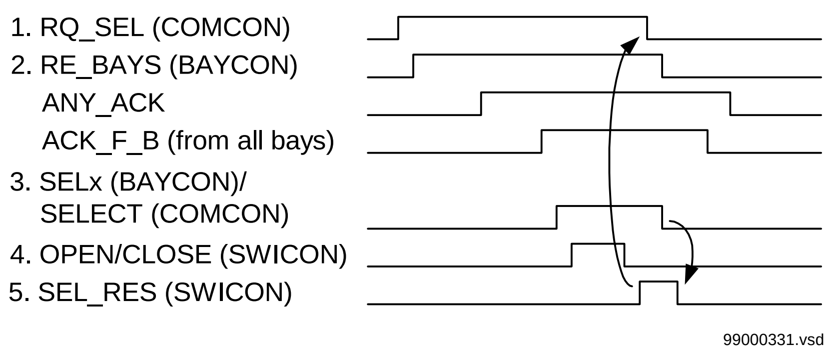


Figure 155: Timing diagram for the reservation function.

For reservation of other bays, signal exchange between the bays is necessary. The signals to reserve other bays and signals to reserve the own bay from other bays are shown in figure 156, which describes the receiving part of the reservation function. Multiple Command Function blocks are used to receive the information from other bays (see document “Command function”).

The module BAYCON requests the reservation of other bays with RE_BAYS and needs to know if other bays are reserved or not. It receives the acknowledgements on the ACK_F_B inputs, which specifies that all bays are reserved and on ANY_ACK that any bay is reserved. It also checks the communication status (V_TX).

The logic to gather these signals from the requested number of bays (in this example from three bays X, Y, Z) is delivery specific and made outside the BAYCON module. This is because the BAYCON is independent of the number of bays to communicate with.

When the request is coming from another bay, there is one signal (RE_RQ_B) for reservation request. V_RE_RQ is the signal for valid request from any bay.

The EX_DA_UP input signal indicates that the program that acknowledges the reservation is running. This signal is not applicable in this application and can be set to 1=FIXD-ON.

With the inputs RE_Bx (x = 1,...8) set to 1= FIXD-ON, it is possible to suppress the reservation of other bays at a request select (RQ_SEL) from a specific apparatus (1,...8) in the own bay. That is, the BAYCON only reserves the own bay.

The signal BLK_RE blocks the reservation. That is, no reservation can be made from the own bay or any other bay. This can be set via a binary input from an external device to prevent operations from another operator place at the same time. This function can be overridden in the own bay with the OVERRIDE signal, for example, from the HMI.

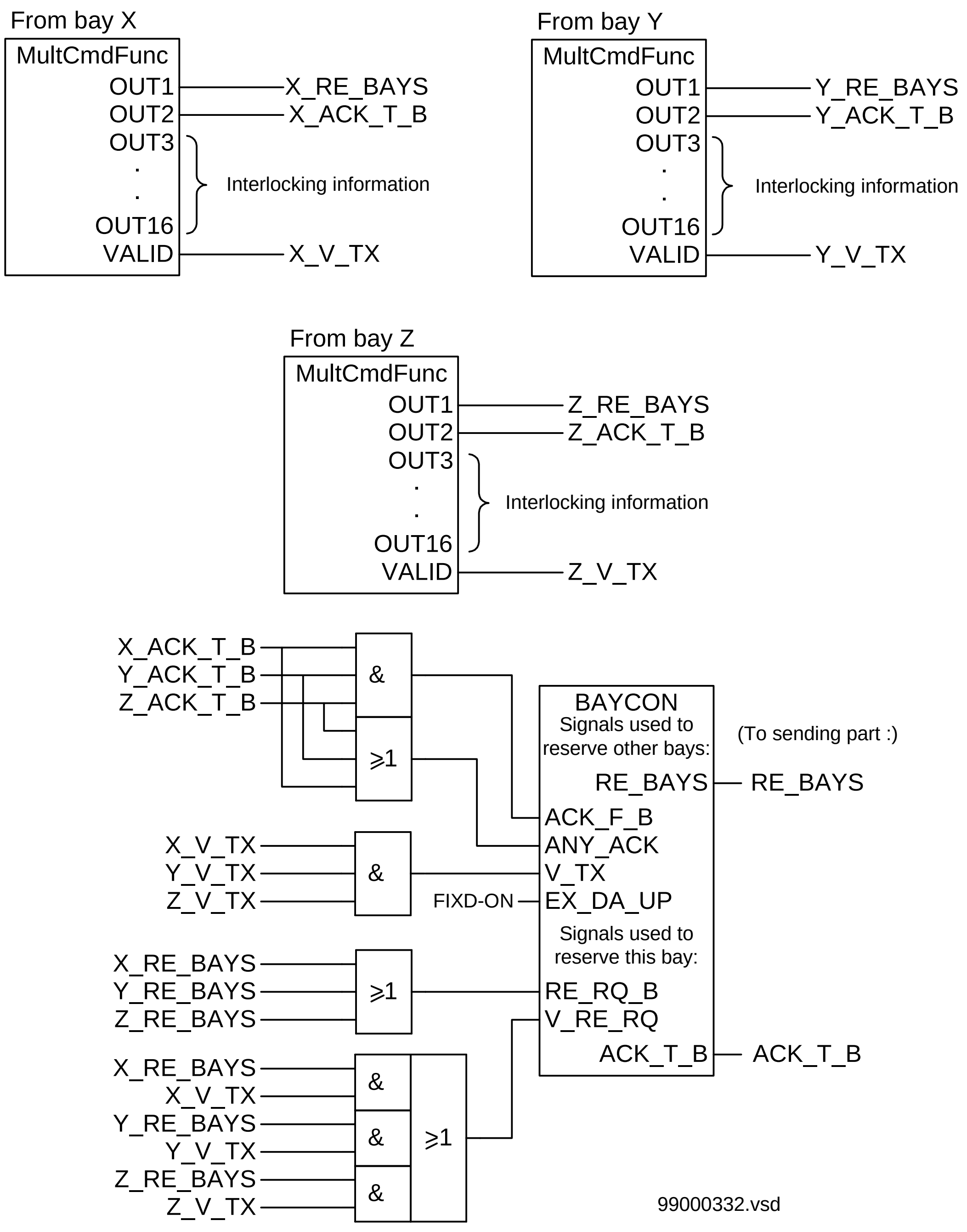


Figure 156: The receiving part of the reservation function between bays.

Figure 157 shows the sending part of the reservation function. From this part, the request (RE_BAYS) from BAYCON to reserve other bays (RE_RQ_B) are sent to other bays by broadcast, that is, to all bays at the same time. Event Function blocks are used to send the information to other bays (see document "Event function").

The connection for acknowledgement (ACK_T_B) from BAYCON gives the result that only the bay that asked for reservation gets the acknowledgement back.

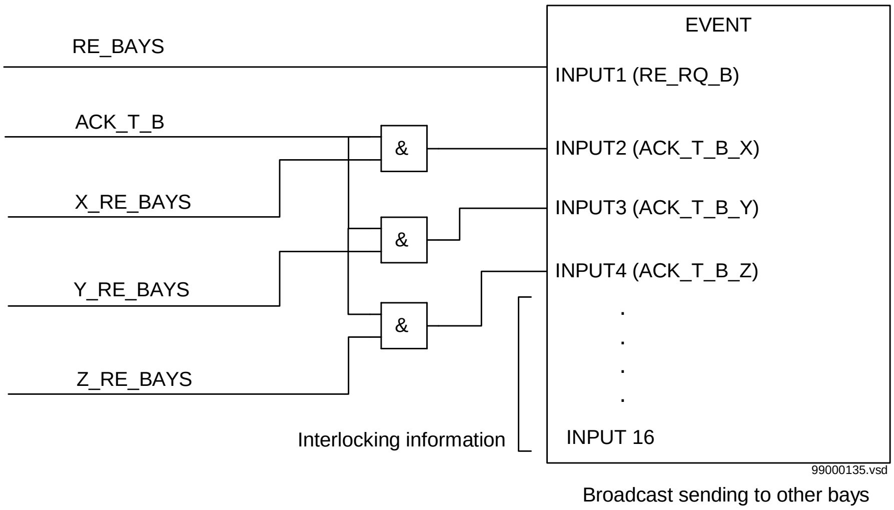


Figure 157: The sending part of the reservation function between bays

In REC561, one or more event function blocks are used to broadcast information from one REC561. One or several REC561s are configured to receive this information. Each command function block can only get information from one event function block.

The first bit in the event function block is used for reserve request (RE_RQ_B). This signal must be steady, so the reserve request equals true means reserve and equals false means release.

After this reserve request bit, there is one reserve acknowledgement bit (ACK_T_Bx) for each bay that can reserve the bay. So if three bays can reserve the bay, three signals are used.

ACK_T_B is reset after RE_RQ_B is reset. If the RE_RQ_B remains (for example due to communication error), ACK_T_B is reset the T_CAN_RE time after V_RE_RQ is reset.

After the reserve acknowledgement signals, the apparatus positions are needed for the interlocking. This information can be of these types:

- Busbar A and busbar B is connected
- Busbar A and busbar B is disconnected

This means that the position for each apparatus is not distributed, if not needed.

If this interlocking information needs additional event blocks for sending, the first bit of all the extra blocks is a reserve acknowledgement signal to acknowledge any bays, see figure 158.

These steps can be defined for the complete execution:

- The command execution bay receives a request for operation, for example by a selection from HMI.
- If the bay is reserved the command is cancelled.
- If other bays should be reserved, the reserve request bit is set in the event function block.
- The request information is broadcasted to all other bays.
- The receiving bays put the data to the command function blocks in the different bays.
- The bays that must be reserved, read the request from the command function block, block all commands in the own bay, evaluate the apparatus positions, and set the interlocking information and the reserve acknowledgement on the event function block.
- The response is broadcasted to all other bays.
- The other bays configured to read this message put the data to the command function blocks.
- The command executing bay receives reserve acknowledgement signals from all the bays that were requested. If one or several bays do not respond within a predefined time, the command is cancelled.
- When all reserve acknowledgement signals are received, the interlocking condition is evaluated. If the command is allowed, it will be performed.
- When the command is executed, the reserve request bit is reset on all event function blocks and broadcasted in the same way as the reserve request.
- The reset reserve request bit is interpreted as a release in the bay that was reserved. So the bay is free, and the reserve acknowledgement bit is reset on the event function block and broadcasted back.
- The command executing bay waits until all reserve acknowledgement signals are reset. When this is done, the bay is ready for a new command.

Example

Figure 158 illustrates the above described step-by-step command execution and bay-to-bay communication.

The example station is a double busbar with only two lines and one bus coupler. The bus coupler also handles the busbar earthing switches.

In this station, Line 1 and Line 2 need information from the bus coupler and the bus coupler need information from Line 1 and Line 2. Figure 158 illustrates the station-wide communication. The signals not used in the figure are removed.

The bus coupler has information for two event function blocks. But for the two lines, one block is enough.

Besides these outputs, a valid bit is available on the command function blocks.

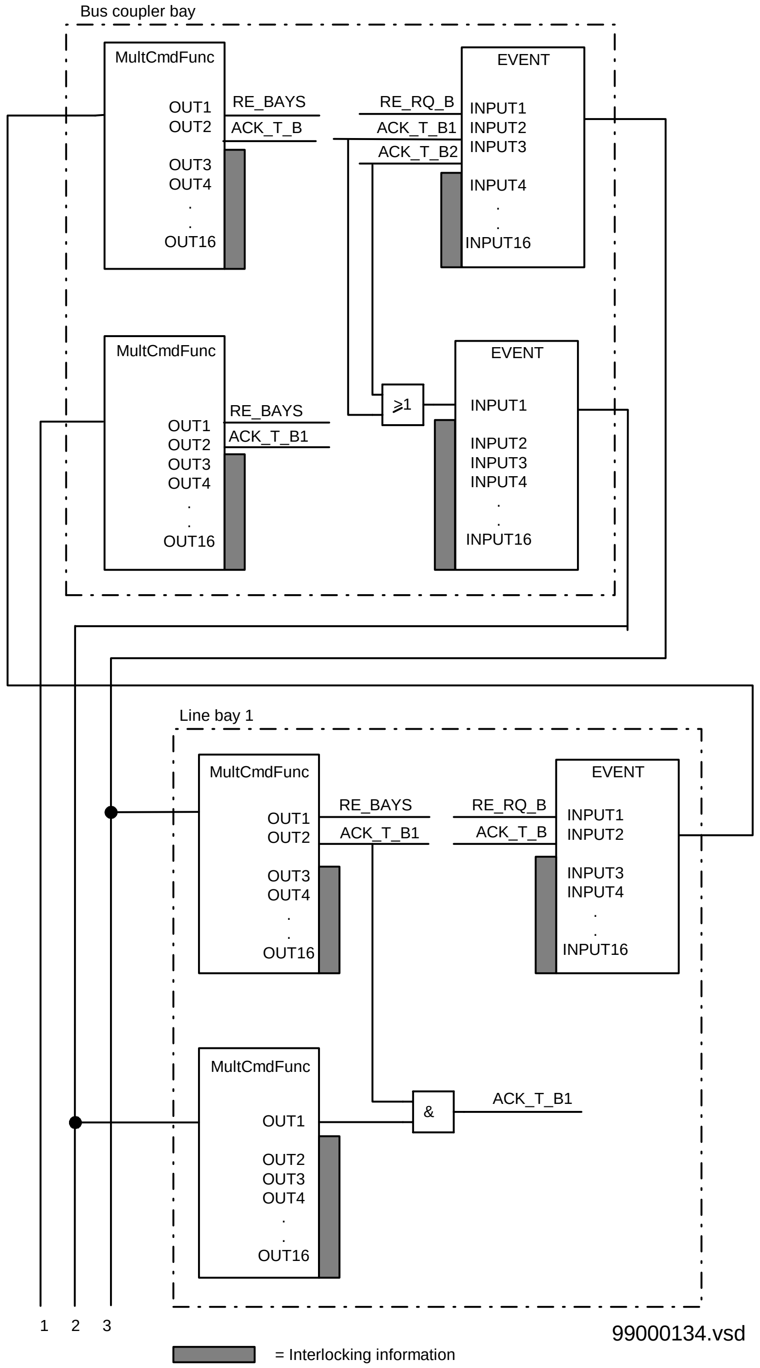


Figure 158: The principle of the communication between bays.

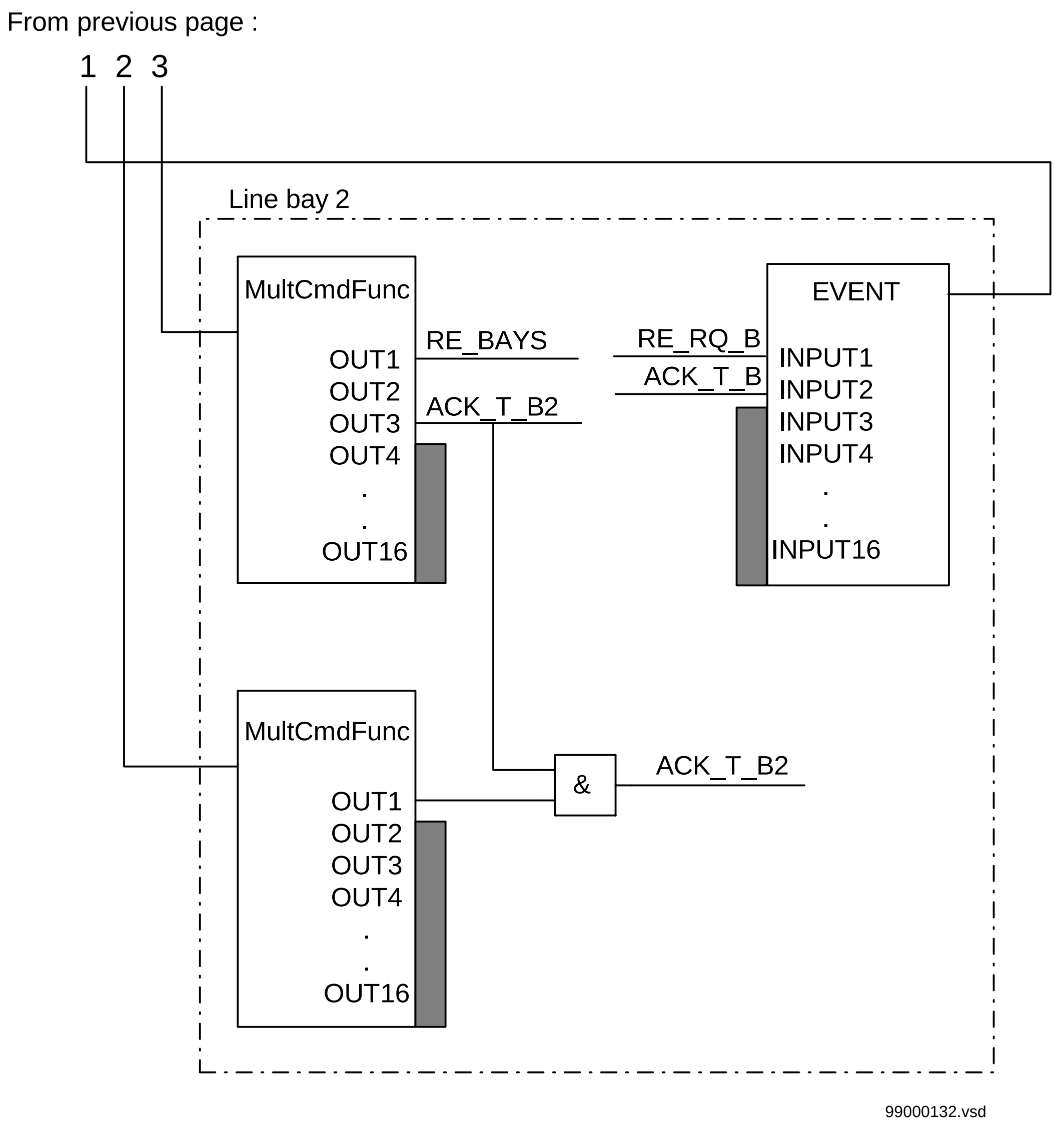


Figure 159: The principle of the communication between bays

4.8.4 Operator place selection

The connections to the operator place selectors can be done as shown in figure 160, where the remote/station selection is performed from the station HMI and the selection for the local control is performed from a switch on a local panel. It has a built-in priority with Local as highest, Station as intermediate and Remote as lowest priority. When two or more inputs are set at the same time, the higher priority prevails. The S_R and S_S inputs have pulse inputs. But the L_L requires a steady signal.

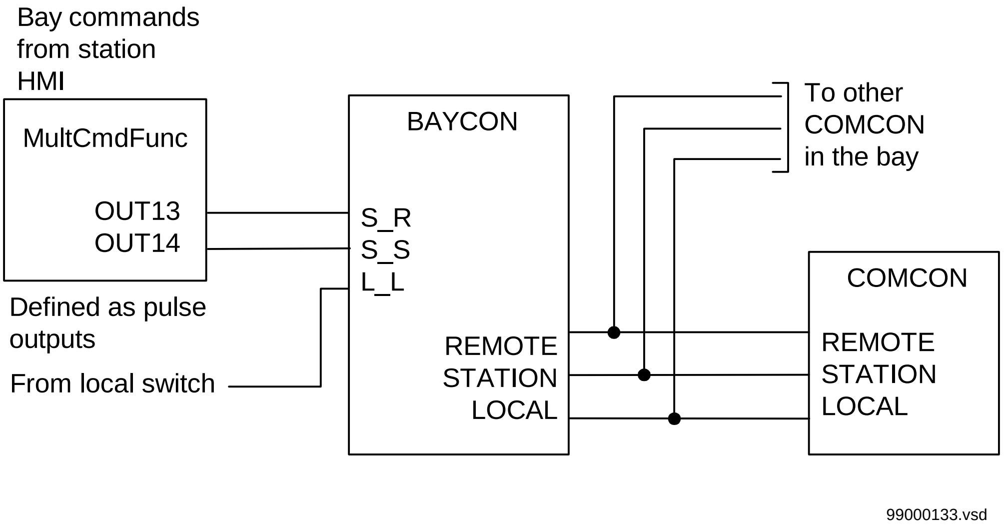


Figure 160: Connection of operator place selection

Some applications require that the operator place selection must be performed without any priority, that is, the desired operator places must be able to be set independent of each other. Figure 161 shows an application example, where the operator from a switch on a local panel can select either the position Off, Local, or Remote/Station/Local. If Off is selected, it is not possible to operate from any place. If Local is selected, it is possible to operate only from the local panel.

If the switch is set to position Remote/Station/Local, it is always possible to operate from the local panel and also from Remote or Station - independent of each other. In this example, it is possible to operate from remote, station and local operator places, if the position Remote is set in the station HMI. If the position Station is set in the station HMI, it is possible to operate only from the station HMI and from the local panel.

The pulse timer in the figure below sets automatically the operator place selection to position Remote at start up of the terminal, if the switch on the local panel is set to position Remote/Station/Local. That means, in this example, that operation from all three operator places is possible.

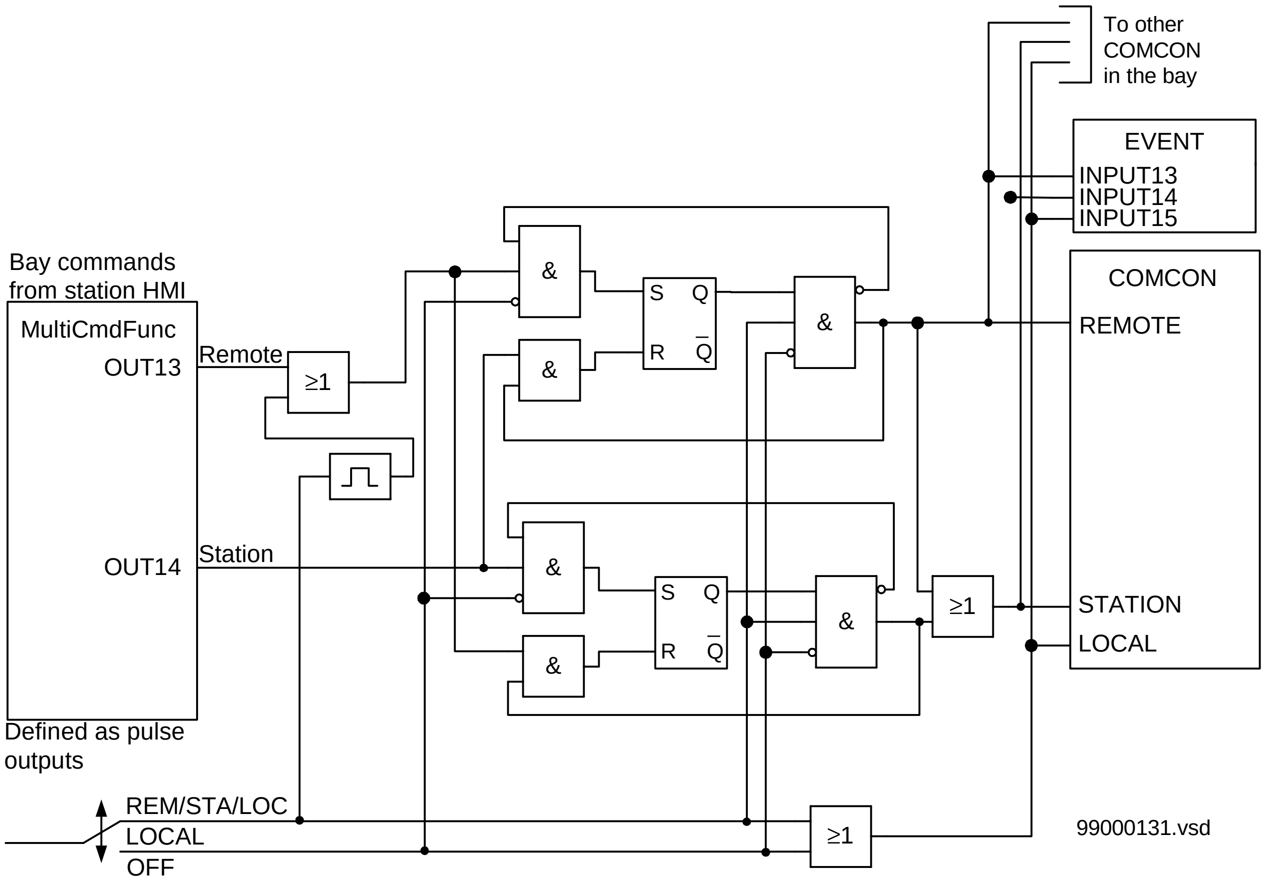


Figure 161: Application example of operator place selection without priority

4.8.5 Station HMI

The connection to the station HMI is made via EVENT-block and MultCmdFunc-block in a standardised way. Figure 162 shows the command connections between the command blocks and the apparatus control modules. Figure 162 also shows how the BLKCON modules are used.

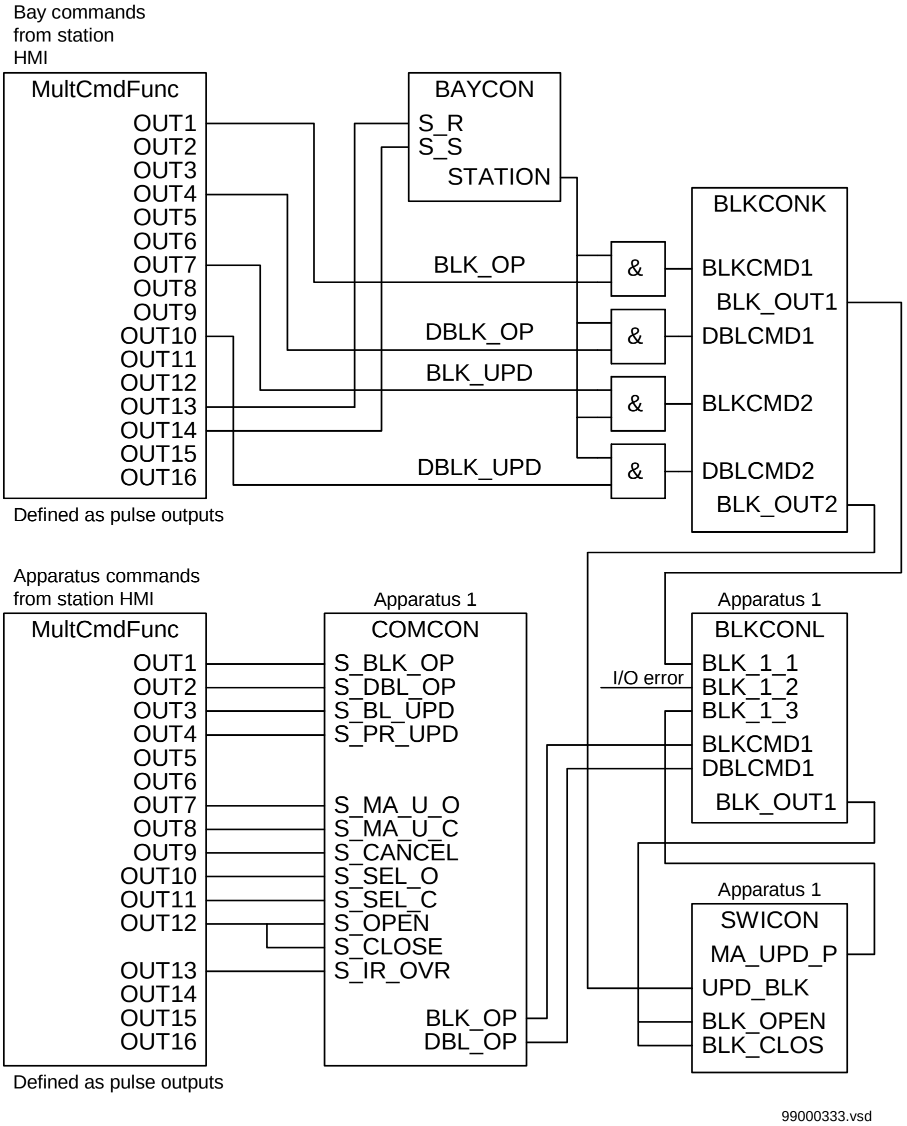


Figure 162: Command connections between the station HMI and apparatus control modules

Figure 163 shows the signals from the apparatus control modules for one apparatus that will be sent to the station HMI. The event input 7 can be connected to the tripping logic to indicate on the station HMI that the circuit breaker was opened due to a trip from the protection. The inputs 3 and 4 are used only for event handling of the positions for one pole of the circuit breaker. For event handling of all three poles separately, an additional Event Function block is needed.

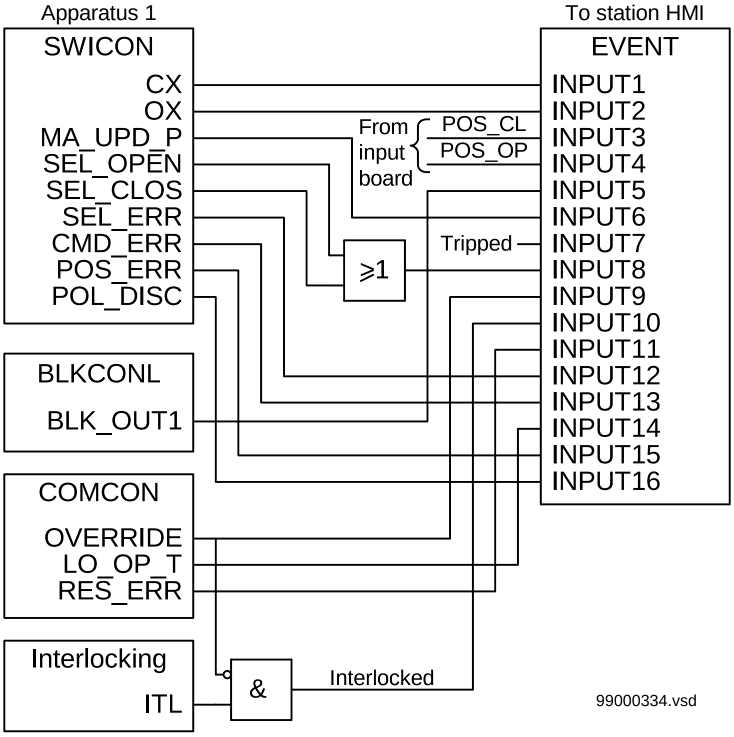


Figure 163: Event connections between the station HMI and apparatus control modules for one apparatus

Figure 164 shows bay-related signals that can be presented on the station HMI.

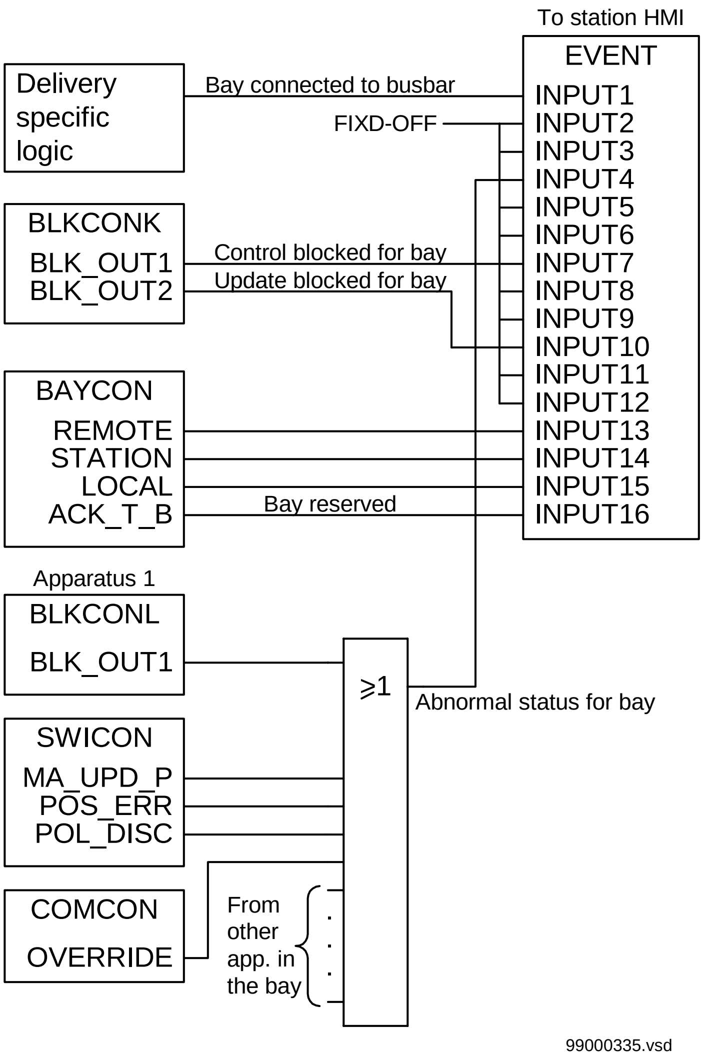


Figure 164: Event connections between station HMI and bay-related signals

4.8.6 Remote control

The command signals from the remote-control gateway are transferred to the control terminal via Single Command function blocks and can be arranged in a way shown in figure 165. All or some of the events defined for the station HMI can also be sent to the remote control gateway.

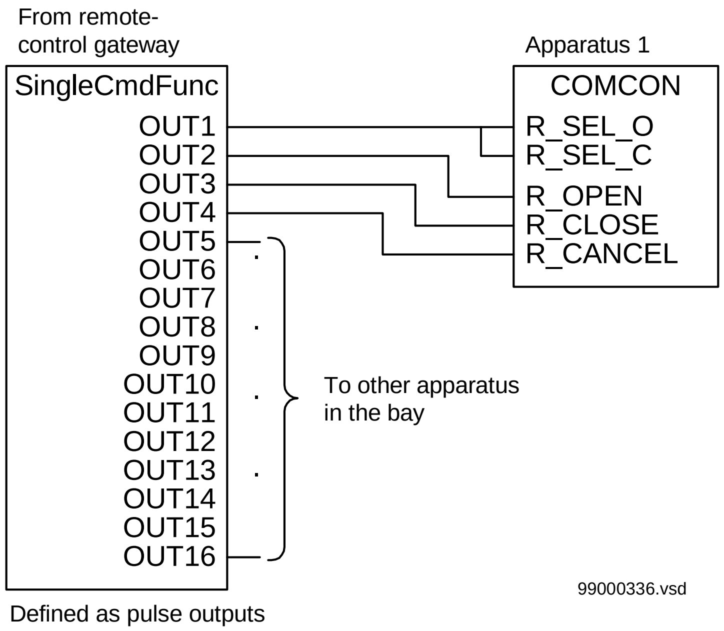


Figure 165: Control commands from remote-control gateway

4.8.7 Local panel (back-up panel)

The connection of an external local panel to the apparatus control modules is done via binary inputs. Figure 166 shows one example of a solution. This solution of local control considers the interlocking function. The panel can also be used as an back-up panel, but the outputs from the panel are then connected directly to the high-voltage apparatuses. The position indications are normally directly connected to the panel to get independent information about the apparatus positions. At use as back-up panel, the select and execute inputs into the control terminal must be blocked, for example, with AND gates with the condition no back-up.

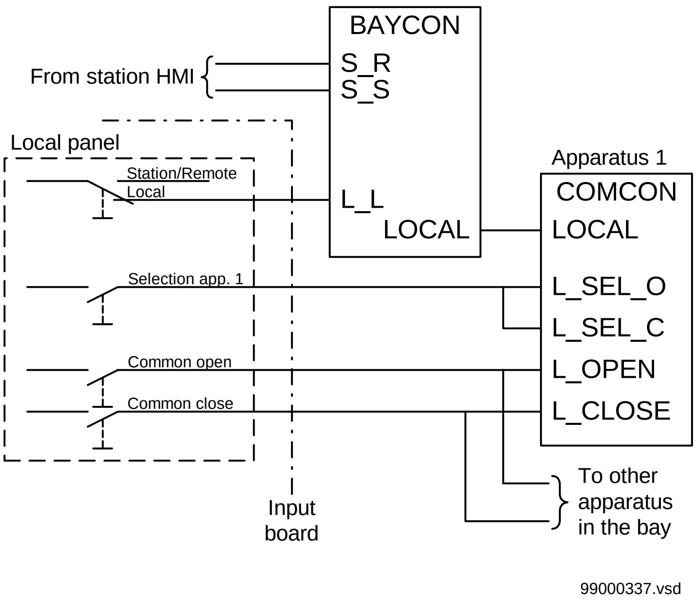


Figure 166: Connection of an external local panel via binary input board to apparatus control modules

4.8.8 Local HMI

The high-voltage apparatus can be operated from the local HMI via the SingleCmdFunc block. The SingleCmdFunc block, which must be accessible from the local HMI, can be defined from the SMS. The naming of the signals in the SingleCmdFunc block can be defined from the SMS and the CAP 531 configuration tool. Figure 167 shows an example how to connect a SingleCmdFunc block to the apparatus control modules. The command dialogue from the local HMI is performed in two steps, see document “Command function”.

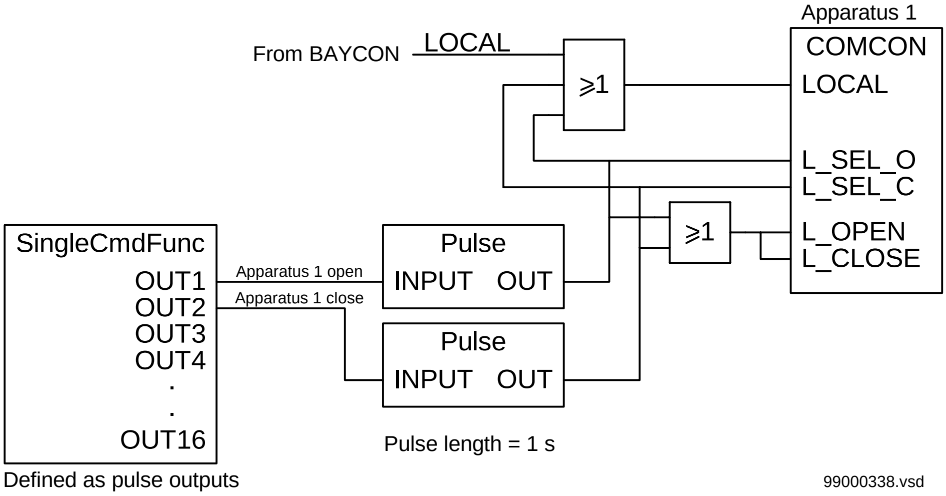


Figure 167: Connections between a SingleCmdFunc-block controlled from the local HMI and the apparatus control modules

4.8.9 Interlocking

Figure 168 shows the connection between an interlocking module and apparatus control modules. The input is activated when the apparatus is interlocked. The interlocking information within the control terminal are taken from the binary input boards. Information from other bays are transferred over the station bus. The section 4.8.3 "Reservation function" describes the method for transferring these data.

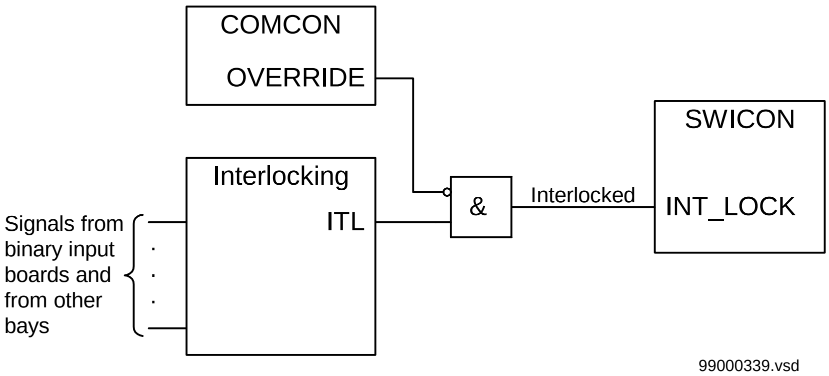


Figure 168: Connection of an interlocking module to apparatus control modules

4.8.10 Synchrocheck with phasing

Connections between the apparatus control modules and the synchrocheck/phasing function can be made either for the built-in synchrocheck/phasing module or for an external synchrocheck relay, for example, type RASC. External synchronization equipment can also be connected to the apparatus control modules. Figure 169 shows the connections for a combined synchrocheck/phasing function that checks the synchrocheck condition continuously and gives a signal on SY_OK if there is synchronism. If the synchrocheck conditions are not fulfilled, the phasing function will start and give a command pulse when the phasing conditions are fulfilled. This is the normal application when the built-in synchrocheck/phasing function is used. Note that the AND/OR-gates connected between the output CLOSECB of the phasing module and the output board must be running with fast execution cyclicity. The interlocking condition for the breaker closing is connected to the BLOCK input of the module.

To close the breaker via the apparatus control function, SWICON can activate the EXE_CLOS output at the activation of the SY_OK signal when the CLOSE and EXECUTE inputs are already set and also when the SEL_CLOS output is set. The input SY_RUN is set to FIXD-ON. Figure 169 also shows an example of how to bypass the synchrocheck/phasing function by a command from the station HMI.

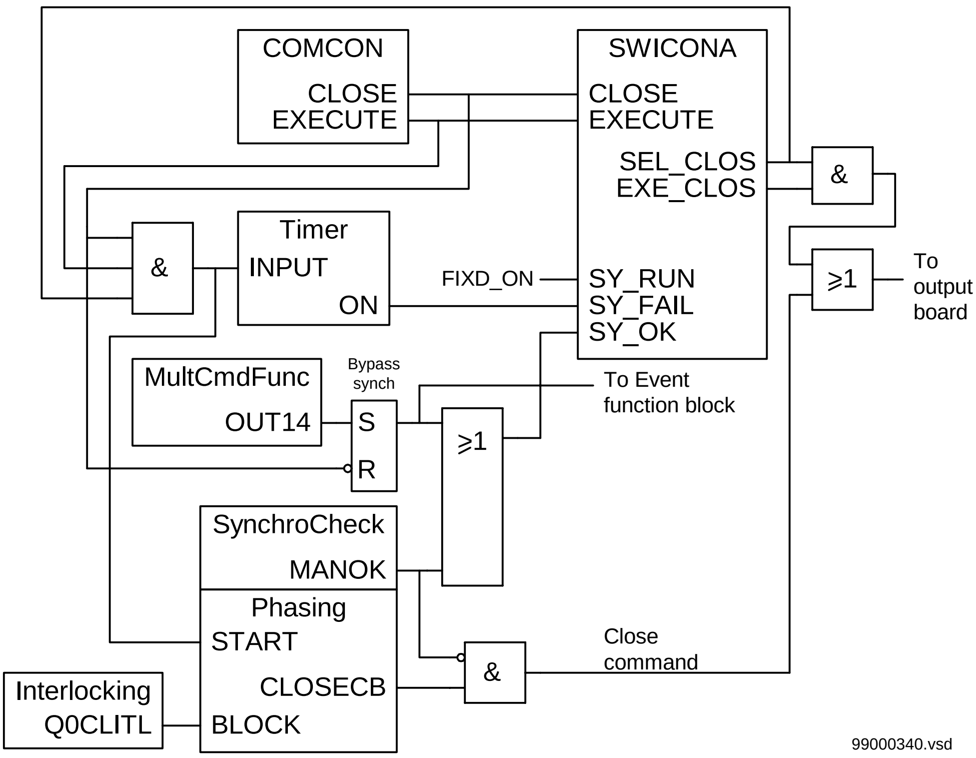


Figure 169: Connection example for the built-in synchrocheck/phasing module and the apparatus control modules

Figure 170, figure 171, and figure 172, show three alternatives of configurations for the SWICONB module when an external synchrocheck or synchronization relay is used. For alternative 1 in figure 170, the synchronization starts when the line and busbar voltages are connected to the synchrocheck relay. For alternative 2 in figure 171, the synchrocheck relay continuously checks the synchronization condition. Alternative 2 can also use the solution in figure 169 if the close command from the synchrocheck relay is connected via a binary input to the SY_OK input on SWICONA. Alternative 3 in figure 172 shows the connection to an external synchronization equipment, for example, type RES 010.

For the external synchronization relay, the close command is normally handled outside the control terminal. At the close command from the operator, COMCON activates the EXECUTE output and SWICONB the SEL_CLOS and EXE_CLOS outputs. SWICONB has two inputs SY_RUN and SY_FAIL, which need the status information of the synchronization sequence. The SY_RUN signal can be connected from the synchronization relay, so it will be activated when the synchronization relay is in progress and waiting for its close command.

The feedback signal of the close command in the figures 170 and 171 is used to start the supervision timer T_START, which supervises the movement of the drive, that is, the position change from open (01) -> 00.

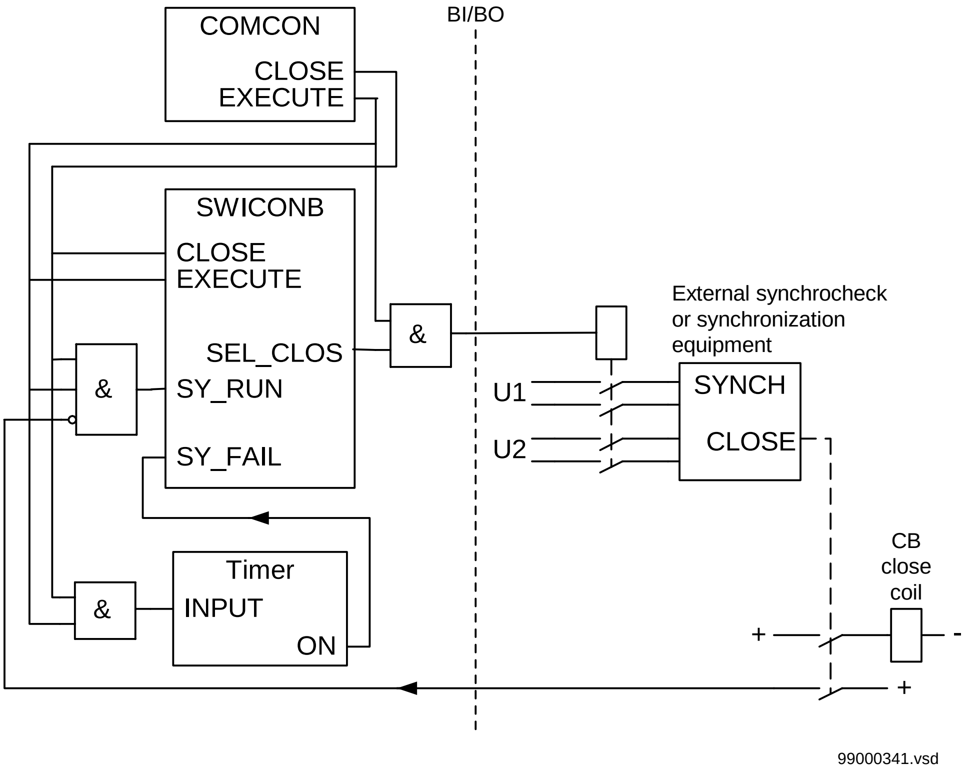


Figure 170: Connection example for external synchrocheck equipment and the apparatus control modules, alternative 1

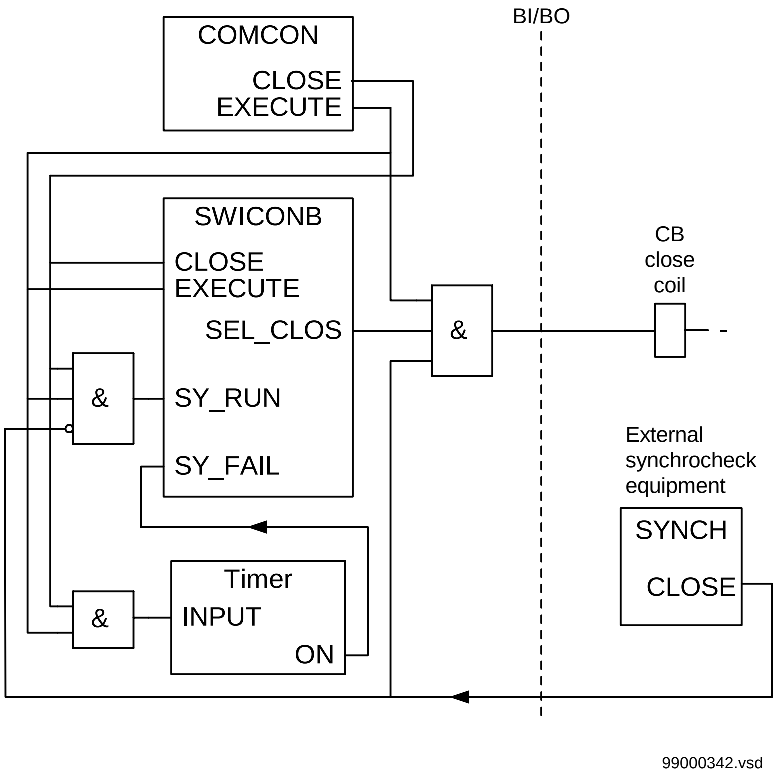


Figure 171: Connection example for external synchrocheck equipment and the apparatus control modules, alternative 2.

