21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRÉ-138 **2012 CIGRÉ Canada Conference**
Hilton Montréal Bonaventure
Montréal, Québec, September 24-26, 2012

# Digital Real-Time Simulator using IEC 61850 communication for testing devices

François Guay, Jacques Cardinal, Éric Lemieux, Sylvain Guérette
Hydro-Québec
Canada

## SUMMARY

The IEC 61850 standard communication networks and systems for substation protection and automation is now used and integrated in most manufacturers equipments. The IEC 61850 defines communication between equipments in the substation. This communication is used for most application such as protection, control, monitoring and measurement in a power system network. Hydro-Québec has developed an electromagnetic transient program called Hypersim and has been using this real-time digital simulator for many years in order to validate, certify and study power system control and protection equipment. Considering the importance and the good value having this standard in the simulator environment, the IEC 61850 standard communication has been integrated in the Hydro-Québec digital real-time simulator.

## KEYWORDS

IEC 61850, GOOSE, samples values, IRIG-B, Merging units (MU), IED, process bus, station bus, digital real time simulation, power system.

guay.francois@ireq.ca

## INTRODUCTION

This paper presents how the IEC 61850 hardware, software and configuration tools has been implemented in the Hypersim simulator environment for power system real time simulation. The Hypersim simulator comprises many tools such as graphical user interface (GUI), a code generator, a waveform and analysing tool called ScopeView and a testing tool called TestView for automatic testing sequences, statistical or criteria analysis, generation of reports and database recording. The real-time simulation is running on SGI Altix series parallel computers. The platform is based on Intel Itanium II processors and SGI's NUMAlink processors interconnect. Actually, the larges Hydro-Québec simulator runs on a 128 processors Altix 4700. This simulator can run in real time electrical networks of more than 750 bus bars including models HVDC, SVC, wind turbines, hydraulic machines, etc. A new generation of SGI Altix UV is now available. Altix UV platform combines the new NUMAlink interconnect with eight or ten-core "Nehalem-EX" Intel Xeon 7500 processors. Recently, a 64-core, SGI Altix UV has been installed at Hydro-Québec power system simulation laboratory.

Up to now, in the Hypersim simulator, standard PCI cards with a digital signal processor (DSP) and digital to analogs have been installed in the SGI to provide external analog and digital inputs-outputs (I/O). That allows the simulator to be connected to external control devices in closed-loop. For a conventional relay with currents transformer (CT) inputs and voltage transformer (VT) inputs, the simulator provides currents and voltages to the relay through analog amplifiers. The breaker status is sent back to the simulator through the digital I/O interface. The relay also sends trip signals used to open the simulated breaker when a fault is applied in the real-time simulation network. Other control/status signals can also be exchange with the relay for advanced testing. A total of six analog outputs and approximately twelve inputs and outputs logic status are sufficient for testing. Thus, many connections are required between the relay and the simulator as shown on figure 1.

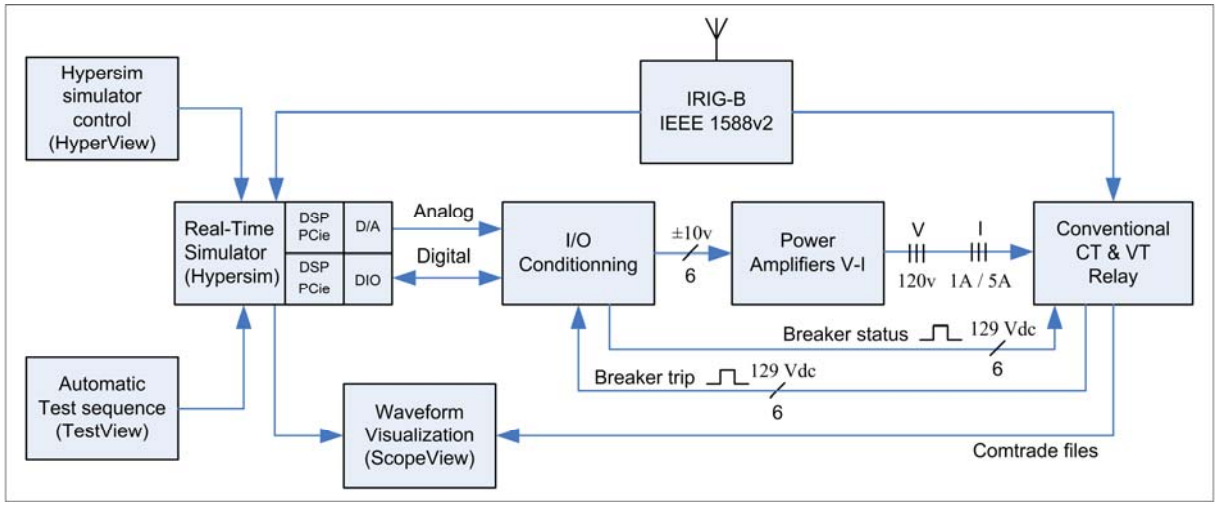


Figure 1: Hypersim simulator configuration for conventional CT & VT relay

## HARDWARE INTEGRATION

Now, for the integration of the IEC 61850 hardware, all the analog amplifiers and digital input/output channels are replaced by an Ethernet peripheral module. The same DSP and PCI card has been reused by simply replacing the mezzanine module, as shown on figure 2.

Basically, there are two specific protocols integrated in the real-time simulator. The first protocol presented is the IEC 61850 8-1 (Generic Object Oriented Substation Event) GOOSE. The second protocol is the IEC 61850 9-2 sampled values. There are also two specific networks for the Ethernet communication. The process bus is a network used to transmit samples values between the process level (Merging unit equipments) and the bay level where intelligent electronic devices (IED) are connected. The station bus is intended for the transmission of data between the station level (HMI operator interface, SCADA, Gateway) and the bay level. The GOOSE and the samples values protocols are directly mapped & encapsulated in the Ethernet standard 802.1Q. They are transmitted through multicast MAC addresses with a publisher or subscriber method.

The sampled values communication is used to send the voltages (Va, Vb, Vc & Vn) and the currents (Ia, Ib, Ic & In) simultaneously from Merging units to the Ethernet Process Bus network. The integration is based on the IEC 61850 9-2LE [1] called "Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2". There are two sampling rates available, one is 80 samples per cycle and the other is 256 samples per cycle. The first one is used for protection applications and the other is used for measurement or waveform recording. One of the biggest advantages of the sampled values is that we will not need many wires and power amplifiers to connect a relay.