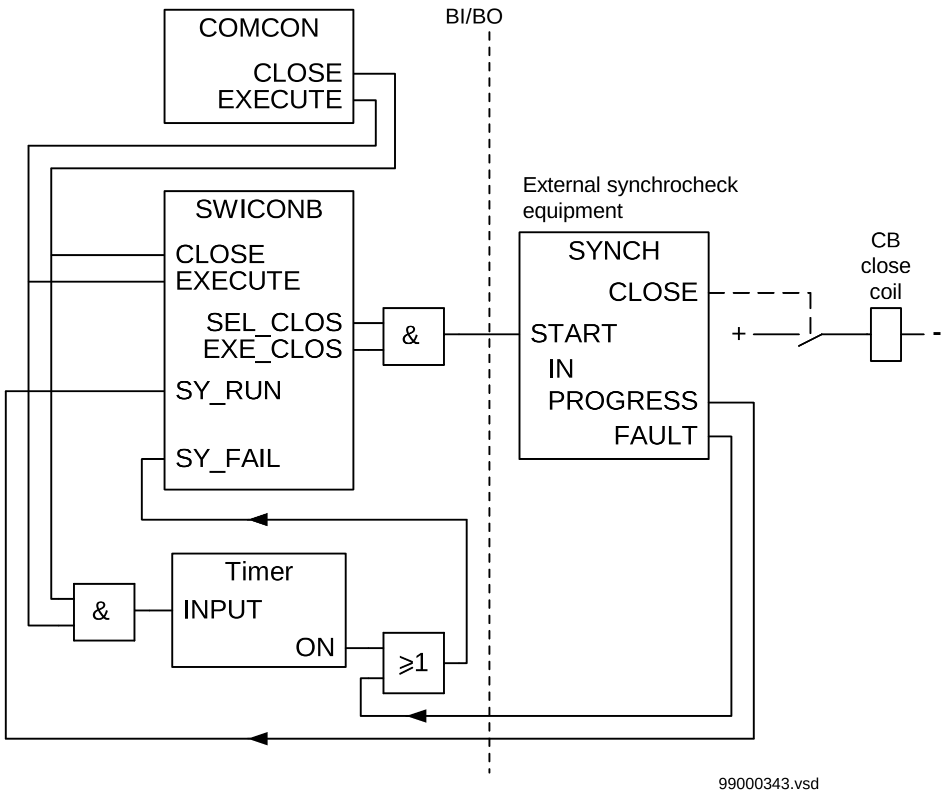


Figure 172: Connection example for external synchronization equipment and the apparatus control modules, alternative 3

In figure 169 to figure 172, the SY_FAIL input supervises the synchronization time. If the relay does not reach synchronism within a certain time, SY_FAIL is activated and resets the complete operation sequence.

4.8.11 Autoreclosing

Figure 173 shows the interaction between the autoreclosing (AR) module and the apparatus control modules. The OR gate for the close signal must have the same execution cyclicity as the autoreclosing module. The signal BLK_AR from SWICON is used to block the autoreclose function at the moment the circuit breaker is under operation.

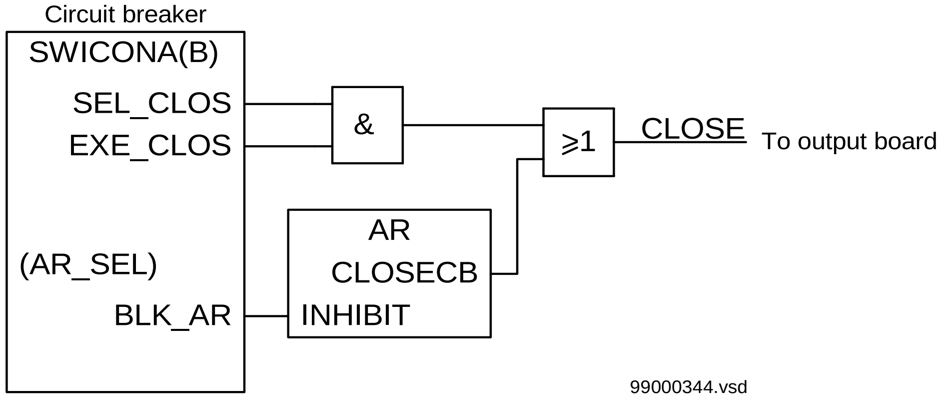


Figure 173: Connections between autoreclosing (AR) module and apparatus control modules.

If the autoreclose function is used with external selection relays according to the principles described in figure in “Selection relay supervision” in “BAYCON”, the input AR_SEL in SWICON is used to select the breaker without any condition checks. When AR_SEL is set, the output SEL_CLOS is activated directly. The close signal from the autoreclose function is connected via the OR gate for close commands in a normal way.

4.8.12 Protections

The protection functions are normally running independent of the apparatus control modules. The trip signals from the protection modules included in the control terminal are connected via the tripping logic function. If a three-phase circuit breaker is used, the GTRIP general trip signal from the tripping logic can be connected to the same open output as for the manual control from SWICON via an OR gate (see figure 174). Here, the OR gate must have the same execution cyclicity as the tripping logic module.

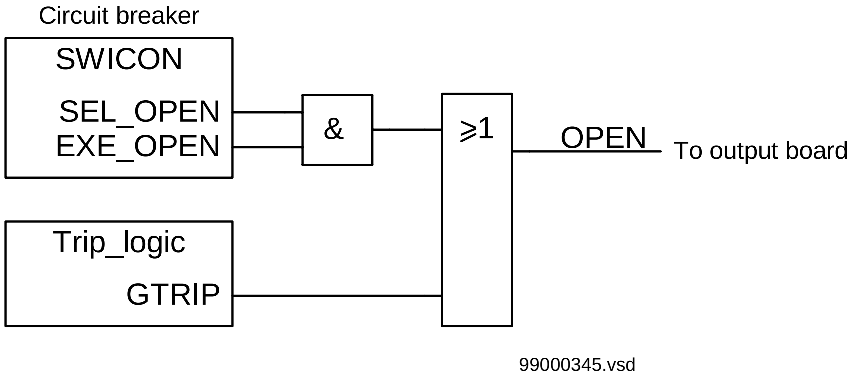


Figure 174: Connections between the tripping logic and the apparatus control modules.

4.8.13 Pole discordance protection

The pole discordance function included in the SWICONA(B) is based on checking the positions of the auxiliary contacts on the breaker. The connection of the trip signal is made according to figure 175 and to the output board in the same way as for other protections (See 4.8.12 "Protections"). The T_POL time delay to trip is set to 2 seconds as a default value. Since only one tripping logic is available in the control terminal, the POL_DISC output is connected directly to the OR gate for the open command, if more than one circuit breaker is included in the terminal.

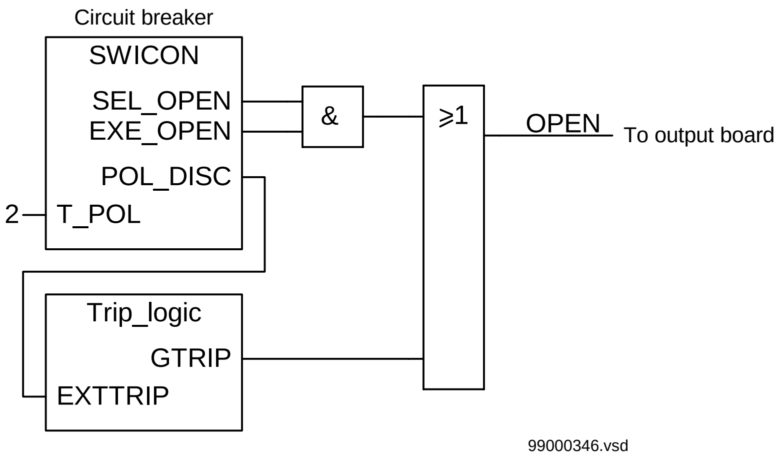


Figure 175: Connection of the pole discordance trip from SWICON via the tripping logic

4.8.14 Automatic functions

Using the same methods as for ordinary commands that come from different operator places, there are inputs (select/execute/cancel) to be connected from other application programs in the form of automatic functions. These programs can be located in the same control terminal, in another terminal, or in a station computer.

One usage for automatic programs is when the apparatuses are included in a sequence, for example, a busbar transfer. Figure 176 shows the signals connected to the COMCON module.

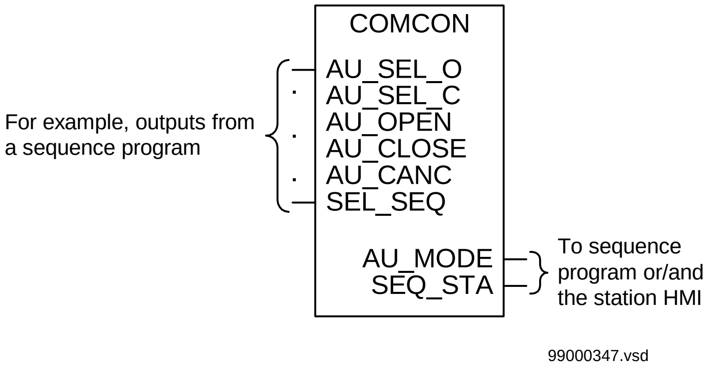


Figure 176: Connections to automatic functions

4.8.15 Command output module

The command outputs from the apparatus control modules can be connected to the output module in different ways depending on functionality. The output module has supervised outputs. That is, the output relays are continuously supervised in a way that an unwanted activation is detected, which stops the continuation of the operation. This is performed by using the ERROR signal connected to BLKCONL for blocking the command. To get a secure command, two contacts are connected in series. The following figures show examples of different configurations. The terminal diagram for the binary output module shows detailed information about the terminal numbering.

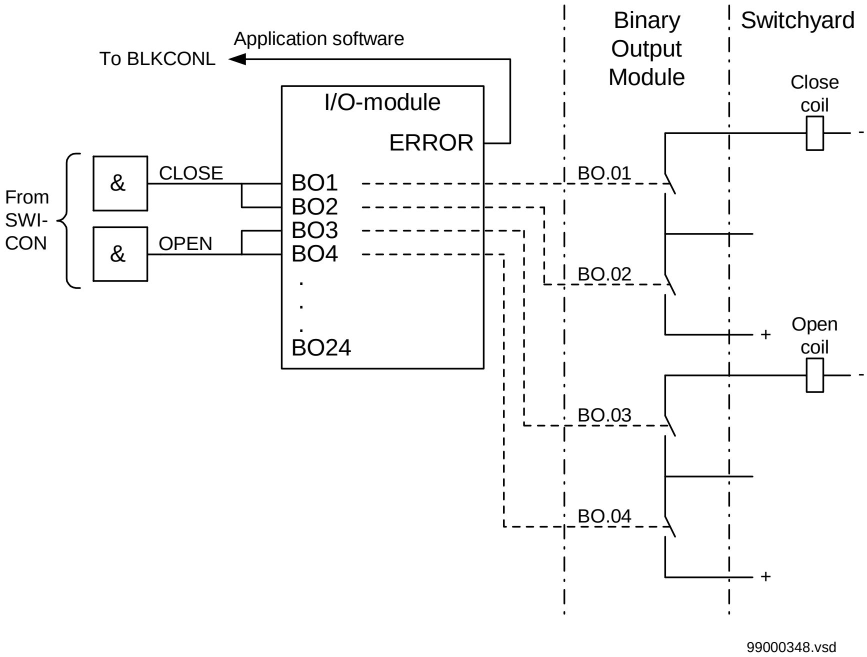


Figure 177: Single pole command outputs with supervision

Figure 177 and figure 178 are the standard configurations during operation of high-voltage apparatuses. The double pole command is normally used to avoid an unwanted operation of the apparatuses, due to an earth fault in the switchyard. The output module is very flexible. So users can mostly find solutions for their own requirements.

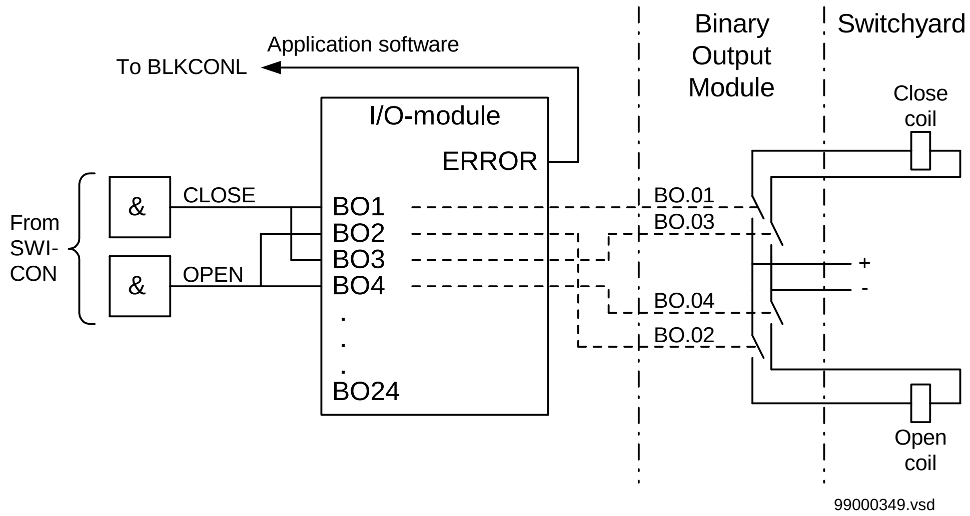


Figure 178: Double pole command outputs with supervision

Figure 179 shows the configuration of single outputs used for purposes other than operating high-voltage apparatuses. Here the ERROR signal is connected to an event function block for alarming or as a condition for another application. The security is limited compared to the solutions above - with two contacts in series.

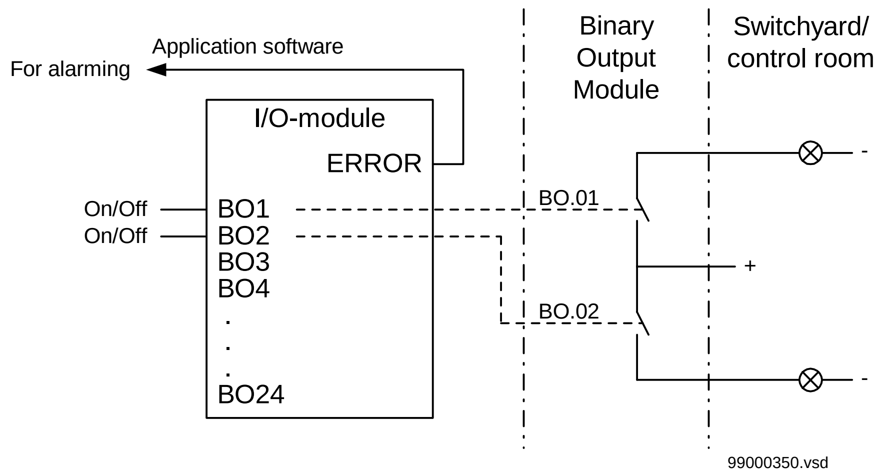


Figure 179: Single output commands

5 Interlocking

5.1 Overview

5.1.1 Application

The interlocking of switchgear operation can have two main purposes:

- To avoid dangerous or damaging operation of switchgear
- To put restrictions on the operation of the substation for other reasons e.g. load configuration. Examples of the latter are to limit the number of parallel transformers to a maximum of two or to assure that energizing is always made from one side, for example, the high voltage side of a transformer.

This document only deals with the first point, and only with restrictions caused by switching devices other than that one to be controlled. This means that switch interlock, because of device alarms, is not part of this document.

Disconnectors and earthing switches have a limited switching capacity. Disconnectors are allowed to operate:

- With basically zero current. The circuit is open at one side and has a small extension. The capacitive current is small (for example < 5A) and power transformers with inrush current are not allowed.
- To connect or disconnect a parallel circuit carrying load current. The switching voltage across the open contacts is thus virtually zero, thanks to the parallel circuit (for example < 1% of rated voltage). Paralleling of power transformers is not allowed.

Earthing switches are allowed to connect and disconnect earthing of isolated points. Due to capacitive or inductive coupling there may be some voltage (for example < 40% of rated voltage) before earthing and some current (for example < 100A) after earthing of a line.

Circuit breakers are usually not interlocked. Closing is only interlocked against running disconnectors in the same bay, and the bus-coupler opening is interlocked during a busbar transfer.

As conditions for operational interlocking, the positions of all switching devices of a bay and from some other bays are used. Conditions from other stations are usually not available. So a line earthing switch is usually not fully interlocked. The operator must be convinced that the line is not energized from the other side before closing the earthing switch. As an option, a voltage indication can be used for interlocking. Take care to avoid a dangerous *enable* condition at loss of VT secondary voltage, for example, because of a blown fuse.

The switch positions used in the operational interlocking logic are obtained from auxiliary contacts or position sensors. For each end position (open or close) a true indication is needed - thus forming a double indication. The apparatus control function continuously checks its consistency. If neither condition is high (1 or TRUE), the switch may be in intermediate position, for example, moving. This moving state may be in progress a certain time, for example, 10 seconds for disconnectors. Should both indications stay low for a longer time, the position indication is interpreted as *unknown*. If both indications stay high, then there is something wrong, and the state is again treated as *unknown*. In both cases an alarm is given to the operator. Indications from position sensors shall be self-checked and system faults indicated by a fault signal. In the interlocking logic, the signals are used to avoid dangerous *enable* or *release* of operation conditions. Unknown positions are not allowed to release operation.

For switches with individual operation gear per phase, the evaluation must consider possible phase discrepancies. This is done by an *AND-function* for all three phases of respectively open and close indication of each apparatus. This leads to an unknown double indication state in case of phase discrepancies.

5.1.2 Functionality

The interlocking function consists of software modules located in each control terminal. The function is distributed and not dependent on any central function. Communication between modules in different bays is performed via the station bus.

The basic method is the use of the reservation function (see the section of apparatus control). This method ensures that the position of the HV apparatuses are not changed during the time gap, which arises between the position updatings. This can occur by reserving all of those HV apparatuses by means of the communication system, which might influence the interlocking condition of the intended operation. The reservation is intended to remain until the operation is performed.

After the selection and reservation of an apparatus, the function has full information on all positions of the apparatuses in the switchyard that are affected by the selection. This status cannot be affected by other operators because the selection is blocked for all apparatuses of which the status is important for the selected one.

The positions of the HV apparatuses are inputs to software modules distributed in the control terminals. Each module contains the interlocking logic for a bay. The interlocking logic in a module is different, depending on the bay function and the switchyard arrangements, that is, double-breaker or 1 1/2 breaker bays have different modules. Specific interlocking conditions and connections between standard interlocking modules are performed by an engineering tool. The signals involved in the bay-level interlocking can consist of these types:

- Positions of HV apparatuses (sometimes per phase)
- Valid positions (if evaluated in the control module)
- External release (to add special conditions for release)
- Line voltage (to block operation of line earthing switch)
- Output signals to release the HV apparatus

The interlocking module is connected to the surrounding functions within a bay as shown in figure 180.

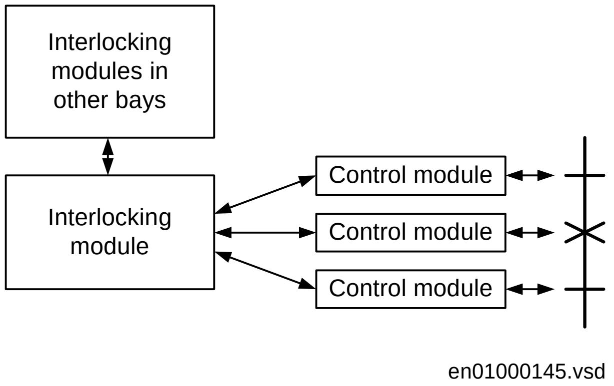


Figure 180: Interlocking module on bay level.

The communication between different bays is performed via the station bus and can consist of signals of these types:

- Unearthed busbars
- The busbars are connected together
- Other bays connected to a busbar

Received data from other bays are valid. Figure 181 shows the principle of data exchange.

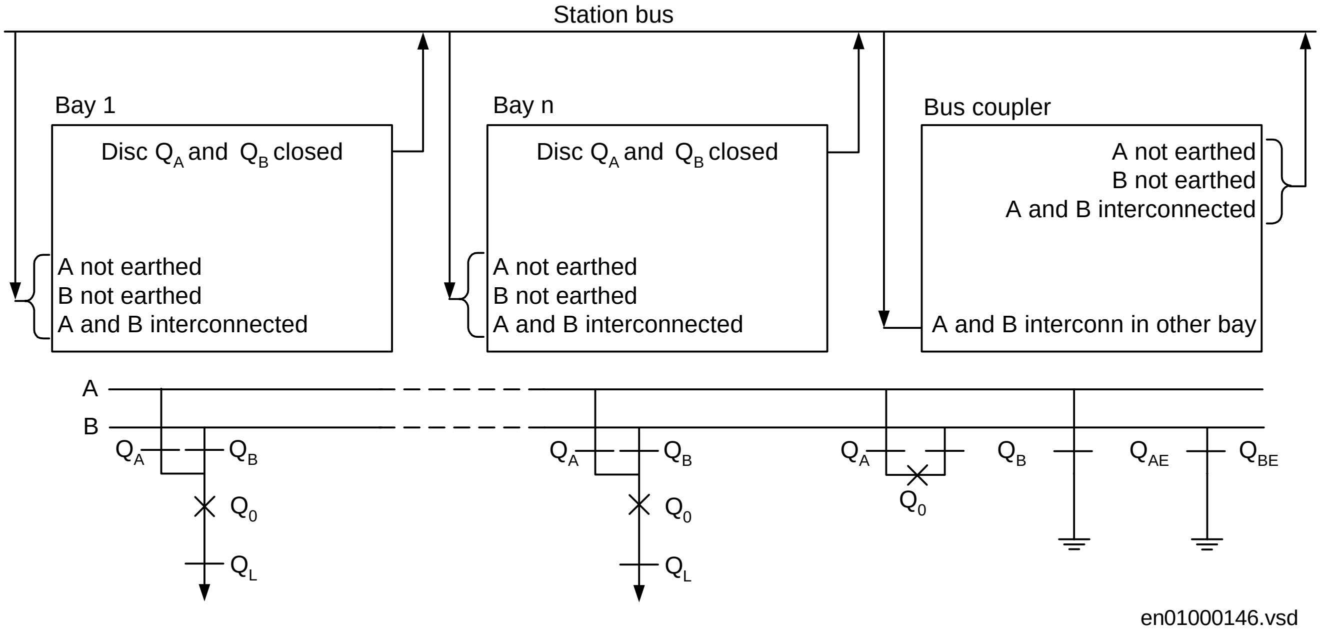


Figure 181: Data exchange between interlocking modules.

The interlocking function in a bay that uses invalid data as conditions does not give a release for command. Invalid data of positions of HV apparatuses can be obtained, for example, at intermediate positions, loss of a control terminal, or at input board error.

On the station HMI an override function exists, which can be used to bypass the interlocking function if not all available data for the condition are valid.

For all interlocking modules these general rules apply:

- The interlocking conditions for opening or closing of disconnectors and earthing switches are always identical.
- Earthing switches at line feeder end, e.g. rapid earthing switches, are normally interlocked only with reference to the conditions in the bay where they are located, not with reference to switches on the other side of the line. So a line voltage indication may be included into line interlocking modules. If there is no line voltage supervision within the bay, then the appropriate inputs must be set to *no voltage*, and the operator must consider this when operating.
- Earthing switches can only be operated at isolated sections e.g. without load/voltage. Circuit breaker contacts cannot be used for isolating of a section, i.e. the status of the circuit breaker is irrelevant for earthing switch operation.
- Disconnectors cannot break power current or connect different voltage systems. Disconnectors in series with a circuit breaker can only be operated if the circuit breaker is open, or if the disconnectors operate in parallel to other closed connection. Other disconnectors can be operated if one side is completely isolated, or if the disconnectors operate in parallel to other closed connection, or if they are earthed on both sides.
- Circuit breaker closing is only interlocked against running disconnectors in its bay or additionally in a transformer bay against the disconnectors and earthing switch on the other side of the transformer, if there is no disconnector between CB and transformer.
- Circuit breaker opening is only interlocked at a bus-coupler bay, if a bus bar transfer is in progress.

5.1.3 Design

General

The implementation of the interlocking is decentralised to each bay. There are different interlocking modules dependent on the topology kind of the substation (breaker and a half or various bus bar arrangements) and the bay types. The interlocking logic for each module is specified in boolean algebra for the switch states. To keep their amount easy to handle, only operating sequences in normal service are permitted. For other uncommon operations, the command handling has an interlock override feature.

Standard modules

To make the implementation of the interlocking function easy, several standard modules are available:

- Line for double and transfer busbars, ABC_LINE
- Bus coupler for double and transfer busbars, ABC_BC
- Transformer bay for double busbars, AB_TRAFO
- Bus-section breaker for double busbars, A1A2_BS
- Bus-section disconnector for double busbars, A1A2_DC
- Busbar earthing switch, BB_ES
- Double CB bay, DB_BUS_A, DB_LINE, DB_BUS_B
- 1 1/2-CB diameter, BH_LINE_A, BH_CONN, BH_LINE_B

In REC 561, these standard modules are available:

For one bay:

- A1A2_DC and
- 3 pcs BB_ES

and either

- AB_TRAFO or
- ABC_LINE or
- ABC_BC or
- A1A2_BS or
- DB_BUS_A,DB_LINE, DB_BUS_B

Option for up to three single breaker bays, two double breakers bays, or one 1 1/2 breaker diameter:

- 2 pcs A1A2_DC and
- 6 pcs BB_ES and
- DB_BUS_A, DB_LINE, DB_BUS_B and
- BH_LINE_A, BH_CONN, BH_LINE_B

and either

- AB_TRAFO or
- ABC_LINE or
- ABC_BC or
- A1A2_BS or
- DB_BUS_A, DB_LINE, DB_BUS_B

and either

- AB_TRAFO or
- ABC_LINE or
- ABC_BC or
- A1A2_BS

and either

- AB_TRAFO or
- ABC_LINE or
- ABC_BC or
- A1A2_BS

Option for two 1 1/2 breaker diameters:

- 2 pcs A1A2_DC and
- 6 pcs BB_ES

and either

- AB_TRAFO or
- ABC_LINE or
- ABC_BC or
- A1A2_BS or
- DB_BUS_A, DB_LINE, DB_BUS_B

and

- 2 pcs BH_LINE_A, 2 pcs BH_CONN, 2 pcs BH_LINE_B

The selection of the different options is made during ordering. The selection of standard modules within the different options of REC 561 is made by a Function Selector tool included in the CAP 531 Configuration tool.

Communication between modules

The interlocking module is implemented per bay, which needs the status indication of all switching devices of the own bay itself and some switching devices of other bays. The communication between modules in different bays is performed via the station bus. For each bay-bay communication direction, there is a need for two communication elements, one for sending and one for receiving. For sending, an Event Function block is used, and for receiving, a Multiple Command Function block is used.

The command function block supervises the transmission itself. Each communication error results in a deactivation of the data valid signal in the command function block, which is used as a condition in the interlocking logic.

The section *"Apparatus Control"*, describes how the interlocking information is exchanged between the bays and also the reservation mechanism.

5.1.4 Configuration

The following sections describe how the interlocking for a certain switchgear configuration can be realised by using standard interlocking modules and their interconnections. They also describe the parameter settings. The EXVVA_xx input signals, which are normally not used, are always set to 1=FIXD-ON. The inputs for delivery specific conditions (QxEXy) are set to 1=FIXD-ON, if they are not used except:

- Q9EX2 and Q9EX4 in modules BH_LINE_A and BH_LINE_B
- Q0EX3 in module AB_TRAFO

which are set to 0=FIXD-OFF.

5.2 Interlocking for line bay

The interlocking module ABC_LINE is used for a line connected to a double busbar arrangement with a transfer busbar according to figure 182. The module can also be used for a double busbar arrangement without transfer busbar or a single busbar arrangement with/without transfer busbar.

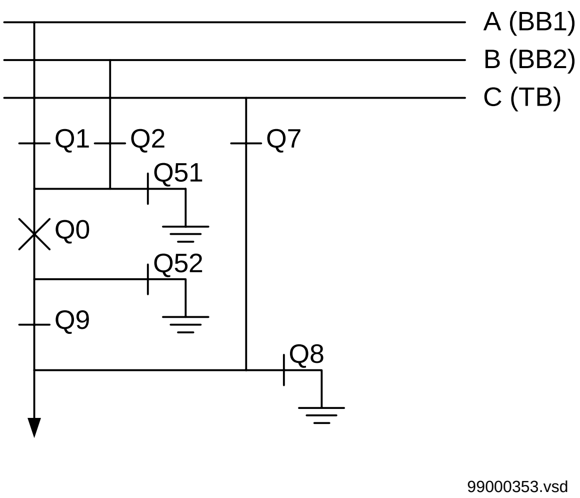


Figure 182: Switchyard layout ABC_LINE

5.2.1 Configuration

The signals from other bays connected to the module ABC_LINE are described below.

Signals from bypass busbar

To derive the signals:

Signal	
C_DC_OP	All line disconnectors on bypass C except in the own bay are open.
VP_C_DC	The switch status of C_DC is valid.
EXDU_BPB	Signal if no transmission error from any bay connected to a bypass busbar.

These signals from each line bay (ABC_LINE) except that of the own bay are needed:

Signal	
Q7OPTR	Q7 is open
VPQ7TR	The switch status Q7 is valid.
EXDU_BPB	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

For bay n, these conditions are valid:

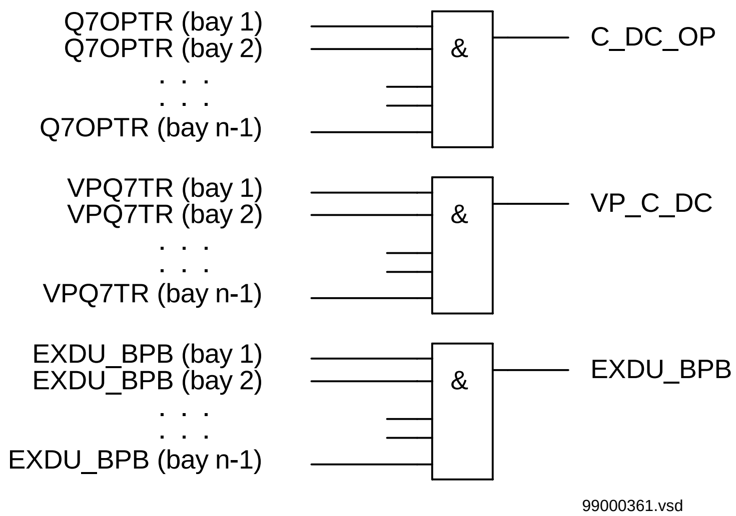


Figure 183: Signals from bypass busbar in line bay n

Signals from bus coupler

If the busbar is divided by bus-section disconnectors into bus sections, the busbar-busbar connection could exist via the bus-section disconnector and bus-coupler within the other bus section.

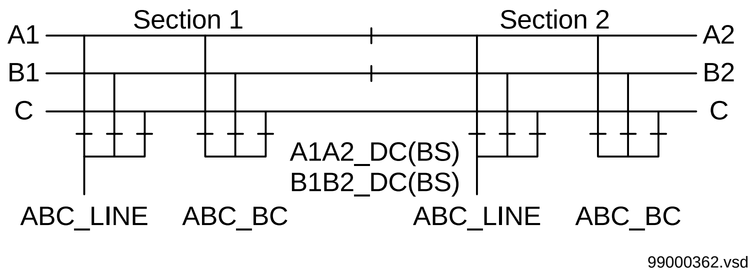


Figure 184: Busbars divided by bus-section disconnectors (circuit breakers)

To derive the signals:

Signal	
BC_AB_CL	Signal if a bus-coupler connection exists between busbar A and B.
BC_AC_OP	Signal if there is no bus-coupler connection between busbar A and C.
BC_AC_CL	Signal if a bus-coupler connection exists between busbar A and C.
BC_BC_OP	Signal if there is no bus-coupler connection between busbar B and C.
BC_BC_CL	Signal if a bus-coupler connection exists between busbar B and C.
VP_BC_AB	The switch status of BC_AB is valid.
VP_BC_AC	The switch status of BC_AC is valid.
VP_BC_BC	The switch status of BC_BC is valid.
EXDUP_BC	Signal if there is no transmission error from bay BC (bus-coupler bay).

These signals from each bus-coupler bay (ABC_BC) are needed:

Signal	
BCABCLTR	Signal if a bus-coupler connection through the own bus coupler exists between busbar A and B.
BCACOPTR	Signal if there is no bus-coupler connection through the own bus coupler between busbar A and C.
BCACCLTR	Signal if a bus-coupler connection through the own bus coupler exists between busbar A and C.

Signal	
BCBCOPTR	Signal if there is no bus-coupler connection through the own bus coupler between busbar B and C.
BCBCCLTR	Signal if a bus-coupler connection through the own bus coupler exists between busbar B and C.
VPBCABTR	The switch status of BC_AB is valid.
VPBCACTR	The switch status of BC_AC is valid.
VPBCBCTR	The switch status of BC_BC is valid.
EXDUP_BC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

These signals from each bus-section disconnector bay (A1A2_DC) are also needed. For B1B2_DC, corresponding signals from busbar B are used. The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnector A1A2_DC and B1B2_DC.

Signal	
DCOPTR	Signal if the bus-section disconnector is open.
DCCLTR	Signal if the bus-section disconnector is closed.
VPDCTR	The switch status of A1A2_DC is valid.
EXDUP_DC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

If the busbar is divided by bus-section circuit breakers, the signals from the bus-section coupler bay (A1A2_BS), rather than the bus-section disconnector bay (A1A2_DC) must be used. For B1B2_BS, corresponding signals from busbar B are used. The same type of module (A1A2_BS) is used for different busbars, that is, for both bus-section circuit breakers A1A2_BS and B1B2_BS.

Signal	
A1A2OPTR	Signal if there is no bus-section coupler connection between bus sections A1 and A2.
A1A2CLTR	Signal if a bus-section coupler connection exists between bus sections A1 and A2.
VPA1A2TR	The switch status of A1A2_DC is valid.
EXDUP_BS	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

For a line bay in section 1, these conditions are valid:

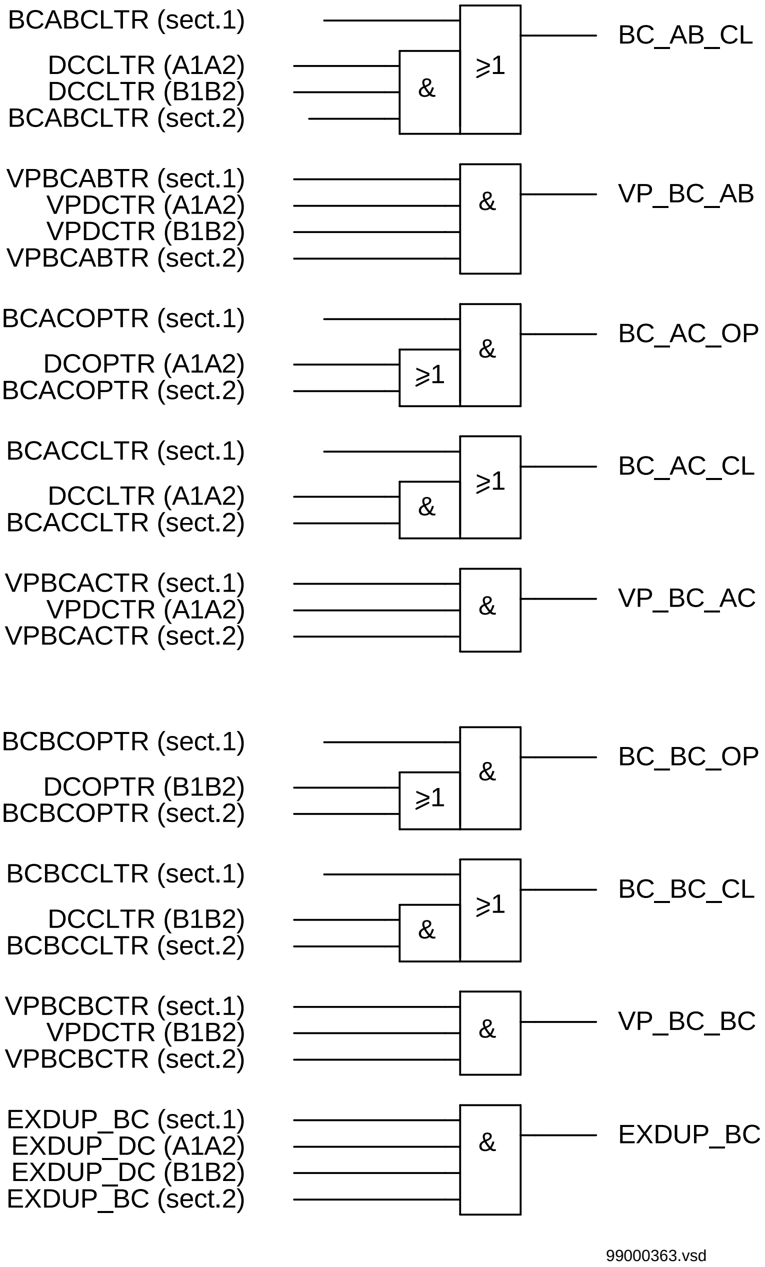


Figure 185: Signals to a line bay in section 1 from the bus-coupler bays in each section

For a line bay in section 2, the same conditions as above are valid by changing section 1 to section 2 and vice versa.

Parameter setting

If there is no bypass busbar and therefore no Q7 disconnector, then the interlocking for Q7 is not used. The states for Q7, Q75, C_DC, BC_AC, BC_BC are set to open by setting the appropriate module inputs as follows. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q7_OP = 1
- Q7_CL = 0

- Q75_OP = 1
- Q75_CL = 0

- C_DC_OP = 1

- BC_AC_OP = 1
- BC_AC_CL = 0
- BC_BC_OP = 1
- BC_BC_CL = 0

- EXDU_BPB = 1

- VP_C_DC = 1
- VP_BC_AC = 1
- VP_BC_BC = 1

If there is no second busbar B and therefore no Q2 disconnector, then the interlocking for Q2 is not used. The state for Q2, Q25, BC_AB, BC_BC are set to open by setting the appropriate module inputs as follows. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q2_OP = 1
- Q2_CL = 0

- Q25_OP = 1
- Q25_CL = 0

- BC_AB_CL = 0
- BC_BC_OP = 1
- BC_BC_CL = 0

- VP_BC_AB = 1

5.3 Interlocking for bus-coupler bay

5.3.1 Configuration

The signals from other bays connected to the bus-coupler module ABC_BC are described below.

Signals from all feeders

To derive the signals:

Signal	
BBTR_OP	Signal if no busbar transfer is in progress concerning this bus coupler.
VP_BBTR	The switch status of BBTR is valid.
EXDUP_AB	Signal if there is no transmission error from any bay connected to the AB busbars.

These signals from each line bay (ABC_LINE), each transformer bay (ABC_TRAFO), and bus-coupler bay (ABC_BC), except the own bus-coupler bay are needed:

Signal	
Q1Q2OPTR	Signal if Q1 or Q2 or both are open.
VPQ1Q2TR	The switch status of Q1 and Q2 are valid.
EXDUP_AB	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

For bus-coupler bay n, these conditions are valid:

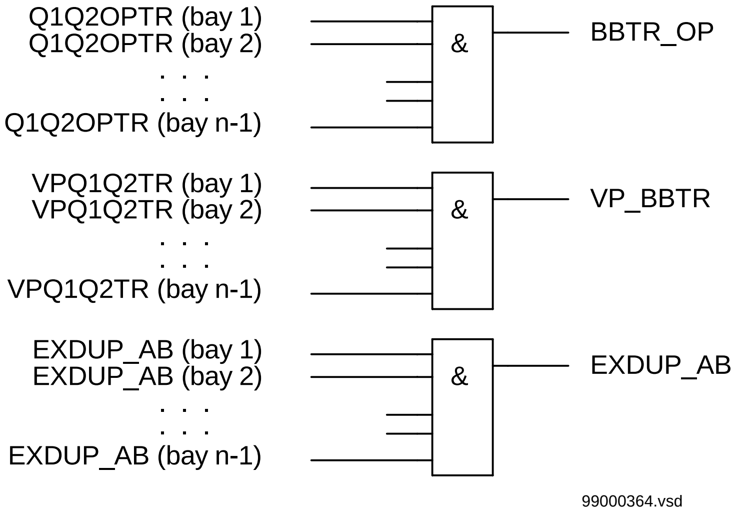


Figure 186: Signals from any bays in bus-coupler bay n

If the busbar is divided by bus-section disconnectors into bus sections, the signals BBTR are connected in parallel - if both bus-section disconnectors are closed. So for the basic project-specific logic for BBTR above, add this logic:

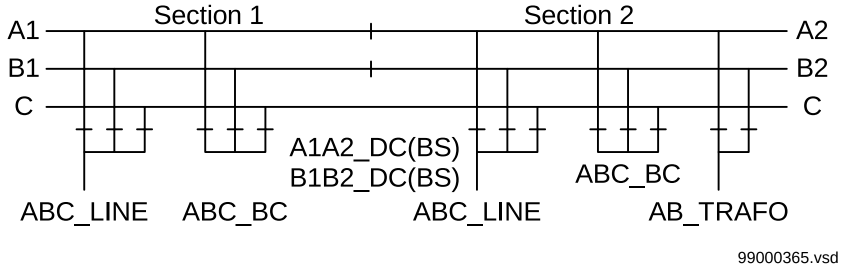


Figure 187: Busbars divided by bus-section disconnectors (circuit breakers)

The following signals from each bus-section disconnector bay (A1A2_DC) are needed. For B1B2_DC, corresponding signals from busbar B are used. The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnector A1A2_DC and B1B2_DC.

Signal	
DCOPTR	Signal if the bus-section disconnector is open.
VPDCTR	The switch status of A1A2_DC is valid.
EXDUP_DC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

If the busbar is divided by bus-section circuit breakers, the signals from the bus-section coupler bay (A1A2_BS), rather than the bus-section disconnector bay (A1A2_DC), have to be used. For B1B2_BS, corresponding signals from busbar B are used. The same type of module (A1A2_BS) is used for different busbars, that is, for both bus-section circuit breakers A1A2_BS and B1B2_BS.

Signal	
A1A2OPTR	Signal if there is no bus-section coupler connection between bus sections A1 and A2.
VPA1A2TR	The switch status of A1A2_DC is valid.
EXDUP_BS	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

For a bus-coupler bay in section 1, these conditions are valid:

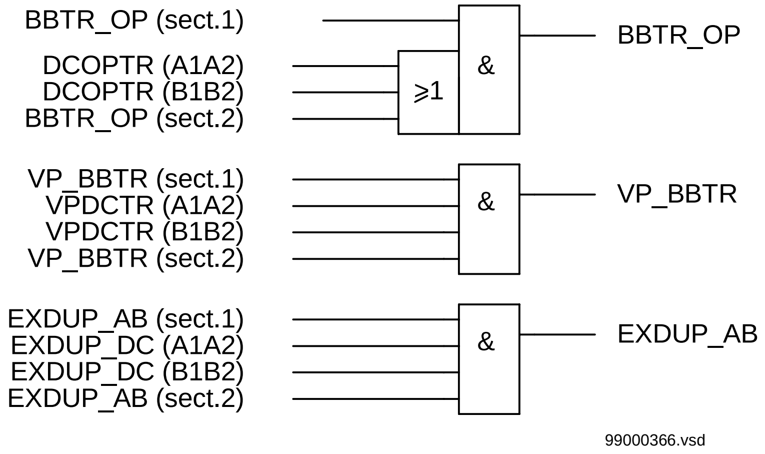


Figure 188: Signals to a bus-coupler bay in section 1 from any bays in each section

For a bus-coupler bay in section 2, the same conditions as above are valid by changing section 1 to section 2 and vice versa.

Signals from bus coupler

If the busbar is divided by bus-section disconnectors into bus sections, the signals BC_AB from the busbar coupler of the other busbar section must be transmitted to the own busbar coupler if both disconnectors are closed.

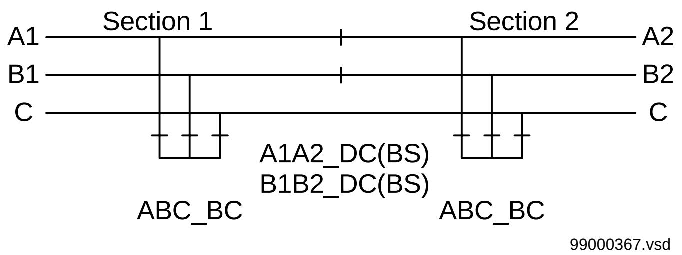


Figure 189: Busbars divided by bus-section disconnectors (circuit breakers)

To derive the signals:

Signal	
BC_AB_CL	Signal if an other bus-coupler connection exists between busbar A and B.
VP_BC_AB	The switch status of BC_AB is valid.
EXDUP_BC	Signal if there is no transmission error from bay BC (bus-coupler bay).

These signals from each bus-coupler bay (ABC_BC), except the own bay are needed:

Signal	
BCABCLTR	Signal if a bus-coupler connection through the own bus coupler exists between busbar A and B.
VPBCABTR	The switch status of BC_AB is valid.
EXDUP_BC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

These signals from each bus-section disconnector bay (A1A2_DC) are also needed. For B1B2_DC, corresponding signals from busbar B are used. The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnector A1A2_DC and B1B2_DC.

Signal	
DCCLTR	Signal if the bus-section disconnector is closed.
VPDCTR	The switch status of A1A2_DC is valid.
EXDUP_DC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

If the busbar is divided by bus-section circuit breakers, the signals from the bus-section coupler bay (A1A2_BS), rather than the bus-section disconnector bay (A1A2_DC), must be used. For B1B2_BS, corresponding signals from busbar B are used. The same type of module (A1A2_BS) is used for different busbars, that is, for both bus-section circuit breakers A1A2_BS and B1B2_BS.

Signal	
A1A2CLTR	Signal if a bus-section coupler connection exists between bus sections A1 and A2.
VPA1A2TR	The switch status of Q0, Q11 and Q12 are valid.
EXDUP_BS	Signal if no transmission error from the bay containing the above information. This signal is taken from the data valid output on the command function block.

For a bus-coupler bay in section 1, these conditions are valid:

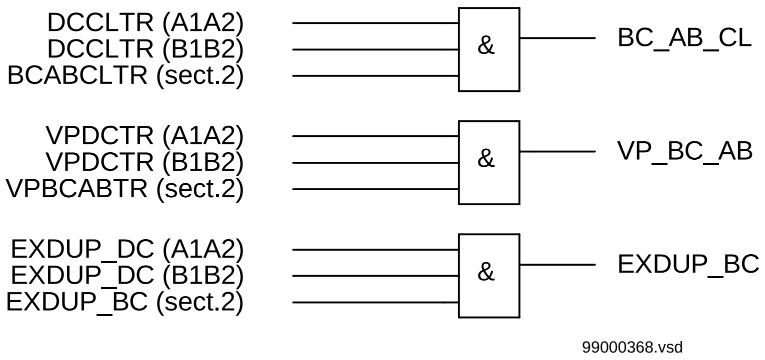


Figure 190: Signals to a bus-coupler bay in section 1 from a bus-coupler bay in another section

For a bus-coupler bay in section 2, the same conditions as above are valid by changing section 1 to section 2 and vice versa.