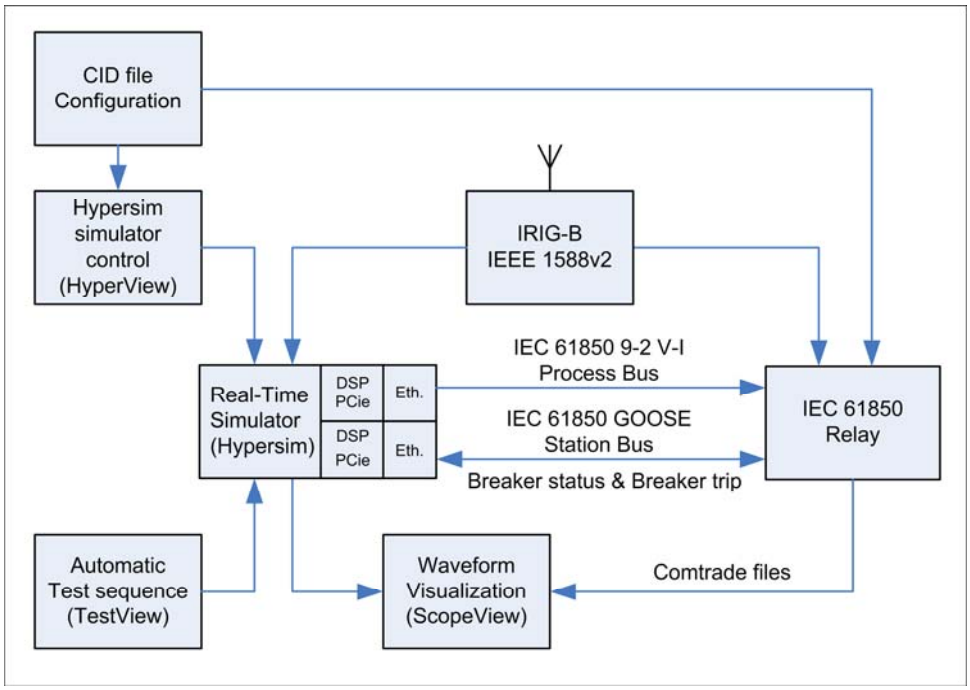


Figure 2: Hypersim simulator configuration for IEC 61850 test setup

The IEC 61850 GOOSE communication is used to send and receive formatted events messages, such as trip commands, breaker status, alarms, etc., on the Station Bus communication network. The message containing the dataset has to be transmitted within a time period of 3-20 ms [2]. A dataset can contents different types of data structures, such as digital status and analog values. Presently, only one type of dataset is supported. A maximum of 32 GOOSE status digital input and 32 GOOSE status digital output signals can be exchanged between the Hypersim simulator and the external equipment. Also, the quality of the signal is integrated in the dataset. However, the software doesn't support MMS call, report, etc. Other dataset will be developed in the future. For relay testing applications, the GOOSE replaces all the digital signals connected to the relay (trip signal, breaker status, etc.).

The simulator is also equipped with an IRIG-B time code receiver for time synchronization. The IRIG-B signal has a resolution of 1 millisecond. The waveforms from Scopeview analysis can be very easily synchronized with the waveforms recorded in the equipment with the same time reference. A synchronization mechanism at 1PPS is also needed for the IEC 61850 9-2. The IEEE 1588 v2 [7] standard clock synchronization is also in development in the actual simulator. This new time synchronization has a resolution of 1 microsecond.

## SOFTWARE INTEGRATION

An IEC 61850 element in the GUI is used to simulate the IEC 61850 communication. The samples values and GOOSE parameters are available in a form attached to the element, in order to configure the communication with the equipment. These parameters are sent to the merging unit and after, the transmission is done on the Ethernet LAN.

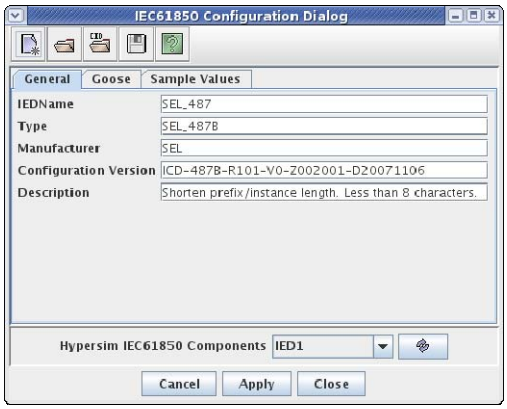


Figure 3: IEC 61850 configuration tools

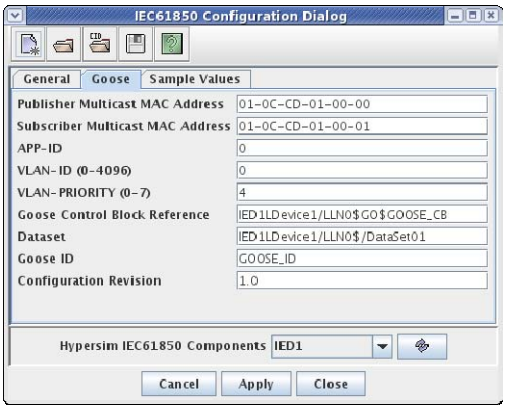


Figure 4: IEC 61850 GOOSE parameters

The Substations Configuration Language (SCL) is used to configure protective relays or control devices. Part 6 of IEC61850 [3] defines the substation configuration language (SCL) for the engineering of IEC 61850 systems. Many types of files formats (IID, ICD, CID, etc…) can be used, depending of the step in the design process of the application. The IED capability description (ICD) defines the complete capability of IED. The configured IED description (CID) defines all communication and information for the initialization of IED with configuration tools. This SCL file also allows interoperability between manufacturers. All those, configuration files are written in XML language and have the same file structure. The result is that effort and cost are minimized so the integration process is much faster. An IEC 61850 configuration tool has been developed in our simulator environment to import SCL object files. See figures 3 and 4. The tools extract information from the file and initialize the Hypersim IEC 61850 model so that it can communicate properly with the equipment under test. Each manufacturer (Areva, SEL, GE, …) has its own tools to configure their equipment.