Parameter setting

If there is no bypass busbar and therefore no Q20 and Q7 disconnectors, then the interlocking for Q20 and Q7 is not used. The states for Q20, Q7, Q75, BC_AB are set to open by setting the appropriate module inputs as follows. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q20_OP = 1
- Q20_CL = 0

- Q7_OP = 1
- Q7_CL = 0

- Q75_OP = 1
- Q75_CL = 0

- BC_AB_CL = 0

If there is no second busbar B and therefore no Q20 and Q2 disconnectors, then the interlocking for Q20 and Q2 are not used. The states for Q20, Q2, Q25, BC_AB, BBTR are set to open by setting the appropriate module inputs as follows. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q20_OP = 1
- Q20_CL = 0

- Q2_OP = 1
- Q2_CL = 0

- Q25_OP = 1
- Q25_CL = 0

- BC_AB_CL = 0

- BBTR_OP = 1

5.4 Interlocking for transformer bay

The interlocking module AB_TRAFO is used for a transformer bay connected to a double busbar arrangement according to figure 191. The module is used when there is no disconnector between circuit breaker and transformer. Otherwise, the module ABC_LINE can be used. This module can also be used for a single busbar arrangement.

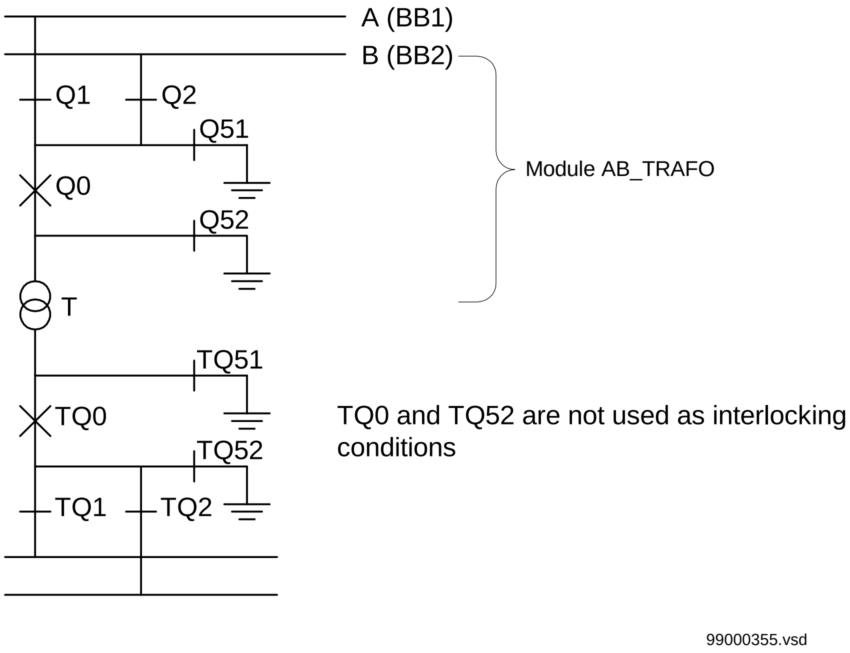


Figure 191: Switchyard layout AB_TRAFO

5.4.1 Configuration

The signals from other bays connected to the module AB_TRAFO are described below.

Signals from bus coupler

If the busbar is divided by bus-section disconnectors into bus sections, the busbar-busbar connection could exist via the bus-section disconnector and bus coupler within the other bus section.

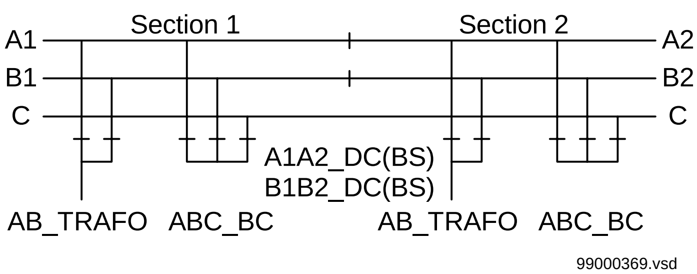


Figure 192: Busbars divided by bus-section disconnectors (circuit breakers)

The project-specific logic for input signals concerning bus coupler are the same as the specific logic for the line bay (ABC_LINE):

Signal	
BC_AB_CL	Signal if a bus-coupler connection exists between busbar A and B.
VP_BC_AB	The switch status of BC_AB is valid.
EXDUP_BC	Signal if there is no transmission error from bay BC (bus-coupler bay).

The logic is identical to the double busbar configuration described in "Signals from bus coupler".

Parameter setting

If there is no second busbar B and therefore no Q2 disconnector, then the interlocking for Q2 is not used. The state for Q2, Q25, BC_AB are set to open by setting the appropriate module inputs as follows. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q2_OP = 1
- Q2_CL = 0

- Q25_OP = 1
- Q25_CL = 0

- BC_AB_CL = 0

If there is no second busbar B at the other side of the transformer and therefore no TQ2 disconnector, then the state for TQ2 is set to open by setting the appropriate module inputs as follows:

- TQ2_OP = 1
- TQ2_CL = 0

5.5 Interlocking for bus-section breaker

The interlocking module A1A2_BS is used for one bus-section circuit breaker between section A1 and A2 according to figure 193. The module can be used for different busbars, which includes a bus-section circuit breaker, that is, not only busbar A.

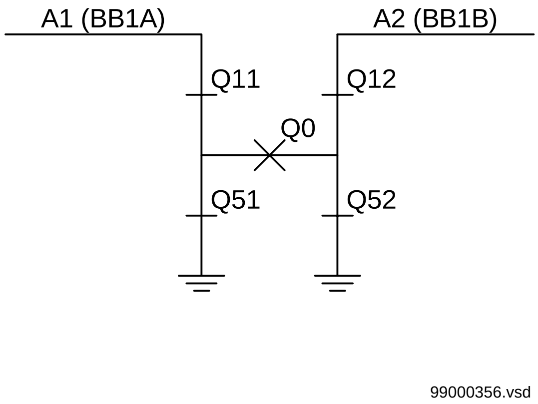


Figure 193: Switchyard layout A1A2_BS

5.5.1 Configuration

The signals from other bays connected to the module A1A2_BS are described below.

Signals from all feeders

If the busbar is divided by bus-section circuit breakers into bus sections and both circuit breaker are closed, the opening of the circuit breaker must be blocked if a bus-coupler connection exists between busbar A and B on one bus-section side and if on the other bus-section side a busbar transfer is in progress:

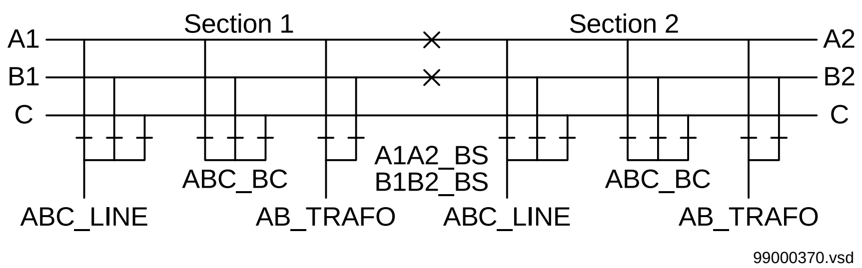


Figure 194: Busbars divided by bus-section circuit breakers

To derive the signals:

Signal	
BBTR_OP	Signal if no busbar transfer is in progress concerning this bus section.
VP_BBTR	The switch status of BBTR is valid.
EXDUP_AB	Signal if there is no transmission error from any bay connected to the AB busbars.

These signals from each line bay (ABC_LINE), each transformer bay (ABC_TRAFO), and bus-coupler bay (ABC_BC) are needed:

Signal	
Q1Q2OPTR	Signal if Q1 or Q2 or both are open.
VPQ1Q2TR	The switch status of Q1 and Q2 are valid.
EXDUP_AB	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

These signals from each bus-coupler bay (ABC_BC) are needed:

Signal	
BCABOPTR	Signal if there is no bus-coupler connection through the own bus coupler between busbar A and B.
VPBCABTR	The switch status of BC_AB is valid.
EXDUP_BC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

These signals from the bus-section circuit breaker bay (A1A2_BS, B1B2_BS) are needed.

Signal	
A1A2OPTR	Signal if there is no bus-section coupler connection between bus sections A1 and A2.
VPA1A2TR	The switch status of A1A2_BS is valid.
EXDUP_BS	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

For a bus-section circuit breaker between A1 and A2 section busbars, these conditions are valid:

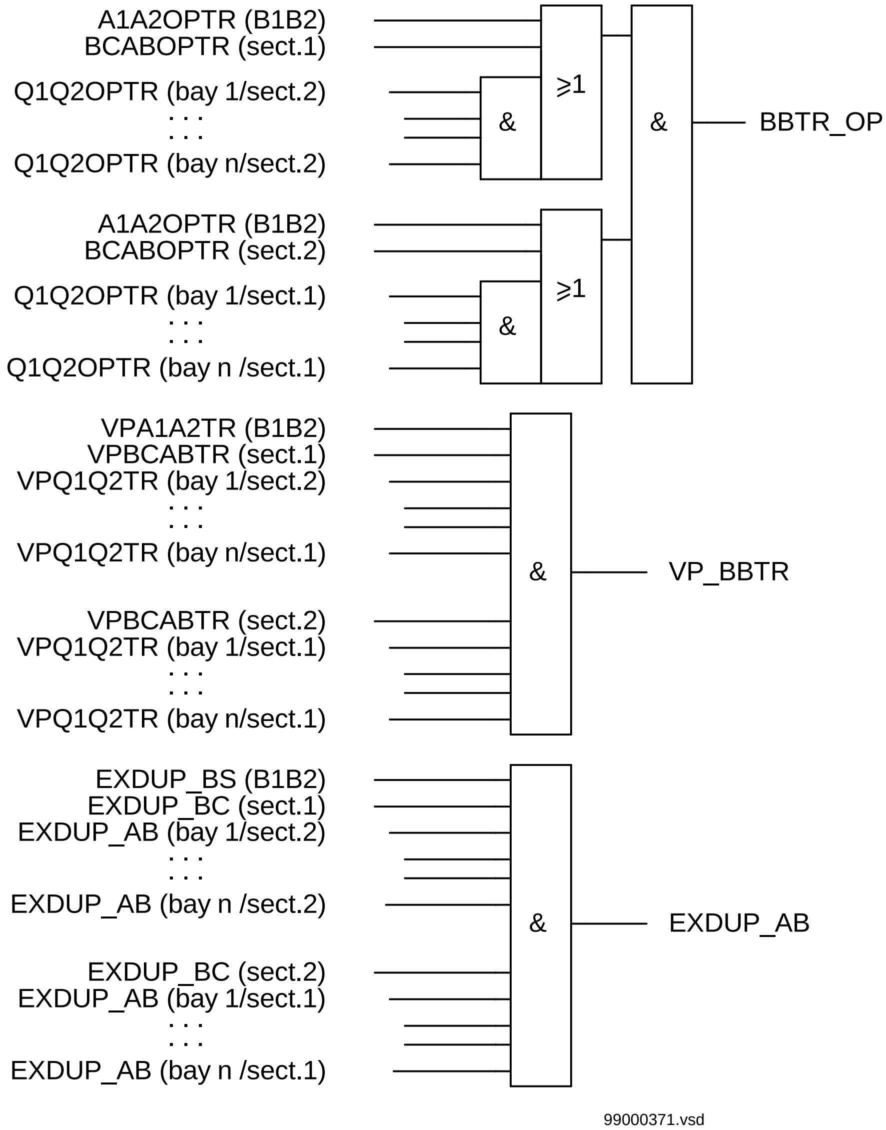


Figure 195: Signals from any bays for a bus-section circuit breaker between sections A1 and A2

For a bus-section circuit breaker between B1 and B2 section busbars, these conditions are valid:

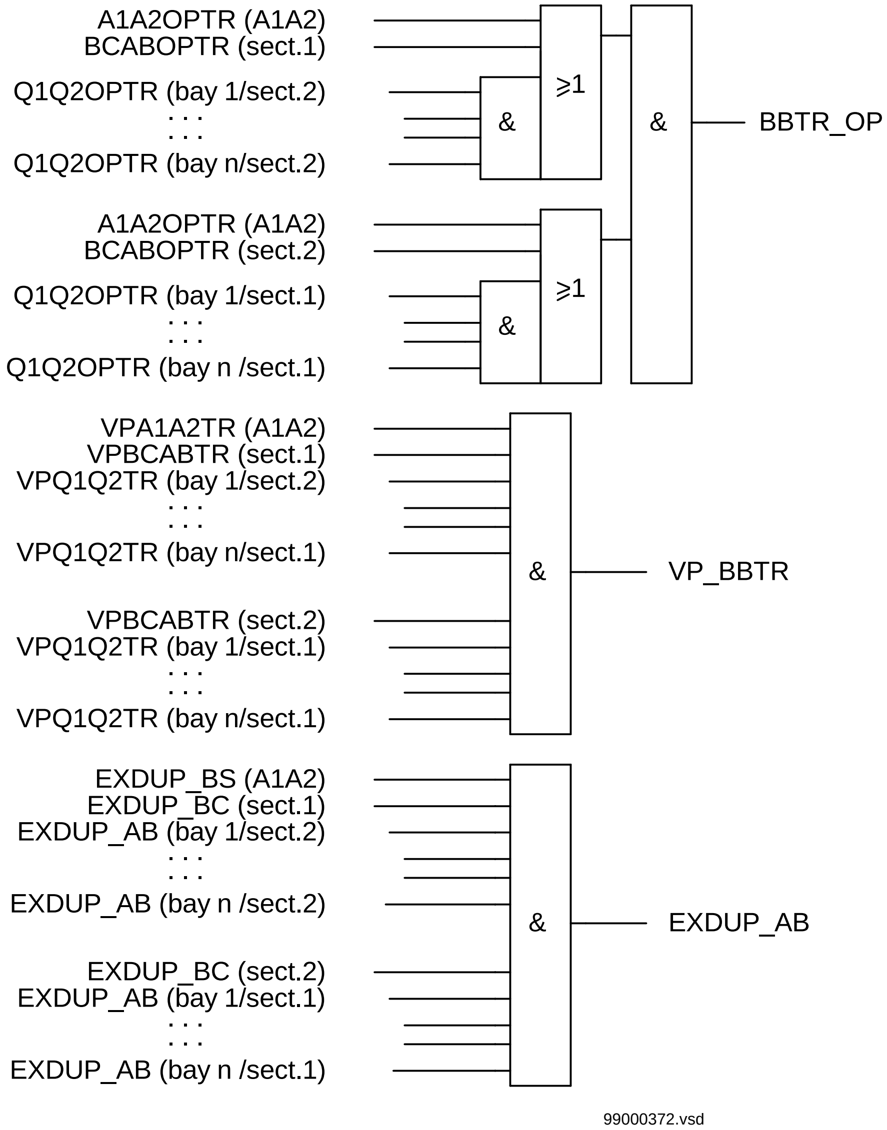


Figure 196: Signals from any bays for a bus-section circuit breaker between sections B1 and B2

Parameter setting

If there is no other busbar via the busbar loops that are possible, then either the interlocking for the Q0 open circuit breaker is not used or the state for BBTR is set to open. That is, no busbar transfer is in progress in this bus section:

- BBTR_OP = 1

5.6 Interlocking for bus-section disconnector

The interlocking module A1A2_DC is used for one bus-section disconnector between section A1 and A2 according to figure 197. The module can be used for different busbars, which includes a bus-section disconnector, that is, not only busbar A.

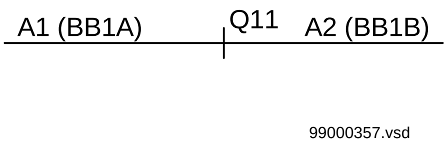


Figure 197: Switchyard layout A1A2_DC

5.6.1 Configuration

The signals from other bays connected to the module A1A2_DC are described below.

Signals in single breaker arrangement

If the busbar is divided by bus-section disconnectors, the condition *no other disconnector connected to the bus section* must be made by a project-specific logic.

The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnector A1A2_DC and B1B2_DC. But for B1B2_DC, corresponding signals from busbar B are used.

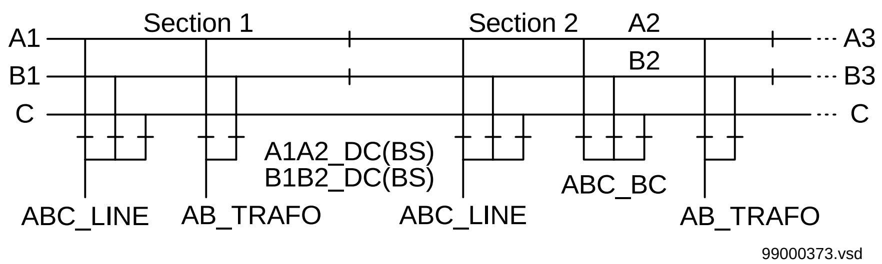


Figure 198: Busbars divided by bus-section disconnectors (circuit breakers)

To derive the signals:

Signal	
A1DC_OP	Signal if all disconnectors on busbar A1 are open.
A2DC_OP	Signal if all disconnectors on busbar A2 are open.
VPA1_DC	The switch status of A1_DC is valid.
VPA2_DC	The switch status of A2_DC is valid.
EXDUP_BB	Signal if there is no transmission error from any bay that contains the above information.

These signals from each line bay (ABC_LINE), each transformer bay (AB_TRAFO), and each bus-coupler bay (ABC_BC) are needed:

Signal	
Q1OPTR	Signal if Q1 is open.
Q2OPTR	Signal if Q2 (AB_TRAFO, ABC_LINE) is open.
Q20OPTR	Signal if Q20 (ABC_BC) is open.
VPQ1TR	The switch status of Q1 is valid.
VPQ2TR	The switch status of Q2 is valid.
VPQ20TR	The switch status of Q2 and Q20 are valid.
EXDUP_BB	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

If there is an additional bus-section disconnector, the signal from the bus-section disconnector bay (A1A2_DC) must be used:

Signal	
DCOPTR	Signal if the bus-section disconnector is open.
VPDCTR	The switch status of A1A2_DC is valid.
EXDUP_DC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

If there is an additional bus-section circuit breaker rather than an additional bus-section disconnector the signals from the bus-section, circuit-breaker bay (A1A2_BS) rather than the bus-section disconnector bay (A1A2_DC) must be used:

Signal	
Q11OPTR	Signal if Q11 is open.
Q12OPTR	Signal if Q12 is open.
VPQ11TR	The switch status of Q11 is valid.
VPQ12TR	The switch status of Q12 is valid.
EXDUP_BS	Signal if there is no transmission error from the bay BS (bus-section coupler bay) that contains the above information. This signal is taken from the data valid output on the command function block.

For a bus-section disconnector, these conditions from the A1 busbar section are valid:

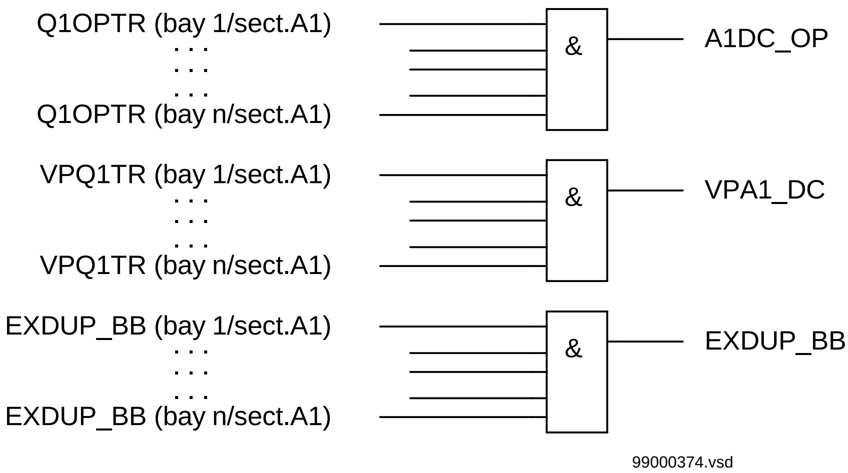


Figure 199: Signals from any bays in section A1 to a bus-section disconnector

For a bus-section disconnector, these conditions from the A2 busbar section are valid:

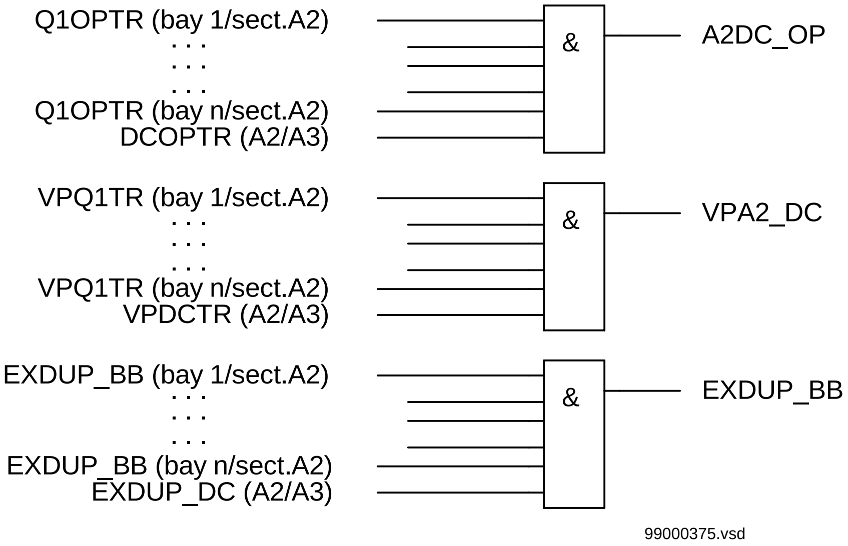


Figure 200: Signals from any bays in section A2 to a bus-section disconnector

For a bus-section disconnector, these conditions from the B1 busbar section are valid:

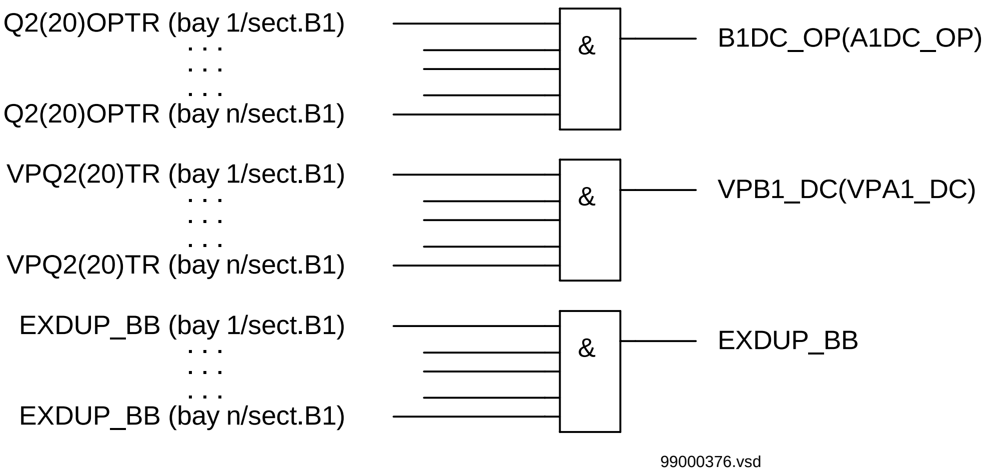


Figure 201: Signals from any bays in section B1 to a bus-section disconnector

For a bus-section disconnector, these conditions from the B2 busbar section are valid:

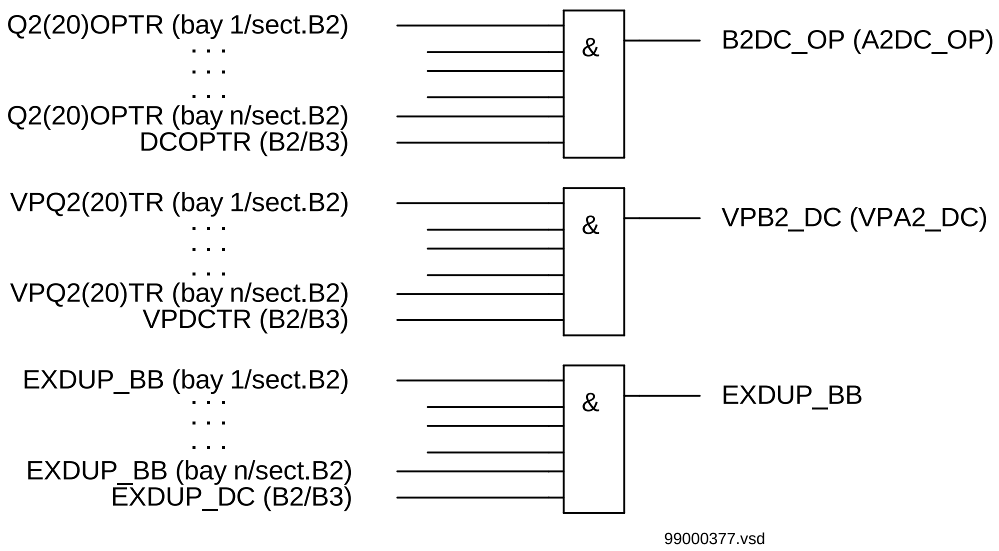


Figure 202: Signals from any bays in section B2 to a bus-section disconnector

Signals in double-breaker arrangement

If the busbar is divided by bus-section disconnectors, the condition for the busbar disconnector bay *no other disconnector connected to the bus section* must be made by a project-specific logic.

The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnector A1A2_DC and B1B2_DC. But for B1B2_DC, corresponding signals from busbar B are used.

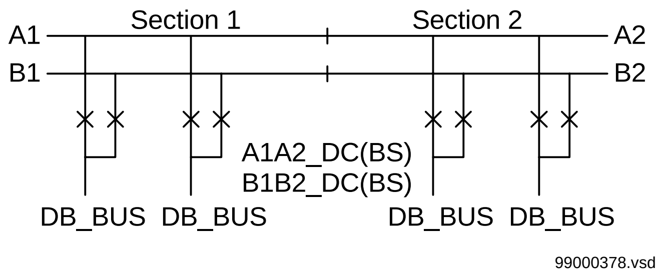


Figure 203: Busbars divided by bus-section disconnectors (circuit breakers)

To derive the signals:

Signal	
A1DC_OP	Signal if all disconnectors on busbar A1 are open.
A2DC_OP	Signal if all disconnectors on busbar A2 are open.
VPA1_DC	The switch status of A1_DC is valid.
VPA2_DC	The switch status of A2_DC is valid.
EXDUP_BB	Signal if there is no transmission error from bay DB (double-breaker bay) that contains the above information.

These signals from each double-breaker bay (DB_BUS) are needed:

Signal	
Q1OPTR	Signal if Q1 is open.
Q2OPTR	Signal if Q2 is open.
VPQ1TR	The switch status of Q1 is valid.
VPQ2TR	The switch status of Q2 is valid.
EXDUP_DB	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

The logic is identical to the double busbar configuration described in "Signals in single breaker arrangement".

For a bus-section disconnector, these conditions from the A1 busbar section are valid:

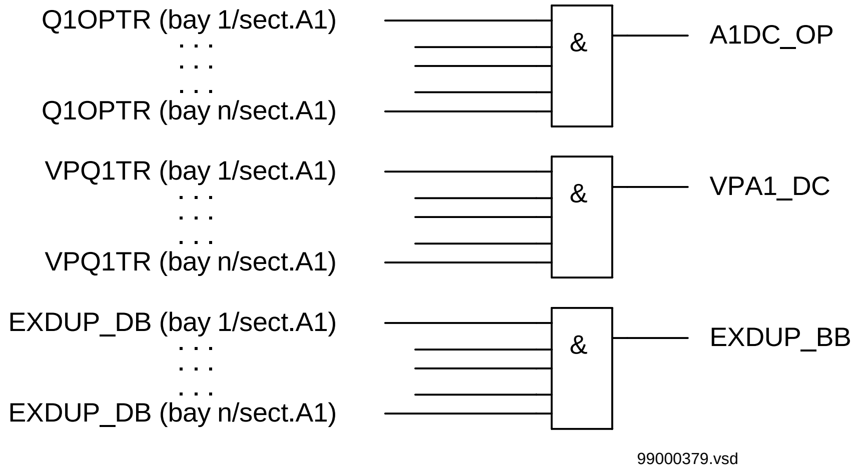


Figure 204: Signals from double-breaker bays in section A1 to a bus-section disconnector

For a bus-section disconnector, these conditions from the A2 busbar section are valid:

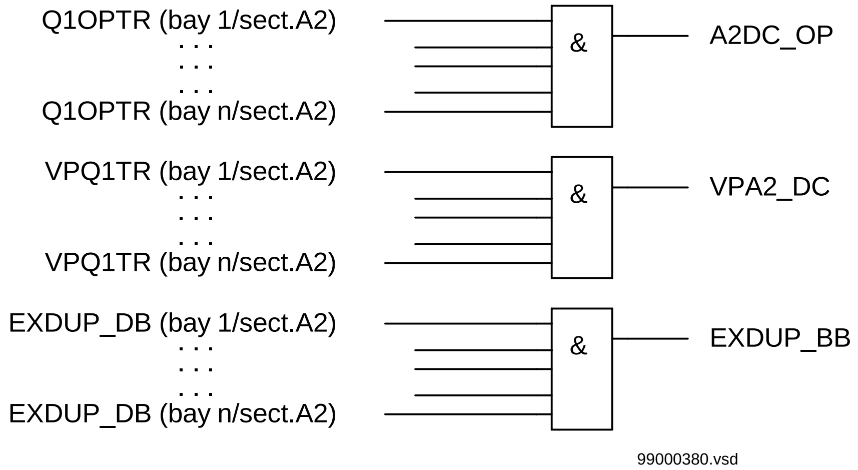


Figure 205: Signals from double-breaker bays in section A2 to a bus-section disconnector

For a bus-section disconnector, these conditions from the B1 busbar section are valid:

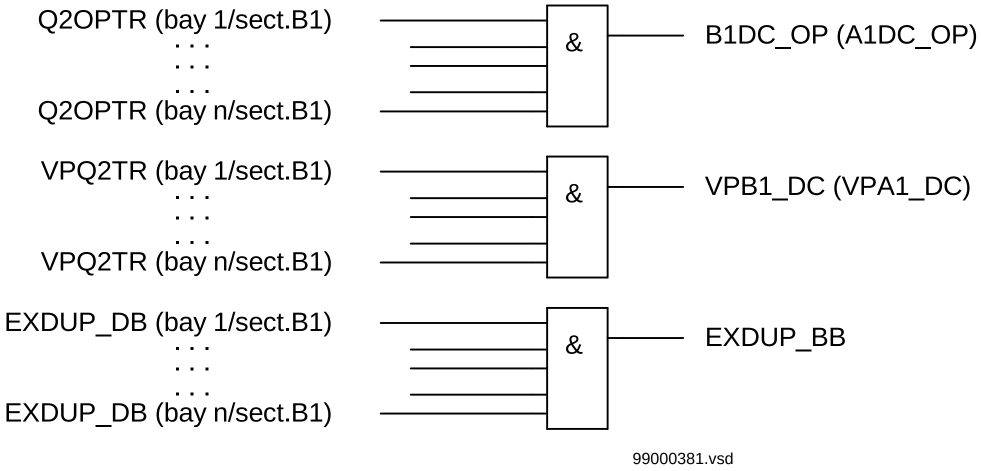


Figure 206: Signals from double-breaker bays in section B1 to a bus-section disconnector

For a bus-section disconnector, these conditions from the B2 busbar section are valid:

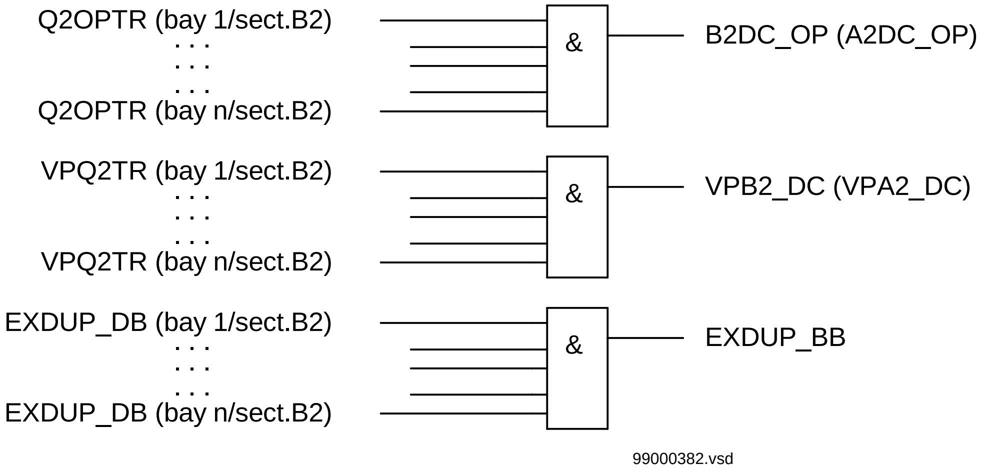


Figure 207: Signals from double-breaker bays in section B2 to a bus-section disconnector

Signals in breaker and a half arrangement

If the busbar is divided by bus-section disconnectors, the condition for the busbar disconnector bay *no other disconnector connected to the bus section* must be made by a project-specific logic.

The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnector A1A2_DC and B1B2_DC. But for B1B2_DC, corresponding signals from busbar B are used.

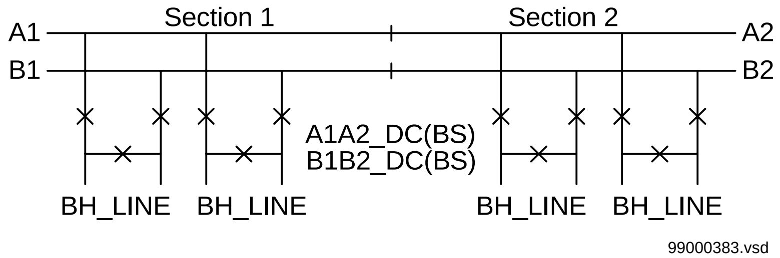


Figure 208: Busbars divided by bus-section disconnectors (circuit breakers)

The project-specific logic are the same as for the logic for the double-breaker configuration.

Signal	
A1DC_OP	Signal if all disconnectors on busbar A1 are open.
A2DC_OP	Signal if all disconnectors on busbar A2 are open.
VPA1_DC	The switch status of A1_DC is valid.
VPA2_DC	The switch status of A2_DC is valid.
EXDUP_BB	Signal if there is no transmission error from bay BH (breaker and a half) that contains the above information.

5.7 Interlocking for busbar earthing switch

The interlocking module BB_ES is used for one busbar earthing switch on any busbar parts according to figure 209.

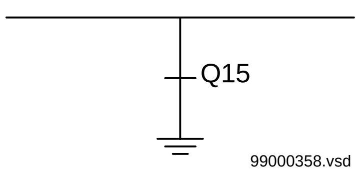


Figure 209: Switchyard layout BB_ES

5.7.1 Configuration

The signals from other bays connected to the module BB_ES are described below.

Signals in single breaker arrangement

The busbar earthing switch is only allowed to operate if all disconnectors of the bus section are open.

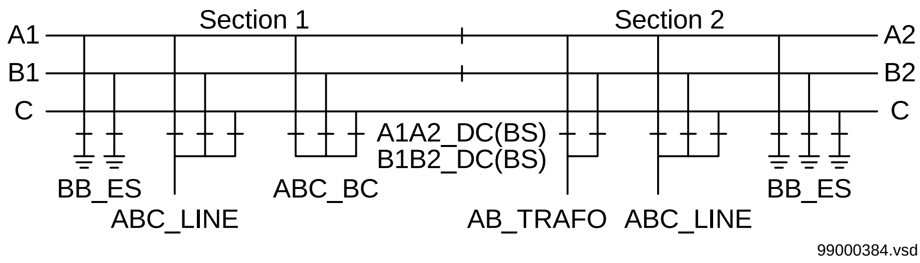


Figure 210: Busbars divided by bus-section disconnectors (circuit breakers)

To derive the signals:

Signal	
ABCDC_OP	Signal if all disconnectors of this busbar section are open.
VP_ABCDC	The switch status of ABCDC is valid.
EXDUP_BB	Signal if no transmission error from any bay containing the above information.

These signals from each line bay (ABC_LINE), each transformer bay (AB_TRAFO), and each bus-coupler bay (ABC_BC) are needed:

Signal	
Q1OPTR	Signal if Q1 is open.
Q2OPTR	Signal if Q2 (AB_TRAFO, ABC_LINE) is open.
Q20OPTR	Signal if Q2 and Q20 (ABC_BC) are open.
Q7OPTR	Signal if Q7 is open.
VPQ1TR	The switch status of Q1 is valid.

Signal	
VPQ2TR	The switch status of Q2 is valid.
VPQ20TR	The switch status of Q2 and Q20 are valid.
VPQ7TR	The switch status of Q7 is valid.
EXDUP_BB	Signal if there is no transmission error from the bay that contains the above information.This signal is taken from the data valid output on the command function block.

These signals from each bus-section disconnector bay (A1A2_DC) are also needed. For B1B2_DC, corresponding signals from busbar B are used. The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnectors A1A2_DC and B1B2_DC.

Signal	
DCOPTR	Signal if the bus-section disconnector is open.
VPDCTR	The switch status of A1A2_DC is valid.
EXDUP_DC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

If no bus-section disconnector exists the signal DCOPTR, VPDCTR and EXDUP_DC are set to 1 (FIXD-ON).

If the busbar is divided by bus-section circuit breakers, the signals from the bus-section coupler bay (A1A2_BS) rather than the bus-section disconnector bay (A1A2_DC) must be used. For B1B2_BS, corresponding signals from busbar B are used. The same type of module (A1A2_BS) is used for different busbars, that is, for both bus-section circuit breakers A1A2_BS and B1B2_BS.

Signal	
Q11OPTR	Signal if Q11 is open.
Q12OPTR	Signal if Q12 is open.

Signal	
VPQ11TR	The switch status of Q11 is valid.
VPQ12TR	The switch status of Q12 is valid.
EXDUP_BS	Signal if there is no transmission error from the bay (bus-section coupler bay) that contains the above information. This signal is taken from the data valid output on the command function block.

For a busbar earthing switch, these conditions from the A1 busbar section are valid:

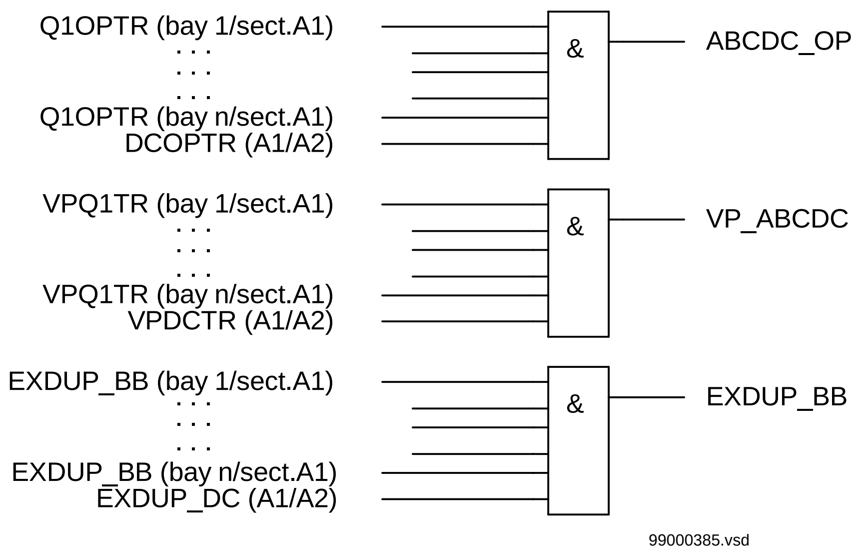


Figure 211: Signals from any bays in section A1 to a busbar earthing switch in the same section

For a busbar earthing switch, these conditions from the A2 busbar section are valid:

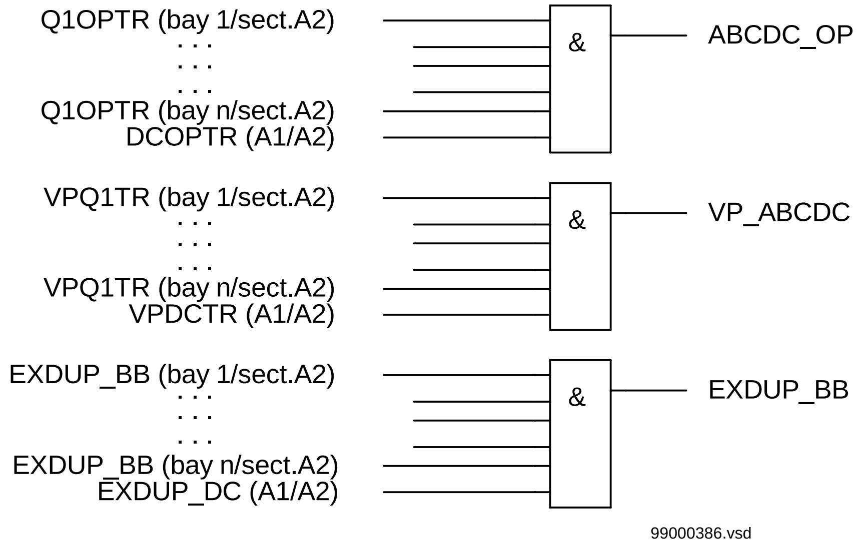


Figure 212: Signals from any bays in section A2 to a busbar earthing switch in the same section

For a busbar earthing switch, these conditions from the B1 busbar section are valid:

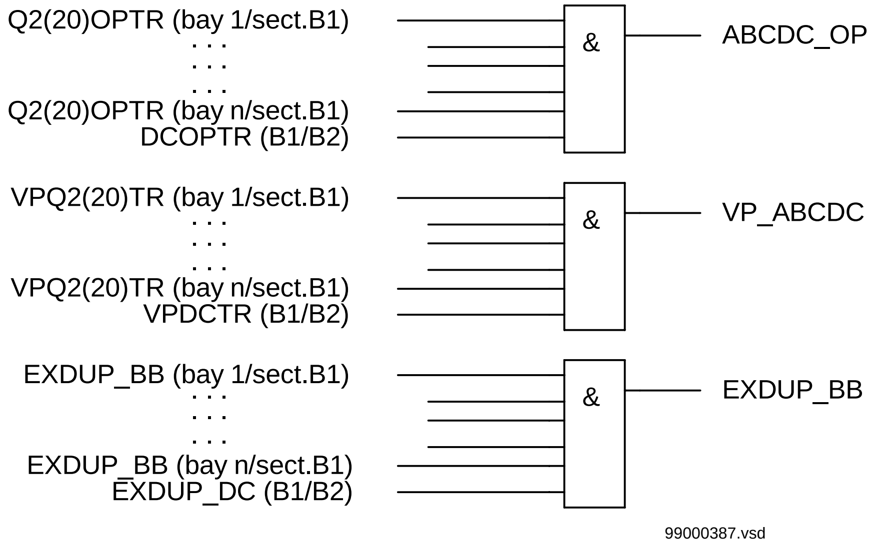


Figure 213: Signals from any bays in section B1 to a busbar earthing switch in the same section

For a busbar earthing switch, these conditions from the B2 busbar section are valid:

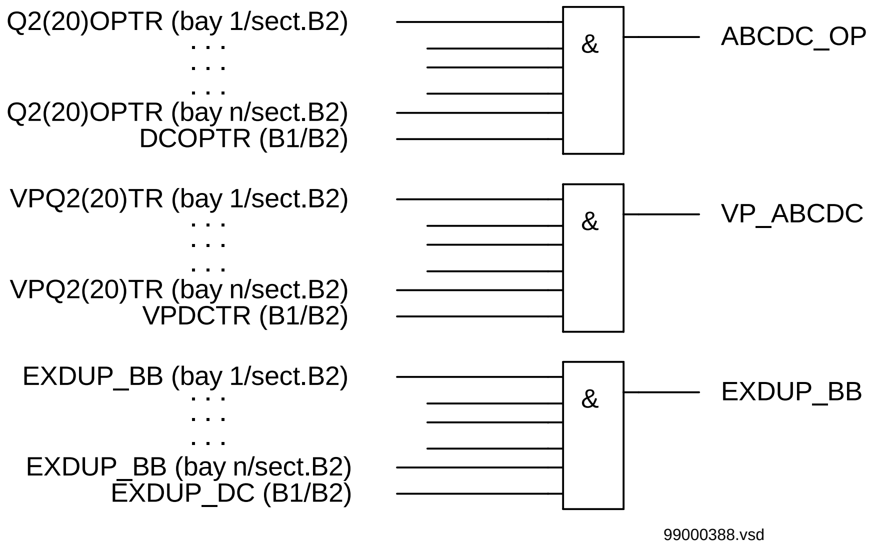


Figure 214: Signals from any bays in section B2 to a busbar earthing switch in the same section

For a busbar earthing switch on bypass busbar C, these conditions are valid:

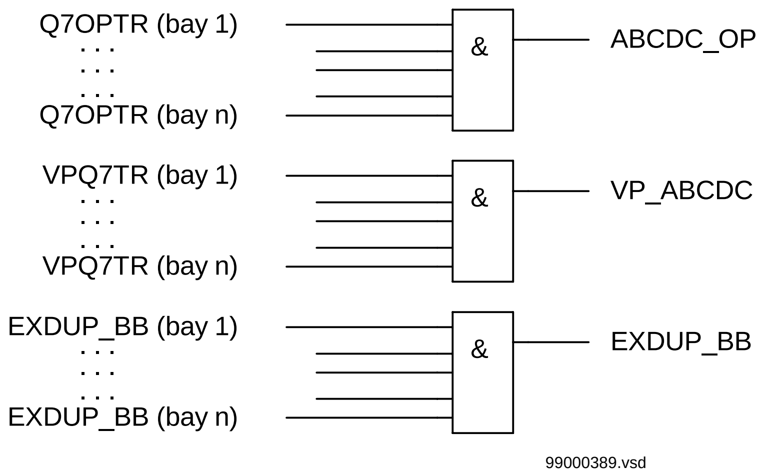


Figure 215: Signals from bypass busbar to busbar earthing switch

Signals in double-breaker arrangement

The busbar earthing switch is only allowed to operate if all disconnectors of the bus section are open.

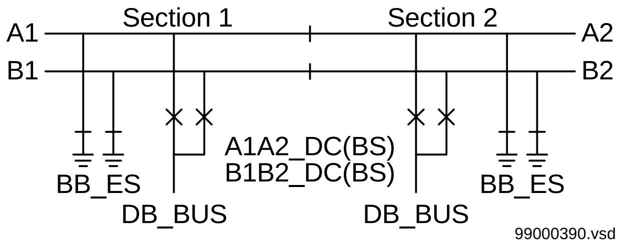


Figure 216: Busbars divided by bus-section disconnectors (circuit breakers)

To derive the signals:

Signal	
ABCDC_OP	Signal if all disconnectors of this busbar section are open.
VP_ABCDC	The switch status of ABCDC is valid.
EXDUP_BB	Signal if there is no transmission error from any bay that contains the above information.

These signals from each double-breaker bay (DB_BUS) are needed:

Signal	
Q1OPTR	Signal if Q1 is open.
Q2OPTR	Signal if Q2 is open.
VPQ1TR	The switch status of Q1 is valid.
VPQ2TR	The switch status of Q2 is valid.
EXDUP_DB	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

These signals from each bus-section disconnector bay (A1A2_DC) are also needed. For B1B2_DC, corresponding signals from busbar B are used. The same type of module (A1A2_DC) is used for different busbars, that is, for both bus-section disconnectors A1A2_DC and B1B2_DC.

Signal	
DCOPTR	Signal if the bus-section disconnector is open.
VPDCTR	The switch status of A1A2_DC is valid.
EXDUP_DC	Signal if there is no transmission error from the bay that contains the above information. This signal is taken from the data valid output on the command function block.

The logic is identical to the double busbar configuration described in "Signals in single breaker arrangement".

Signals in breaker and a half arrangement

The busbar earthing switch is only allowed to operate if all disconnectors of the bus section are open.

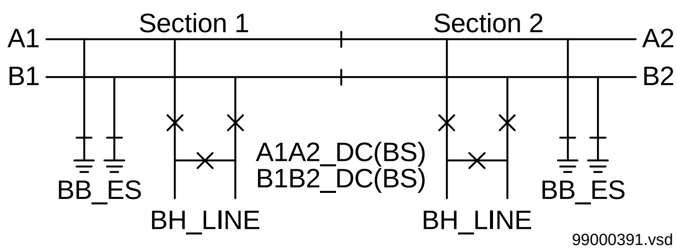


Figure 217: Busbars divided by bus-section disconnectors (circuit breakers)

The project-specific logic are the same as for the logic for the double busbar configuration described in "Signals in single breaker arrangement".

Signal	
ABCDC_OP	Signal if all disconnectors of this busbar section are open.
VP_ABCDC	The switch status of ABCDC is valid.
EXDUP_BB	Signal if there is no transmission error from any bay that contains the above information.

5.8 Interlocking for double CB bay

5.8.1 Configuration

For a double circuit-breaker bay, the modules DB_BUS_A, DB_LINE and DB_BUS_B must be used.

Parameter setting

For application without Q9 and Q8, just set the appropriate inputs to open state and disregard the outputs. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q9_OP = 1
- Q9_CL = 0

- Q8_OP = 1
- Q8_CL = 0

If, in this case, a line voltage supervision is added, then rather than setting Q9 to open state, specify the state of the voltage supervision:

- Q9_OP = VOLT_OP
- Q9_CL = VOLT_CL

If there is no voltage supervision, then set the corresponding inputs as follows:

- VOLT_OP = 1
- VOLT_CL = 0

5.9 Interlocking for 1 1/2 CB diameter

5.9.1 Configuration

For a breaker-and-a-half arrangement, the modules BH_LINE_A, BH_CONN and BH_LINE_B must be used.

Parameter setting

For application without Q9 and Q8, just set the appropriate inputs to open state and disregard the outputs. In the functional block diagram, 0 and 1 are designated 0=FIXD-OFF and 1=FIXD-ON:

- Q9_OP = 1
- Q9_CL = 0

- Q8_OP = 1
- Q8_CL = 0

If, in this case, a line voltage supervision is added, then rather than setting Q9 to open state, specify the state of the voltage supervision:

- Q9_OP = VOLT_OP
- Q9_CL = VOLT_CL

If there is no voltage supervision, then set the corresponding inputs as follows:

- VOLT_OP = 1
- VOLT_CL = 0

Chapter 10 Logic

About this chapter

This chapter describes the logic functions.

1 Trip logic (TR)

1.1 Application

All trip signals from the different protection functions shall be routed through the trip logic. In its most simple alternative the logic will only link the trip signal and assure a sufficient duration of the trip signal.

The tripping logic in REx 5xx protection, control and monitoring terminals offers three different operating modes:

- Three-phase tripping for all kinds of faults (3ph operating mode)
- Single-phase tripping for single-phase faults and three-phase tripping for multi-phase and evolving faults (1ph/3ph operating mode). The logic also issues a three-phase tripping command when phase selection within the operating protection functions is not possible, or when external conditions request three-phase tripping.
- Single-phase tripping for single-phase faults, two-phase tripping for ph-ph and ph-ph-E faults and three-phase tripping for three-phase faults (1ph/2ph/3ph operating mode). The logic also issues a three-phase tripping command when phase selection within the operating protection functions is not possible or at evolving multi-phase faults.

The three phase trip for all faults gives a simple solution and is often sufficient in well meshed transmission systems and in sub-transmission systems.

As most faults, especially on the highest voltage levels, are single phase to earth faults, single phase tripping can be of great value. If the faulted phase is tripped only, power can be transferred on the line also during the dead time before reclosing. The single phase tripping at single phase faults must be combined with single pole reclosing.

Two phase tripping can be valuable on lines running parallel to each other.

1.2 Functionality

The minimum duration of a trip output signal from the TR function is 150ms. This is to secure the fault clearance.

The three-pole TR function has a single input through which all trip output signals from the protection functions within the terminal, or from external protection functions via one or more of the terminal’s binary inputs, are routed. It has a single trip output for connection to one or more of the terminal’s binary outputs, as well as to other functions within the terminal requiring this signal.

The expanded TR function for single- and two-pole tripping has additional phase segregated inputs for this, as well as inputs for faulted phase selection. The latter inputs enable single- and two-pole tripping for those functions which do not have their own phase selection capability, and therefore which have just a single trip output and not phase segregated trip outputs for routing through the phase segregated trip inputs of the expanded TR function. Examples of such protection functions are the residual overcurrent protections. The expanded TR function has two inputs for these functions, one for impedance tripping (e.g. carrier-aided tripping commands from the scheme communication logic), and one for earth fault tripping (e.g. tripping output from a residual overcurrent protection). Additional logic secures a three-pole final trip command for these protection functions in the absence of the required phase selection signals.

The expanded TR function has three trip outputs, one per phase, for connection to one or more of the terminal’s binary outputs, as well as to other functions within the terminal requiring these signals. There are also separate output signals indicating single pole, two pole or three pole trip. These signals are important for the cooperation with the auto-reclosing function.

The expanded TR function is equipped with logic which secures correct operation for evolving faults as well as for reclosing on to persistent faults. A special input is also provided which disables single- and two-pole tripping, forcing all tripping to be three-pole.

1.3 Design

The function consists of the following basic logic parts:

- A three-phase front logic that is activated when the terminal is set into exclusive three-phase operating mode.
- A phase segregated front logic that is activated when the terminal is in 1ph/3ph or 1ph/2ph/3ph operating mode.
- An additional logic for evolving faults and three-phase tripping when the function operates in 1ph/3ph operating mode.
- An additional logic for evolving faults and three-phase tripping when the function operates in 1ph/2ph/3ph operating mode.
- The final tripping circuits.

Three-phase front logic

Figure 218 shows a simplified block diagram of a three-phase front logic. Descriptions of different signals are available in signal list.

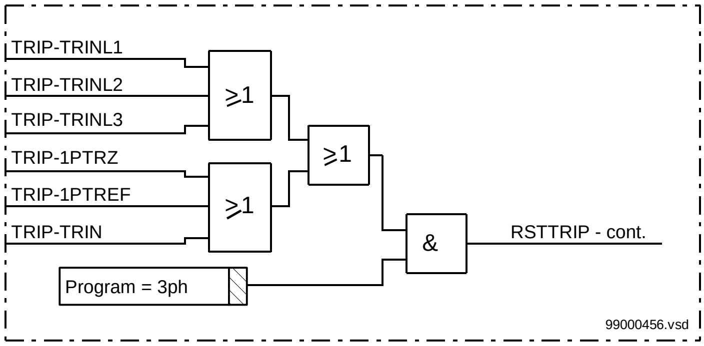


Figure 218: Three-phase front logic - simplified logic diagram

Any of active functional input signals activates the RSTTRIP internal signal, which influences the operation of the final tripping circuits.

Phase segregated front logic

The following input signals to the single-phase front logic influence the single-phase tripping of the terminal (see figure 219):

- Phase related tripping signals from different built-in protection functions that can operate on a phase segregated basis and are used in the terminal. The output signals of these functions should be configured to the TRIP-TRINLn (n = 1...3) functional inputs.
- Internal phase-selective tripping signals from different phase selection functions within the terminal, like PHS (phase selection for distance protection) or GFC (general fault criteria). The output signals of these functions should be configured to the TRIP-PSLn (n = 1...3) functional inputs. It is also possible to connect to these functional inputs different external phase selection signals.
- Single-phase tripping commands from line distance protection or carrier aided tripping commands from scheme communication logic for distance protection, which initiate single-phase tripping. These signals should be configured to the TRIP-1PTRZ functional input. It is also possible to configure a tripping output from an earth-fault overcurrent protection, to initiate the single-pole trip in connection with some external phase selection function. This signal should be configured to the TRIP-1PTREF functional input.

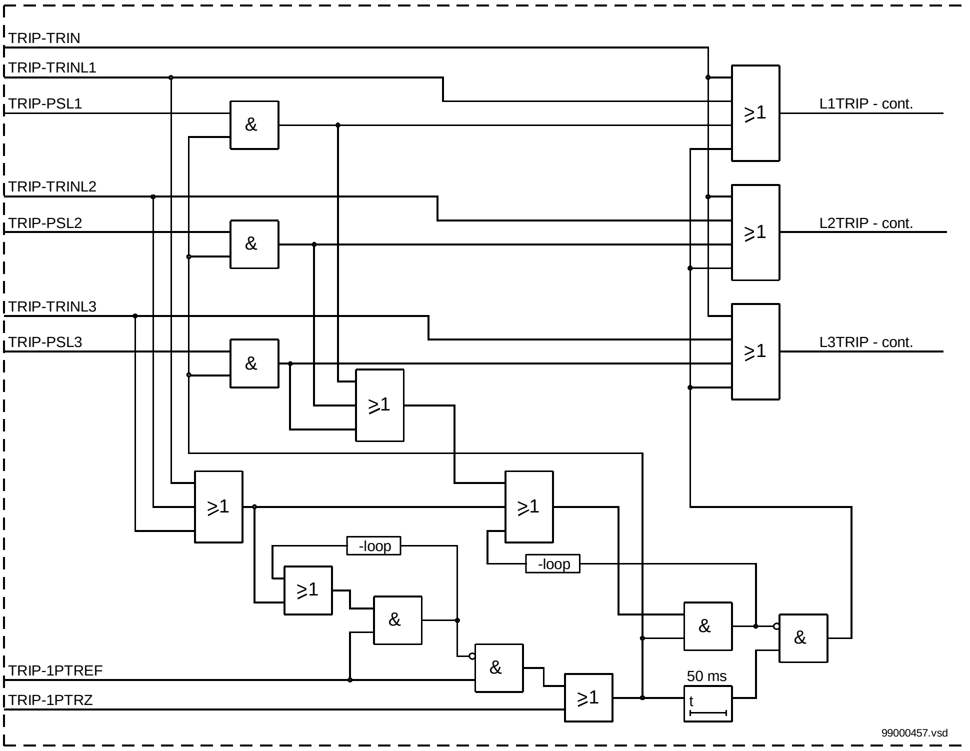


Figure 219: Phase segregated front logic

The TRIP-1PTRZ signal enables tripping corresponding to phase selection signals without any restriction while any phase selective external tripping signals prevent such tripping from the TRIP-1PTREF signal.

If any of these signals continues for more than 50 ms without the presence of any phase selection signals, three-phase tripping command is issued.

It is possible to configure the TRIP-1PTREF signal to the output signal of the EF---TRIP overcurrent, earth-fault, protection function (directional and nondirectional). This enables single-phase tripping when the faulty phase is detected by some other phase-selection element such as the phase selection in distance protection.

Additional logic for 1ph/3ph operating mode

Figure 220 presents the additional logic when the trip function is in 1ph/3ph operating mode. A TRIP-P3PTR functional input signal activates a three pole tripping if at least one phase within the front logic initiates a trip command.

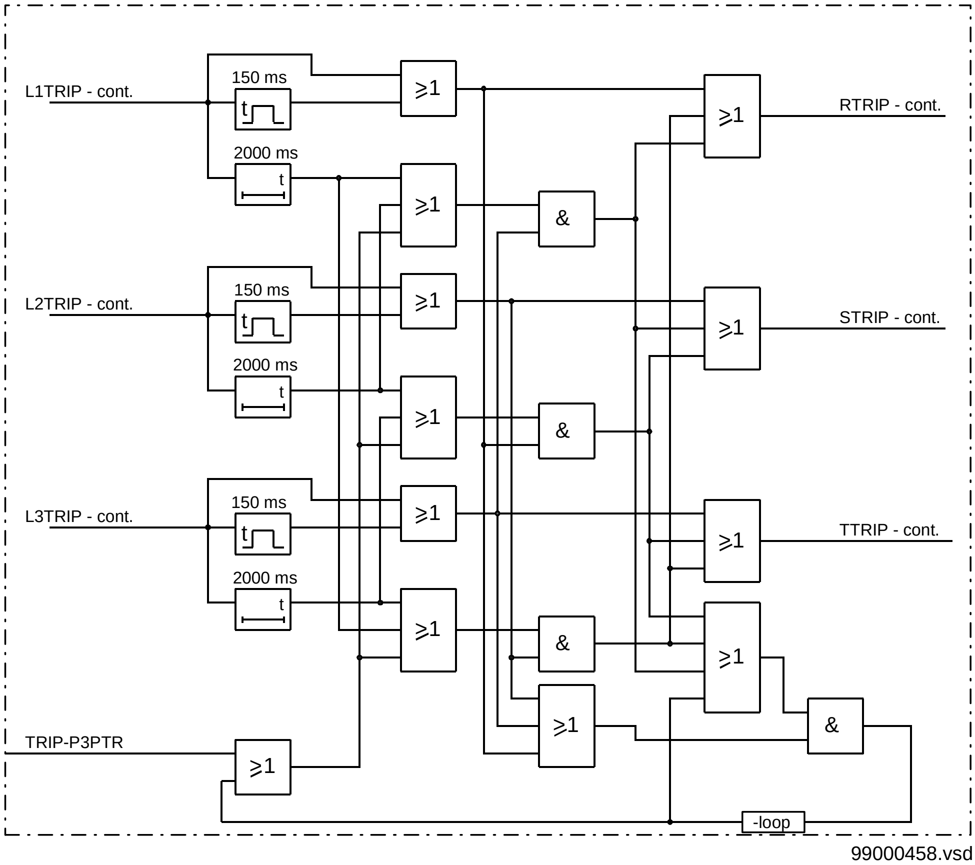


Figure 220: Additional logic for the 1ph/3ph operating mode

If only one of internal signals LnTRIP is present without the presence of a TRIP-P3PTR signal, a single pole tripping information is send to the final tripping circuits. A three-phase tripping command is initiated in all other cases.

Built-in drop-off delayed (two second) timers secure a three-phase tripping for evolving faults if the second fault occurs in different phase than the first one within a two second interval after initiation of a first tripping command.

Additional logic for 1ph/2ph/3ph operating mode

Figur 220 presents the additional logic, when the trip function is in 1ph/2ph/3ph operating mode. A TRIP-P3PTR functional input signal activates a three pole tripping if at least one phase within the front logic initiates a trip command.

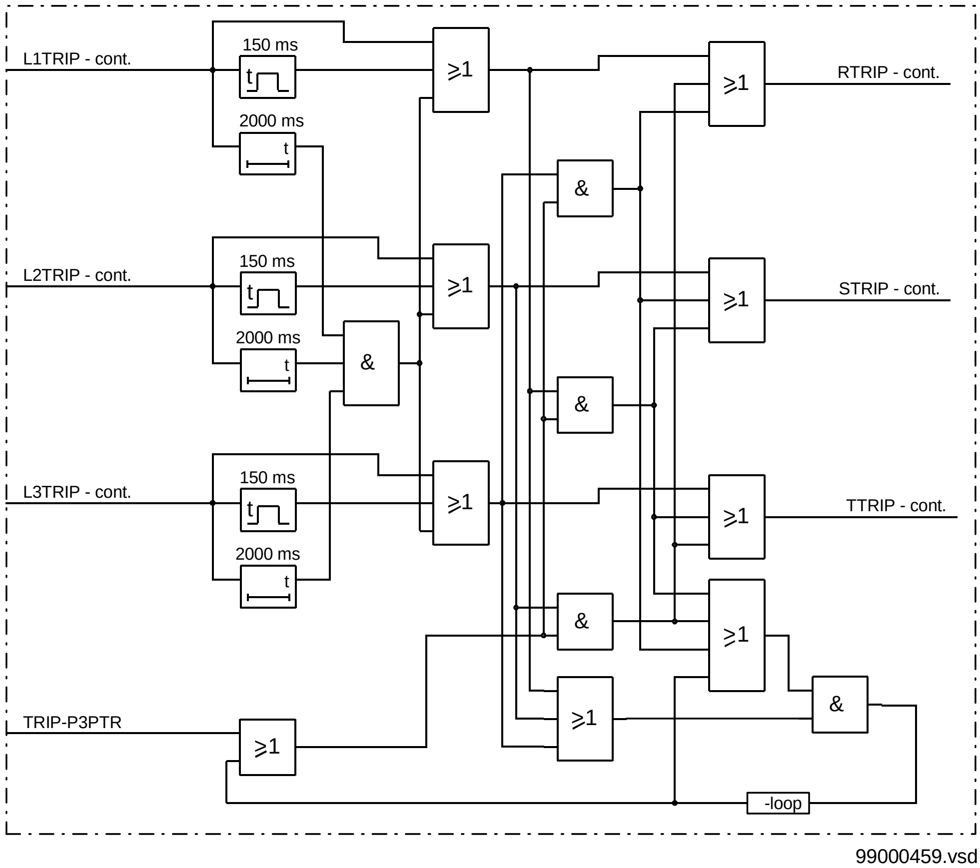


Figure 221: Additional logic for the 1ph/2ph/3ph operating mode

The logic initiates a single-phase tripping information to the final logic circuits, if only one of internal input signals (LnTRIP) is active. A two phase tripping information is send in case, when two out of three input signals LnTRIP are active. A three phase tripping information requires all three LnTRIP input signals to be active.

The built in drop-off delayed (two seconds) timers secure correct three-phase tripping information, when the faults are detected within two seconds in all three phases.

Final tripping circuits

Figur 222 present the final tripping circuits for a tripping function within the REx 5xx terminals. The TRIP-BLOCK functional input signal can block the operation of a function, so that no functional output signals become logical one. Detailed explanation of functional output signals is available in signal list.

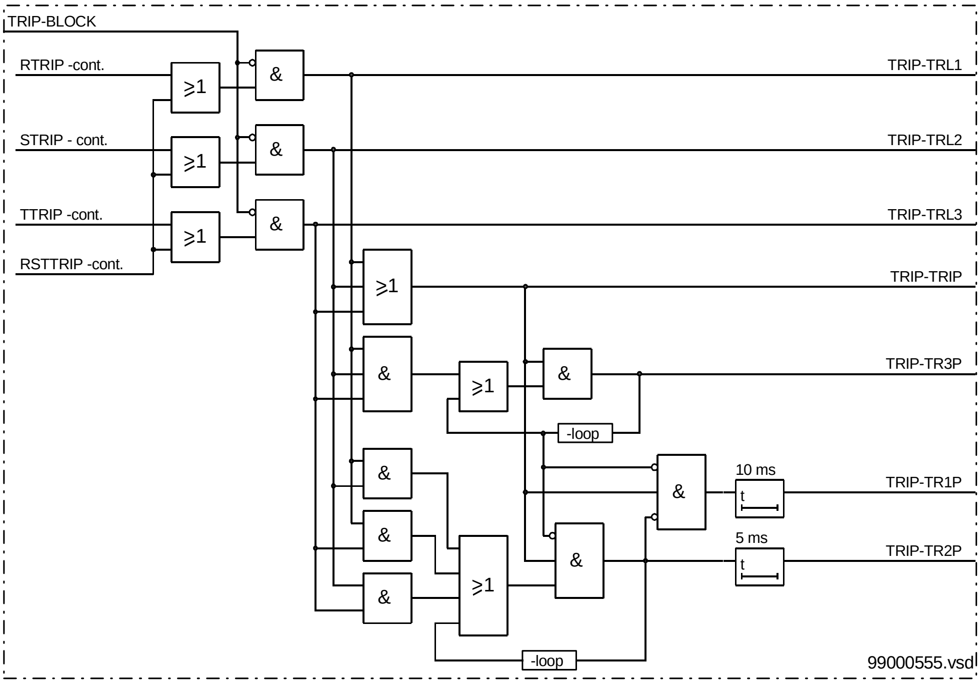


Figure 222: Final tripping circuits

2 Pole discordance protection (PD)

2.1 Application

Circuit breaker pole position discordance can occur on the operation of a breaker with independent operating gears for the three poles. The reason may be an interruption in the trip coil circuits, or a mechanical failure resulting in a stuck breaker pole. A pole discordance can be tolerated for a limited time, for instance during a single-phase trip-auto-reclose cycle.

The pole discordance logic (PD) detects a breaker pole position discrepancy not generated by a single pole reclosing and generates a three phase command trip to the circuit breaker itself.

2.2 Functionality

2.2.1 Functionality for current and contact based pole discordance

The operation of the current and contact based pole discordance function is based on checking the position of the circuit breaker and in parallel making a comparison between the phase currents.

The contact based function checks the position of the circuit breaker through six of its auxiliary contacts: three parallel connected normally open contacts are connected in series with three parallel connected normally closed contacts. This hard-wired logic is very often integrated in the circuit breaker control cabinets and gives a closed signal in case of pole discordance in the circuit breaker. This signal is connected to the PD---POLDISC input of the pole discordance function. If the function is enabled, after a short delay, the activation of this input causes a trip command (PD---TRIP).

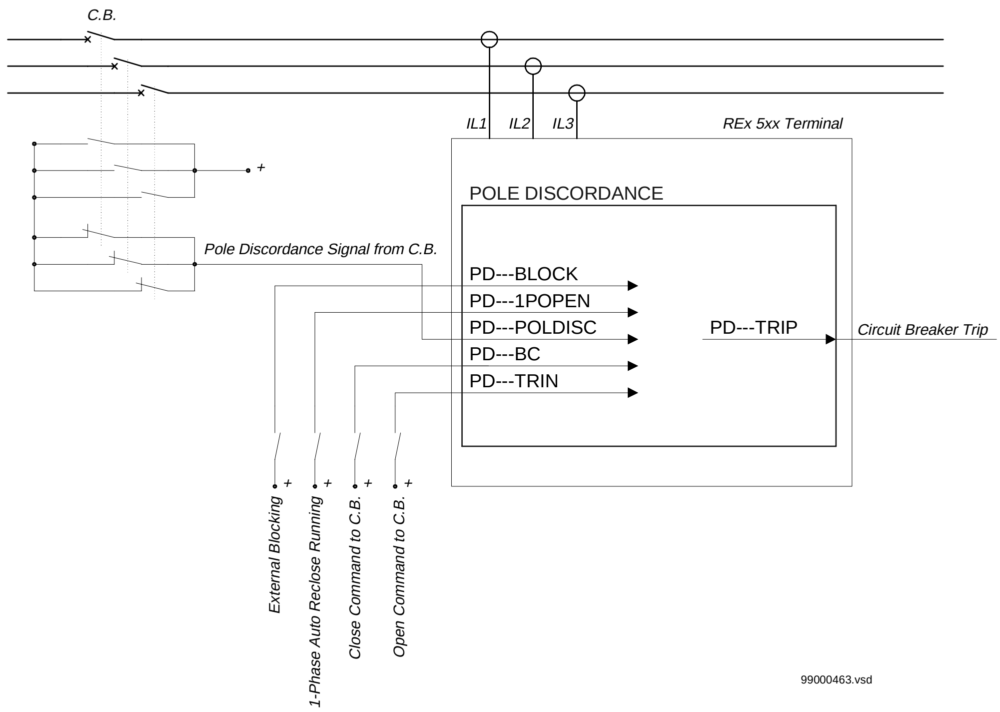


Figure 223: Typical connection diagram for pole discordance function - contact and current based

The current based function performs a parallel detection of pole discordance based on current comparison in the breaker poles. This current based detection is enabled only for a short time after the breaker has received a closing or opening command in order to avoid unwanted operation in case of unsymmetrical load in service. If the circuit breaker has received a command (open or close), the PD function is enabled, and the current conditions are fulfilled, then a trip command is generated from the pole discordance function (PD---TRIP) after a short delay.

Figure 223 shows the typical application connection for the current and contact based pole discordance function.

2.3 Design

The simplified block diagram of the current and contact based pole discordance function is shown in figure 224.

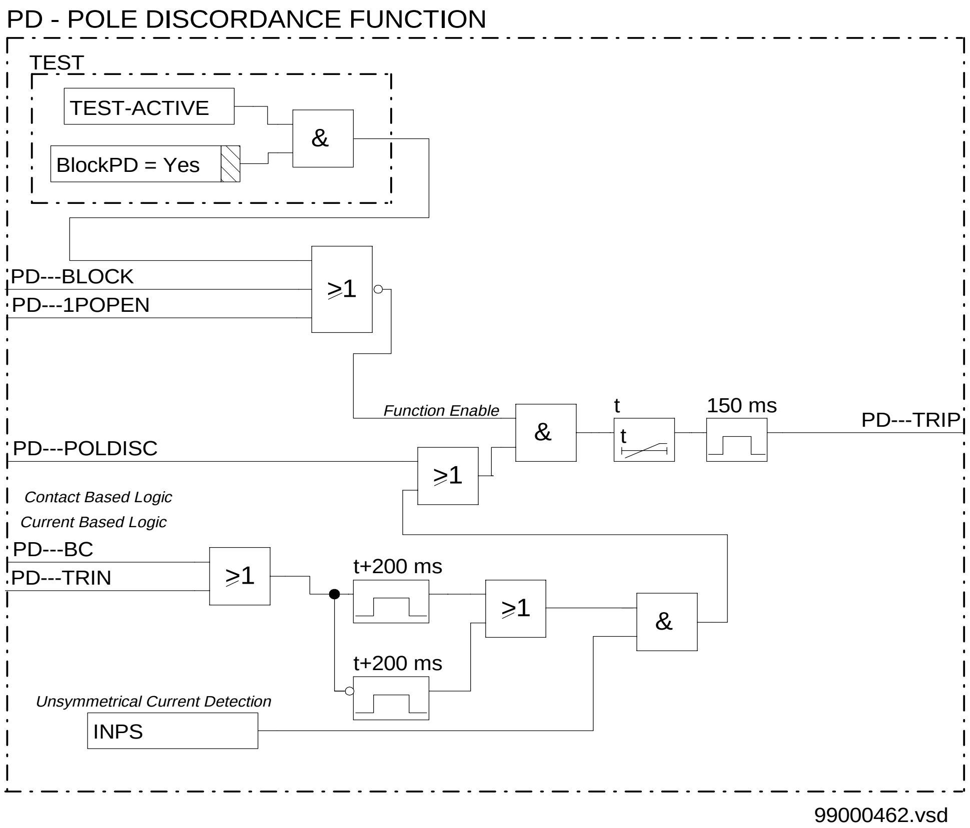


Figure 224: Simplified block diagram of pole discordance function - contact and current based

The pole discordance function is disabled if:

- The terminal is in TEST status (TEST-ACTIVE is high) and the function has been blocked from the HMI (BlockPD=Yes)
- The input signal PD---BLOCK is high
- The input signal PD---1POPEN is high

The PD---BLOCK signal is a general purpose blocking signal of the pole discordance function. It can be connected to a binary input of the terminal in order to receive a block command from external devices or can be software connected to other internal functions of the terminal itself in order to receive a block command from internal functions. Through OR gate it can be connected to both binary inputs and internal function outputs.

The PD---1POPEN signal blocks the pole discordance operation when a single phase auto-reclosing cycle is in progress. It can be connected to the output signal AR01-1PT1 if the autoreclosing function is integrated in the terminal; if the auto-reclosing function is an external device, then PD---1POPEN has to be connected to a binary input of the terminal and this binary input is connected to a signallisation “1phase auto-reclosing in progress” from the external auto-reclosing device.

If the pole discordance function is enabled, then two different criteria will generate a trip signal (PD---TRIP):

- Pole discordance signalling from the circuit breaker.
- Unsymmetrical current detection.

Pole discordance signalling from circuit breaker

If one or two poles of the circuit breaker have failed to open or to close (pole discordance status), then the function input PD---POLDISC is activated from the pole discordance signal derived from the circuit breaker auxiliary contacts (one NO contact for each phase connected in parallel, and in series with one NC contact for each phase connected in parallel) and, after a settable time interval t (0-60 s), a 150 ms trip pulse command (PD---TRIP) is generated by the pole discordance function.

Unsymmetrical current detection

The unsymmetrical current detection is based on the checking that:

- any phase current is lower than 80% of the highest current in the remaining two phases
- the highest phase current is greater than 10% of the rated current

If these conditions are true, an unsymmetrical condition is detected and the internal signal INPS is turned high. This detection is enabled to generate a trip after a set time delay t (0-60 s) if the detection occours in the next 200 ms after the circuit breaker has received a command to open trip or close and if the unbalance persists. The 200 ms limitation is for avoiding unwanted operation during unsymmetrical load conditions.

The pole discordance function is informed that a trip or close command has been given to the circuit breaker through the inputs PD---BC (for closing command information) and PD---TRIN (for opening command information). These inputs can be connected to terminal binary inputs if the information are generated from the field (i.e. from auxiliary contacts of the close and open push buttons) or may be software connected to the outputs of other integrated functions (i.e. close command from a control function or a general trip from integrated protections).

2.4 Calculations

2.4.1 Setting instructions

The setting parameters are accessible through the HMI. The parameters for the pole discordance function are found in the HMI-tree under:

Settings
  Functions
    Group 1,2,3 and 4
      PoleDiscord

The parameters and their setting ranges are shown in the appendix.

Comments regarding settings:

Operation:	Pole discordance protection On/Off. Activation or de-activation of the function.
Time delay , t:	Delay timer. The time delay is not critical because the pole discordance function operates mainly with load conditions. If only the contact based function is used, the time delay should be chosen between 0.5 and 1 s.If also the current detection function is used, it is recommended to set the time delay at 3-4 s, depending on the application, in order for the unbalance to stabilize. The setting range of the time delay is 0 - 60 s.

3 Binary signal transfer to remote end (RTC)

3.1 Application

The binary signal transfer function is preferably used for sending communication scheme related signals, transfer trip and/or other binary signals required at the remote end. Up to 32 selectable binary send signals, internal or external, and 32 selectable binary receive signals can be transmitted.

Together with the binary signals internal to the terminal, the function is utilising binary inputs and outputs. The function can be provided with various 56/64 kbit/s communication modules for optical fibre or galvanic connection.

The communication can be done via direct galvanic communication line for shorter distances, via dedicated optical fibres up to around 30 km and via a communication network for longer distances.

3.2 Design

The function Binary signal transfer to remote end consists of two function blocks, RTC1 and RTC2, each handling 16 inputs (SEND01-16) and 16 outputs (REC01-16). Figure 225 shows the signal diagram for RTC1. This diagram is also valid for RTC2 since the signal inputs and outputs are the same.

A signal applied to an input of one function block, eg. RTC1-SEND01, in one terminal will be transmitted, via a data communication link, to a remote terminal and there appear at the corresponding output of the corresponding function block, that is in the example RTC1-REC01. The transmission takes 10 - 25 ms plus communication link delay. No additional security actions to that included in the communication handling, that is CRC-check, checking length of telegram and addressing, is incorporated.

Both function blocks have an input BLOCK, which is available to block the operation. When the input is energized, all 16 binary input signals of that function block will be sent as zeroes. Incoming signals from remote end are not affected.

An output COMFAIL is also available to announce an alarm when there is a failure in the communication with the remote terminal. The COMFAIL for both function blocks works in parallel so information will appear simultaneously on both function blocks. At COMFAIL all 16 output signal on both function blocks will be set to zero.

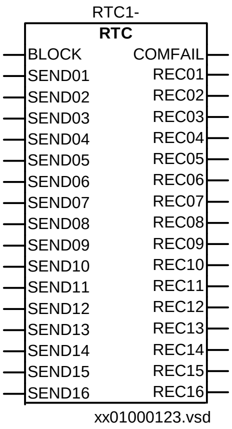


Figure 225: Binary signal transfer to remote end RTC1, signal inputs and outputs

User defined names can be applied to the inputs and outputs.These identities are set from the configuration tool CAP 531.

A service report provides information of the status of all function block outputs as well as inputs. The status can be viewed on the local HMI under:

ServiceReport
I/O
RemTermCom1
RemTermCom2

Remote end data communication

The “Binary signal transfer to remote end” function uses the same communication functionality and hardware for communication with remote end as used for the line differential function. These items are described in the chapter “Data communication” in the application maual. The settings that has to be made for these items are also desribed in each chapter respectively.

Status information of the Remote end data communication is available on the local HMI under:

TerminalReport
SelfSuperv
RemTermCom

4 Event function (EV)

4.1 Application

When using a Substation Automation system, events can be spontaneously sent or polled from the terminal to the station level. These events are created from any available signal in the terminal that is connected to the event function block. The event function block can also handle double indication, that is normally used to indicate positions of high-voltage apparatuses. With this event function block, data also can be sent to other terminals over the interbay bus.

4.2 Functionality

The events can be created from both internal logical signals and binary input channels. The internal signals are time tagged in the main processing module, while the binary input channels are time tagged directly on each I/O module. The events are produced according to the set event masks. The event masks are treated commonly for both the LON and SPA channels. All events according to the event mask are stored in a buffer, which contains up to 1000 events. If new events appear before the oldest event in the buffer is read, the oldest event is overwritten and an overflow alarm appears.

The outputs from the event function block are formed by the reading of status and events by the station HMI on either every single input or double input. The user-defined name for each input is intended to be used by the station HMI.

Twelve of the event function blocks are executed with fast cyclicity. That means that the time-tagging resolution on the events that are emerging from internal logical signals, created from configurable logic, is the same as the cyclicity of this logic. The time tagging resolution on the events that are emerging from binary input signals have a resolution of 1 ms.

Two special signals for event registration purposes are available in the terminal, *Terminal restarted and Event buffer overflow.*

4.3 Design

General

As basic, 12 event function blocks EV01-EV12 running with a fast cyclicity, are available in REx 5xx. When the function Apparatus control is included in the terminal, additional 32 event function blocks EV13-EV44, running with a slower cyclicity, are available.

Each event function block has 16 connectables corresponding to 16 inputs INPUT1 to INPUT16. Every input can be given a name with up to 19 characters from the CAP 531 configuration tool.

The inputs can be used as individual events or can be defined as double indication events.

The inputs can be set individually from the Parameter Setting Tool (PST) under the Mask-Event function as:

- No events
- OnSet, at pick-up of the signal
- OnReset, at drop-out of the signal
- OnChange, at both pick-up and drop-out of the signal

Also an input PrColxx (xx=01-44) is available on the function block to define on which protocol the events shall be sent.

The event function blocks EV01-EV06 have inputs for information numbers and function type, which are used to define the events according to the communication standard IEC 60870-5-103.

Double indication

Double indications are used to handle a combination of two inputs at a time, for example, one input for the open and one for the close position of a circuit breaker or disconnector. The double indication consists of an odd and an even input number. When the odd input is defined as a double indication, the next even input is considered to be the other input. The odd inputs has a suppression timer to suppress events at 00 states.

To be used as double indications the odd inputs are individually set from the SMS under the Mask-Event function as:

- Double indication
- Double indication with midposition suppression

Here, the settings of the corresponding even inputs have no meaning.

These states of the inputs generate events. The status is read by the station HMI on the status indication for the odd input:

- 00 generates an intermediate event with the read status 0
- 01 generates a close event with the read status 1
- 10 generates an open event with the read status 2
- 11 generates an undefined event with the read status 3

Communication between terminals

The BOUND and INTERVAL inputs are available on the event function block.

The BOUND input set to 1 means that the output value of the event block is bound to another control terminal on the LON bus. The event function block is then used to send data over the LON bus to other REx 5xx terminals. The most common use is to transfer interlocking information between different bays. That can be performed by an event function block used as a send block and with a Multiple Command function block used as a receive block. The document *Apparatus Control* describes how to transfer the interlocking information. The configuration of the communication between control terminals is made by the LON Network Tool.

The INTERVAL input is applicable only when the BOUND input is set to 1. The INTERVAL is intended to be used for cyclic sending of data to other control terminals via the LON bus with the interval time as set. This cyclic sending of data is used as a backup of the event-driven sending, which always is performed. With cyclic sending of data, the communication can be supervised by a corresponding INTERVAL input on the Multiple Command function block in another control terminal connected to the LON bus. This INTERVAL input time is set a little bit longer than the interval time set on the event function block. With INTERVAL=0, only event-driven sending is performed.

4.4 Calculations

The event reporting can be set from the PST as:

- Use event masks
- Report no events
- Report all events

Use of event masks is the normal reporting of events, that is, the events are reported as defined in the database.

An event mask can be set individually for each available signal in the terminal. The setting of the event mask can only be performed from the PST.

All event mask settings are treated commonly for all communication channels of the terminal.

Report no events means blocking of all events in the terminal.

Report all events means that all events, that are set to OnSet/OnReset/OnChange are reported as OnChange, that is, both at set and reset of the signal. For double indications when the suppression time is set, the event ignores the timer and is reported directly. Masked events are still masked.

Parameters to be set for the event function block are:

- T_SUPRyy including the suppression time for double indications.
- NAMEyy including the name for each input.
- PrColxx including the type of protocol for sending the events.
- INTERVAL used for the cyclic sending of data.
- BOUND telling that the block has connections to other terminals over the LON bus.
- FuncTEVx (for EV01-EV06) including the function type for sending events via IEC 60870-5-103.
- InfoNoyy (for EV01-EV06) including the information number for the events sending via IEC 60870-5-103.

These parameters are set from the CAP 531 configuration tool. When the BOUND parameter is set, the settings of the event masks have no meaning.

5 Event counter (CN)

5.1 Application

The function consists of six counters which are used for storing the number of times each counter has been activated. It is also provided with a common blocking function for all six counters, to be used for example at testing. Every counter can separately be set on or off by a parameter setting.

5.2 Functionality

The function block has six inputs for increasing the counter values for each of the six counters respectively. The content of the counters are stepped one step for each positive edge of the input respectively. The maximum count up speed is 10 pulses per second. The maximum counter value is 10 000. For counts above 10 000 the counter will stop at 10 000 and no restart will take place. At power interrupt the counter values are stored.

The function block also has an input BLOCK. At activation of this input all six counters are blocked. The input can for example be used for blocking the counters at testing.

All inputs are configured via configuration tool CAP 531.

Reporting

The content of the counters can be read in the local HMI under the menu:

ServiceReport
  Functions
    Counters
      Count
        Counters

Reset of counters can be performed in the local HMI under the menu:

ServiceReport
  Functions
    Counters
      Count
        ClearCounters

Reading of content and resetting of the counters can also be performed remotely, for example via SPA-communication.

5.3 Calculations

The parameters for the counters, Operation = Off/On, are set in the local HMI under the menu:

Settings
  Functions
    Group n
      Counters

or via the PST Parameter Setting Tool.

Chapter 11 Monitoring

About this chapter

This chapter describes the monitoring functions.

1 LED indication function (HL, HLED)

1.1 Application

The LED indication module is an additional feature for the REx 500 terminals for protection and control and consists totally of 18 LEDs (Light Emitting Diodes). It is located on the front of the protection and control terminal. The main purpose is, to present on site an immediate visual information on:

- actual signals active (or not active) within the protected bay (terminal).
- alarm signals handled as a simplified alarm system.
- last operation of the terminal. Here we understand the presentation of the signals appeared during the latest start(s) or trip(s) since the previous information has been reset.

The user of this information is the technician in substation or the protection engineer during the testing activities. The protection engineer can also be able to read the status of all LEDs over the SMS in his office as well as to acknowledge/reset them locally or remotely.

1.2 Functionality

Each LED indication can be set individually to operate in six different sequences; two as follow type and four as latch type. Two of the latching types are intended to be used as a protection indication system, either in collecting or re-starting mode, with reset functionality. The other two are intended to be used as a signaling system in collecting mode with an acknowledgment functionality.

Priority

Each LED can show green, yellow or red light, each with its own activation input. If more than one input is activated at the time a priority is used with green as lowest priority and red as the highest.

Operating modes

Collecting mode

LEDs which are used in collecting mode of operation are accumulated continuously until the unit is acknowledged manually. This mode is suitable when the LEDs are used as a simplified alarm system.

Re-starting mode

In the re-starting mode of operation each new start resets all previous active LEDs and activates only those which appear during one disturbance. Only LEDs defined for re-starting mode with the latched sequence type 6 (LatchedReset-S) will initiate a reset and a restart at a new disturbance. A disturbance is defined to end a settable time after the reset of the activated input signals or when the maximum time limit has been elapsed.

Acknowledgment/reset

From local HMI

The active indications can be acknowledged/reset manually. Manual acknowledgment and manual reset have the same meaning and is a common signal for all the operating sequences and LEDs. The function is positive edge triggered, not level triggered. The acknowledgment/reset is performed via the C-button on the Local HMI according to the sequence in figure 226.

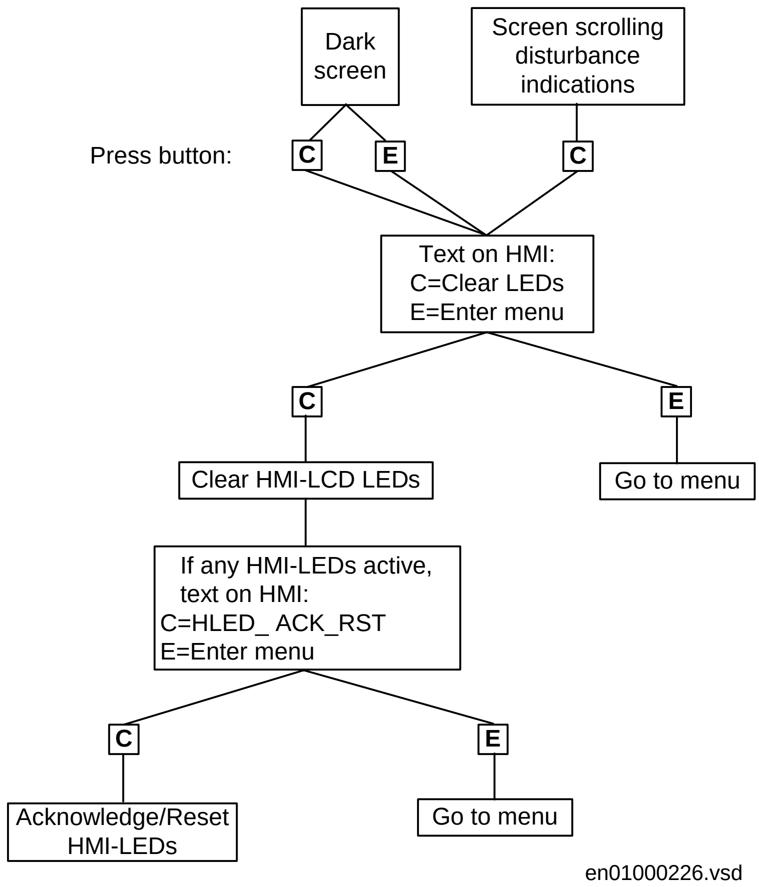


Figure 226: Acknowledgment/reset from local HMI

From function input

The active indications can also be acknowledged/reset from an input (ACK_RST) to the function. This input can for example be configured to a binary input operated from an external push button. The function is positive edge triggered, not level triggered. This means that even if the button is continuously pressed, the acknowledgment/reset only affects indications active at the moment when the button is first pressed.

From SMS/SCS

It is also possible to perform the acknowledgment/reset remotely from SMS/SCS. To do that, the function input (ACK_RST) has to be configured to an output of a command function block (CD or CM). The output from these command function blocks can then be activated from the SMS/SCS.

Automatic reset

The automatic reset can only be performed for indications defined for re-starting mode with the latched sequence type 6 (LatchedReset-S). When the automatic reset of the LEDs has been performed, still persisting indications will be indicated with a steady light.

Operating sequences

The sequences can be of type Follow or Latched. For the Follow type the LED follow the input signal completely. For the Latched type each LED latches to the corresponding input signal until it is reset.

The figures below show the function of available sequences selectable for each LED separately. For sequence 1 and 2 (Follow type), the acknowledgment/reset function is not applicable. Sequence 3 and 4 (Latched type with acknowledgement) are only working in collecting mode. Sequence 5 is working according to Latched type and collecting mode while sequence 6 is working according to Latched type and re-starting mode. The letters S and F in the sequence names have the meaning S = Steady and F = Flash.

At the activation of the input signal, the indication obtains corresponding color corresponding to the activated input and operates according to the selected sequence diagrams below.

In the sequence diagrams the LEDs have the following characteristics:

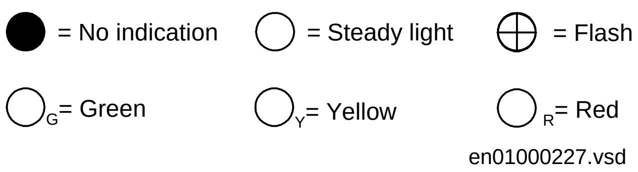


Figure 227: Symbols used in the sequence diagrams

Sequence 1 (Follow-S)

This sequence follows all the time, with a steady light, the corresponding input signals. It does not react on acknowledgment or reset. Every LED is independent of the other LEDs in its operation.

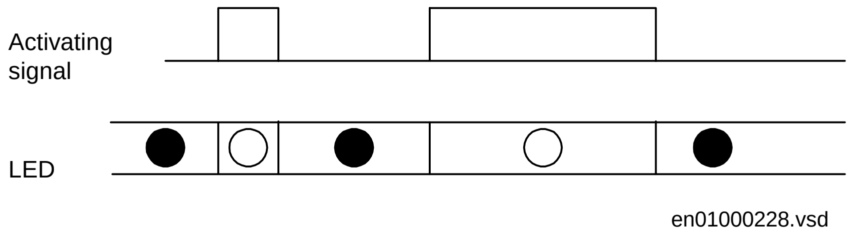


Figure 228: Operating sequence 1 (Follow-S)

If inputs for two or more colors are active at the same time to one LED the priority is as described above. An example of the operation when two colors are activated in parallel is shown in figure 229.

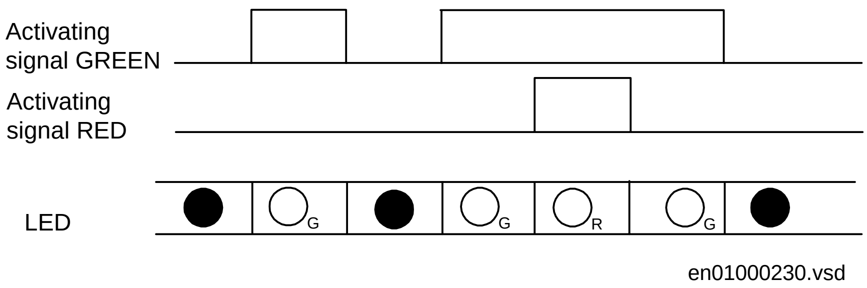


Figure 229: Operating sequence 1, two colors

Sequence 2 (Follow-F)

This sequence is the same as sequence 1, Follow-S, but the LEDs are flashing instead of showing steady light.

Sequence 3 (LatchedAck-F-S)

This sequence has a latched function and works in collecting mode. Every LED is independent of the other LEDs in its operation. At the activation of the input signal, the indication starts flashing. After acknowledgment the indication disappears if the signal is not present any more. If the signal is still present after acknowledgment it gets a steady light.