## AUTOMATIC TEST SEQUENCE

When protection engineers perform studies with a real time simulator, they are doing many tests with the equipment in order to observe the reliability, the security, if the performance and the specification of the equipment are respected. It is required to store all the waveforms and test results of the study in a database. The automatic testing tool called TestView has been integrated in the Hypersim real time simulator. Engineers can program automatic testing

sequences for breaker operation, harmonics generation, etc. The results are automatically saved in comtrade files in a database. After collecting test results, many statistical or criteria analysis can be done. At the end of the study, generation of reports and tables of results are also possible. See the figure 5 below for an example of a fault breaker operation programming sequence.

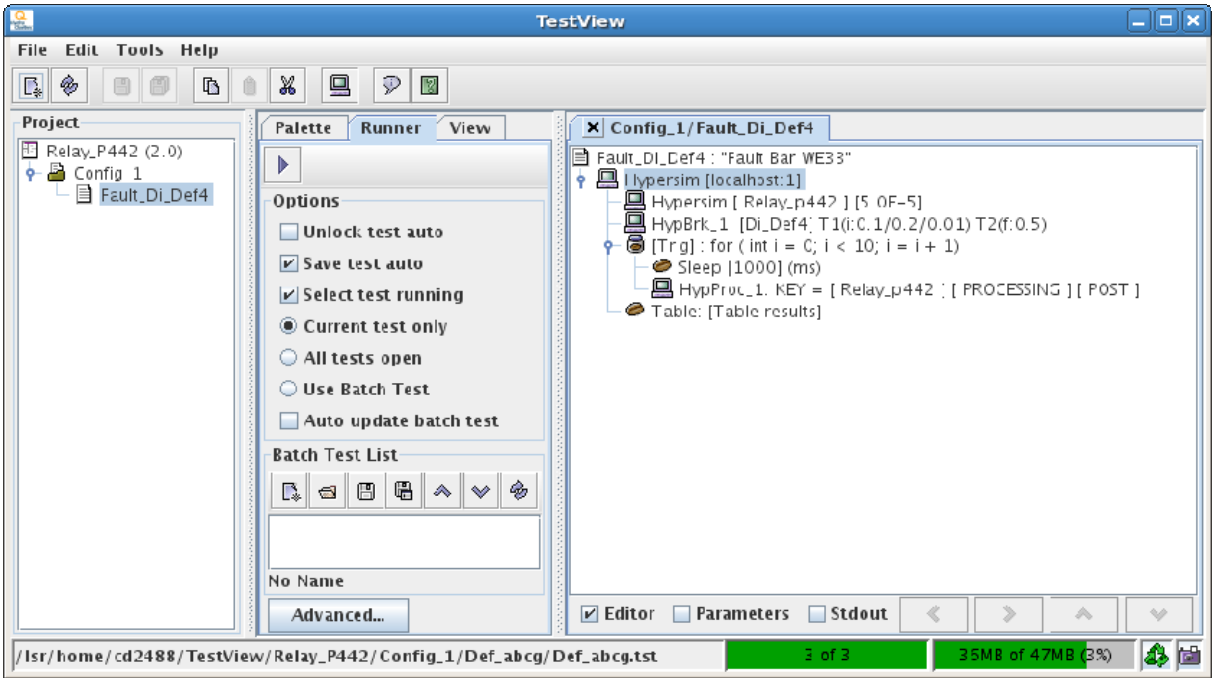


Figure 5: TestView (automatic test sequence)

## APPLICATION TEST

In order to validate and test the IEC 61850 communication protocol, a typical power transmission network (figure 6) has been simulated by the real-time simulator. A distance protection relay with the IEC 61850 interface was connected. Also, a second relay with analogs amplifiers and digital interface was connected. For the IEC 61850, currents and voltages are sent to the relay with sampled values running on the Ethernet process bus. GOOSE is used for trip orders, breaker status and other control signals on the Ethernet station bus.