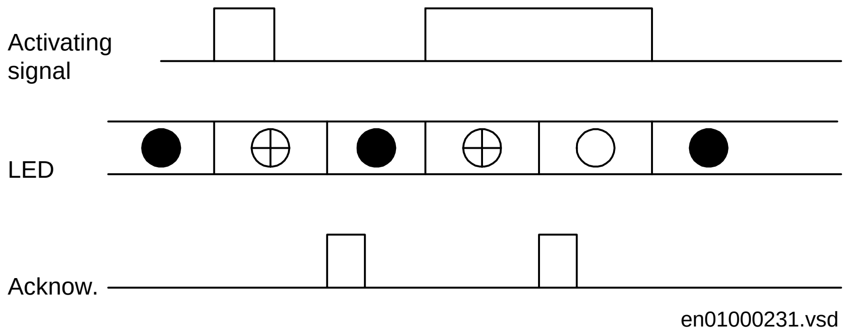


Figure 230: Operating sequence 3 (LatchedAck-F-S)

When an acknowledgment is performed, all indications that appear before the indication with higher priority has been reset, will be acknowledged, independent of if the low priority indication appeared before or after acknowledgment. In figure 231 is shown the sequence when a signal of lower priority becomes activated after acknowledgment has been performed on a higher priority signal. The low priority signal will be shown as acknowledged when the high priority signal resets.

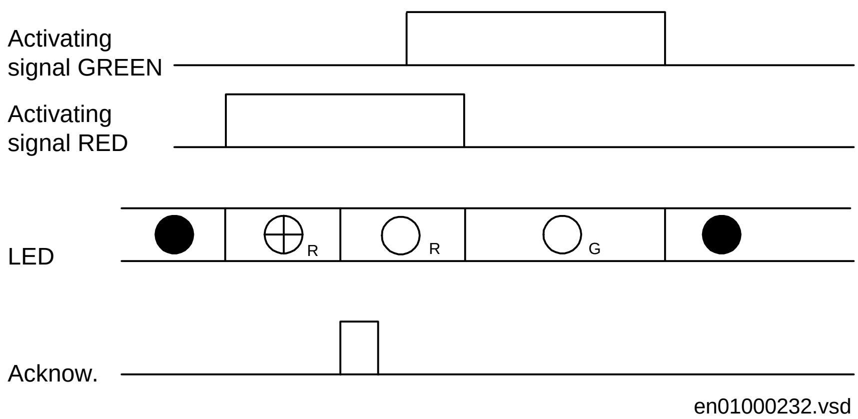


Figure 231: Operating sequence 3, two colors involved

If all three signals are activated the order of priority is still maintained. Acknowledgment of indications with higher priority will acknowledge also low priority indications which are not visible according to figure 232.

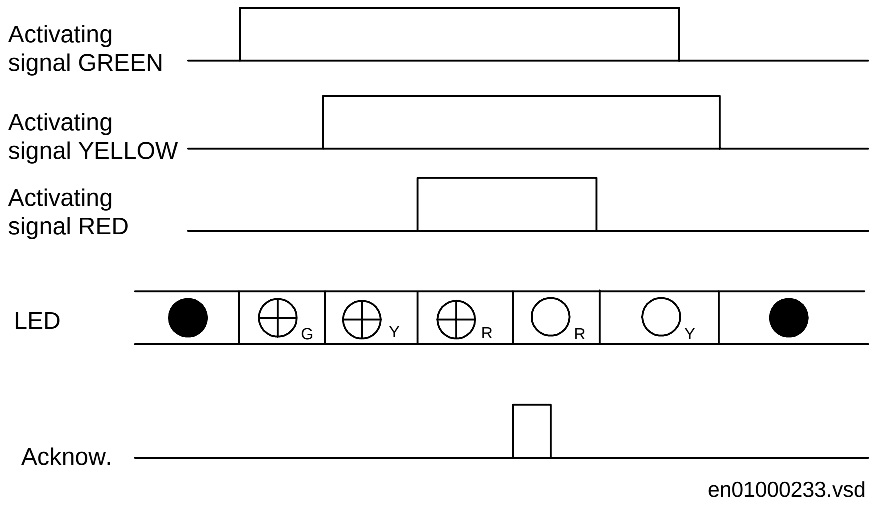


Figure 232: Operating sequence 3, three colors involved, alternative 1

If an indication with higher priority appears after acknowledgment of a lower priority indication the high priority indication will be shown as not acknowledged according to figure 233.

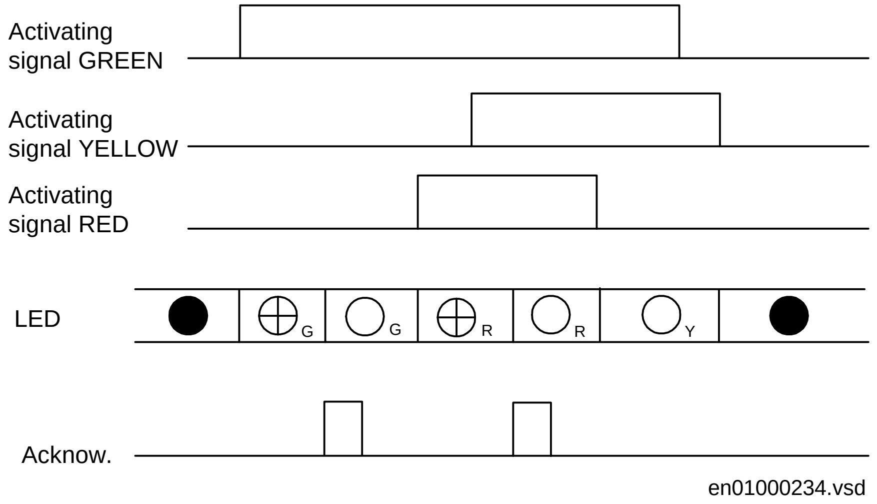


Figure 233: Operating sequence 3, three colors involved, alternative 2

Sequence 4 (LatchedAck-S-F)

This sequence has the same functionality as sequence 3, but steady and flashing light have been alternated.

Sequence 5 (LatchedColl-S)

This sequence has a latched function and works in collecting mode. At the activation of the input signal, the indication will light up with a steady light. The difference to sequence 3 and 4 is that indications that are still activated will not be affected by the reset i.e. immediately after the positive edge of the reset has been executed a new reading and storing of active signals is performed. Every LED is independent of the other LEDs in its operation.

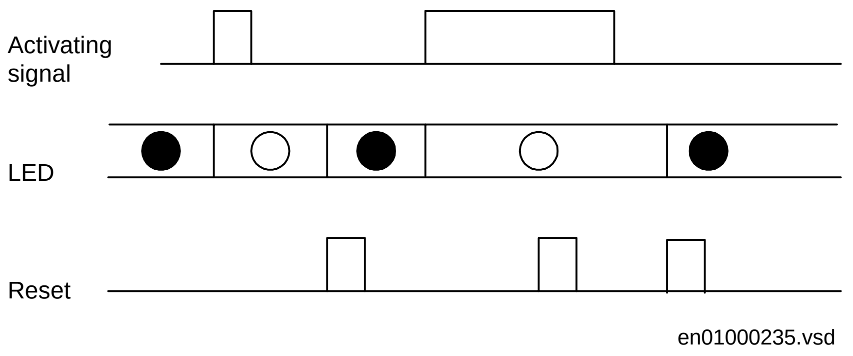


Figure 234: Operating sequence 5 (LatchedColl-S)

That means if an indication with higher priority has reset while an indication with lower priority still is active at the time of reset, the LED will change color according to figure 235.

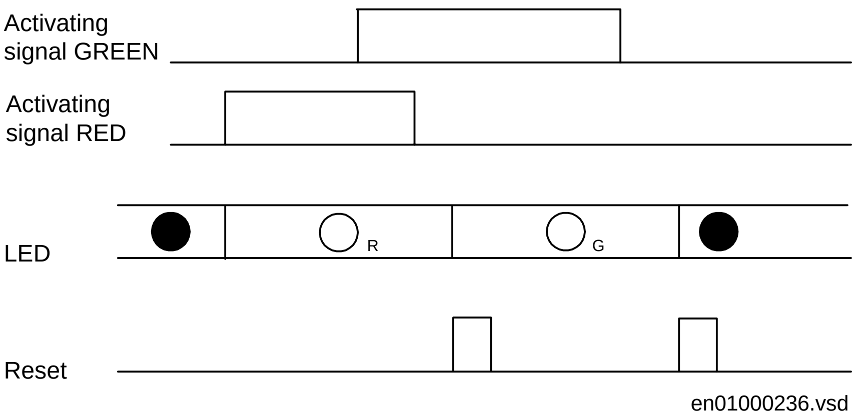


Figure 235: Operating sequence 5, two colors

Sequence 6 (LatchedReset-S)

In this mode all activated LEDs, which are set to sequence 6 (LatchedReset-S), are automatically reset at a new disturbance when activating any input signal for other LEDs set to sequence 6 (LatchedReset-S). Also in this case indications that are still activated will not be affected by manual reset, i.e. immediately after the positive edge of that the manual reset has been executed a new reading and storing of active signals is performed. LEDs set for sequence 6 are completely independent in its operation of LEDs set for other sequences.

Definition of a disturbance

A disturbance is defined to last from the first LED set as LatchedReset-S is activated until a settable time, tRestart, has elapsed after that all activating signals for the LEDs set as LatchedReset-S have reset. However if all activating signals have reset and some signal again becomes active before tRestart has elapsed, the tRestart timer does not restart the timing sequence. A new disturbance start will be issued first when all signals have reset after tRestart has elapsed. A diagram of this functionality is shown in figure 236.

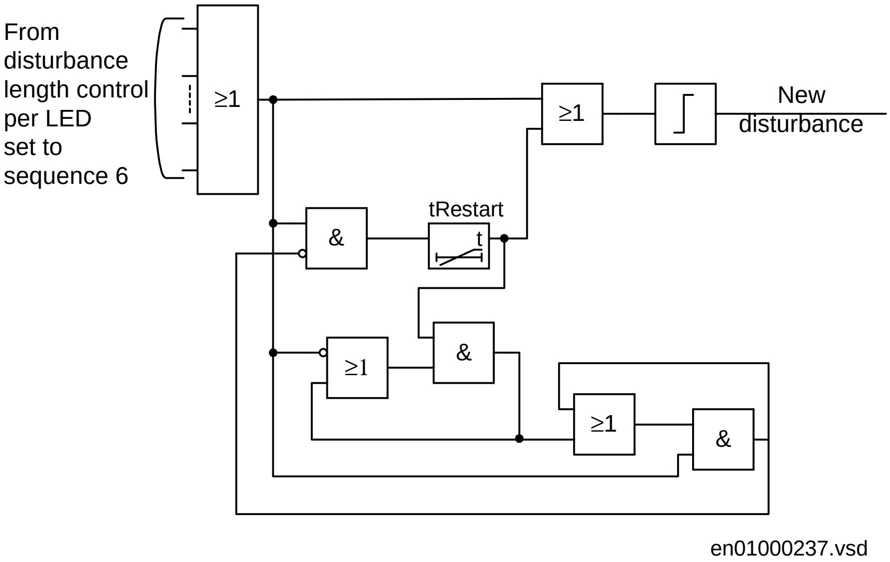


Figure 236: Activation of new disturbance

In order not to have a lock-up of the indications in the case of a persisting signal each LED is provided with a timer, tMax, after which time the influence on the definition of a disturbance of that specific LED is inhibited. This functionality is shown i diagram in figure 237.

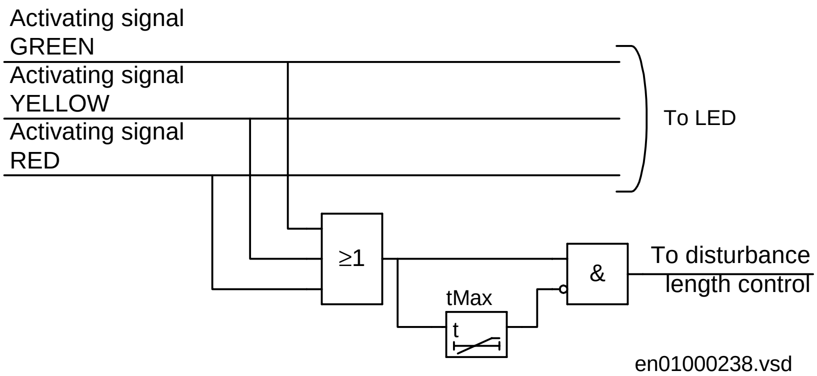


Figure 237: Length control of activating signals

Timing diagram for sequence 6

Figure 238 shows the timing diagram for two indications within one disturbance.

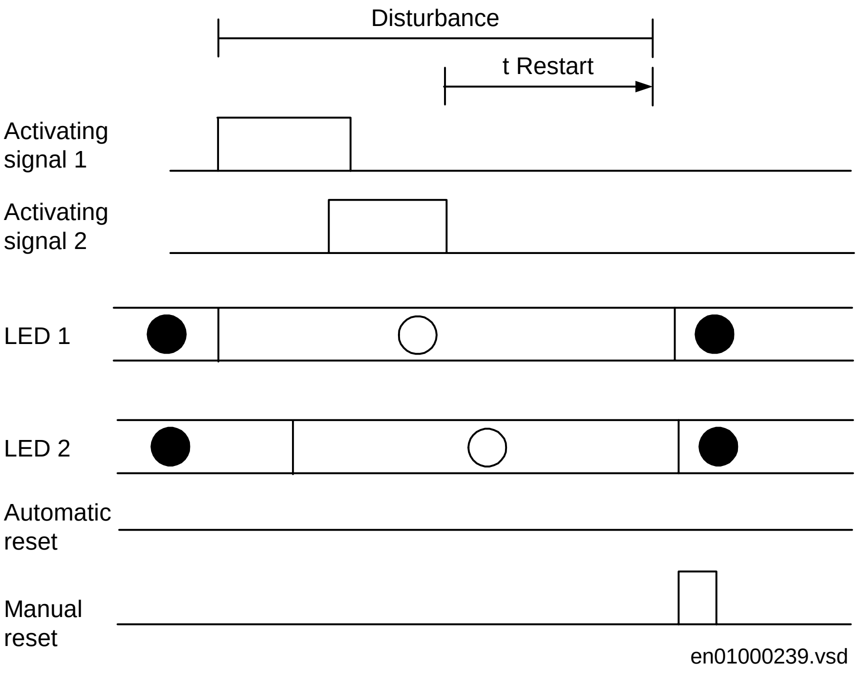


Figure 238: Operating sequence 6 (LatchedReset-S), two indications within same disturbance

Figure 239 shows the timing diagram for a new indication after tRestart time has elapsed.

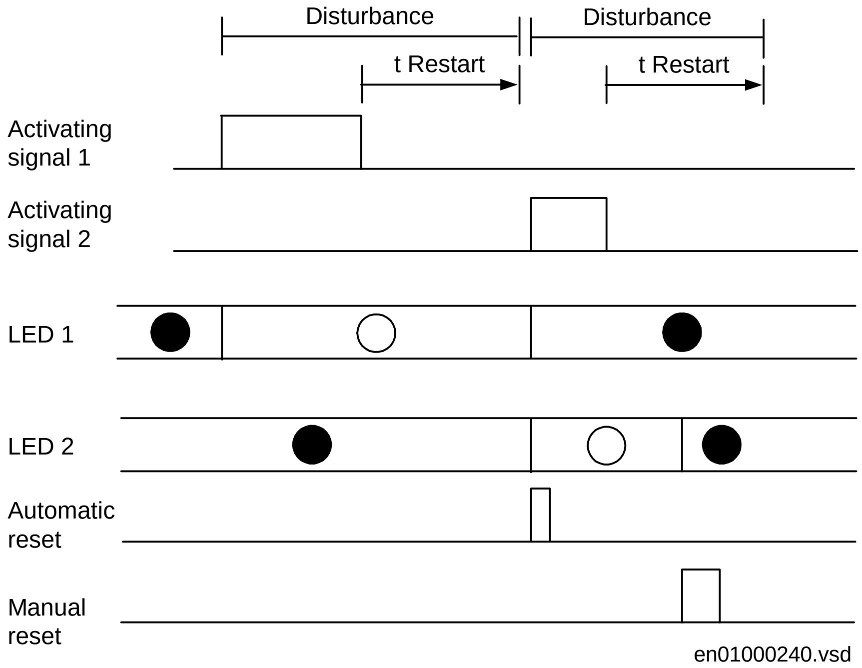


Figure 239: Operating sequence 6 (LatchedReset-S), two different disturbances

Figure 240 shows the timing diagram when a new indication appears after the first one has reset but before tRestart has elapsed.

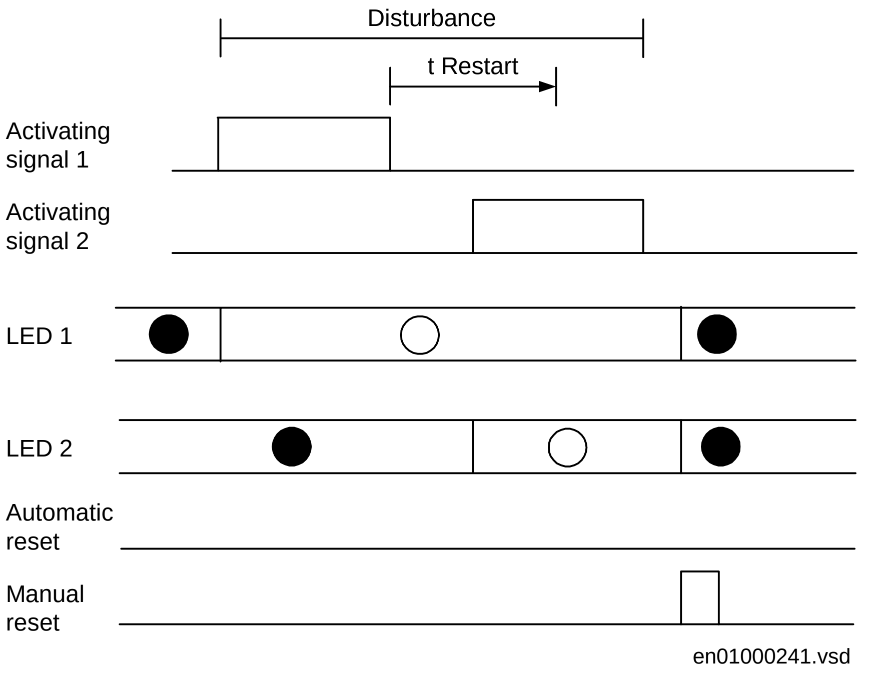


Figure 240: Operating sequence 6 (LatchedReset-S), two indications within same disturbance but with reset of activating signal between

Figure 241 shows the timing diagram for manual reset.

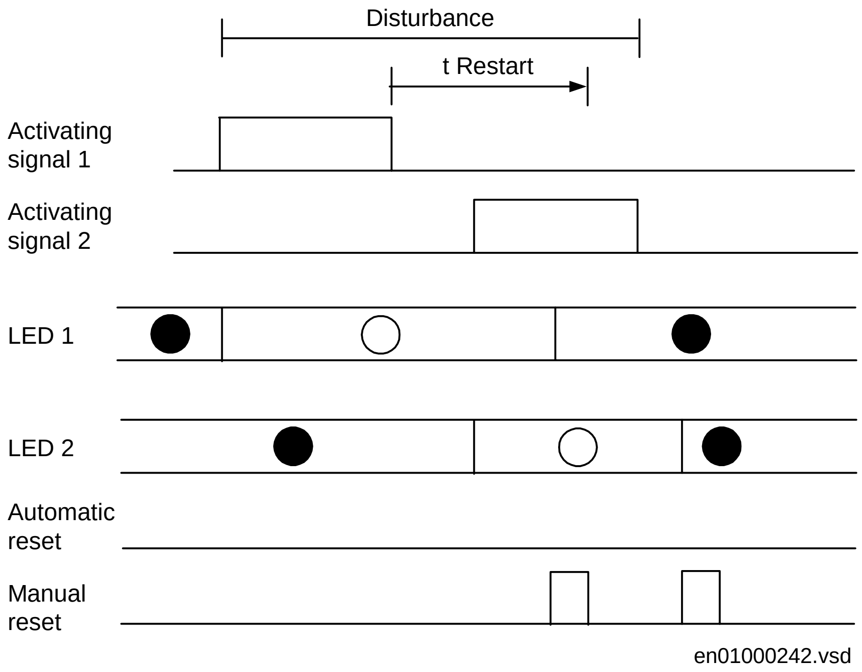


Figure 241: Operating sequence 6 (LatchedReset-S), manual reset

1.3 Calculations

Settings can be performed from the local HMI in a separate menu-tree or from the PST. Change of settings is restricted by the activation of a local HMI function.

From the local HMI, the parameters can be set via the sub-menu:

Setting
Functions
Groupx
HMI LED

2 Disturbance report (DRP)

2.1 Application

Use the disturbance report to provide the network operator with proper information about disturbances in the primary network. Continuous collection of system data and, at occurrence of a fault, storing of a certain amount of pre-fault, fault and post-fault data, contributes to the highest possible quality of electrical supply. The stored data can be used for analysis and decision making to find and eliminate possible system and equipment weaknesses.

The function comprises several sub functions enabling different users to access relevant information in a structured way.

2.2 Functionality

The disturbance report is a common name for several facilities to supply the operator with more information about the disturbances in the system. Some of the facilities are basic and some are optional in the different products. For some products not all facilities are available.

The facilities included in the disturbance report are:

- General disturbance information
- Indications
- Event recorder
- Fault locator
- Trip values (phase values)
- Disturbance recorder

The whole disturbance report can contain information for up to 10 disturbances, each with the data coming from all the parts mentioned above, depending on the options installed. All information in the disturbance report is stored in non-volatile flash memories. This implies that no information is lost in case of loss-of-power supply

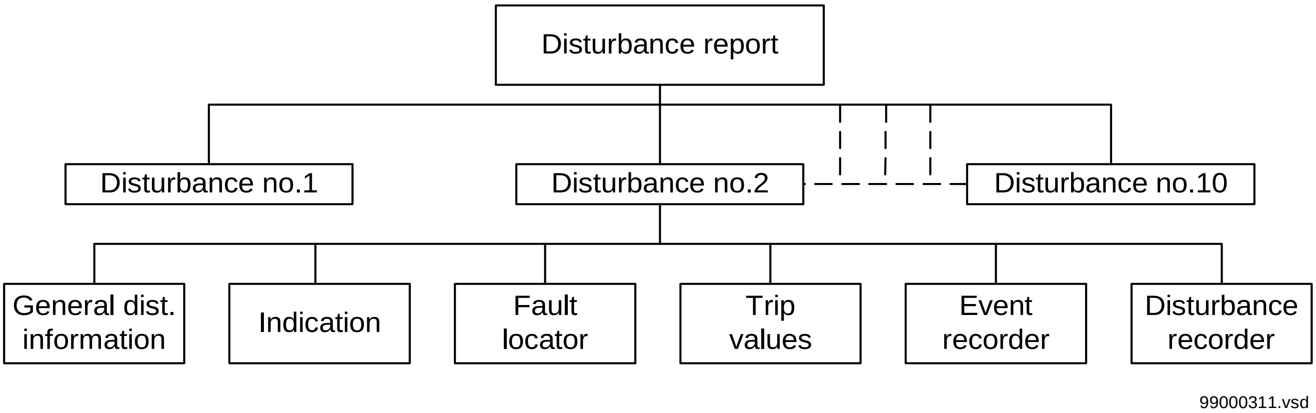


Figure 242: Disturbance report structure

Up to 10 disturbances can always be stored. If a new disturbance is to be recorded when the memory is full, the oldest disturbance is over-written by the new one. The nominal memory capacity for the disturbance recorder is measured with 10 analog and 48 binary signals recorded, which means that in the case of long recording times, fewer than 10 disturbances are stored. If fewer analog signals are recorded, a longer total recording time is available. This memory limit does not affect the rest of the disturbance report.

Disturbance information

The indications, the fault locator result (when applicable), and the trip values are available on the local HMI. For a complete disturbance report, front communication with a PC or remote communication with SMS is required.

Disturbance overview is a summary of all the stored disturbances. The overview is available only on a front-connected PC or via the Station Monitoring System (SMS). The overview contains:

- Disturbance index
- Date and time
- Trip signals
- Trigger signal that activated the recording
- Distance to fault (requires Fault locator)
- Fault loop selected by the Fault locator (requires Fault locator)

Disturbance Summary is automatically scrolled on the local human-machine interface (HMI). Here the two latest disturbances (DisturbSummary 1, which is the latest and DisturbSummary 2 which is the second latest) are presented with:

- Date and time
- Selected indications (set with the Indication mask)
- Distance to fault and fault loop selected by the Fault locator

Disturbance data on the HMI is presented at:

DisturbReport/Disturbances/Disturbance n (n=1 - 10)

The date and time of the disturbance, the trigger signal, the indications, the fault locator result and the trip values are available, provided that the corresponding functions are installed.

Indications

Indications is a list of signals that were activated during the fault time of the disturbance. A part (or all) of these signals are automatically scrolled on the local HMI after a disturbance.

Event recorder

The event recorder contains an event list with time-tagged events. In the Station Monitoring System, this list is directly connected to a disturbance.

Fault locator

The fault locator contains information about the distance to the fault and about the measuring loop that was selected for the calculation. After changing the system parameters in the terminal, a recalculation of the distance to the fault can be made in the protection

Trip values

Trip values includes phasors of currents and voltages before the fault and during the fault

Disturbance recorder

The disturbance recorder records analog and binary signal data before, during and after the fault.

Recording times

The disturbance report records information about a disturbance during a settable timeframe. The recording times are valid for the whole disturbance report. The disturbance recorder and the event recorder register disturbance data and events during *tRecording*, the total recording time. Indications are only registered during the fault time.

The total recording time, *tRecording*, of a recorded disturbance is:

tRecording = tPre + tFault + tPost or tPre + tLim, depending on which criterion stops the current disturbance recording

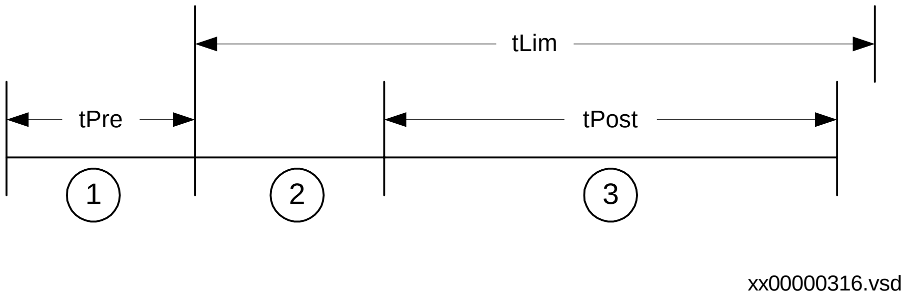


Table 11: Definitions

1	Pre-fault or pre-trigger recording time. The time before the fault including the operate time of the trigger. Use the setting tPre to set this time.
2	Fault time of the recording. The fault time cannot be set. It continues as long as any valid trigger condition, binary or analog, persists (unless limited by tLim the limit time).
3	Post fault recording time. The time the disturbance recording continues after all activated triggers are reset. Use the setting tPost to set this time.
tLim	Limit time. The maximum allowed recording time after the disturbance recording was triggered. The limit time is used to eliminate the consequences of a trigger that does not reset within a reasonable time interval. It limits the maximum recording time of a recording and prevents subsequent overwriting of already stored disturbances.Use the setting tLim to set this time.

Figure 243: The recording times definition

Analog signals

Up to 10 analog signals (five voltages and five currents from the transformer module) can be selected for recording and triggering if the disturbance recorder function is installed. If fewer than 10 signals are selected, the maximum storing capacity in the flash memories, regarding total recording time are increased.

A user-defined name for each of the signals can be programmed in the terminal.

For each of the 10 analog signals, *Operation = On* means that it is recorded by the disturbance recorder. The trigger is independent of the setting of *Operation*, and triggers even if operation is set to *Off*. Both undervoltage and overvoltage can be used as trigger condition. The same applies for the current signals.

The check of the trigger condition is based on peak-to-peak values. When this is found, the absolute average value of these two peak values is calculated. If the average value is above the threshold level for an overvoltage or overcurrent trigger, this trigger is indicated with a greater than (>) sign with the user-defined name.

If the average value is below the set threshold level for an undervoltage or undercurrent trigger, this trigger is indicated with a less than (<) sign with its name. The procedure is separately performed for each channel.

This method of checking the analog start conditions gives a function which is insensitive to DC offset in the signal. The operate time for this start is typically in the range of one cycle, 20 ms for a 50 Hz network.

The analog signals are presented only in the disturbance recording, but they affect the entire disturbance report when being used as triggers.

Binary signals

Up to 48 binary signals can be selected from the signal list, where all available signals are grouped under each function. The 48 signals can be selected from internal logical signals and binary input signals. Each of the 48 signals can be selected as a trigger of the disturbance report. It is also possible to set if the trigger should be activated on a logic 1 or a logic 0. A binary signal can be selected to activate the red LED on the local HMI.

A user-defined name for each of the signals can be programmed in the terminal.

The selected 48 signals are presented in the event list and the disturbance recording. But they affect the whole disturbance report when they are used as triggers.

The indications, that are to be automatically scrolled on the HMI when a disturbance has been recorded are also selected from these 48 signals with the HMI Indication Mask.

Trigger signals

The trigger conditions affect the entire disturbance report. As soon as a trigger condition is fulfilled, a complete disturbance report is recorded. On the other hand, if no trigger condition is fulfilled, there is no disturbance report, no calculation of distance to fault, no indications, and so on. This implies the importance of choosing the right signals as trigger conditions.

A trigger can be of type:

- Manual trigger
- Binary-signal trigger
- Analog-signal trigger (over/under function)

Manual trigger

A disturbance report can be manually triggered from the local HMI, a front-connected PC, or SMS. When the trigger is activated, the manual trigger signal is generated. This feature is especially useful for testing.

Manual trigger from the local HMI is found at:

DisturbReport
ManualTrig

Binary trigger

Any binary signal state (logic one or a logic zero) can be selected to generate a trigger. The binary signal must remain in a steady state for at least 15 ms to be valid.

When a binary signal is selected to generate a trigger from a logic zero, the selected signal will not be listed in the indications list of the disturbance report.

Analog trigger

All analog signals are available for trigger purposes, no matter if they are recorded in the disturbance recorder or not. But the disturbance recorder function must be installed in the terminal.

Retrigger

Under certain circumstances the fault condition may reoccur during the postfault recording, for instance by automatic reclosing to a still faulty network. In order to capture the new fault it is possible to allow retriggering during the PostFault recording.

2.3 Calculations

The main part of the settings for the Disturbance Report is found on the local human-machine interface (HMI) at:

Settings
DisturbReport

The settings include:

Operation	Disturbance Report (On/Off)
ReTrig	Re-trigger during post-fault state (On/Off)
SequenceNo	Sequence number (0-255) (normally not necessary to set)
RecordingTimes	Recording times for the Disturbance Report and the event/indication logging, including pre-fault time, post-fault time, and limit time for the entire disturbance
BinarySignals	Selection of binary signals, trigger conditions, HMI indication mask and HMI red LED option
AnalogSignals	Recording mask and trigger conditions
FaultLocator	Distance measurement unit (km/miles/%)
	km or miles selected under line reference

User-defined names of analog signals can be set at:

Configuration
AnalogInputs

The user-defined names of binary signals can be set at:

Configuration
DisturbReport
Input n (n=1-48)

The analog and binary signals appear with their user-defined names.

Settings during normal conditions

Table 12: How the settings affect different functions in the disturbance report

HMI Setting menu	**Function**	**Distur-bance summary (on HMI)**	**Distur-bance recorder**	**Indica-tions**	**Event list (SMS)**	**Trip values**	**Fault loca-tor**
Operation	Operation (On/Off)	Yes	Yes	Yes	Yes	Yes	Yes
Record-ing times	Recording times (tPre, tPost, tLim)	No	Yes	No	Yes	No	No
Binary sig-nals	Trigger operation and trigger level	Yes	Yes	Yes	Yes	Yes	Yes
	Indication mask (for automatic scrolling)	Yes	No	No	No	No	No
Analog signals	Operation (On/Off)	No	Yes	No	No	Yes	Yes
	Trigger over/under function	Yes	Yes	Yes	Yes	Yes	Yes
Fault Locator	Fault locator set-tings (Distance Unit)	No	No	No	No	No	Yes

Operation

HMI submenu:

Settings
DisturbReport
Operation

Operation can be set to On or Off. If Off is selected, note that no disturbance report is registered, including indications, fault locator, event recorder, and disturbance recorder.

Operation = Off:

- Disturbances are not stored.
- LED information (yellow - start, red - trip) is not stored or changed.
- No disturbance summary is scrolled on the local HMI.

Operation = On:

- Disturbances are stored, disturbance data can be read from the local HMI and from a front-connected PC or Station Monitoring System (SMS).
- LED information (yellow - start, red - trip) is stored.
- The disturbance summary is automatically scrolled on the local HMI for the two latest registered disturbances, until cleared.

Post re-trigger can be set to On or Off

Postretrig = On:

Re-trigger during the set post-fault time is enabled.

Postretrig = Off:

Re-trigger during the set post fault time is not accepted.

Sequence number

HMI submenu:

Settings
DisturbReport
SequenceNo

Normally, this setting option is seldom used. Each disturbance is assigned a number in the disturbance report. The first disturbance each day normally receives *SequenceNo = 0*. The value of *SequenceNo* that can be read in the service report is the number that will be assigned to the next disturbance registered during that day.

In normal use, the sequence number is increased by one for each new disturbance until it is reset to zero each midnight.

Recording times

HMI submenu:

Settings
DisturbReport
RecordingTimes

Under this submenu, the different recording times for the disturbance report are set (the pre-fault time, post-fault time, and limit time). These recording times affect the disturbance recorder and event recorder functions. The total recording time, tRecording, of a recorded disturbance is:

tRecording =	tPre + tFault + tPost, or tPre + tLim, depending on which criterion stops the current disturbance recording.

Binary signals

HMI submenu:

Configuration
DisturbReport
Input n (n=1-48)

Up to 48 binary signals can be selected from the signal list, where all available signals are grouped function by function. The 48 signals can be selected among internal logical signals and binary input signals. Each selected signal is registered by the disturbance recorder, event recorder, and indication functions during a recording.

A user-defined name for each of the signals can be entered. This name can comprise up to 13 characters.

HMI submenu:

Settings
DisturbReport
BinarySignals

For each of the 48 signals, it is also possible to select if the signal is to be used as a trigger for the start of the disturbance report (*TrigOperation*), and if the trigger should be activated at a logical 1 or 0 level (*TrigLevel*).

The indications in the disturbance summary, that are automatically scrolled on the HMI when a disturbance is registered, are also selected from these 48 signals using the indication mask.

Analog signals

HMI submenu:

Settings
DisturbReport
AnalogSignals

This HMI submenu is only available when the disturbance recorder option is installed. For each of the 10 analog signals (five voltages and five currents), Operation = On means that it is recorded by the disturbance recorder. If fewer than 10 signals are selected, the maximum storing capacity in the flash memories for total recording time becomes longer.

Both undervoltage and overvoltage can be used as trigger condition. The same applies for the current signals. The trigger is independent of the setting of *Operation* and triggers even if *Operation = Off*.

A user-defined name for each of the signals can be entered. It can consist of up to 13 characters. It is found at:

Configuration
AnalogInputs

Behaviour during test mode

When the terminal is set to test mode, the behaviour of the disturbance report can be controlled by the test mode disturbance report settings **Operation** and **DisturbSummary** available on the local HMI under:

Test/Testmode/DisturbReport

The impact of the settings are according to the following table:

Table 13: Disturbance report settings

Operation	Disturb-Summary	Then the results are...
Off	Off	• Disturbances are not stored. • LED information is not displayed on the HMI and not stored. • No disturbance summary is scrolled on the HMI.
Off	On	• Disturbances are not stored. • LED information (yellow - start, red - trip) are displayed on the local HMI but not stored in the terminal. • Disturbance summary is scrolled automatically on the local HMI for the two latest recorded disturbances, until cleared. • The information is not stored in the terminal.
On	On or Off	• The disturbance report works as in normal mode. • Disturbances are stored. Data can be read from the local HMI, a front-connected PC, or SMS.- LED information (yellow - start, red - trip) is stored. • The disturbance summary is scrolled automatically on the local HMI for the two latest recorded disturbances, until cleared. • All disturbance data that is stored during test mode remains in the terminal when changing back to normal mode.

3 Indications

3.1 Application

The indications from all the 48 selected binary signals are shown on the local human-machine interface (HMI) and on the Station Monitoring System (SMS) for each recorded disturbance in the disturbance report. The LEDs on the front of the terminal display start and trip indications.

3.2 Functionality

The indications shown on the HMI and SMS give an overview of the status of the 48 event signals during the fault. On the HMI, the indications for each recorded disturbance are presented at:

DisturbReport
Disturbances
Disturbance n (n=1-10)

All selected signals can be internally produced signals or emerge from binary input channels.

The indications are registered only during the fault time of a recorded disturbance, as long as any trigger condition is activated. A part or all of these indications can be automatically scrolled on the local HMI after a disturbance is recorded, until acknowledged with the C button on the HMI. They are selected with the indication mask.

The signal name for internal logical signals presented on the screen follows the signal name, which can be found in the signal list in each function description of the “Technical reference manual”. Binary input signals are displayed with their user-defined names.

The LED indications display this information:

Green LED:

- Steady light — In Service
- Flashing light — Internal fail, the INT--FAIL internal signal is high
- Dark — No power supply

Yellow LED:

- Steady light — A disturbance report is triggered
- Flashing light — The terminal is in test mode or in configuration mode

Red LED:

- Steady light — Trig on binary signal with HMI red LED option set
- Flashing light — The terminal is in configuration mode

3.3 Calculations

The signals to be displayed as indications are selected in the disturbance report setting. This can be found on the local HMI at:

Settings
  DisturbReport
    BinarySignals
      Input n (n=1-48)

4 Disturbance recorder

4.1 Application

Use the disturbance recorder to achieve a better understanding of the behavior of the power network and related primary and secondary equipment during and after a disturbance. An analysis of the recorded data provides valuable information that can be used to improve existing equipment. This information can also be used when planning for and designing new installations.

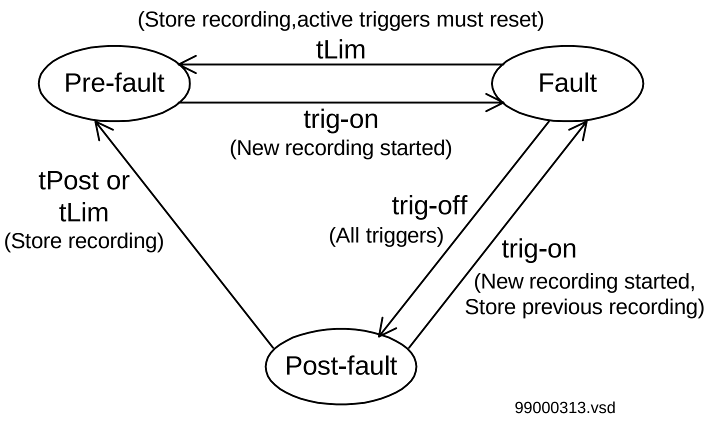
The disturbance recording function in the REx 5xx terminals is characterized by great flexibility as far as starting conditions and recording times, and large storage capacity are concerned. Thus, the disturbance recorders are not dependent on the operation of protective functions, and they can record disturbances that were not discovered by protective functions for one reason or another.

The disturbance recording function in the REx 5xx terminals is fully adequate for the recording of disturbances for the protected object.

Use available software tools to retrieve the recordings and the evaluation software REVAL to analyze, evaluate and print recordings.

4.2 Functionality

Disturbance recording is based on the continuous collection of network data, analog values and binary signals, in a cyclic buffer. The buffer operates according to the FIFO principle, old data will be overwritten as new data arrives when the buffer is full. The size of this buffer is determined by the set pre-fault recording time.



Upon detection of a fault condition (triggering), the data storage continues in another part of the memory. The storing goes on as long as the fault condition prevails - plus a certain additional time. The length of this additional part is called the post-fault time and it can be set in the disturbance report. The above mentioned two parts form a disturbance recording. The whole memory acts as a cyclic buffer and when it is full, the oldest recording is overwritten.

A user-defined name for each of the signals can be programmed in the terminal.

Recording Capacity

The recording function can record all analog inputs in the transformer module and up to 48 binary signals. To maximise the use of the memory, the number of analog channels to be recorded is user-selectable by programming and can be set individually for each analog input. The recorded binary signals can be either true binary input signals or internal logical signals created by the functions.

Memory capacity

The maximum number of recordings stored in the memory is 10. So depending on the set recording times and the recording of the enabled number of channels, the memory can contain a minimum of six and a maximum of 10 disturbance recordings comprising of both header part and data part. But the header part for the last 10 recordings is always available.

Time tagging

The terminal has a built-in, real-time clock and calendar. This function is used for time tagging of the recorded disturbances. The time tagging refers to the activation of the trigger that starts the disturbance recording.

Signal processing

The processing of analog signals is handled by a dedicated DSP (digital signal processor). Other functions are implemented in the main CPU. The memory is shared with other functions.

The numerical signals coming from the A/D conversion module in serial form are converted to parallel form in a dedicated DSP. The analog trigger conditions are also checked in the DSP.

A check of the start conditions is performed by searching for a maximum value. This is a positive peak. The function also seeks a minimum value, which is the negative peak.

When this is found, the absolute average value is calculated. If this value is above the set threshold level for the overfunction on the channel in question, an overfunction start on that channel is indicated. The overfunction is indicated with a greater than (>) sign.

Similarly, if the average value is below the set threshold level for underfunction on the channel in question, an underfunction start on that channel is indicated. The underfunction is indicated with a less than (<) sign.

The procedure is separately performed for each channel. This method of checking the analog start conditions gives a function that is insensitive to DC offset in the signal. The operating time for this start is typically in the range of one cycle, 20 ms in a 50 Hz network.

The numerical data, along with the result of the trigger condition evaluation, are transmitted to the main CPU. The main CPU handles these functions:

- Evaluation of the manual start condition
- Evaluation of the binary start condition, both for true binary input signals and for internally created logical signals
- Storage of the numerical values for the analog channels

The numerical data for the analog channels are stored in a cyclic pre-fault buffer in a RAM. When a trigger is activated, the data storage is moved to another area in the RAM, where the data for the fault and the subsequent post-fault period are stored. Thus, a complete disturbance recording comprises the stored data for the pre-fault, fault, and post-fault period.

The RAM area for temporary storage of recorded data is divided into sub-areas, one for each recording. The size of a subarea is governed by the sum of the set pre-fault (tPre) and maximum post-trigger (tLim) time. There is a sufficient memory capacity for at least four consecutive recordings with a maximum number of analog channels recorded and with maximum time settings. Should no such area be free at the time of a new trigger, the oldest recording stored in the RAM is overwritten.

When a recording is completed, a post recording processing occurs.

This post-recording processing comprises:

- Merging the data for analog channels with corresponding data for binary signals stored in an event buffer
- Compression of the data, which is performed without losing any data accuracy
- Storing the compressed data in a non-volatile memory (flash memory)

The recorded disturbance is now ready for retrieval and evaluation. The recording comprises the stored and time-tagged disturbance data along with relevant data from the database for configuration and parameter set-up.

Some parameters in the header of a recording are stored with the recording, and some are retrieved from the parameter database in connection with a disturbance. This means that if a parameter that is retrieved from the parameter database was changed between the time of recording and retrieval, the collected information is not correct in all parts. For this reason, all recordings should be transferred to the Station Monitoring System (SMS) workstation and then deleted in the terminal before any such parameters are changed.

4.3 Design

The recordings can be divided into two parts, the header and the data part. The data part contains the numerical values of recorded analog and binary channels. The header contains clearly written basic information about the disturbance. A part of this information is also used by REVAL to reproduce the analog and binary signals in a correct and user-friendly way. Such information is primary and secondary instrument transformer ratings.

Table 14: Disturbance header

Parameter	**Parameter database**	**Stored with disturbance**
General		
Station, object and ID	x	
Date and time		x
Sequence number		x
CT earthing	x	
Time synchronization source	x	
Collection window parameters tPre, tPost, tLim		x
Prefault phase-to-phase voltage and current RMS values		x
Trig signal and test flag		x
Analog signals		
Signal name	x	
Primary and secondary instrument transformer rating	x	
Undertrig: level and operation	x	
Overtrig: level and operation	x	

Parameter	Parameter database	Stored with disturbance
Undertrig status at time of trig		x
Overtrig status at time of trig		x
Instantaneous phase voltage at time of trig		x
Instantaneous phase current at time of trig		x
Phase voltage and phase current before trig (prefault)		x
Phase voltage and phase current after trig (fault)		x
Binary signals		
Signal name		x
Type of contact (trig level)	x	
Trig operation	x	
Signal status at time of trig		x
Trig status at time of trig		x

4.4 Calculations

The setting parameters specific for the disturbance recording function are available in the menu tree under:

Settings
DisturbReport
Operation
SequenceNo
RecordingTimes
BinarySignals
AnalogSignals

The list of parameters in the “Technical reference manual”, explains the meaning of the abbreviations used in connection with setting ranges.

Remember that values of parameters set elsewhere in the menu tree are linked to the information on a recording. Such parameters are, for example, station and object identifiers, CT and PT ratios.

The sequence number of the recordings is a specific parameter for the disturbance recorder and is used to identify the different recordings. By combining the date and the sequence number for a recording, the recording can be uniquely identified. The sequence number is also shown under:

Settings
DisturbReport
SequenceNo

The read value on the local human-machine interface (HMI) display is the sequence number that the next recorded disturbance receives. The number is automatically increased by one for each new recording and is reset to zero at each midnight. The sequence number can also be set manually.

5 Event recorder

5.1 Application

When using a front-connected PC or Station Monitoring System (SMS), an event list can be available for each of the recorded disturbances in the disturbance report. Each list can contain up to 150 time-tagged events. These events are logged during the total recording time, which depends on the set recording times (pre-fault, post-fault and limit time) and the actual fault time. During this time, the first 150 events for all the 48 selected binary signals are logged and time tagged. This list is a useful instrument for evaluating a fault and is a complement to the disturbance recorder.

To obtain this event list, the event recorder function (basic in some terminals and optional in others) must be installed.

5.2 Functionality

When one of the trig conditions for the disturbance report is activated, the events are collected by the main processing unit, from the 48 selected binary signals. The events can come from both internal logical signals and binary input channels. The internal signals are time tagged in the main processing module, while the binary input channels are time tagged directly on each I/O module. The events are collected during the total recording time, *tRecording*, and they are stored in the disturbance report memory at the end of each recording.

The name of the binary input signal that appears in the event list is the user-defined name that can be programmed in the terminal.

The time tagging of events emerging from internal logical signals and binary input channels has a resolution of 1 ms.

5.3 Calculations

The settings of the event recorder consist of the signal selection and the recording times. It is possible to select up to 48 binary signals, either internal signals or signals coming from binary input channels. These signals coincide with the binary signals recorded by the disturbance recorder. The disturbance summary indications that are to scroll automatically on the local human-machine interface (HMI), can only be selected from these 48 event channels.

The signal selection is found at:

Settings
DisturbReport
BinarySignals
Input n (n=1-48)

Each of the up to 48 event channels can be selected from the signal list, consisting of all available internal logical signals and all binary input channels.

For each of the binary input and output signals, a user-defined name can be programmed at:

Configuration
I/O
Slotnn-XXXX (ex. Slot15-BOM3)

6 Trip value recorder

6.1 Application

The main objective of line protection and monitoring terminals is fast, selective and reliable operation for faults on a protected object. Besides this, information on the values of the currents and voltages before and during the fault is valuable to understand the severity of the fault.

The trip value recorder in the REx 5xx series of terminals provides this information on the HMI and via SCS/SMS. The function is an optional software module in the terminal.

The function calculates the pre-fault and fault values of currents and voltages and presents them as phasors with amplitude and argument.

6.2 Design

Pre-fault and fault phasors of currents and voltages are filtered from disturbance data stored in digital sample buffers.