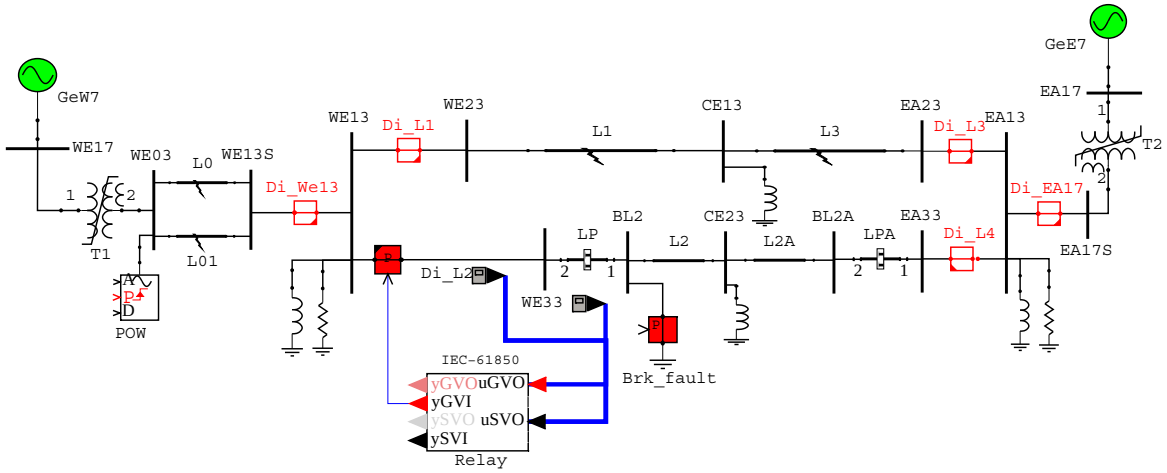


Figure 6: Power transmission network

The currents and voltages results seen by the real time simulator were superimposed with the waveforms recorded by both relays. The figure 7 presents the comparison. It shows that the transient aspect of the currents and voltages recorded by the relay under sampled values is identical to that of the simulator. At 0.1 sec, a typical six-cycle (100 msec) ABC fault was applied to the bus bar BL2. At 0.2 sec, the breakers Di_L1, Di_L2, Di_L3 and Di_We13 opened the lines to clear the fault. All breakers were then reclosed at 0.3 sec.

The trip order from the relay was sent by a GOOSE message and recorded to measure the trip time between the fault detection and the breaker operation in the simulator. Essentially, the average time operations were 19 msec for the GOOSE and 21 msec for the conventional relay contact.