When the disturbance report function is triggered, the trip value recorder function starts to calculate the frequency of the analogue channel U1. If the calculation fails, a default frequency is read from database to ensure further execution of the function.

Then the sample for the fault interception is looked for by checking the non-periodic changes. The channel search order is U1, U2, U3, I1, I2, I3, I4, I5 and U5.

If no error sample is found, the trig sample is used as the start sample for the Fourier estimation of the complex values of currents and voltages. The estimation uses samples during one period before the trig sample. In this case the calculated values are used both as pre-fault and fault values.

If an error sample is found the Fourier estimation of the prefault values starts 1.5 period before the fault sample. The estimation uses samples during one period. The postfault values are calculated using the Recursive Least Squares (RLS) method. The calculation starts a few samples after the fault sample and uses samples during 1/2 - 2 periods depending on the shape of the signals.

The pre-fault time (tPre) should be at least 0.1 s to ensure enough samples for the estimation of pre-fault trip values.

6.3 Calculations

Customer specific names for all the ten analogue inputs (five currents and five voltages) can be entered. Each name can have up to 13 alphanumeric characters. These names are common for all functions within the disturbance report functionality.

The user-defined names for the analogue inputs are set under the menu:

Configuration
  AnalogInputs
    U1 (U2..U5, I1..I5)

7 Monitoring of AC analog measurements

7.1 Application

Fast, reliable supervision of different analogue quantities is of vital importance during the normal operation of a power system.

Operators in the control centres can, for example:

- Continuously follow active and reactive power flow in the network
- Supervise the busbar voltage and frequency

Different measuring methods are available for different quantities. Current and voltage instrument transformers provide the basic information on measured phase currents and voltages in different points within the power system. At the same time, currents and voltages serve as the input measuring quantities to power and energy meters, protective devices and so on.

Further processing of this information occurs within different control, protection, and monitoring terminals and within the higher hierarchical systems in the secondary power system.

7.2 Functionality

The REx 5xx protection, control, and monitoring terminals have as basic the functionality to measure and further process information about up to five input currents and five input voltages. The number of processed alternate measuring quantities depends on the type of terminal and built-in options. Additional information is also available:

- Mean values of measured currents I in the first three current measuring channels.
- Mean values of measured voltages U in the first three voltage measuring channels.
- Three-phase active power P as measured by the first three current and voltage measuring channels.
- Three-phase reactive power Q as measured by the first three current and voltage measuring channels.
- Three-phase apparent power S as measured by the first three current and voltage measuring channels.
- Frequency f.

The accuracy of measurement depends on the requirements. Basic accuracy satisfies the operating (information) needs. An additional calibration of measuring channels is necessary and must be ordered separately when the requirements on accuracy of the measurement are higher. Refer to the technical data and ordering particulars for the particular terminal.

The information on measured quantities is then available for the user at different locations:

- Locally by means of the local human-machine interface (HMI) unit.
- Locally by means of a front-connected personal computer (PC).
- Remotely over the LON bus to the station control system (SCS)
- Remotely over the SPA port to the station monitoring system (SMS).

User-defined measuring ranges

Each measuring channel has an independent measuring range from the others. This allows the users to select the most suitable measuring range for each measuring quantity on each monitored object of the power system. This gives a possibility to optimize the functionality of the power system.

Continuous monitoring of the measured quantity

Users can continuously monitor the measured quantity in each channel by means of four built-in operating thresholds (figure 244). The monitoring has two different modes of operating:

- Overfunction, when the measured current exceeds the HiWarn or HiAlarm pre-set values.
- Underfunction, when the measured current decreases under the LowWarn or LowAlarm pre-set values.

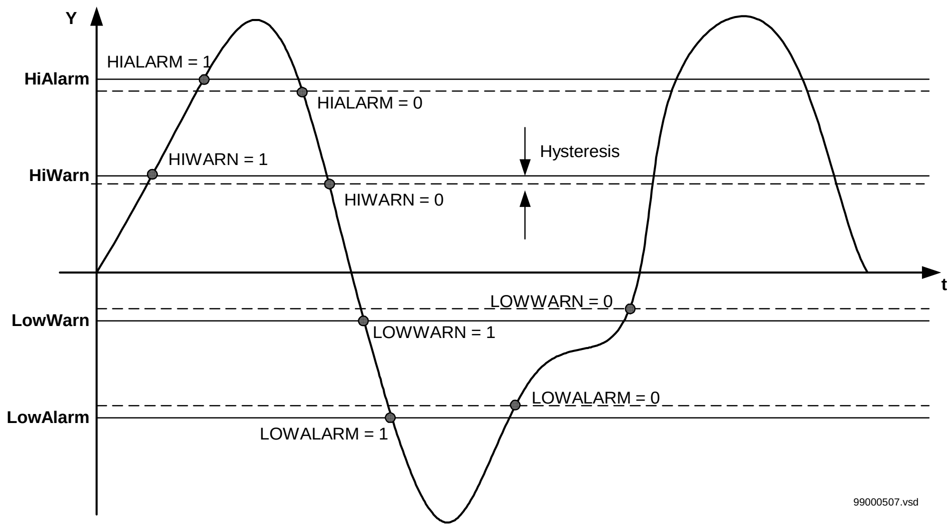


Figure 244: Presentation of the operating limits.

Each operating level has its corresponding functional output signal:

- HIWARN
- HIALARM
- LOWWARN
- LOWALARM

The logical value of the functional output signals changes according to Figure 244.

The user can set the hysteresis, which determines the difference between the operating and reset value at each operating point, in wide range for each measuring channel separately. The hysteresis is common for all operating values within one channel.

Continuous supervision of the measured quantity

The actual value of the measured quantity is available locally and remotely. The measurement is continuous for each channel separately, but the reporting of the value to the higher levels depends on the selected reporting mode. The following basic reporting modes are available:

- Periodic reporting.
- Periodic reporting with dead-band supervision in parallel.
- Periodic reporting with dead-band supervision in series.
- Dead-band reporting.

Users can select between two types of dead-band supervision:

- Amplitude dead-band supervision (ADBS).
- Integrating dead-band supervision (IDBS).

Amplitude dead-band supervision

If a measuring value is changed, compared to the last reported value, and the change is larger than the +/- ΔY predefined limits that are set by user, then the measuring channel reports the new value to a higher level, if this is detected by a new measuring sample. This limits the information flow to a minimum necessary. Figure 245 shows an example of periodic reporting with the amplitude dead-band supervision. The picture is simplified: the process is not continuous but the values are evaluated with a time interval of one second from each others.

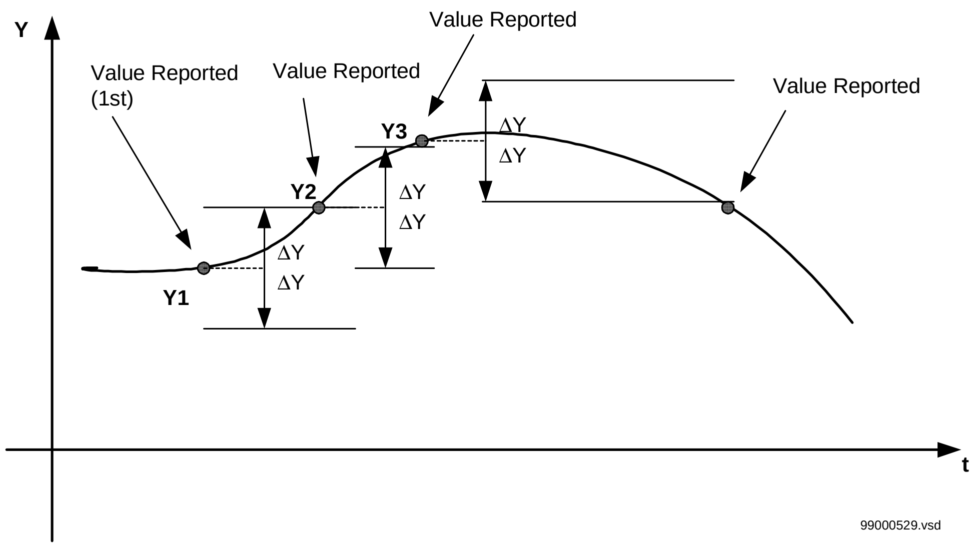


Figure 245: Amplitude dead-band supervision reporting

After the new value is reported, the +/- ΔY limits for dead-band are automatically set around it. The new value is reported only if the measured quantity changes more than defined by the +/- ΔY set limits.

Integrating dead-band supervision

The measured value is reported if the time integral of all changes exceeds the pre-set limit (figure 246), where an example of reporting with integrating dead-band supervision is shown. The picture is simplified: the process is not continuous but the values are evaluated with a time interval of one second from each other.

The last value reported (Y1 in figure 246) serves as a basic value for further measurement. A difference is calculated between the last reported and the newly measured value during new sample and is multiplied by the time increment (discrete integral). The absolute values of these products are added until the pre-set value is exceeded. This occurs with the value Y2 that is reported and set as a new base for the following measurements (as well as for the values Y3, Y4 and Y5).

The integrating dead-band supervision is particularly suitable for monitoring signals with small variations that can last for relatively long periods.

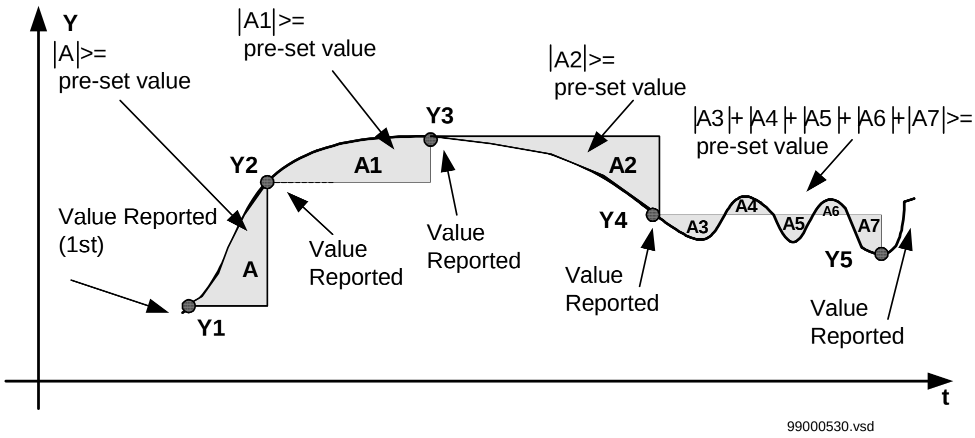


Figure 246: Reporting with integrating dead-band supervision.

Periodic reporting

The user can select the periodic reporting of measured value in time intervals between 1 and 3600 s. The measuring channel reports the value even if it has not changed for more than the set limits of amplitude or integrating dead-band supervision. To disable periodic reporting, set the reporting time interval to 0 s (figure 247).

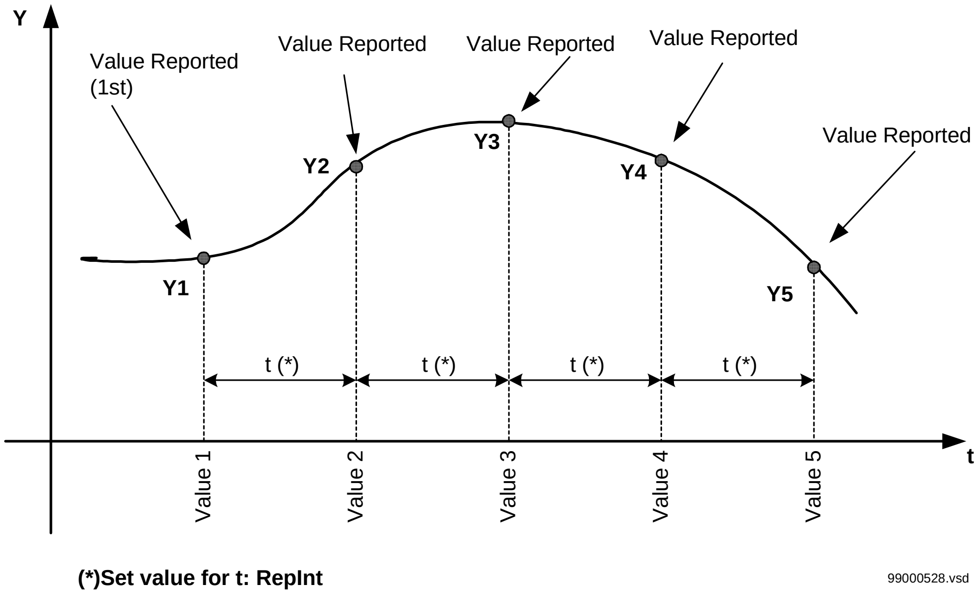


Figure 247: Periodic reporting.

Periodic reporting with parallel dead-band supervision

The newly measured value is reported:

- After each time interval for the periodic reporting expired or
- When the new value is detected by the dead-band supervision function.

The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.

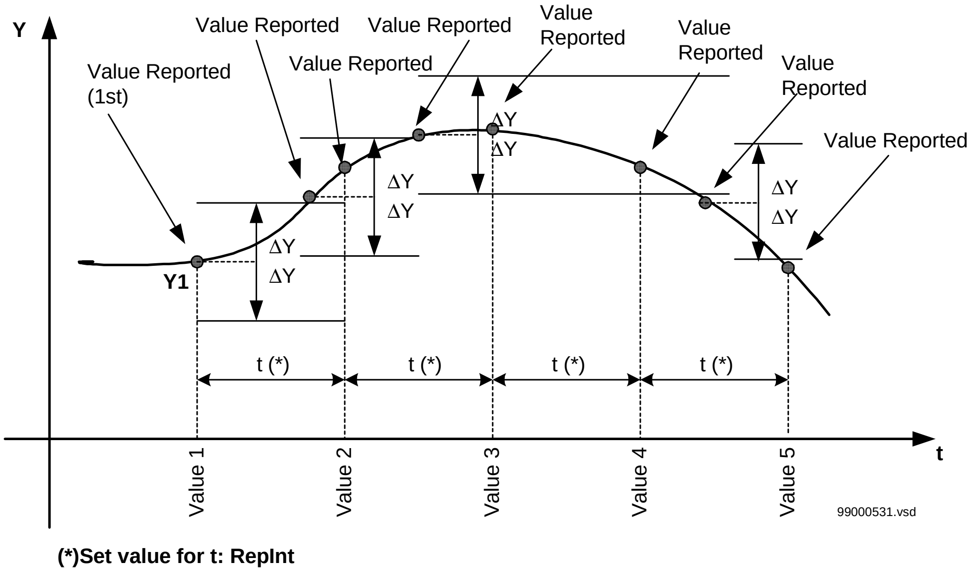
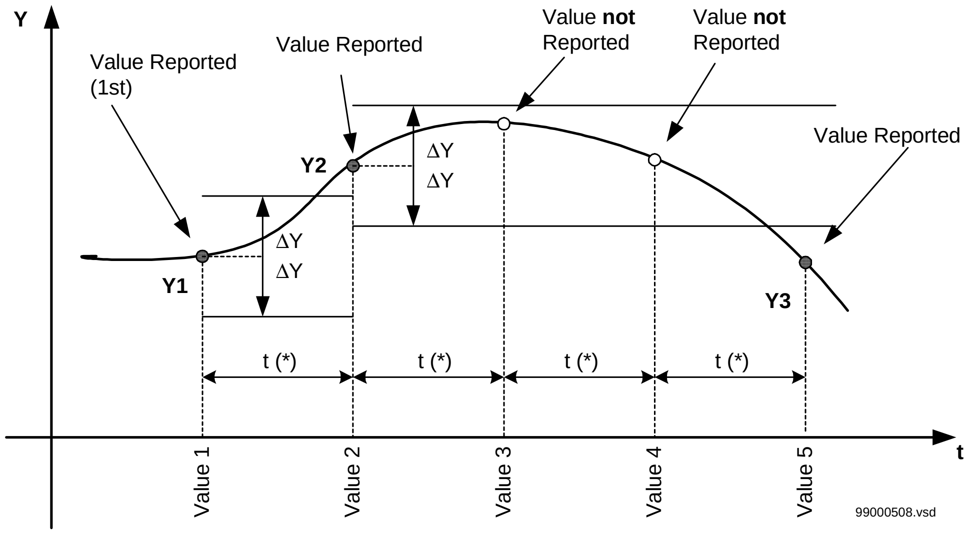


Figure 248: Periodic reporting with amplitude dead-band supervision in parallel.

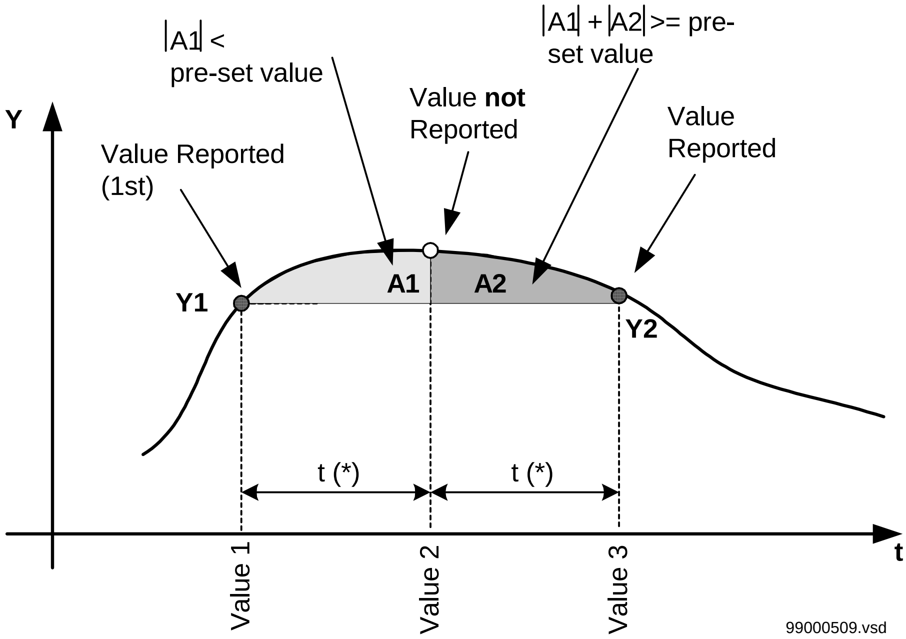
Periodic reporting with serial dead-band supervision

Periodic reporting can operate serially with the dead-band supervision. This means that the new value is reported only if the set time period expired and if the dead-band limit was exceeded during the observed time (figures 249 and 250). The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.



(*)Set value for t: RepInt

Figure 249: Periodic reporting with amplitude dead-band supervision in series.



(*)Set value for t: RepInt

Figure 250: Periodic reporting with integrating dead-band supervision in series

Combination of periodic reportings

The reporting of the new value depends on setting parameters for the dead-band and for the periodic reporting. Table 15 presents the dependence between different settings and the type of reporting for the new value of a measured quantity.

Table 15: Dependence of reporting on different setting parameters:

EnDeadB*	EnIDeadB*	EnDeadBP*	RepInt*	Reporting of the new value
Off	Off	Off	0	No measured values is reported.
Off	On	On	t>0	The new measured value is reported only if the time t period expired and if, during this time, the integrating dead-band limits were exceeded (periodic reporting with integrating dead-band supervision in series).
On	Off	On	t>0	The new measured value is reported only if the time t period has expired and if, during this time, the amplitude dead-band limits were exceeded (periodic reporting with amplitude dead-band supervision in series).
On	On	On	t>0	The new measured value is reported only if the time t period expired and if at least one of the dead-band limits were exceeded (periodic reporting with dead-band supervision in series).
Off	On	Off	0	The new measured value is reported only when the integrated dead-band limits are exceeded.
On	Off	Off	0	The new measured value is reported only when the amplitude dead-band limits were exceeded.
On	On	Off	0	The new measured value is reported only if one of the dead-band limits was exceeded.
x	x	Off	t>0	The new measured value is updated at least after the time t period expired. If the dead-band supervision is additionally selected, the updating also occurs when the corresponding dead-band limit was exceeded (periodic reporting with parallel dead-band supervision).
* Please see the setting parameters in the Technical reference manual for further explanation				

7.3 Design

The design of the alternating quantities measuring function follows the design of all REx 5xx-series protection, control, and monitoring terminals that have distributed functionality, where the decision levels are placed as closely as possible to the process.

The measuring function uses the same input current and voltage signals as other protection and monitoring functions within the terminals. The number of input current and voltage transformers depends on the type of terminal and options included. The maximum possible configuration comprises five current and five voltage input channels.

Measured input currents and voltages are first filtered in analogue filters and then converted to numerical information by an A/D converter, which operates with a sampling frequency of 2 kHz.

The numerical information on measured currents and voltages continues over a serial link to one of the built-in digital signal processors (DSP). An additional Fourier filter numerically filters the received information, and the DSP calculates the corresponding values for the following quantities:

- Five input measured voltages (U1, U2, U3, U4, U5), RMS values
- Five input measured currents (I1, I2, I3, I4, I5), RMS Values
- Mean RMS value, U, of the three phase-to-phase voltages calculated from the first three phase-to-earth voltages U1, U2 and U3
- Mean RMS value, I, of the first three measured RMS values I1, I2, and I3
- Three-phase active power, P, related to the first three measured currents and voltages (I1, U1, I2, U2, I3, U3)
- Three-phase, reactive power, Q, related to the first three measured currents and voltages (I1, U1, I2, U2, I3, U3)
- Three-phase apparent power, S, related to the first three measured currents and voltages (I1, U1, I2, U2, I3, U3)
- Mean value of frequencies, f, as measured with voltages U1, U2, and U3

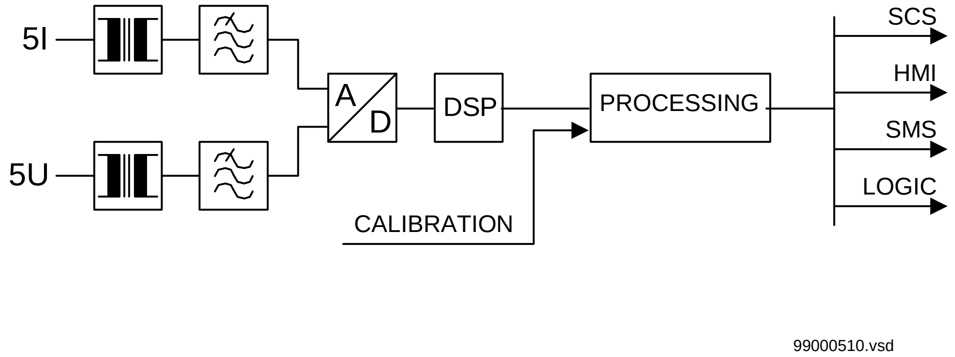


Figure 251: Simplified diagram for the function

This information is available to the user for operational purposes.

7.4 Calculations

The basic terminal parameters can be set from the HMI under the submenu:

Configuration
AnalogInputs
General
fr,CTEarth

So users can determine the rated parameters for the terminal:

- Rated frequency fr
- Position of the earthing point of the main CTs (CTEarth), which determines whether the CT earthing point is towards the protected object or the busbar

The other basic terminal parameters, related to any single analog input, can be set under the submenu:

Configuration
AnalogInputs
U1, U2, U3, U4, U5, I1, I2, I3, I4, I5, U, I, P, Q, S, f

So the users can determine the base values, the primary CTs and VTs ratios, and the user-defined names for the analog inputs of the terminal.

Under U1:

- ac voltage base value for analog input U1: U1b
- voltage transformer input U1 nominal primary to secondary scale value: U1Scale
- Name (of up to 13 characters) of the analog input U1: Name

Under U2:

- ac voltage base value for analog input U2: U2b
- voltage transformer input U2 nominal primary to secondary scale value: U2Scale
- Name (of up to 13 characters) of the analog input U2: Name

Under U3:

- ac voltage base value for analog input U3: U3b
- voltage transformer input U3 nominal primary to secondary scale value: U3Scale
- Name (of up to 13 characters) of the analog input U3: Name

Under U4:

- ac voltage base value for analog input U4: U4b
- voltage transformer input U4 nominal primary to secondary scale value: U4Scale
- Name (of up to 13 characters) of the analog input U4: Name

Under U5:

- ac voltage base value for analog input U5: U5b
- voltage transformer input U5 nominal primary to secondary scale value: U5Scale
- Name (of up to 13 characters) of the analog input U5: Name

Under I1:

- ac current base value for analog input I1: I1b
- current transformer input I1 nominal primary to secondary scale value: I1Scale
- Name (of up to 13 characters) of the analog input I1: Name

Under I2:

- ac current base value for analog input I2: I2b
- current transformer input I2 nominal primary to secondary scale value: I2Scale
- Name (of up to 13 characters) of the analog input I2: Name

Under I3:

- ac current base value for analog input I3: I3b
- current transformer input I3 nominal primary to secondary scale value: I3Scale
- Name (of up to 13 characters) of the analog input I3: Name

Under I4:

- ac current base value for analog input I4: I4b
- current transformer input I4 nominal primary to secondary scale value: I4Scale
- Name (of up to 13 characters) of the analog input I4: Name

Under I5:

- ac current base value for analog input I5: I5b
- current transformer input I5 nominal primary to secondary scale value: I5Scale
- Name (of up to 13 characters) of the analog input I5: Name

Under U:

- Name (of up to 13 characters) of the average voltage U: Name

Under I:

- Name (of up to 13 characters) of the average current I: Name

Under P:

- Name (of up to 13 characters) of the active power P: Name

Under Q:

- Name (of up to 13 characters) of the reactive power Q: Name

Under S:

- Name (of up to 13 characters) of the apparent power S: Name

Under f:

- Name (of up to 13 characters) of the frequency value f: Name

The names of the first 10 quantities automatically appears in the REVAL evaluation program for each reported disturbance.

The PST Parameter Setting Tool has to be used in order to set all remaining parameters that are related to different alternating measuring quantities.

In the settings menu it is possible to set all monitoring operating values and the hysteresis directly in the basic units of the measured quantities for each channel and for each quantity:

Settings
DisturbReport
AnalogSignals

The dead-band limits can be set directly in the corresponding units of the observed quantity for the:

- Amplitude dead-band supervision (ADBS)
- Integrating dead-band supervision (IDBS)

The IDBS area is defined by the following formula:

$$IDBS = \frac{IDeadB}{ReadFreq} = IDeadB \cdot ts$$

(Equation 151)

Where:

IDeadB	is a set operating value for IDBS in corresponding unit.
ReadFreq	is the reading frequency. It has a constant value of 1Hz.
ts = 1/ReadFreq	is the time between two samples (fixed to 1s).

The setting value for IDBS is IDeadB, and is expressed in the measuring unit of the monitored quantity (kV, A, MW, Mvar, MVA or Hz). The value is reported if the time integral area is greater than the value IDBS.

If a 0.1 Hz variation in the frequency for 10 minutes (600 s) is the event that should cause the reporting of the frequency monitored value, than the set value for IDeadB is 60 Hz.

The hysteresis can be set under the setting Hysteres.

Alarm and warning thresholds have to be set respectively under the settings HiAlarm (LowAlarm) and HiWarn (LowWarn).

See the Technical reference manual for a list of all the setting parameters.

Note!

It is important to set the time for periodic reporting and deadband in an optimized way to minimize the load on the station bus.

8 Monitoring of DC analog measurements

8.1 Application

Fast, reliable supervision of different analogue quantities is of vital importance during the normal operation of a power system. Operators in the control centres can, for example:

- Continuously follow active and reactive power flow in the network
- Supervise the busbar voltages
- Check the temperature of power transformers, shunt reactors
- Monitor the gas pressure in circuit breakers

Different measuring methods are available for different quantities. Current and voltage instrument transformers provide the basic information on measured phase currents and voltages in different points within the power system. At the same time, currents and voltages serve as the input measuring quantities to power and energy meters.

Different measuring transducers provide information on electrical and non-electrical measuring quantities such as voltage, current, temperature, and pressure. In most cases, the measuring transducers change the values of the measured quantities into the direct current. The current value usually changes within the specified mA range in proportion to the value of the measured quantity.

Further processing of the direct currents obtained on the outputs of different measuring converters occurs within different control, protection, and monitoring terminals and within the higher hierarchical systems in the secondary power system.

8.2 Functionality

The REx 5xx control, protection and monitoring terminal have a built-in option to measure and further process information from 6 up to 36 different direct current information from different measuring transducers. Six independent measuring channels are located on each independent mA input module and the REx 5xx terminals can accept from one up to six independent mA input modules, depending on the case size. Refer to the technical data and ordering particulars for the particular terminal.

Information about the measured quantities is then available to the user on different locations:

- Locally by means of the local human-machine-interface (HMI)
- Locally by means of a front-connected personal computer (PC)
- Remotely over the LON bus to the station control system (SCS)
- Remotely over the SPA port to the station monitoring system (SMS)

User-defined measuring ranges

The measuring range of different direct current measuring channels is settable by the user independent on each other within the range between -25 mA and +25 mA in steps of 0.01 mA. It is only necessary to select the upper operating limit I_Max higher than the lower one I_Min.

The measuring channel can have a value of 2 of the whole range I_Max - I_Min above the upper limit I_Max or below the lower limit I_Min, before an out-of-range error occurs. This means that with a nominal range of 0-10 mA, no out-of-range event will occur with a value between -0.2 mA and 10.2 mA.

User can this way select for each measuring quantity on each monitored object of a power system the most suitable measuring range and this way optimize a complete functionality together with the characteristics of the used measuring transducer.

Continuous monitoring of the measured quantity

The user can continuously monitor the measured quantity in each channel by means of six built-in operating limits (figure 252). Two of them are defined by the operating range selection: I_Max as the upper and I_Min as the lower operating limit. The other four operating limits operate in two different modes:

- Overfunction, when the measured current exceeds the HiWarn or HiAlarm pre-set values
- Underfunction, when the measured current decreases under the LowWarn or LowAlarm pre-set values

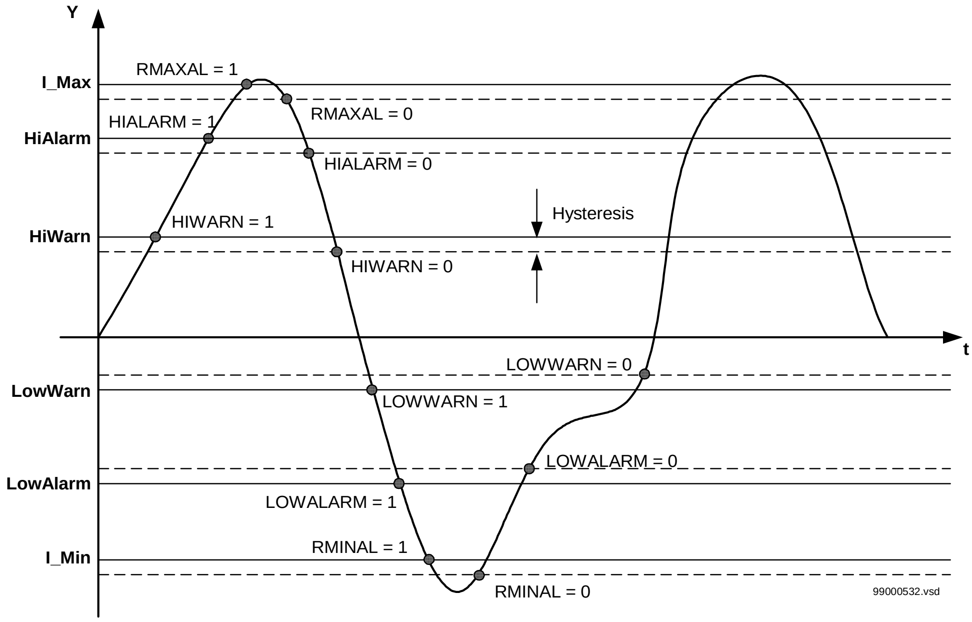


Figure 252: Presentation of the operating limits

Each operating level has its corresponding functional output signal:

- RMAXAL
- HIWARN
- HIALARM
- LOWWARN
- LOWALARM
- RMINAL

The logical value of the functional output signals changes according to figure 252.

The user can set the hysteresis, which determines the difference between the operating and reset value at each operating point, in wide range for each measuring channel separately. The hysteresis is common for all operating values within one channel.

Continuous supervision of the measured quantity

The actual value of the measured quantity is available locally and remotely. The measurement is continuous for each channel separately, but the reporting of the value to the higher levels (control processor in the unit, HMI and SCS) depends on the selected reporting mode. The following basic reporting modes are available:

- Periodic reporting
- Periodic reporting with dead-band supervision in parallel
- Periodic reporting with dead-band supervision in series
- Dead-band reporting

Users can select between two types of dead-band supervision:

- Amplitude dead-band supervision (ADBS).
- Integrating dead-band supervision (IDBS).

Amplitude dead-band supervision

If the changed value —compared to the last reported value— is larger than the +/- ΔY predefined limits that are set by users, and if this is detected by a new measuring sample, then the measuring channel reports the new value to a higher level. This limits the information flow to a minimum necessary. Figure 253 shows an example of periodic reporting with the amplitude dead-band supervision.

The picture is simplified: the process is not continuous but the values are evaluated at time intervals depending on the sampling frequency chosen by the user (SampRate setting).

After the new value is reported, the new +/- ΔY limits for dead-band are automatically set around it. The new value is reported only if the measured quantity changes more than defined by the new +/- ΔY set limits.

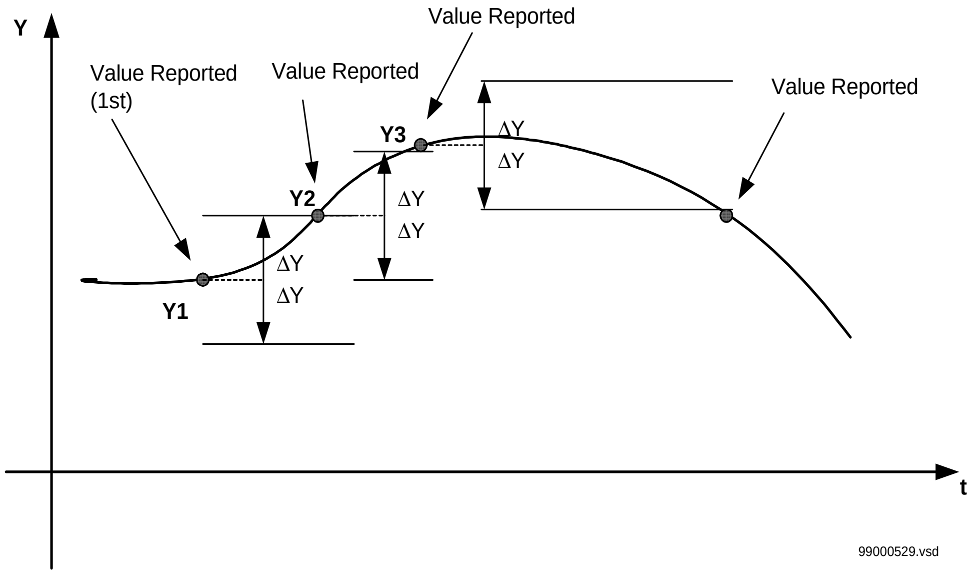


Figure 253: Amplitude dead-band supervision reporting

Integrating dead-band supervision

The measured value is updated if the time integral of all changes exceeds the pre-set limit (figure 254), where an example of reporting with integrating dead-band supervision is shown. The picture is simplified: the process is not continuous but the values are evaluated at time intervals depending on the sampling frequency chosen by the user (SampRate setting).

The last value reported (Y1 in figure 254) serves as a basic value for further measurement. A difference is calculated between the last reported and the newly measured value during new sample and is multiplied by the time increment (discrete integral). The absolute values of these products are added until the pre-set value is exceeded. This occurs with the value Y2 that is reported and set as a new base for the following measurements (as well as for the values Y3, Y4 and Y5).

The integrating dead-band supervision is particularly suitable for monitoring signals with low variations that can last for relatively long periods.

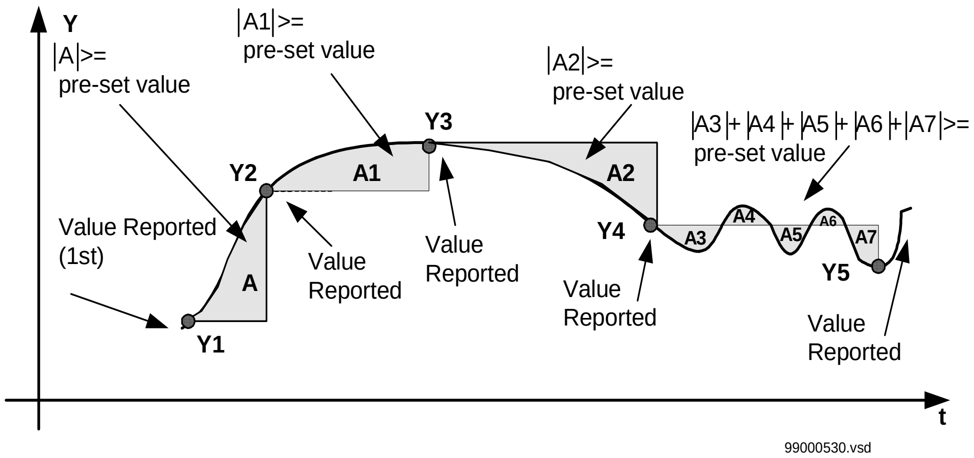


Figure 254: Reporting with integrating dead-band supervision

Periodic reporting

The user can select the periodic reporting of measured value in time intervals between 1 and 3600 s (setting RepInt). The measuring channel reports the value even if it has not changed for more than the set limits of amplitude or integrating dead-band supervision (figure 255). To disable periodic reporting, set the reporting time interval to 0 s.

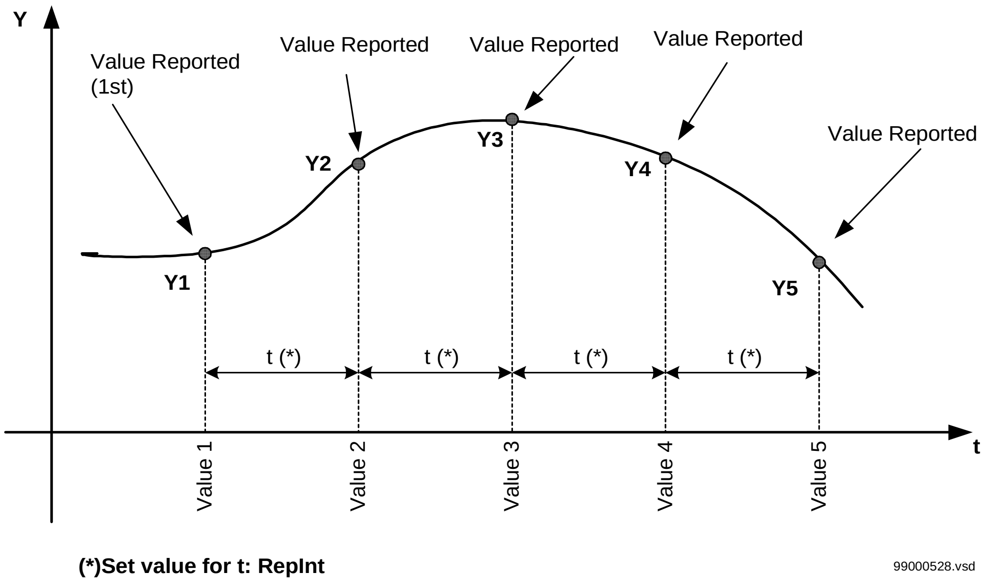


Figure 255: Periodic reporting

Periodic reporting with parallel dead-band supervision

The newly measured value is reported:

- After each time interval for the periodic reporting expired, **OR**;
- When the new value is detected by the dead-band supervision function.

The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.

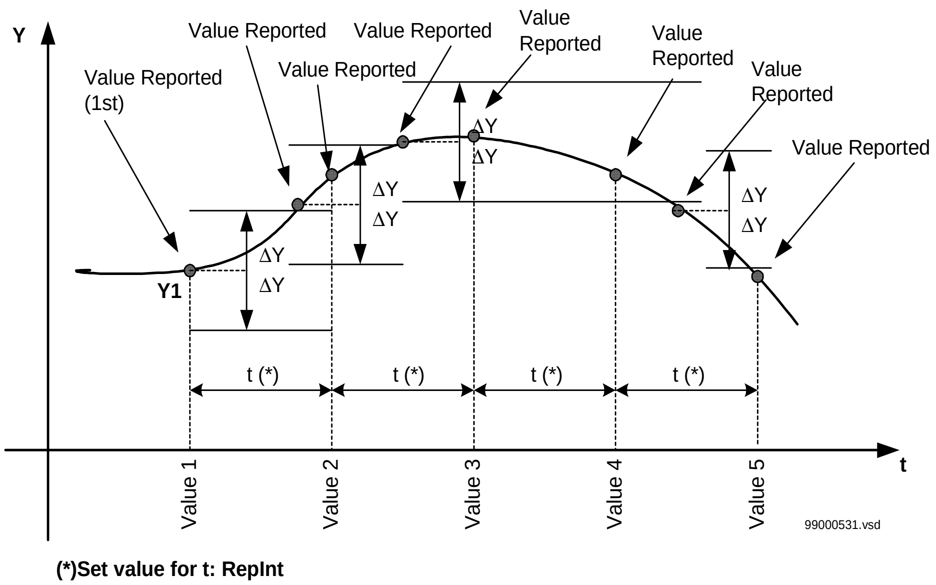
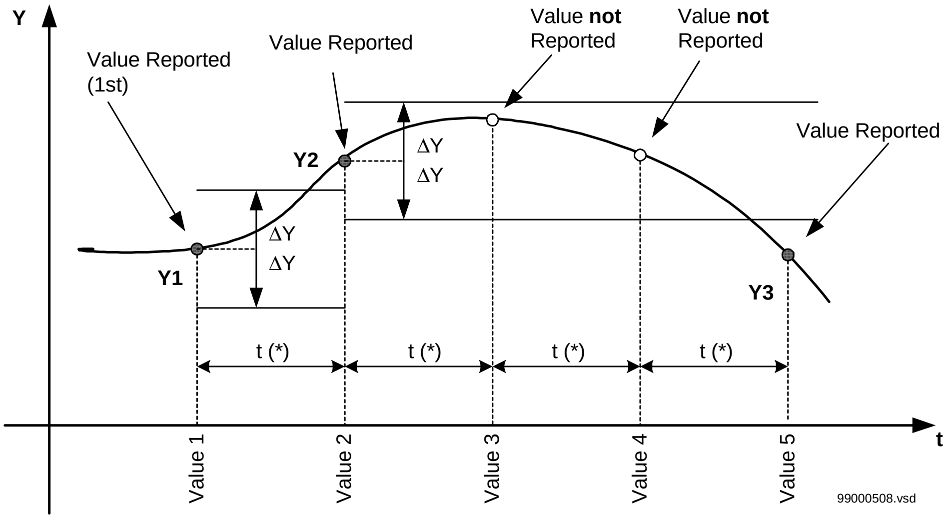


Figure 256: Periodic reporting with amplitude dead-band supervision in parallel.

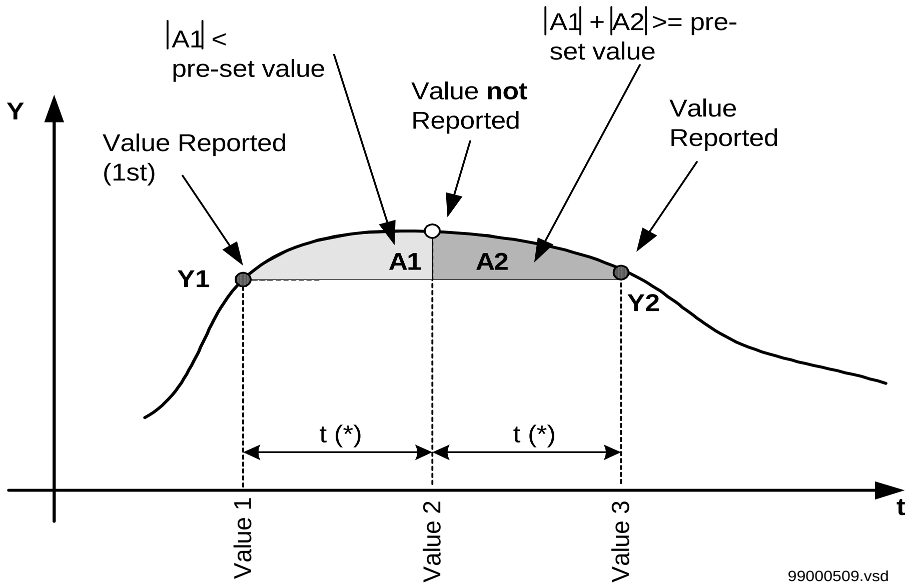
Periodic reporting with serial dead-band supervision

Periodic reporting can operate serially with the dead-band supervision. This means that the new value is reported only if the set time period expired **AND** if the dead-band limit was exceeded during the observed time (figures 257 and 258). The amplitude dead-band and the integrating dead-band can be selected. The periodic reporting can be set in time intervals between 1 and 3600 seconds.



(*)Set value for t: RepInt

Figure 257: Periodic reporting with amplitude dead-band supervision in series



(*)Set value for t: RepInt

Figure 258: Periodic reporting with integrating dead-band supervision in series

Combination of periodic reportings

The reporting of the new value depends on setting parameters for the dead-band and for the periodic reporting. Table 1 presents the dependence between different settings and the type of reporting for the new value of a measured quantity.

Table 16: Dependence of reporting on different setting parameters:

EnDeadB *	**EnIDeadB ***	**EnDeadBP ***	**RepInt ***	**Reporting of the new value**
Off	Off	Off	0	No measured values is reported
Off	On	On	t>0	The new measured value is reported only if the time t period expired and if, during this time, the integrating dead-band limits were exceeded (periodic reporting with integrating dead-band supervision in series)
On	Off	On	t>0	The new measured value is reported only if the time t period has expired and if, during this time, the amplitude dead-band limits were exceeded (periodic reporting with amplitude dead-band supervision in series)
On	On	On	t>0	The new measured value is reported only if the time t period expired and if at least one of the dead-band limits were exceeded (periodic reporting with dead-band supervision in series)
Off	On	Off	0	The new measured value is reported only when the integrated dead-band limits are exceeded
On	Off	Off	0	The new measured value is reported only when the amplitude dead-band limits were exceeded

EnDeadB *	EnIDeadB *	EnDeadBP *	RepInt *	Reporting of the new value
On	On	Off	0	The new measured value is reported only if one of the dead-band limits was exceeded
x	x	Off	t>0	The new measured value is updated at least after the time t period expired. If the dead-band supervision is additionally selected, the updating also occurs when the corresponding dead-band limit was exceeded (periodic reporting with parallel dead-band supervision)
* Please see the setting parameters in the Technical reference manual for further explanation				

8.3 Design

The design of the mA input modules follows the design of all REx 5xx-series protection, control, and monitoring terminals that have distributed functionality, where the decision levels are placed as closely as possible to the process.

Each independent measuring module contains all necessary circuitry and functionality for measurement of six independent measuring quantities related to the corresponding measured direct currents.

On the accurate input shunt resistor (R), the direct input current (from the measuring converter) is converted into a proportional voltage signal (the voltage drop across the shunt resistor is in proportion to the measured current). Later, the voltage signal is processed within one differential type of measuring channel (figure 259).

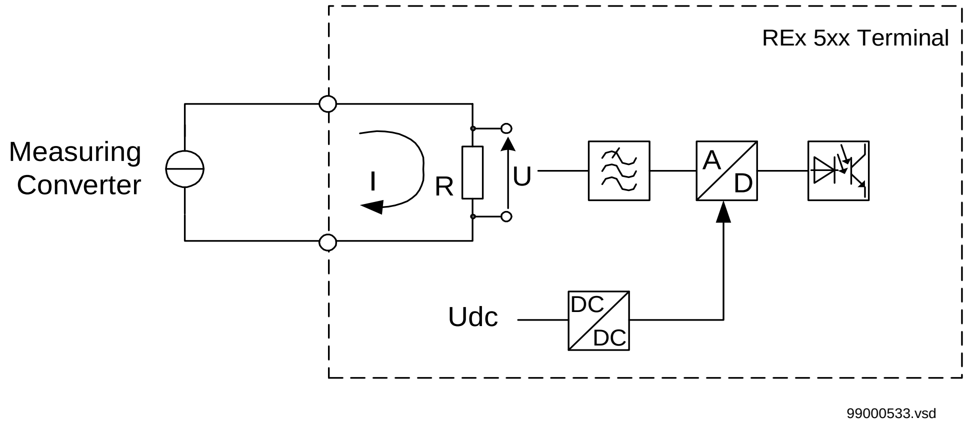


Figure 259: Simplified diagram for the function

The measured voltage is filtered by the low-pass analogue filter before entering the analogue to digital converter (A/D). Users can set the sampling frequency of the A/D converter between 5 Hz and 255 Hz to adapt to different application requirements as best as possible.

The digital information is filtered by the digital low-pass filter with the $(\sin x/x)^3$ response. The filter notch frequency automatically follows the selected sampling frequency. The relation between the frequency corresponding to the suppression of -3 dB and the filter notch frequency corresponds to the equation:

$$f_{-3dB} = 0,262 \cdot f_{notch}$$

(Equation 152)

Using optocouplers and DC/DC conversion elements that are used separately for each measuring channel, the input circuitry of each measuring channel is galvanically separated from:

- The internal measuring circuits
- The control microprocessor on the board

A microprocessor collects the digitized information from each measuring channel. The microprocessor serves as a communication interface to the main processing module (MPM).

All processing of the measured signal is performed on the module so that only the minimum amount of information is necessary to be transmitted to and from the MPM. The measuring module receives information from the MPM on setting and the command parameters; it reports the measured values and additional information—according to needs and values of different parameters.

Each measuring channel is calibrated very accurately during the production process. The continuous internal zero offset and full-scale calibration during the normal operation is performed by the A/D converter. The calibration covers almost all analogue parts of the A/D conversion, but neglects the shunt resistance.

Each measuring channel has built in a zero-value supervision, which greatly rejects the noise generated by the measuring transducers and other external equipment. The value of the measured input current is reported equal to zero (0) if the measured primary quantity does not exceed +/-0.5% of the maximum measuring range.

The complete measuring module is equipped with advanced self-supervision. Only the outermost analogue circuits cannot be monitored. The A/D converter, optocouplers, digital circuitry, and DC/DC converters, are all supervised on the module. Over the CAN bus, the measuring module sends a message to the MPM for any detected errors on the supervised circuitry.

8.4 Calculations

The PST Parameter Setting Tool has to be used in order to set all the parameters that are related to different DC analogue quantities.

Users can set the 13 character name for each measuring channel.

All the monitoring operating values and the hysteresis can be set directly in the mA of the measured input currents from the measuring transducers.

The measured quantities can be displayed locally and/or remotely according to the corresponding modules that are separately set for each measuring channel by the users (five characters).

The relation between the measured quantity in the power system and the setting range of the direct current measuring channel corresponds to this equation:

$$Value = ValueMin + (I - IMin) \cdot \frac{ValueMax - ValueMin}{IMax - IMin}$$

(Equation 153)

Where:

I_Min	is the set value for the minimum operating current of a channel in mA.
I_Max	is the set value for the maximum operating current of a channel in mA.
ValueMin	is the value of the primary measuring quantity corresponding to the set value of minimum operating current of a channel, I_Min.
ValueMax	is the value of the primary measuring quantity corresponding to the set value of maximum operating current of a channel, I_Max.
Value	is the actual value of the primary measured quantity.

Figure 260 shows the relationship between the direct mA current I and the actual value of the primary measured quantity, Value.

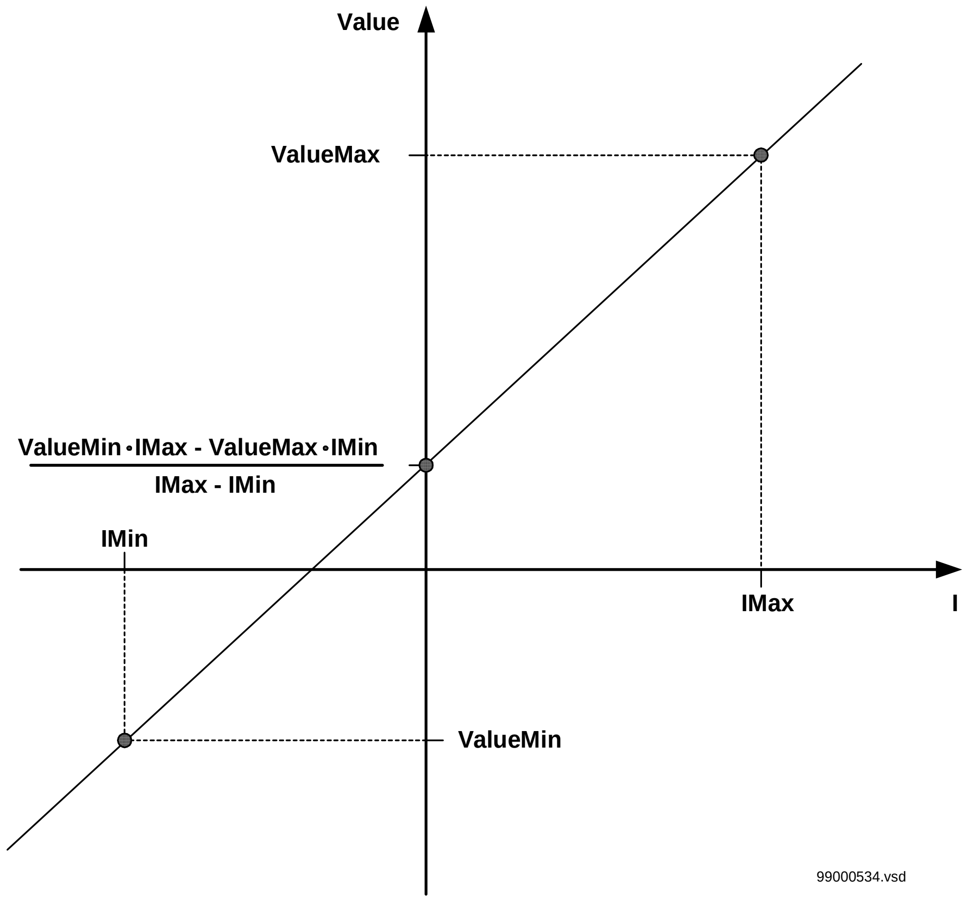


Figure 260: Relationship between the direct current (I) and the measured quantity primary value (Value)

The dead-band limits can be set directly in the mA of the input direct current for:

- Amplitude dead-band supervision ADBS
- Integrating dead-band supervision IDBS

The IDBS area [mAs] is defined by the following equation:

$$IDBS = \frac{IDeadB}{SampRate} = IDeadB \cdot ts$$

(Equation 154)

where:

IDeadB	is the set value of the current level for IDBS in mA.
SampRate	is the sampling rate (frequency) set value, in Hz.
ts = 1/SampRate	is the time between two samples in s.

If a 0.1 mA variation in the monitored quantity for 10 minutes (600 s) is the event that should cause the trigger of the IDBS monitoring (reporting of the value because of IDBS threshold operation) and the sampling frequency (SampRate) of the monitored quantity is 5 Hz, than the set value for IDBS (IDeadB) will be 300 mA:

$$IDBS = 0.1 \cdot 600 = 60[mA\ s]$$

(Equation 155)

$$IDeadB = IDBS \cdot SampRate = 60 \cdot 5 = 300[mA]$$

(Equation 156)

The polarity of connected direct current input signal can be changed by setting the ChSign to On or Off. This way it is possible to compensate by setting the possible wrong connection of the direct current leads between the measuring converter and the input terminals of the REx 5xx series unit.

The setting table lists all setting parameters with additional explanation.

Note:

It is important to set the time for periodic reporting and deadband in an optimized way to minimize the load on the station bus.

Chapter 12 Metering

About this chapter

This chapter describes the metering functions.

1 Pulse counter logic (PC)

1.1 Application

The pulse counter function provides the Substation Automation system with the number of pulses, which have been accumulated in the REx 5xx terminal during a defined period of time, for calculation of, for example, energy values. The pulses are captured on the Binary Input Module (BIM) that is read by the pulse counter function. The number of pulses in the counter is then reported via LON to the station HMI or read via SPA as a service value.

The normal use for this function is the counting of energy pulses for kWh and kvarh in both directions from external energy meters. Up to 12 binary inputs in a REx 5xx can be used for this purpose with a frequency of up to 40 Hz.

1.2 Functionality

The registration of pulses is done for positive transitions (0->1) on one of the 16 binary input channels located on the Binary Input Module (BIM). Pulse counter values are read from the station HMI with predefined cyclicity without reset, and an event is created.

The integration time period can be set in the range from 30 seconds to 60 minutes and is synchronised with absolute system time. That means, a cycle time of one minute will generate a pulse counter reading every full minute. Interrogation of additional pulse counter values can be done with a command (intermediate reading) for a single counter. All active counters can also be read by the LON General Interrogation command (GI).

The pulse counter in REx 5xx supports unidirectional incremental counters. That means only positive values are possible. The counter uses a 32 bit format, that is, the reported value is a 32-bit, signed integer with a range 0...+2147483647. The counter is reset at initialisation of the terminal or by turning the pulse counter operation parameter Off/On.

The reported value to station HMI over the LON bus contains Identity, Value, Time, and Pulse Counter Quality. The Pulse Counter Quality consists of:

- Invalid (board hardware error or configuration error)
- Wrapped around
- Blocked
- Adjusted

The transmission of the counter value by SPA can be done as a service value, that is, the value frozen in the last integration cycle is read by the station HMI from the database. The pulse counter function updates the value in the database when an integration cycle is finished and activates the NEW_VAL signal in the function block. This signal can be connected to an Event function block, be time tagged, and transmitted to the station HMI. This time corresponds to the time when the value was frozen by the function.

1.3 Design

The function can be regarded as a function block with a few inputs and outputs. The inputs are divided into two groups: settings and connectables (configuration). The outputs are divided into three groups: signals (binary), service value for SPA, and an event for LON.

Figure 261 shows the pulse counter function block with connections of the inputs and outputs.

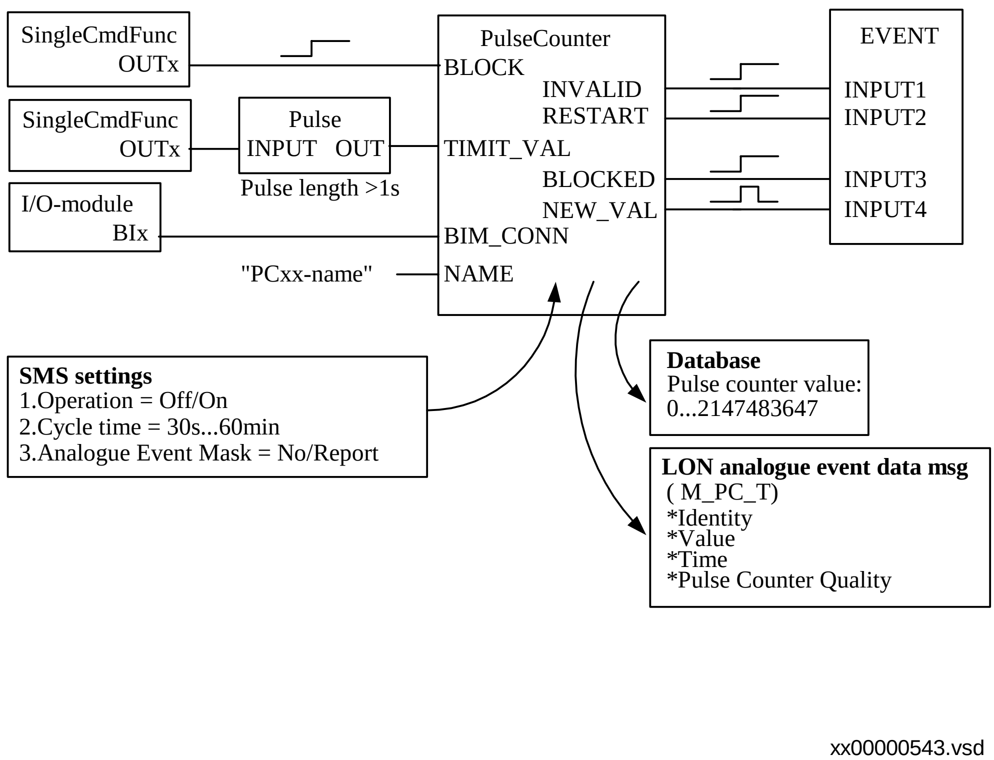


Figure 261: Overview of the pulse counter function

The BLOCK and TMIT_VAL inputs can be connected to Single Command blocks, which are intended to be controlled either from the station HMI or/and the local HMI. As long as the BLOCK signal is set, the pulse counter is blocked. The signal connected to TMIT_VAL performs one additional reading per positive flank. The signal must be a pulse with a length >1 second.

The BIM_CONN input is connected to the used input of the function block for the Binary Input Module (BIM). If BIM_CONN is connected to another function block, the INVALID signal is activated to indicate the configuration error.

The NAME input is used for a user-defined name with up to 19 characters.

Each pulse counter function block has four output signals: INVALID, RESTART, BLOCKED, and NEW_VAL. These signals can be connected to an Event function block for event recording.

The INVALID signal is a steady signal and is set if the Binary Input Module, where the pulse counter input is located, fails or has wrong configuration.

The RESTART signal is a steady signal and is set when the reported value does not comprise a complete integration cycle. That is, in the first message after terminal start-up, in the first message after deblocking, and after the counter has wrapped around during last integration cycle.

The BLOCKED signal is a steady signal and is set when the counter is blocked. There are two reasons why the counter is blocked:

- The BLOCK input is set, or
- The Binary Input Module, where the counter input is situated, is inoperative.

The NEW_VAL signal is a pulse signal. The signal is set if the counter value was updated since last report.

1.4 Calculations

1.4.1 Setting

From the PST Parameter Setting Tool under SETTINGS/PC01-12 (Pulse Counter) in the terminal tree, these parameters can be set individually for each pulse counter:

- Operation = Off/On
- Cycle Time = 30s / 1min / 1min30s / 2min / 2min30s / 3min / 4min / 5min / 6min / 7min30s / 10min / 12min / 15min / 20min / 30min / 60min.

Under EVENT MASKS/Analogue events/Pulse Counter in PST, the reporting of the analogue events can be masked:

- Event Mask = No Events/Report Events

The configuration of the inputs and outputs of the pulse counter function block is made by the CAP 531 configuration tool.

On the Binary Input Module, the debounce filter time is fixed set to 5 ms, that is, the counter suppresses pulses with a pulse length less than 5 ms. The input oscillation blocking frequency is preset to 40 Hz. That means that the counter finds the input oscillating if the input frequency is greater than 40 Hz. The oscillation suppression is released at 30 Hz. From the PST under CONFIGURATION/Binary I/O-modules/ Oscillation in the terminal tree and from the local HMI, the values for blocking/release of the oscillation can be changed.

Note!

The setting is common for all channels on a Binary Input Module, that is, if changes of the limits are made for inputs not connected to the pulse counter, the setting also influences the inputs on the same board used for pulse counting.

Chapter 13 Data communication

About this chapter

This chapter describes the data communication and the associated hardware.

1 Remote end data communication

1.1 Application

General

The hardware communication modules (or modems) for the Remote end data communication are available in basically three different versions:

- for optical communication
- for short range pilot wire communication
- for galvanic connection to communication equipment according to ITU (former CCITT) and EIA interface standards.

All systems are designed to be able to work at 64 kbit/s. Some of them can also work at North American standard of 56 kbit/s. This is especially pointed out in the description under each module.

If the protection terminal is located at a long distance (>100 m for V.36, X.21 and RS530 and >10m for G.703) from the communication equipment or multiplexer or if the cables run through a noisy area, optical communication should be used to interconnect the protection terminal and the communication equipment. In this case the protection terminal contains module used for optical fibre communication and a suitable optical to electrical converter is installed close to the communication equipment due to the fact that there exists no standard for optical connections to communication equipment. The optical-to-electrical converters that can be used are FOX6Plus (and FOX20) from ABB and 21-15xx or 21-16xx from FIBERDATA. The FOX6Plus together with optical fibre modem supports the G.703 co-directional interfacing and with restrictions for X.21 and V.36. 21-15xx supports V.35 and V.36 while 21-16xx supports X.21, G.703 and RS530 co-directional and contra-directional. For 21-15xx and 21-16xx short range optical fibre modem is needed.

NOTE!

When using galvanic connection between protection terminal and communication equipment or point to point galvanic connection between two protection terminals it is essential that the cable installation is carefully done. See Installation and commissioning manual for further information.

Optical connection of multiplexer is only possible if the multiplexer is of type FOX6Plus or FOX20 from ABB. The terminal can then be connected optically to the multiplexer, provided the protection is equipped with the optical fibre modem , not the short range fibre optical modem, and the FOX is equipped with an Optical Terminal Module of type N3BT.

1.2 Design

The Remote end data communication consists of two parts, one software part that handles the message structure, packing different pieces together, activate sending of the messages, unpacking received messages etc, and one hardware part forming the interface against external communication equipments. The hardware part, or built-in modems, can have either galvanic or optical connection. To ensure compatibility with a wide range of communication equipment and media, the terminal is designed to work within the signalling bandwidth of a standard CCITT PCM channel at 64 kbits/s. To enable the use in North American EIA PCM systems working at 56 kbits/s, some of the interfacing modules can be adapted to this bit rate.

The message is based on the HDLC protocol. This is a protocol for the flow management of the information on a data communication link that is widely used. The basic information unit on an HDLC link is a frame. A frame consists of:

- start (or opening) flag
- address and control fields (if included)
- data to be transmitted
- CRC word
- end (or closing) flag.

The start and stop flags are 8 bit each and the Cyclic Redundancy Check (CRC) 16 bits. The data field differs if between a message sent from a slave to a master and a message sent from a master to a slave. The principle design is according to figure 262.

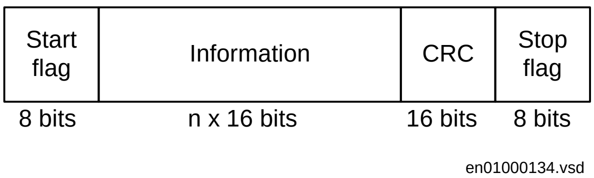


Figure 262: Data message structure

The start and stop flags are the 0111 1110 sequence (7E hexadecimal) defined in HDLC standard. The CRC is designed according to standard CRC16 definition.

The optional address field in the HDLC frame is not used, instead a separate addressing is included in the data field.

The address field is used for checking that the received message originates from the correct equipment. There is always a risk of multiplexers occasionally mixing up the messages. Each terminal is given different terminal numbers. The terminal is then programmed to accept messages only from a specific terminal number.

If the CRC function detects a faulty message, the message is thrown away and not used in the evaluation. No data restoration or retransmission are implemented.

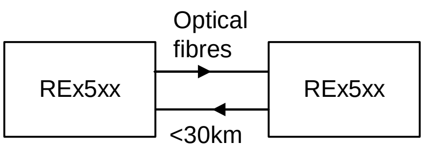
The hardware, consisting of a Data communication module, is placed in an applicable slot in the terminal. To add or remove the module, a reconfiguration of the terminal is done from the graphical configuration tool, CAP 531.

2 Optical fibre communication module

2.1 Application

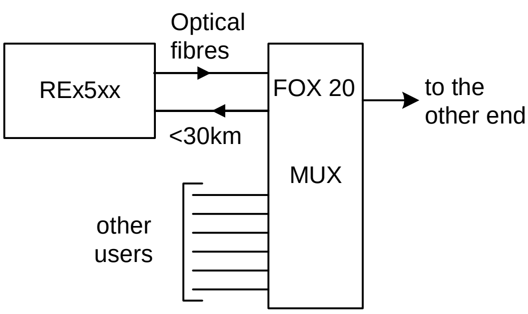
Optical fibre modem

This module is designed for point to point optical communication, see figure 263, but can also be used for direct optical communication to a multiplexer of type FOX6Plus or FOX20, see figure 264 from ABB, provided it is equipped with an Optical Terminal Module of type N3BT. The FOX6Plus can also be used as an optical to electrical converter supporting the G.703 co-directional interfacing according to ITU (former CCITT), see figure 265. FOX6Plus can also in some cases be used for X.21 and V.36 interface but special attention must be paid to how to connect the signal. Used as an optical to electrical converter the FOX6Plus only supports 64 kbit/s data transmission.



xx00000536.vsd

Figure 263: Dedicated link, opticalfibre connection.



xx00000538.vsd

Figure 264: Multiplexed link, optical fibre connection.

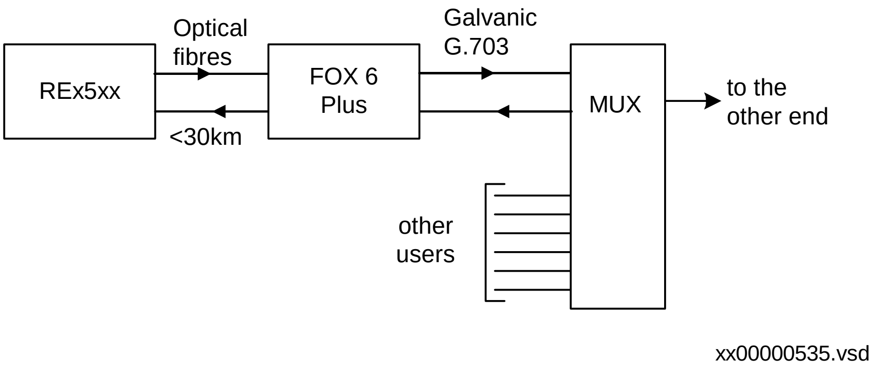
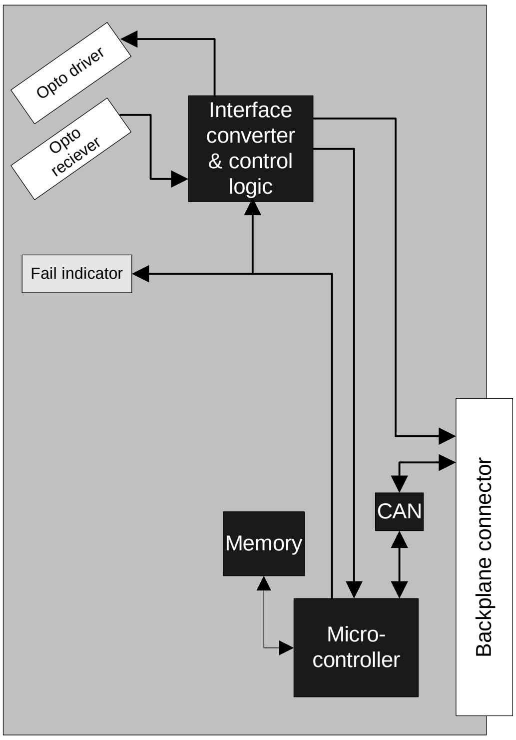


Figure 265: Multiplexed link, fibre optical-galvanic connection with FOX6Plus

2.2 Design

The optical communication module is designed to work with both 9/125 µm single-mode fibres and 50/125 or 62,5/125 µm multimode fibres at 1300 nm wavelength. The connectors are of type FC-PC (SM) or FC (MM) respectively. Two different levels of optical output power are used to cover distances from 0 to approximately 30 km. The leverl of optical power is selected with a setting. The attenation fibres is normally approximately 0.8 dB/km for multimode and 0.4 dB/km for single-mode. Additional attenuation due to installation can be estimated to be 0.2dB/km for multimode and 0.1 dB/km for single-mode fibres. For single-mode fibre and high output power this results in a maximum distance of 32km.



99000224.vsd

Figure 266: Block diagram for the optical communication module.

3 Galvanic data communication module

3.1 Application

Interface modules for V.36, X.21 and RS530

These interface modules are intended for connection to commercially available communication equipments or multiplexers and can be used both with 56 and 64 kbit/s data transmission.

Since the protection communicates continuously, a permanent communication circuit is required. Consequently, the call control and handshaking features specified for some interfacing recommendations are not provided.

Even if the standard claims that the reach for these interfaces are up to 1 km at 64 kbit/s it is not recommended to use that distance for protection purposes where the communication has to be reliable also under primary power system faults. This is due to the low level of the communication signals which gives low margin between signal and noise. If the protection terminal is in the same building as the multiplexing equipment and the environment is relatively free from noise, the protection terminal may be connected directly to the multiplexer via shielded and properly earthed cables with twisted pairs for distances less than 100 m.

Modules are available for the following interface recommendations, specifying the interconnection of the digital equipment to a PCM multiplexer:

- V.35/36 co-directional galvanic interface
- V.35/36 contra-directional galvanic interface
- X.21 galvanic interface
- RS530/422 co-directional galvanic interface
- RS530/422 contra-directional galvanic interface

Note!

Due to problems of timing co-directional operation for V.35/36 and RS530 is only recommended to be used for direct back-to-back operation, for example during laboratory testing!

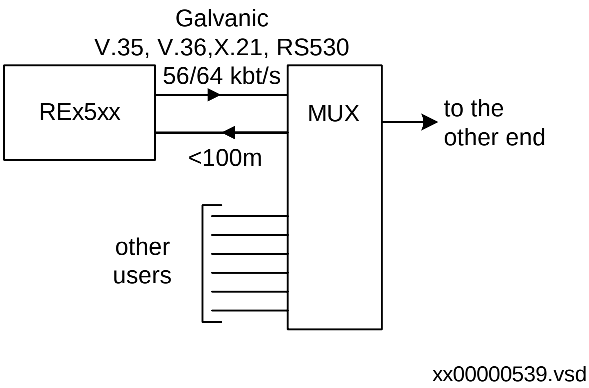


Figure 267: Multiplexed link, galvanic connection

3.2 Design

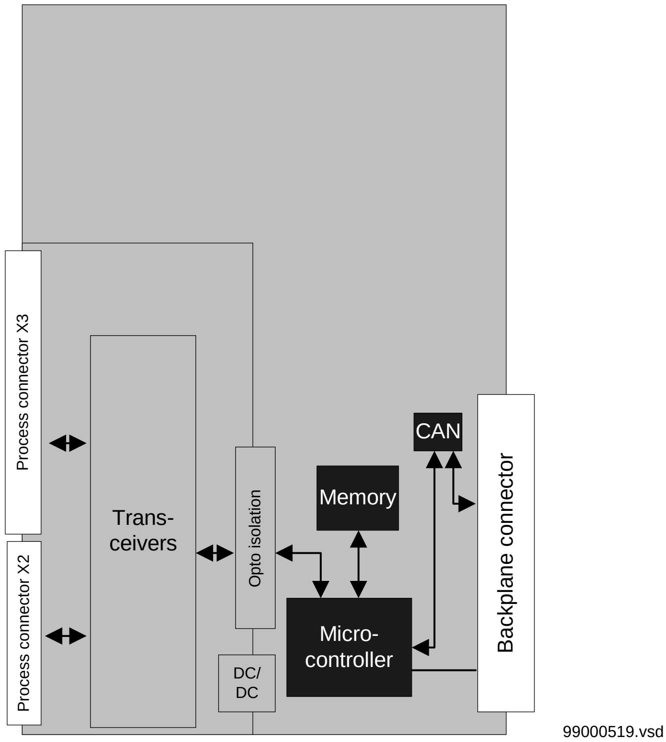


Figure 268: Block diagram for the galvanic communication module

4 Short range galvanic module

4.1 Application

Short range galvanic modem

The short range galvanic modem is used for point to point synchronous data transmission at 64 kbit/s at distances up to 4 km. Transmission is performed simultaneously in both directions, full duplex, over four wires in a communication (pilot wire) line according to figure 269.

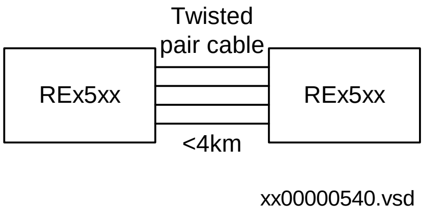


Figure 269: Dedicated link, short range galvanic modem

Compared to normal data transmission standards, for example V.36, X.21 etc., the short range modem increase the operational security and admits longer distances of transmission. This is achieved by a careful choice of transmission technology, modified M-3 balanced current loop and galvanic isolation between the transmission line and the internal logic of the protection terminal.

The reach will depend on the used cable. Higher capacitance between conductors and higher resistance will reduce the reach. The use of screened cables will increase the capacitance and thereby shorten the reach but this will often be compensated by the reduced noise giving a better operational security. Maximum ranges as a function of cable parameters are given in the diagram in figure 270.

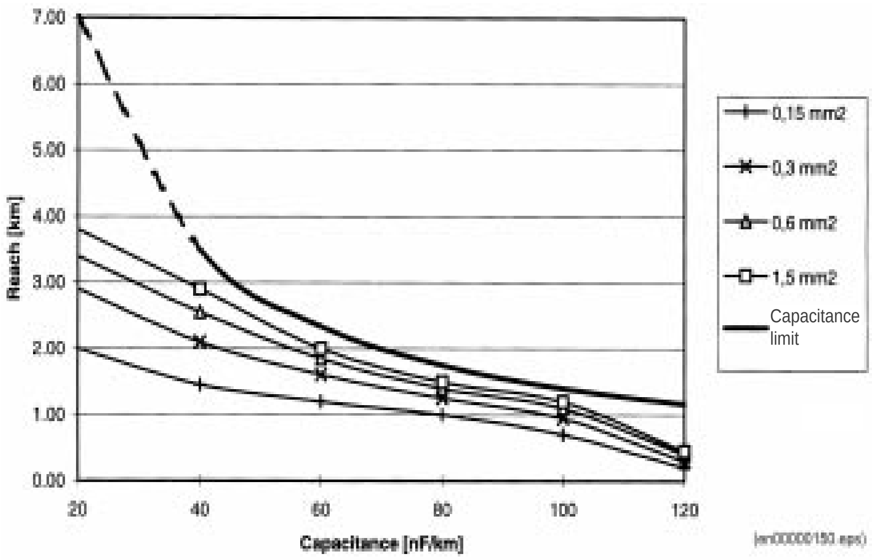


Figure 270: Maximum reach for short range galvanic modem

Note!

The reaches in the diagram, figure 270, are given for twisted-pair and double-screened cables, one screen for each pair and one common outer screen. For non twisted-pair cables, the reach has to be reduced by 20%. For non pair-screened cables, the reach also has to be reduced by 20%. For non twisted and single screened cables, one common outer screen, the reach will therefor be reduced by 40%.

5 Short range optical fibre module

5.1 Application

The short range optical fibre modem is used for point to point synchronous 64 kbit/s data transmission at distances up to 5 km, the principle is according to figure 271. It can also be used together with optic fibre transceiver type 21-15xx/16xx from FIBERDATA in order to get an optical link between the protection terminal and a remotely located communication equipment as in figure 272.

21-15xx supports interfaces according to ITU (former CCITT) standards V.35 and V.36 co- and contra-directional. 21-16xx supports interfaces standards X21 and G.703 according to ITU (former CCITT) and RS.530 according to EIA co- and contra-directional.

Transmission is performed simultaneously in both directions, full duplex, over two optical fibres. The fibres shall be of multi mode type, 50/125 µm or 62.5/125 µm.

The short range optical module has ST type connectors.

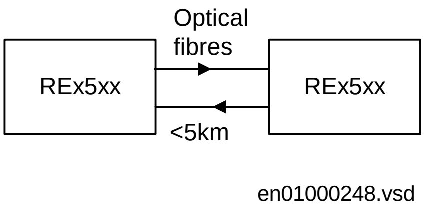


Figure 271: Dedicated link, optical fibre connection

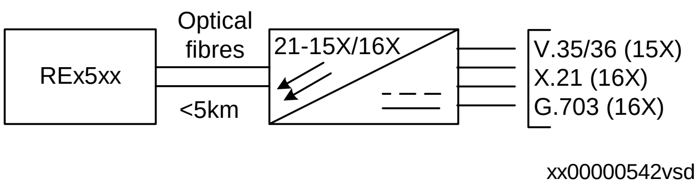


Figure 272: Multiplexed link, short range optical fibre connection

The reach will depend on the properties of the used optical fibre. In the optical budget has also to be accounted for losses in splices, connectors and also ageing of the cable. The connection to the protection terminal shall not be accounted for in the optical budget. 15 dB optical budget gives up to 5 km reach under normal conditions.

6 G.703 module

6.1 Application

Interface modules for G.703 co-directional

This interface module is intended for connection to commercially available communication equipments or multiplexers with G.703 interface. It can only be used with transmission rate of 64 kbit/s. Furthermore it only supports co-directional operation. Contra-directional and centralised clock are not supported.

Even if the standard claims that the reach can be rather long at 64 kbit/s, it is not recommended to use this for protection purposes where the communication has to be reliable also under primary power system faults. This is due to the low level of the communication, signals only 1 V, which gives low margin between signal and noise. If the protection and the communication equipment are located in the same room and the environment is free of noise, the protection terminal may be connected directly to the multiplexer via shielded and properly earthed cables with twisted pairs, same as shown in figure for V.36 etc, for distances up to 10 m.

7 Carrier module

7.1 Application

Use the carrier module with the appropriate galvanic or optical communication sub-module for short range communication of binary signals. Use the optical communication module when connecting a FIBERDATA 21-15X or FIBERDATA 21-16X optical-to-electric modem. The 21-15X model supports V.35 and V.36 standards, and the 21-16X model X.21, RS530 or G.703 standards.

7.2 Design

The carrier module is used to connect a communication sub-module to the platform. It adds the CAN-communication and the interface to the rest of the platform. By this the capability to transfer binary signals between for example two distance protection units is added.

The following three types of sub-modules can be added to the carrier module:

- Short range galvanic communication module
- Short range optical communication module
- G.703 communication module

The carrier module senses the type of sub-module via one of the two connectors.

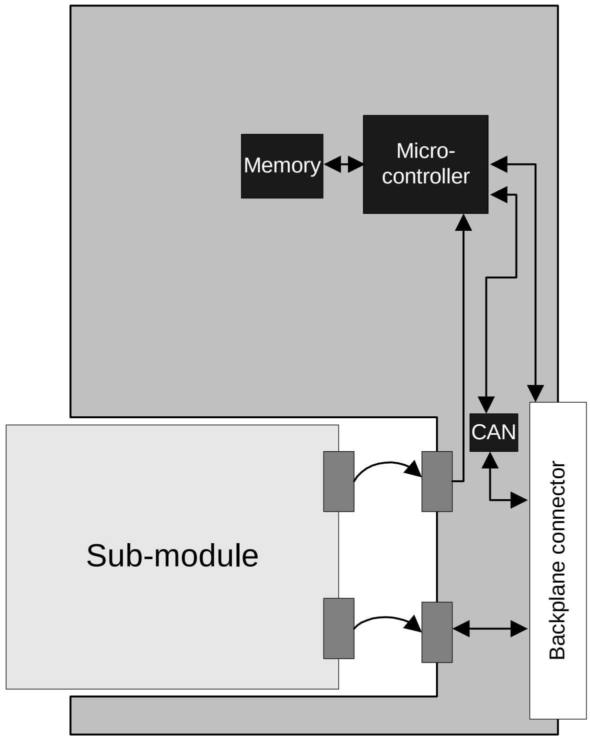


Figure 273: Block diagram for the carrier module.

8 Serial communication

8.1 Application

The serial communication can be used for different purposes, which enable better access to the information stored in the terminals. The serial communication is also used for communication directly between terminals (bay-to-bay communication).

The serial communication can be used with a station monitoring system (SMS) or with a substation control system (SCS). Normally, SPA communication is used for SMS and SCS; LON communication is used for SCS. Additionally, LON communication can also be used for SMS 510. SPA communication is also applied when using the front communication port, but for this purpose, no special serial communication function is required in the terminal. Only the software in the PC and a special cable for front connection is needed.

The rear SPA-port can alternatively be set up for IEC 60870-5-103 communication. IEC 60870-5-103 is a standard protocol for protection functions.

9 Serial communication, SPA

9.1 Application

The SPA communication is mainly used for SMS. It can include different numerical relays/terminals with remote communication possibilities. Connection to a personal computer (PC) can be made directly (if the PC is located in the substation) or by telephone modem through a telephone network with CCITT characteristics.

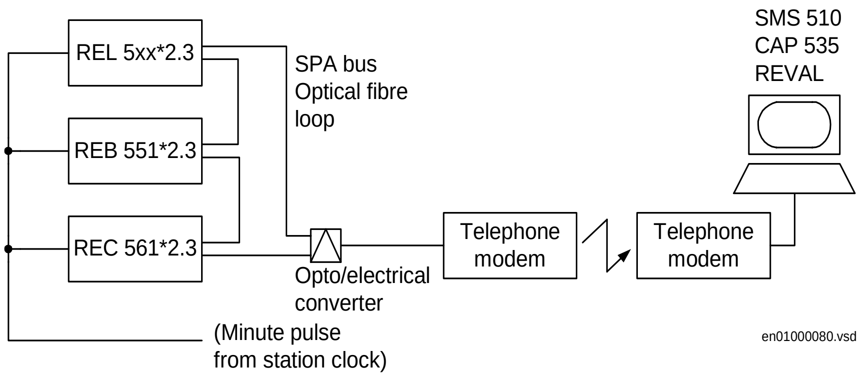


Figure 274: Example of SPA communication structure for a station monitoring system

9.2 Functionality

The SPA protocol V2.5 is an ASCII-based protocol for serial communication. The communication is based on a master-slave principle, where the terminal is a slave and the PC is the master. Only one master can be applied on each optic fibre loop. A program is needed in the master computer for interpretation of the SPA-bus codes and for translation of the settings sent to the terminal.

9.3 Design

When communicating locally with a Personal Computer (PC) in the station, using the rear SPA port, the only hardware needed for a station monitoring system is:

- Optical fibres
- Opto/electrical converter fo the PC
- PC

When communicating remotely with a PC using the rear SPA port, the same hardware is needed plus telephone modems.

The software needed in the PC, either local or remote, is:

- CAP 535 (Ver. 1.0 or higher) for configuration and parameter setting
- SMS 510 (Ver 1.0 or higher) for reading of disturbance records, events, distance to fault and trip value settings
- REVAL (Ver 2.0 or higher) for evaluation of the disturbance recorder data

When communicating to a front-connected PC, the only hardware required is the special front-connection cable. The software needed in a front connected PC is:

- CAP 535 (Ver. 1.0 or higher) for configuration and parameter setting
- SMS 510 (Ver 1.0 or higher) for reading of disturbance records, events, distance to fault and trip value settings
- REVAL (Ver 2.0 or higher) is also required if the same PC is used for evaluation of the disturbance recorder data.

9.4 Calculations

The SPA and the IEC use the same rear communication port. To define the protocol to be used, a setting is done on the local HMI under the menu:

Configuration
  TerminalCom
    SPA-IECPort

When the type of communication protocol is defined, the power to the terminal has to be switched off and on.

The most important settings in the terminal for SPA communication are the slave number and baud rate (communication speed). These settings are absolutely essential for all communication contact to the terminal.

These settings can only be done on the local HMI for rear channel communication at:

Configuration
TerminalCom
SPACOMM
Rear

and for front connection at:

Configuration
TerminalCom
SPACOMM
Front

The slave number can be set to any value from 1 to 899, as long as the slave number is unique within the used SPA loop.

The baud rate, which is the communication speed, can be set to between 300 and 38400 bits/s. The baud rate should be the same for the whole station, although different baud rates in a loop are possible. If different baud rates in the same fibre optical loop are used, consider this when making the communication setup in the communication master, the PC. The maximum baud rate of the front connection is limited to 9600 bit/s.

For local communication, 19200 or 38400 bit/s is the normal setting. If telephone communication is used, the communication speed depends on the quality of the connection and on the type of modem used. But remember that the terminal does not adapt its speed to the actual communication conditions, because the speed is set on the HMI of the terminal.

10 Serial communiction, IEC

10.1 Application

The IEC 60870-5-103 communication protocol is mainly used when a protection terminal communicates with a third party control or monitoring system. This system must have a software that can interpret the IEC 60870-5-103 communication messages.

10.2 Functionality

The IEC 60870-5-103 is an unbalanced (master-slave) protocol for coded-bit serial communication exchanging information with a control system. In IEC terminology a primary station is a master and a secondary station is a slave. The communication is based on a point to point principle. The master must have a software that can interpret the IEC 60870-5-103 communication messages. For detailed information about IEC 60870-5-103, refer to the IEC60870 standard part 5: Transmission protocols, and to the section 103: Companion standard for the informative interface of protection equipment.

10.3 Design

General

The protocol implementation in REx 5xx consists of the following functions:

- Event handling
- Report of analog service values (measurands)
- Fault location
- Command handling
  - Autorecloser ON/OFF
  - Teleprotection ON/OFF
  - Protection ON/OFF
  - LED reset
  - Characteristics 1 - 4 (Setting groups)
- File transfer (disturbance files)
- Time synchronization

Hardware

When communicating locally with a Personal Computer (PC) or a Remote Terminal Unit (RTU) in the station, using the SPA/IEC port, the only hardware needed is:

- Optical fibres, glass/plastic
- Opto/electrical converter for the PC/RTU
- PC/RTU

Events

The events created in the terminal available for the IEC 60870-5-103 protocol are based on the event function blocks EV01 - EV06. These function blocks include the function type and the information number for each event input, which can be found in the IEC-document. See also the description of the Event function.

Measurands

The measurands can be included as type 3.1, 3.2, 3.3, 3.4 and type 9 according to the standard.

Fault location

The fault location is expressed in reactive ohms. In relation to the line length in reactive ohms, it gives the distance to the fault in percent. The data is available and reported when the fault locator function is included in the terminal.

Commands

The commands defined in the IEC 60870-5-103 protocol are represented in a dedicated function block. This block has output signals according to the protocol for all available commands.

File transfer

The file transfer functionality is based on the Disturbance recorder function. The analog and binary signals recorded will be reported to the master. The eight last disturbances, that are recorded, are available for transfer to the master. A file that has been transferred and acknowledged by the master it cannot be transferred again.

The binary signals, that are reported, are those that are connected to the disturbance function blocks DRP1 - DRP3. These function blocks include the function type and the information number for each signal. See also the description of the Disturbance report.

The analog channels, that are reported, are the first four current inputs and the first four voltage inputs.

10.4 Calculations

Settings from the local HMI

The SPA and the IEC use the same rear communication port. To define the protocol to be used, a setting is done on the local HMI under the menu:

Configuration
TerminalCom
SPA-IECPort

When the type of communication protocol is defined, the power to the terminal has to be switched off and on.

The settings for IEC 60870-5-103 communication are the following:

- Individually blocking of commands
- Setting of measurand type
- Setting of main function type and activation of main function type
- Settings for slave number and baud rate (communication speed)
- Command for giving Block of information command

The settings for individually blocking of commands can be found on the local HMI at:

Configuration
TerminalCom
IECCom
Commands

Each command has its own blocking setting and the state can be set to OFF or ON. The OFF state corresponds to non-blocked state and ON corresponds to blocked state.

The settings for type of measurand can be found on the local HMI at:

Configuration
TerminalCom
IECCom
Measurands

The type of measurands can be set to report standardised types, Type 3.1, Type 3.2, Type 3.3, Type 3.4 or Type 9.

The use of main function type is to facilitate the engineering work of the terminal. The settings for main function type and the activation of main function type can be found on the local HMI at:

Configuration
TerminalCom
IECCom
FunctionType

The main function type can be set to values according to the standard, this is, between 1 and 255. The value zero is used as default and corresponds to not used.

The setting for activation of main function type can be set to OFF or ON. The OFF state corresponds to non-activated state and ON corresponds to activated state. Upon activated the main function type overrides all other settings for function type within the terminal, that is, function type settings for event function and disturbance recorder function. When set to OFF, function type settings for event function and disturbance recorder function use their own function type settings made on the function blocks for the event function and disturbance recorder respectively. Though for all other functions they use the main function type even when set to OFF.

The settings for communication parameters slave number and baud rate can be found on the local HMI at:

Configuration
TerminalCom
IECCom
Communication

The slave number can be set to any value between 0 to 255.

The baud rate, the communication speed, can be set either to 9600 bits/s or 19200 bits/s.

The settings for issuing a block-of-information command can be found on the local HMI at:

Configuration
TerminalCom
IECCom
BlockOfInfo

Information command with the value one (1) blocks all information sent to the master and abort any GI procedure or any file transfer in process. Thus issuing the command with the value set to zero (0) will allow information to be polled by the master.

The dialogue to operate the output from the BlockOfInformation command function is performed from different state as follows:

1. Selection active; select the:
   - C button, and then the No box activates.
   - Up arrow, and then New: 0 changes to New: 1. The up arrow changes to the down arrow.
   - E button, and then the Yes box activates.
2. Yes box active; select the:
   - C button to cancel the action and return to the BlockOfInfo window.
   - E button to confirm the action and return to the BlockOfInfo window.
   - Right arrow to activate the No box.
3. No box active; select the:
   - C button to cancel the action and return to the BlockOfInfo window.
   - E button to confirm the action and return to the BlockOfInfo window.
   - Left arrow to activate the Yes box.

Settings from the CAP 535 tool

Event

For each input of the Event function there is a setting for the information number of the connected signal. The information number can be set to any value between 0 and 255. In order to get proper operation of the sequence of events the event masks in the event function shall be set to ON_CHANGE. For single-command signals, the event mask shall be set to ON_SET.

In addition there is a setting on each event block for function type. Refer to description of the Main Function type set on the local HMI.

Commands

As for the commands defined in the protocol there is a dedicated function block with eight output signals. The configuration of these signals are made by using the CAP 531 tool.

To realise the BlockOfInformation command, which is operated from the local HMI, the output BLKINFO on the IEC command function block ICOM has to be connected to an input on an event function block. This input shall have the information number 20 (monitor direction blocked) according to the standard.

File transfer

For each input of the Disturbance recorder function there is a setting for the information number of the connected signal. The information number can be set to any value between 0 and 255.

Furthermore there is a setting on each input of the Disturbance recorder function for the function type. Refer to description of Main Function type set on the local HMI.

11 Serial communication, LON

11.1 Application

An optical network can be used within the Substation Automation system. This enables communication with the terminal through the LON bus from the operator’s workplace, from the control center and also from other terminals.

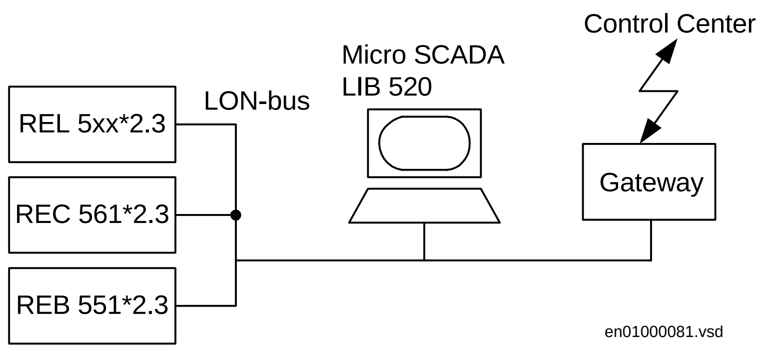


Figure 275: Example of LON communication structure for substation automation

11.2 Functionality

The LON protocol is specified in the LonTalkProtocol Specification Version 3 from Echelon Corporation. This protocol is designed for communication in control networks and is a peer-to-peer protocol where all the devices connected to the network can communicate with each other directly. For more information of the bay-to-bay communication, refer to the documents Event function and Multiple command function.

11.3 Design

The hardware needed for applying LON communication depends on the application, but one very central unit needed is the LON Star Coupler and optical fibres connecting the star coupler to the terminals. To communicate with the terminals from MicroSCADA, the application library LIB 520 is needed.