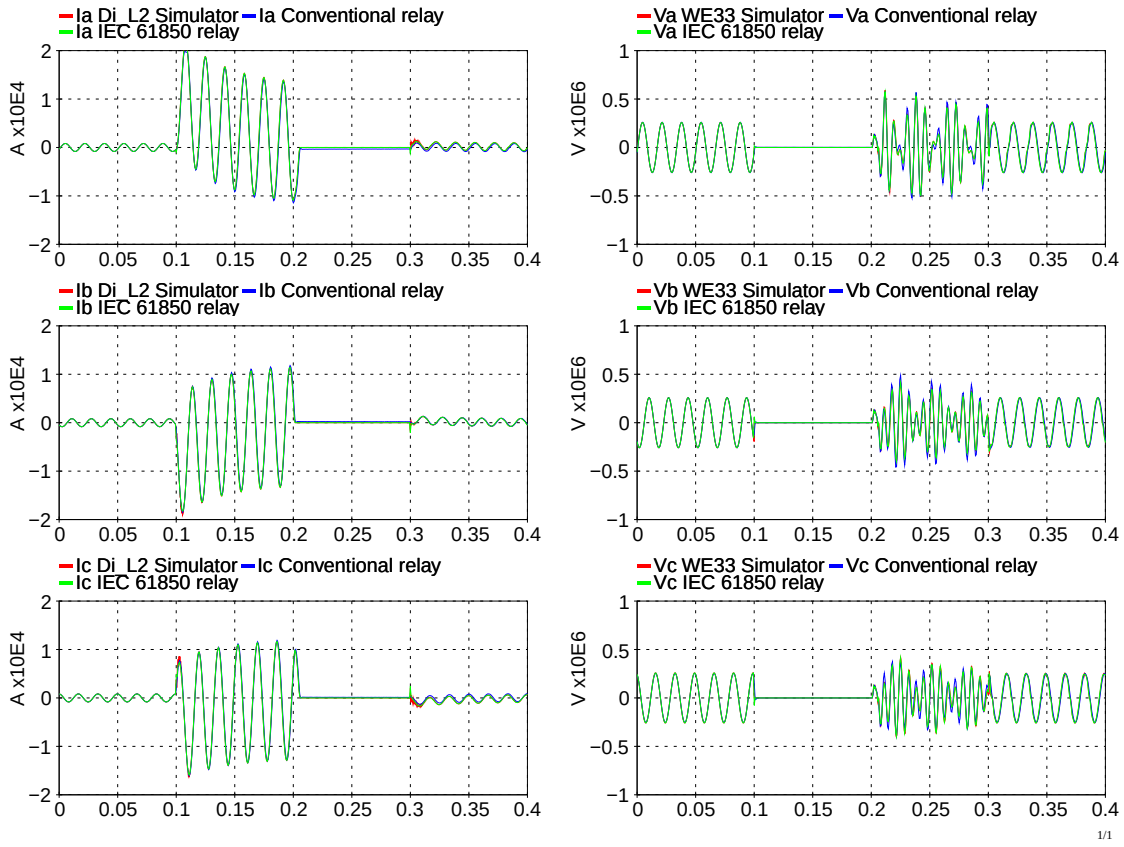


Figure 7: Voltage and current comparison between conventional and IEC 61850 relay

Also, a loop back for a GOOSE ping-pong was done with the relay. A GOOSE loop was made inside the programmable scheme logic of the relay. A pulse was sent to the relay and read back by the simulation. This loop back time is very interesting because it measures the total loop back time as seen from the simulator. The average results were 5.052 msec with a minimum time of 5 msec and a maximum time of 5.3 msec. In the real-time simulator, there is only one timestep delay to process the sampled values. For the GOOSE delay inside the simulator, there is one timestep delay for outputs and one timestep delay for inputs. In this case, the timestep delay (50 µsec) for GOOSE is negligible for the loop back test results.

## CONCLUSION

The IEC 61850 is now fully integrated in the Hydro-Québec digital real-time simulator. The hardware and software support the IEC 61850 8-1 GOOSE and IEC 61850 9-2 sampled values communication, and have been optimised for our real time simulator application. The test results show that the sampled values works very well to send transient signal with 80 samples per cycles resolution. The GOOSE average response time respect the criteria defined in the IEC 61850-5 and are matching that of a conventional relay with standard output contacts.

There are many advantages to use the IEC 61850 communication in a real-time simulation environment:

- The number of connections between the simulator and the equipment is greathly reduced.
- No amplifiers and calibration are needed for current and voltage.
- The SCL files allow interoperability between manufacturers and are used to configure the protection relay.
- The commissioning time and cost are reduced.

## BIBLIOGRAPHY


Standards:

[1] IEC 61850-9-2 LE: Implementation Guideline for Digital Interface to Instrument Transformers Using IEC 61850-9-2
UCA International Users Group

[2] IEC 61850 Communication networks and systems in substations
All parts, Reference number IEC 61850-SER.

Papers:

[3] Working Group B5.11 of Cigre, “The Introduction of IEC 61850 and Its Impact on Protection and Automation Within Substations”,
*CIGRE,* Aug. 2007

[4] A. Apostolov, “IEC 61850 9-2 Process Bus Application and Benefits”,
26 July 2010, DPSP 2010

[5] Jian-Cheng Tan; Green, V.; Ciufo, J.; “Testing IEC 61850 based multi-vendor substation automation systems for interoperability”,
24 April 2009, PSCE ’09 IEEE PES

[6] Aguilar, R.; Ariza, J.; “Testing and configuration of IEC 61850 multivendor protection schemes”,
14 June 2010, T&D 2010 IEEE PES

Periodicals:

[7] R. Moore, “Time Synchronization with IEEE 1588”, PAC World Magazine, Summer 2009 Issue, pp. 45