The HV/Control and the HV/REx 500 software modules are included in the LIB 520 high-voltage process package, which is a part of the Application Software Library within MicroSCADA applications.

The HV/Control software module is intended to be used for control functions in REx 5xx terminals. This module contains the process picture, dialogues and process database for the control application in the MicroSCADA.

The HV/REx 500 software module is used for setting and monitoring of the terminal via the MicroSCADA screen. At use of this function the PST Parameter Setting Tool (of v1.1 or higher) is required.

11.4 Calculations

Use the LNT, LON Network Tool to set the LON communication. This is a software tool applied as one node on the LON bus. In order to communicate via LON, the terminals need to know which node addresses the other connected terminals have, and which network variable selectors should be used. This is organised by the LNT.

The node address is transferred to the LNT via the local HMI at:

Configuration
  TerminalCom
    LONComm
      ServicePinMsg

By setting YES, the node address is sent to the LNT via the LON bus. Or, the LNT can scan the network for new nodes.

The speed of the LON bus is set to the default of 1.25 MHz. This can be changed by the LNT.

If the LON communication from the terminal stops, caused by setting of illegal communication parameters (outside the setting range) or by another disturbance, it is possible to reset the LON port of the terminal. This is performed at the local HMI at:

Configuration
  TerminalCom
    LONComm
      LONDefault

By setting YES, the LON communication is reset in the terminal, and the addressing procedure can start from the beginning again.

There are a number of session timers which can be set via the local HMI. These settings are only for advanced use and should only be changed after recommendation from ABB Automation Products AB. The time values below are the default settings. The settings can be found at:

Configuration
  TerminalCom
    LONComm
      SessionTimers

12 Serial communication modules (SCM)

12.1 SPA/IEC

The serial communication module for SPA/IEC is placed in a slot at the rear part of the main processing module. The serial communication module can have connectors for two plastic fibre cables or two glass fibre cables. The incoming optical fibre is connected to the RX receiver input and the outgoing optical fibre to the TX transmitter output. Pay special attention to the instructions concerning the handling, connection, etc. of the optical fibres.

12.2 LON

The serial communication module for LON is placed in a slot at the rear part of the Main processing module. The serial communication module can have connectors for two plastic fibre cables or two glass fibre cables. The incoming optical fibre is connected to the RX receiver input and the outgoing optical fibre to the TX transmitter output. Pay special attention to the instructions concerning the handling, connection, etc. of the optical fibres.

Chapter 14 Hardware modules

About this chapter

This chapter describes the different hardware modules.

1 Platform

1.1 General

The REx 5xx platform consists of a case, hardware modules and a set of basic functions.

The closed and partly welded steel case makes it possible to fulfill stringent EMC requirements. Three different sizes of the case are available to fulfill the space requirements of different terminals. The degree of protection is IP 40 according to IEC 529 for cases with the widths 1/2x19” and 3/4x19”. For case size 1/1x19” IP 30 applies for the top and bottom part. IP 54 can be obtained for the front area with accessories for flush and semiflush mounting. Mounting kits are available for rack, flush, semiflush or wall mounting.

All connections are made on the rear of the case. Screw compression type terminal blocks are used for electrical connections. Serial communication connections are made by optical fibre connectors type Hewlett Packard (HFBR) for plastic fibres or bayonet type ST for glass fibres

A set of hardware modules are always included in a terminal. Application specific modules are added to create a specific terminal type or family.

The basic functions provide a terminal with basic functionality such as self supervision, I/O-system configurator, real time clock and other functions to support the protection and control system of a terminal.

1.2 Platform configuration

Table 17: Basic, always included, modules

Module	Description
Combined backplane module (CBM)	Carries all internal signals between modules in a terminal. The size of the module depends on the size of the case. 1/1x19”: 13 slots available for I/O. 3/4x19”: 8 slots available for I/O. 1/2x19”: 3 slots available for I/O.
Power supply module (PSM)	Available in two different versions, each including a regulated DC/DC converter that supplies auxiliary voltage to all static circuits. • For case size 1/2x19” and 3/4x19” a version with four binary inputs and four binary outputs are used. An internal fail alarm output is also available. PSM output power 20W. • For case size 1/1x19” a version without binary I/O:s and increased output power is used. An internal fail alarm output is available. PSM output power 30W.
Main processing module (MPM)	Module for overall application control. All information is processed or passed through this module, such as configuration, settings and communication.
Human machine interface (LCD-HMI)	The module consist of LED:s, a LCD, push buttons and an optical connector for a front connected PC

Table 18: Application specific modules

Module	Description
Signal processing module (SPM)	Module for protection algorithm processing. Carries up to 12 digital signal processors, performing all measuring functions.
Milliampere input module (MIM)	Analog input module with 6 independent, galvanically separated channels.
Binary input module (BIM)	Module with 16 optically isolated binary inputs
Binary output module (BOM)	Module with 24 single outputs or 12 double-pole command outputs including supervision function
Binary I/O module (IOM)	Module with 8 optically isolated binary inputs, 10 outputs and 2 fast signalling outputs.
Data communication modules (DCMs)	Modules used for digital communication to remote terminal.
Transformer input module (TRM)	Used for galvanic separation of voltage and/or current process signals and the internal circuitry.
A/D conversion module (ADM)	Used for analog to digital conversion of analog process signals galvanically separated by the TRM.
Optical receiver module (ORM)	Used to interface process signals from optical instrument transformers.
Serial communication module (SCM)	Used for SPA/LON/IEC communication
LED module (LED-HMI)	Module with 18 user configurable LEDs for indication purposes

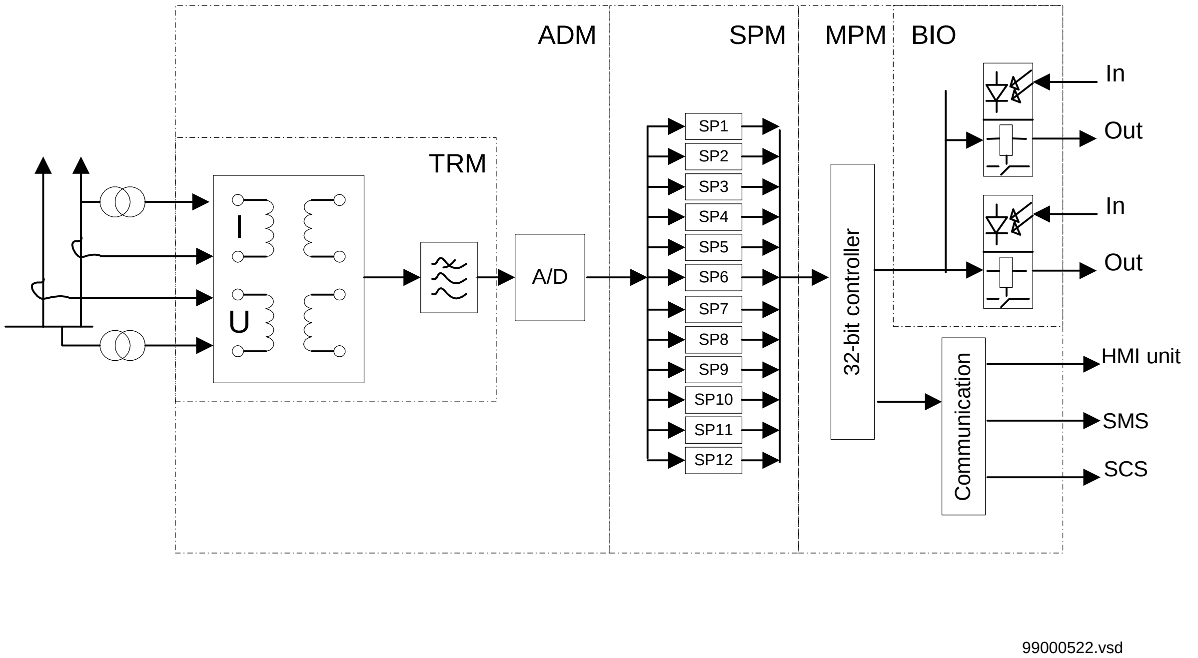


Figure 276: Basic block diagram

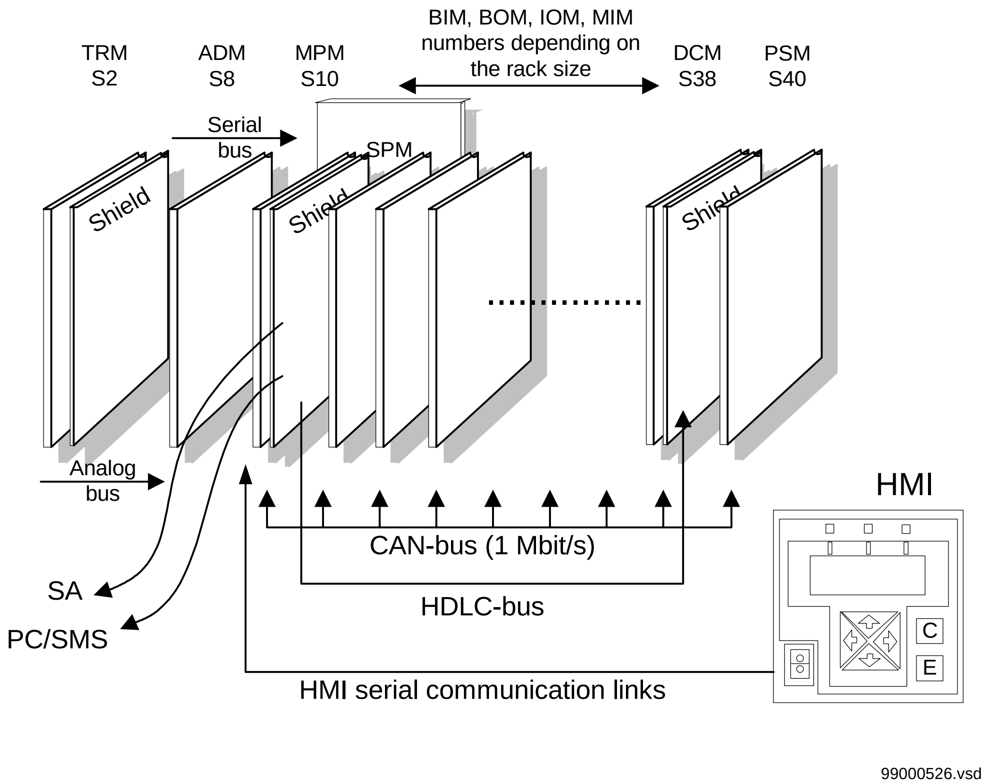


Figure 277: Internal hardware structure showing a full width case configuration

1.3 1/1x19" platform

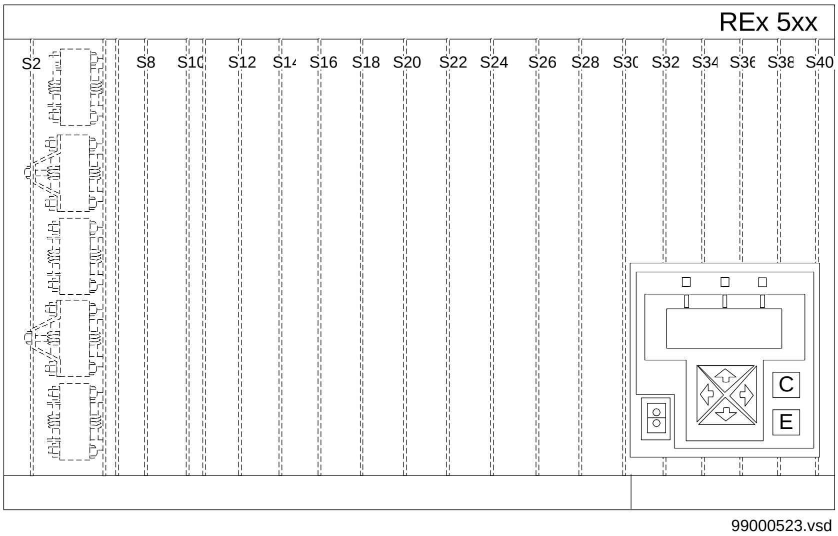


Figure 278: Hardware structure of the 1/1x19” case.

1.4 3/4x19" platform

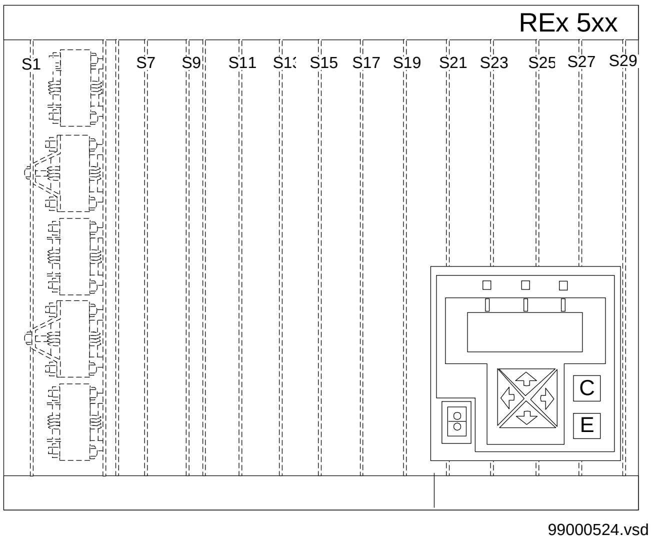


Figure 279: Hardware structure of the 3/4x19” case

1.5 1/2x19" platform

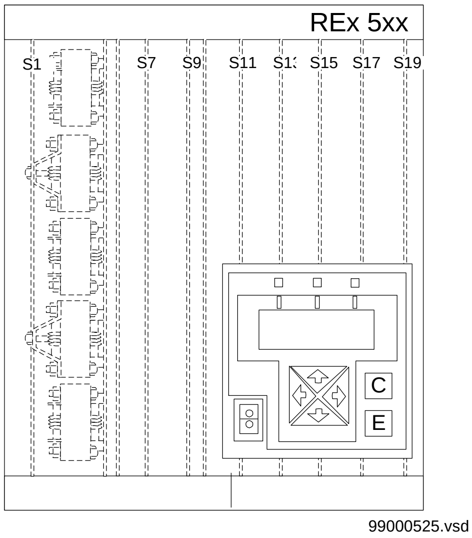


Figure 280: Hardware structure of the 1/2x19” case

2 Transformer input module (TRM)

Current and voltage input transformers form an insulating barrier between the external wiring and internal circuits of the terminal. They adapt the values of the measuring quantities to the static circuitry and prevent the disturbances to enter the terminal. Maximum 10 analog input quantities can be connected to the transformer module (TRM). A TRM with maximum number of transformers has:

- Five voltage transformers. The rated voltage is selected at order.
- Five current transformers. The rated currents are selected at order.

The input quantities are the following:

- Three phase currents
- Residual current of the protected line
- Residual current of the parallel circuit (if any) for compensation of the effect of the zero sequence mutual impedance on the fault locator measurement or residual current of the protected line but from a parallell core used for CT circuit supervision function or independent earthfault function.
- Three phase voltages
- Open delta voltage for the protected line (for an optional directional earth-fault protection)
- Phase voltage for an optional synchronism and energizing check.

The actual configuration of the TRM depends on the type of terminal and included functions. See figure 281 and figure 282.

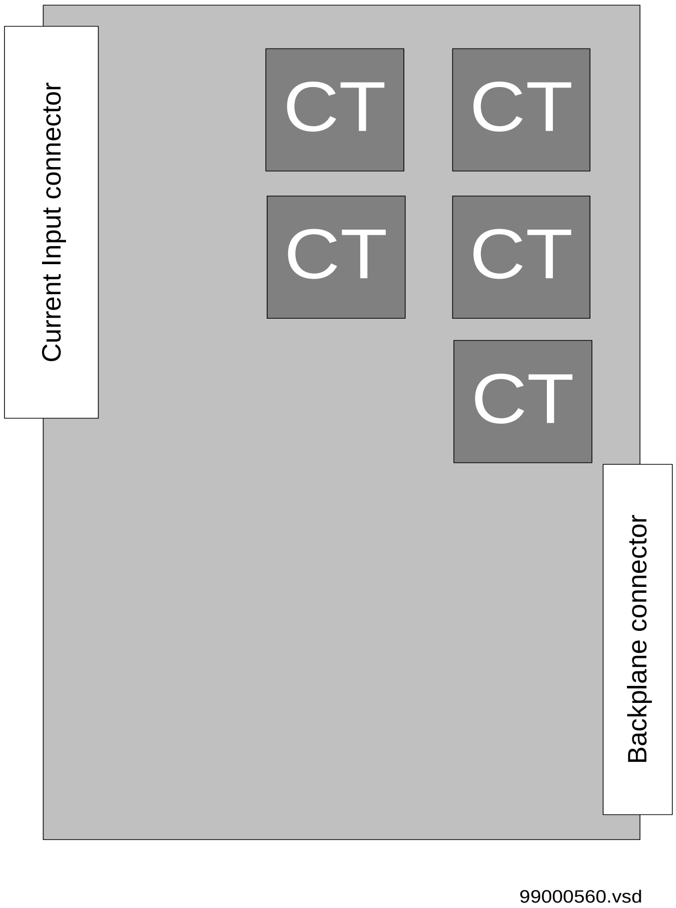


Figure 281: Block diagram of the TRM for REL 551, Line differential protection

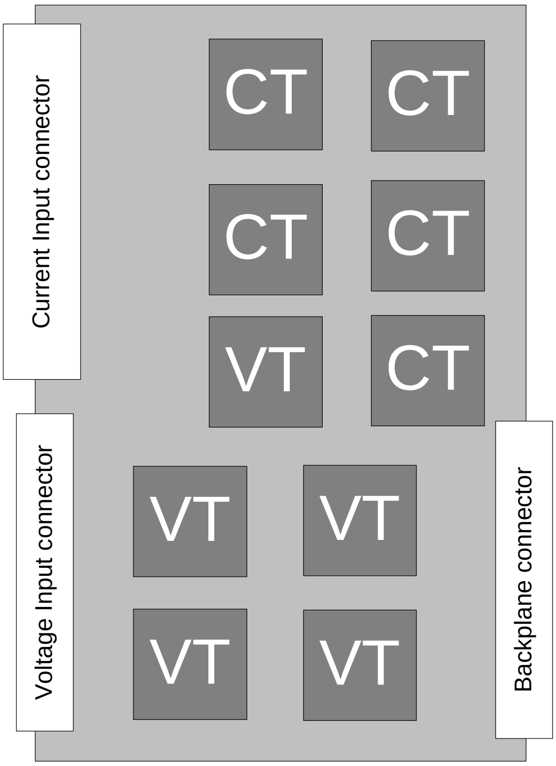


Figure 282: Block diagram of the TRM with maximum number of transformers used in most REx 5xx.

3 A/D-conversion module (ADM)

The incoming signals from the intermediate current transformers are adapted to the electronic voltage level with shunts. To gain dynamic range for the current inputs, two shunts with separate A/D channels are used for each input current. By that a 16-bit dynamic range is obtained with a 12 bits A/D converter.

The next step in the signal flow is the analogue filter of the first order, with a cut-off frequency of 500 Hz. This filter is used to avoid aliasing problems.

The A/D converter has a 12-bit resolution. It samples each input signal (5 voltages and 2x5 currents) with a sampling frequency of 2 kHz.

Before the A/D-converted signals are transmitted to the signal processing module, the signals are band-pass filtered and down-sampled to 1 kHz in a digital signal processor (DSP).

The filter in the DSP is a numerical filter with a cut-off frequency of 250 Hz.

The transmission of data between the A/D-conversion module and the signal processing module is done on a supervised serial link of RS485 type. This transmission is performed once every millisecond and contains information about all incoming analog signals.

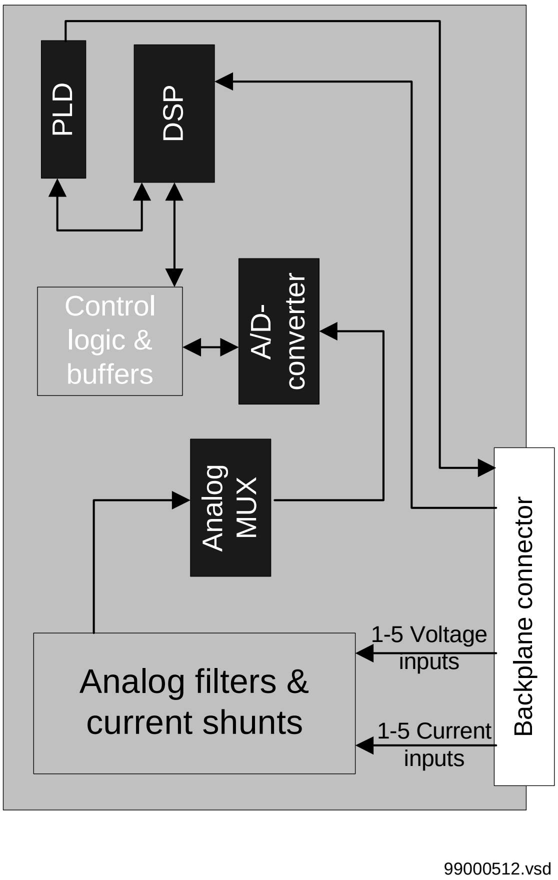


Figure 283: Block diagram for the ADM

4 Optical receiver module (ORM)

The optical receiver module (ORM) is used to interface signals from optical instrument transformer platform (OITP) to the terminal. The ORM will replace the conventional analog input modules. Either 50 or 60 Hz signals is handled by the module. Only one of the frequencies must be selected and used for all inputs.

The optical receiver module has four optical input channels that handles data from optical instrument transformer platform (OITP). It converts the OITP data to a format used in the terminal. The received data is processed in different ways depending on the setting of the eight pole dip-switch of the module.

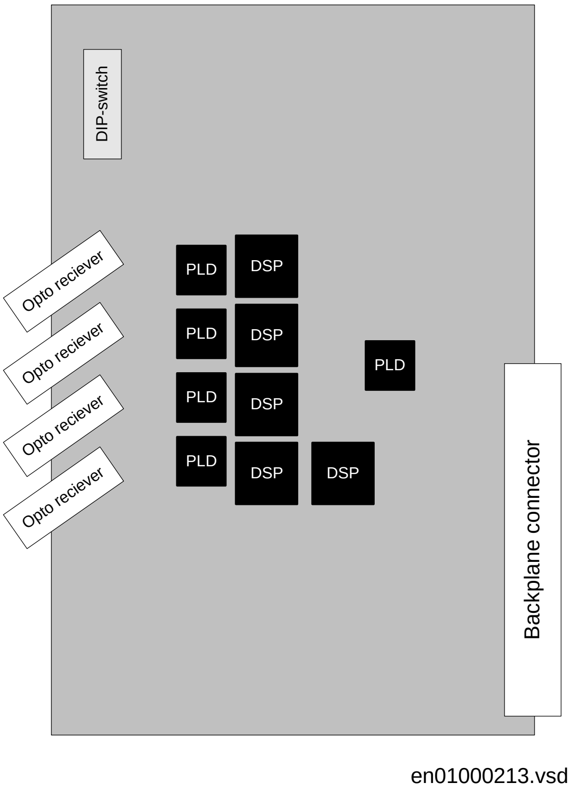


Figure 284: Block diagram for the ORM

5 Main processing module (MPM)

The terminal is based on a pipelined multi-processor design. The 32-bit main controller receives the result from the Signal processing module every millisecond.

All memory management are also handled by the main controller. The module has 8MB of disc memory and 1MB of code memory. It also has 8MB of dynamic memory.

The controller also serves four serial links: one high-speed CAN bus for Input/Output modules and three serial links for different types of HMI communication.

The main controller makes all decisions, based on the information from the Signal processing module and from the binary inputs. The decisions are sent to the different output modules and to these communication ports:

- Local HMI module including a front-connected PC, if any, for local human-machine communication.
- LON communication port at the rear (option).
- SPA/IEC communication port at the rear (option)

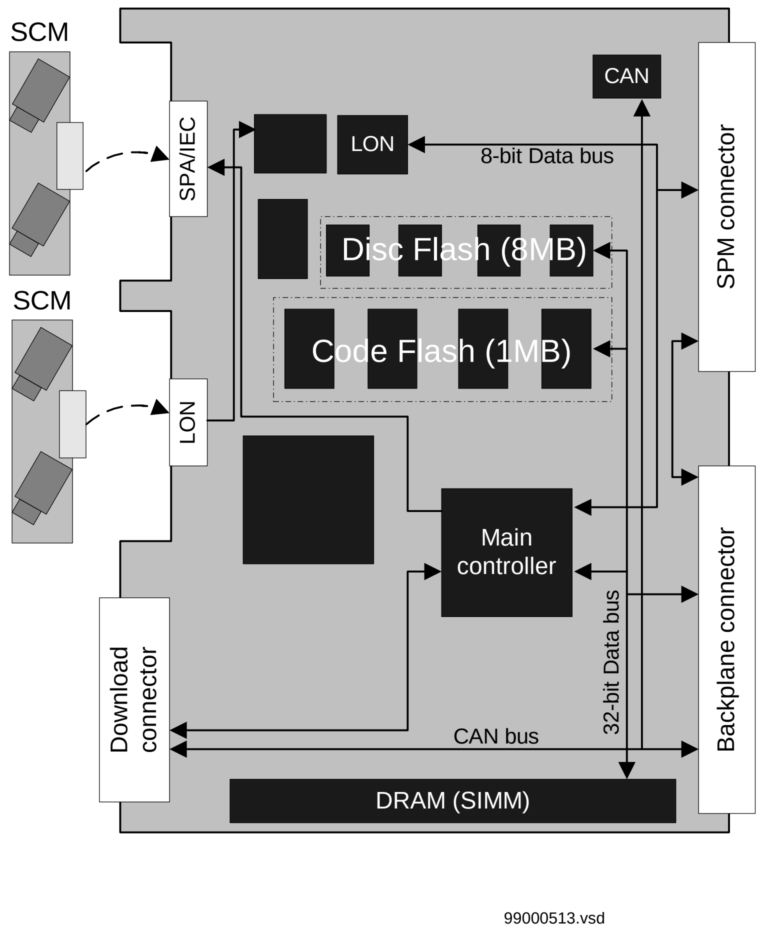


Figure 285: Block diagram for the MPM

To allow easy upgrading of software in the field a special connector is used, the Download connector.

6 Signal processing module (SPM)

All numerical data is received in all of the up to 12 (16 bits) digital signal processors (DSP). In these DSPs, the main part of the filtering and the calculations take place. The result from the calculations in the DSPs is sent every millisecond on a parallel bus to the (32 bit) main controller on the Main processing module.

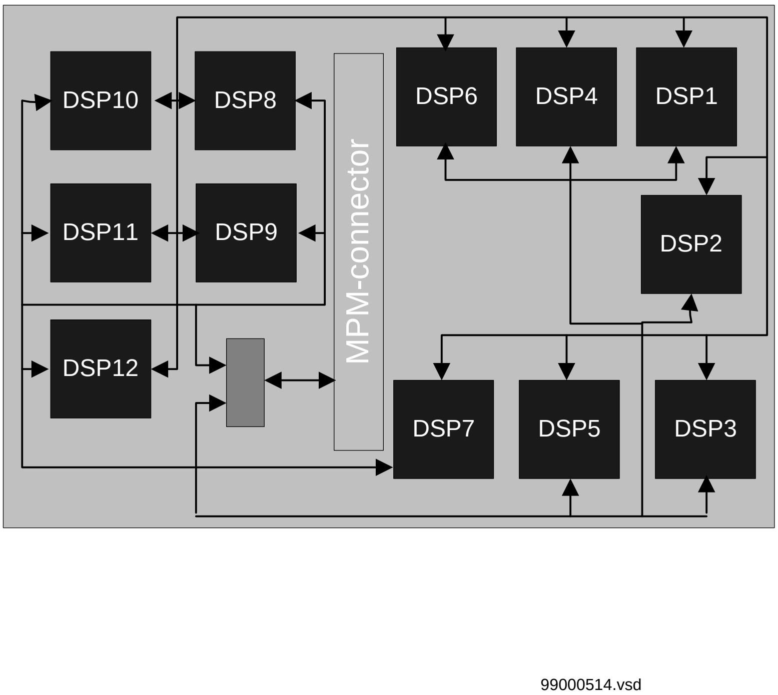


Figure 286: Block diagram of the SPM

7 Input/Output modules

7.1 General

The number of inputs and outputs in a REx 5xx terminal can be selected in a variety of combinations depending on the size of the rack. There is no basic I/O configuration of the terminal. The table below shows the number of available inputs or output modules for the different platform sizes.

Platform size	1/1x19”	3/4x19”	1/2x19”
I/O slots available	13	8	3

A number of signals are available for signalling purposes in the terminal and all are freely programmable. The voltage level of the input/output modules is selectable at order. Available versions are RL 48, 110, or 220 (48/60 V +/-20%, 110/125 V +/-20% or 220/250 V +/-20%). The Binary in/out module and the Binary input module are also available in an RL 24 version (24/30 V +/-20%).

Figure 287 shows the operating characteristics of the binary inputs of the four voltage levels.

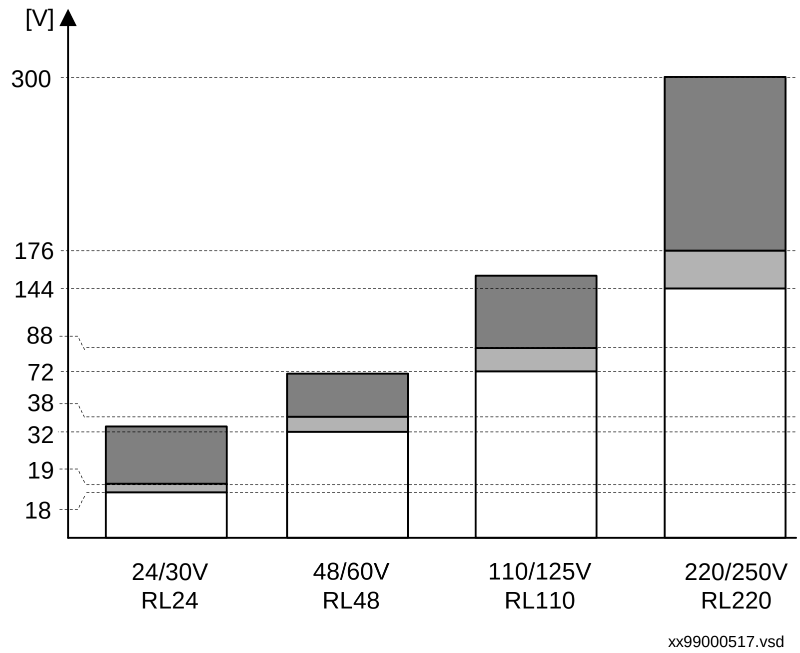


Figure 287: Voltage dependence for the binary inputs

Table 19: Input voltage ranges explained

	Guaranteed operation
	Operation uncertain
	No operation

The I/O modules communicates with the Main Processing Module via the CAN-bus on the backplane.

The design of all binary inputs enables the burn off of the oxide of the relay contact connected to the input, despite the low, steady-state power consumption, which is shown in figure 288.

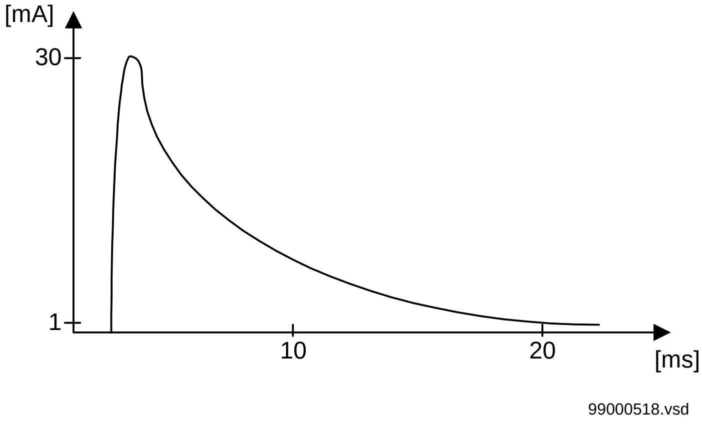


Figure 288: Current through the relay contact

7.2 Binary input module (BIM)

The binary input module contains 16 optically isolated binary inputs. The binary inputs are freely programmable and can be used for the input logical signals to any of the functions. They can also be included in the disturbance recording and event recording functions. This enables the extensive monitoring and evaluation of operation for the terminal and for all associated electrical circuits. The voltage level of the binary input modules can be selected at order.

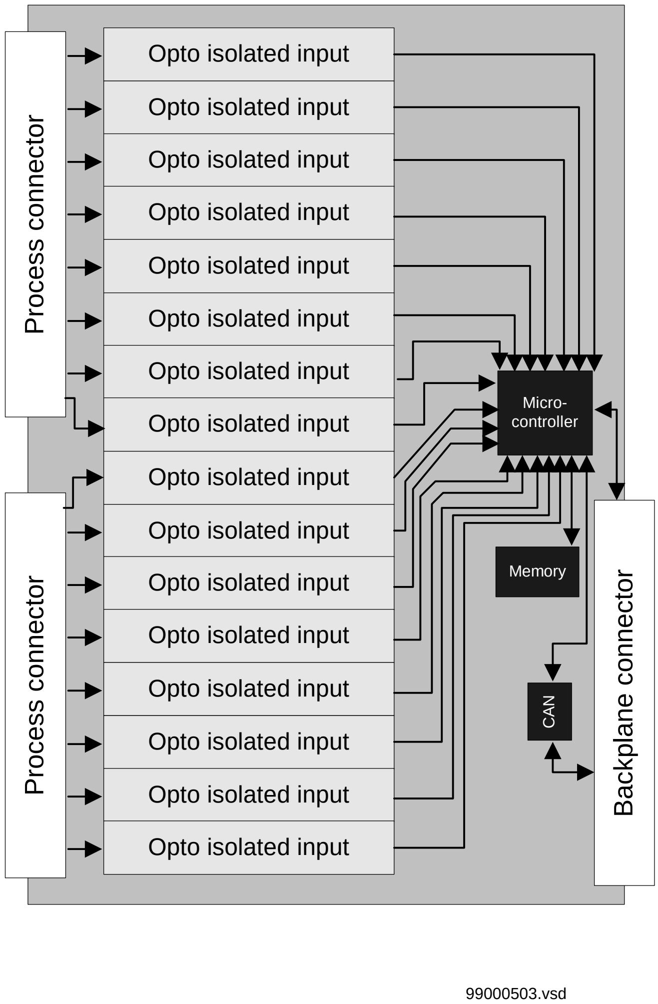


Figure 289: Block diagram of the binary input module

7.3 Binary output module (BOM)

The Binary output module has 24 single-output relays or 12 command-output relays. They are grouped together as can be seen in figure 290 and 291. All the output relays have contacts with a high switching capacity (trip and signal relays).

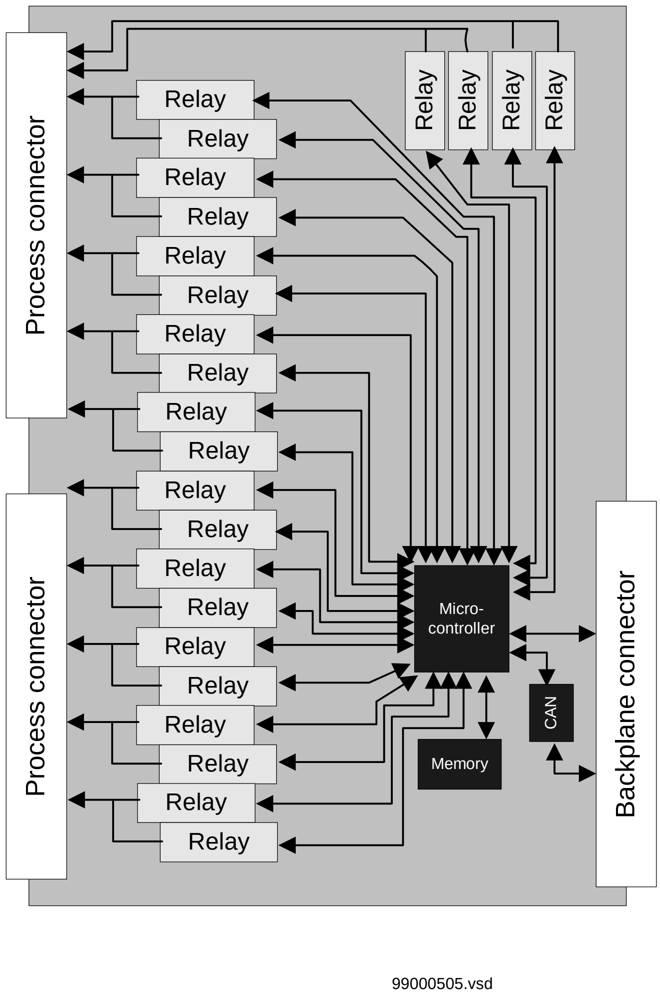


Figure 290: Block diagram of the binary output module

Two single output relay contacts can be connected in series (which gives a command output) in order to get a high security at operation of high voltage apparatuses.

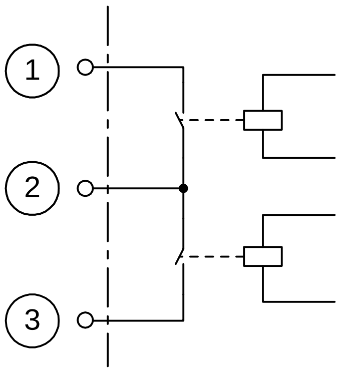


Figure 291: One of twelve binary output groups

The output relays are provided with a supervision function to ensure a high degree of security against unwanted operation. The status of the output circuits is continuously read back and compared with the expected status. If any discrepancy occurs, an error is reported. This function covers:

- interrupt or short circuit in an output relay coil
- failure of an output relay driver.

7.4 Binary I/O module (IOM)

The binary in/out module contains eight optically isolated binary inputs and twelve binary output contacts. Ten of the output relays have contacts with a high-switching capacity (trip and signal relays). The remaining two relays are of reed type and for signalling purpose only. The relays are grouped together as can be seen in the terminal diagram.

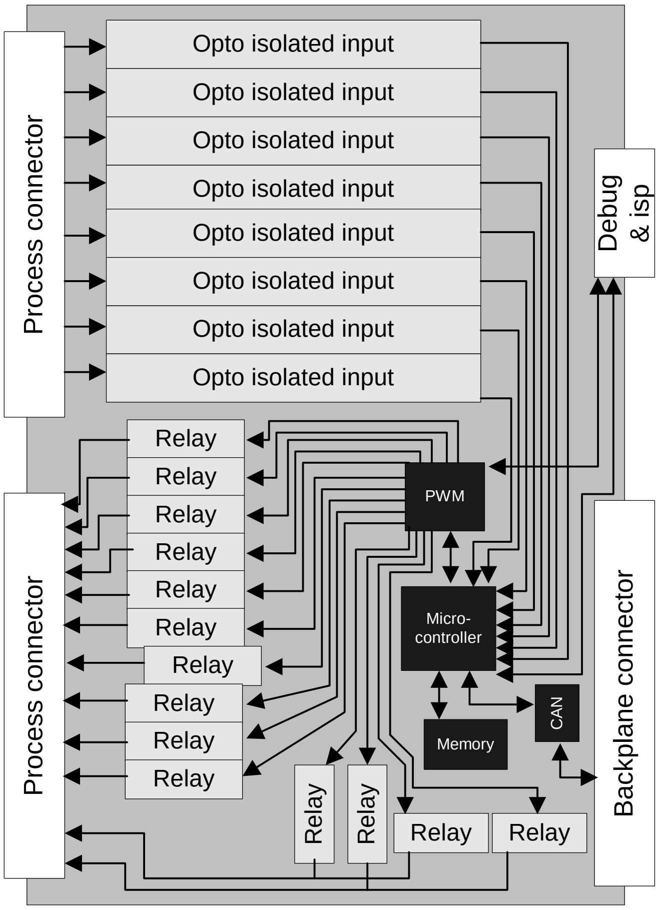
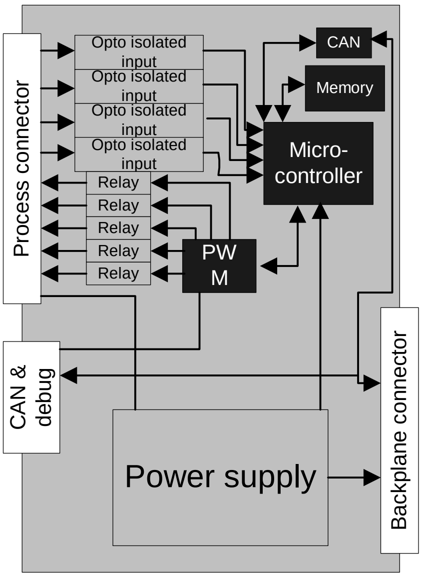


Figure 292: Block diagram for the binary input/output module

8 Power supply module (PSM)

The power supply module (PSM) contains a built-in, self-regulated DC/DC converter that provides full isolation between the terminal and the external battery system. The wide input voltage range of the DC/DC converter converts an input voltage range from 48 to 250V, including a +/-20% tolerance on the EL voltage. The output voltages are +5, +12 and -12 Volt.

The PSM, used in the 1/2x19” and 3/4x19” platforms, has built-in binary I/O with four optically isolated inputs and five outputs. One of the binary outputs is dedicated for internal fail. The PSM can provide power up to 20W.



99000515.vsd

Figure 293: Block diagram for the PSM used in 1/2x19” and 3/4x19” cases.

The power supply module (PSM) used in 1/1x19” cases contains a built-in, self-regulated DC/DC converter that provides full isolation between the terminal and the external battery system. The wide input voltage range of the DC/DC converter converts an input voltage range from 48 to 250V, including a +/-20% tolerance on the EL voltage. The output voltages are +5, +12 and -12 Volt.

The PSM can provide 30W for the extended number of modules in the 1/1x19” platform.

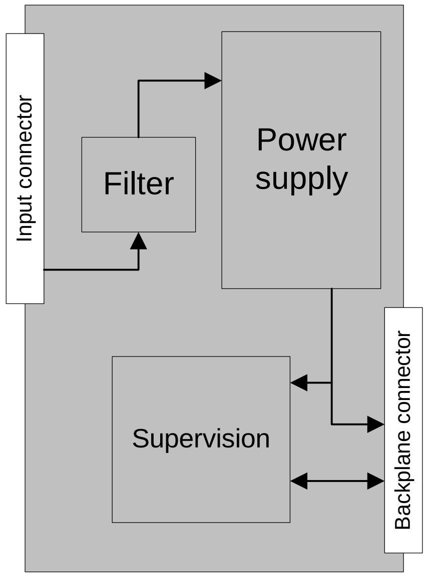


Figure 294: Block diagram for the PSM used in the 1/1x19" case.

9 mA input module (MIM)

The mA input module (MIM) has six independent analog channels with separated protection, filtering, reference, A/D-conversion and optical isolation for each input making them galvanically isolated from each other and from the rest of the module.

The analog inputs measure DC and low frequency currents in range of up to +/- 20mA. The A/D converter has a digital filter with selectable filter frequency. All inputs are calibrated separately and stored in a non-volatile memory and the module will self-calibrate if the temperature should start to drift. This module communicates, like the other I/O- modules, with the Main Processing Module via the CAN-bus.

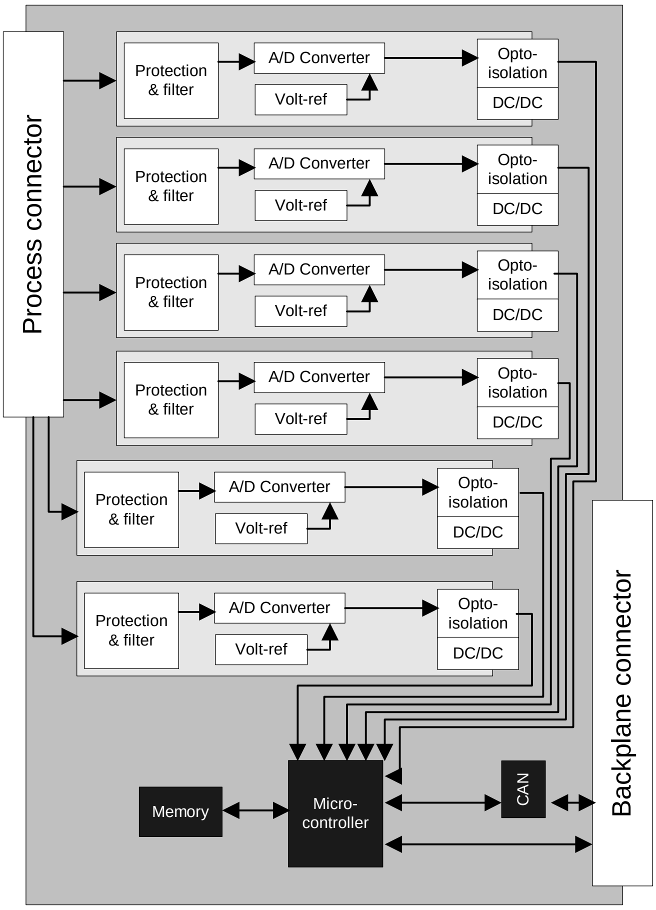


Figure 295: Block diagram of the mA input module

10 Human-machine interface (HMI)

The local HMI module consists of three LEDs (red, yellow, and green), an LCD with four lines, each containing 16 characters, six buttons and an optical connector for PC communication.

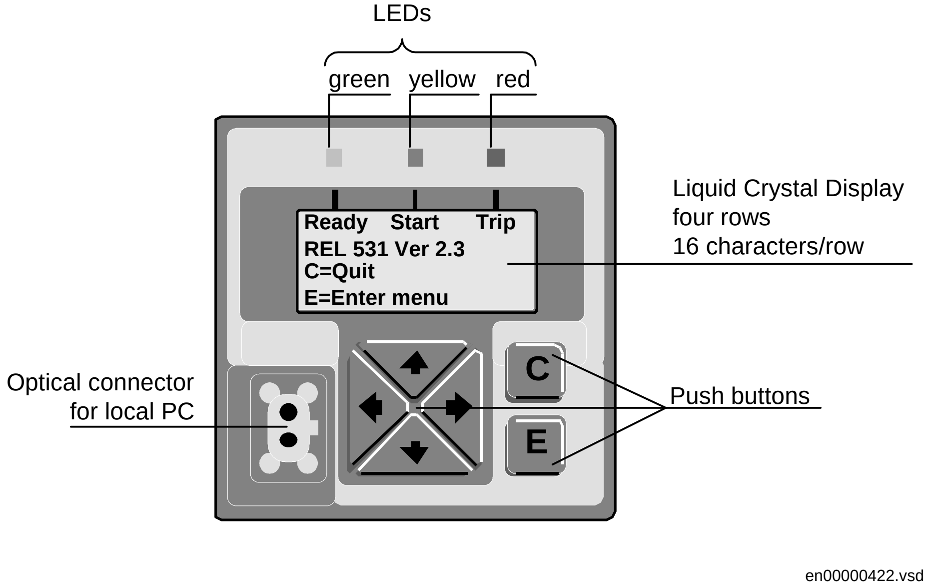


Figure 296: Local HMI

The PC is connected via a special cable, that has a built-in optical to electrical interface. Thus, disturbance-free local serial communication with the personal computer is achieved. Software tools are available from ABB for this communication. A PC greatly simplifies the communication with the terminal. It also gives the user additional functionality which is unavailable on the HMI because of insufficient space. The LEDs on the HMI display this information:

Table 20: The local HMI LED display

LED indication	Information
Green:	
Steady	In service
Flashing	Internal failure
Dark	No power supply
Yellow:	
Steady	Disturbance Report triggered
Flashing	Terminal in test mode
Red:	
Steady	Trip command issued from a protection function or disturbance recorder started
Flashing	Blocked