Electrical Association

Overcurrent Protection
Based on 2017 NEC
Part 2

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This educational offering is recognized by the Minnesota Department of Labor and Industry as satisfying 2 hours of code credit toward Electrical Continuing Education requirements.

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- Comments in green text are interpretations by MEA
- Please see the National Electrical Code 2017 (NFPA 70) for complete review of the code articles.

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Part Two

2 hours

Overcurrent Protection

3

Part V: Plug fuses, Fuseholders and adapters 240.50

(A) Maximum voltage for plug fuses for circuits not exceeding 125 volts between conductors and for circuits with a grounded neutral where the line to neural voltage does not exceed 150V

(B) Each fuse shall be marked with the ampere rating

(C) Plug fuses 15A and lower will have a hexagonal window design

(D) When installed they have no energized parts exposed

(E) The crew shell of the plug fuse is connected to the LOAD side of the circuit

240.51 Edison-Base Fuses

- (A) Classification. Plug fuses of the Edison-base type shall be classified at not over 125 volts and 30 amperes and below.
- (B) Replacement Only. Plug fuses of the Edison-base type shall be used only for replacements in existing installations where there is no evidence of over fusing or tampering.

Edison base

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Plug Fuses

W Series Fast Acting
Ampere Ratings: 1/8 - 30 Amps
Voltage Rating: 125V AC
Element is a simple fusible, metal link. For general purpose circuit protection. Quickly opens when short-circuit or overload occurs. Use for lighting and other non-motor circuits. Edison base.

SL and TL Series Time-Delay, Loaded Link
Ampere Ratings: 15 - 30 Amps **Voltage Rating:** 125V AC
Heat absorbing metal bead on element link for time-delay. Passes motor overload starting currents without needlessly opening. Edison base (TL), Rejection base (SL).

S and T Series Time-Delay, Dual-Element
Ampere Ratings: Type S:1/4A - 30 Amps
Type T: 3/10 - 30 Amps **Voltage Rating:** 125V AC

Hexagonal 15A or lower

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240.52 Edison-Base Fuseholders

Fuseholders of the Edison-base type shall be installed only where they are made to accept Type S fuses by the use of adapters.

Type S

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240.53 Type S Fuses

- Type S fuses shall be of the plug type and shall comply with 240.53 A-B (below)
- (A) Classification. Type S fuses shall be classified at not over 125 V and 0 to 15 amps,16 to 20 amps, and 21 to 30 amps.
- (B) Non-interchangeable. Type S fuses of an ampere classification as specified in 240.53(A) shall not be interchangeable with a lower ampere classification. They shall be designed so that they cannot be used in any fuseholder other than a Type S fuseholder or a fuseholder with a Type S adapter inserted.

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Type S fuses – continued

- **(C) Non-removable.** Type S adapters shall be designed so that once inserted in a fuseholder, they cannot be removed.
- **(D) Non-tamperable.** Type S fuses, fuseholders, and adapters shall be designed so that tampering or shunting (bridging) would be difficult.
- **(E) Interchangeability.** Dimensions of Type S fuses, fuseholders, and adapters shall be standardized to permit interchangeability regardless of the manufacturer.

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Part VI Cartridge fuses and fuseholders 240.60 General

(A) Maximum Voltage — 300-Volt Type. Cartridge fuses and holders of the 300 V type shall be permitted to be used in:

(1) Circuits not exceeding 300 V between conductors

(2) Single-phase line-to-neutral circuits supplied from a 3-phase, 4-wire, solidly grounded neutral source where the line-to-neutral voltage does not exceed 300 V

Eg: 120/208 For 300V fuses

(B) Noninterchangeable — 0–6000-Ampere Cartridge Fuseholders. Fuseholders shall be so that it will be difficult to put a fuse of any given class into a fuseholder that is designed for a current lower, or voltage higher, than that of the class to which the fuse belongs. Fuseholders for current-limiting fuses shall not permit insertion of fuses that are not current-limiting.

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240.60 (C) General.

(C) Marking. Fuses shall be plainly marked, either by printing on the fuse barrel or by a label attached to the barrel showing the following:

(1) Ampere rating

(2) Voltage rating

(3) Interrupting rating where other than 10,000 amperes

(4) Current limiting where applicable

(5) The name or trademark of the manufacturer

The interrupting rating shall not be required to be marked on fuses used for supplementary protection.

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240.61 Classification

- Cartridge fuses and fuseholders shall be classified according to voltage and amperage ranges.
- Fuses rated 1000 volts, nominal, or less shall be permitted to be used for voltages at or below their ratings.

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Class G fuses – Various Voltages

EXHIBIT 240.13 Two fuses rated 300 volts with marking to indicate they are Class G. (Courtesy of Cooper Bussmann, a division of Cooper Industries PLC)

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Fuse Bases for Bolt in fuses (Blocks)

Stud Type

Connector Type

Fixed Center Base Style

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TRON Clip-Clamps

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Fuse Reducers for Class J Dimension Fuses

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Fuse dimensions

- 250V fuses 1/10 0- 30A ferrule end 2" long with ferrule 9/16" diameter
- 250V fuses 31-60A ferrule end 3" long with ferrule 13/16" diameter
- 600V fuses 1/0=10-30A ferrule are 5 inches long ferrule 13/16" diameter
- 600V fuses 31-60A are 5-1/2" long with ferrule 1-1/16" diameter
- Fuses over 60 A -600A are knife blade ends

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Classes of Fuses

- The industry has developed basic physical specifications and electrical performance requirements for fuses with voltage ratings of 600 volts or less. These are standards.
- If a type of fuse meets the requirements of a standard, it can fall into that class.
- Typical classes are K, RK1, RK5, G, L, H, T, CC, and J.

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Class R (Rejection) current Limiting
RK1- RK-5

Rejection Feature

Class H fuse

Non current Limiting

10kA IC

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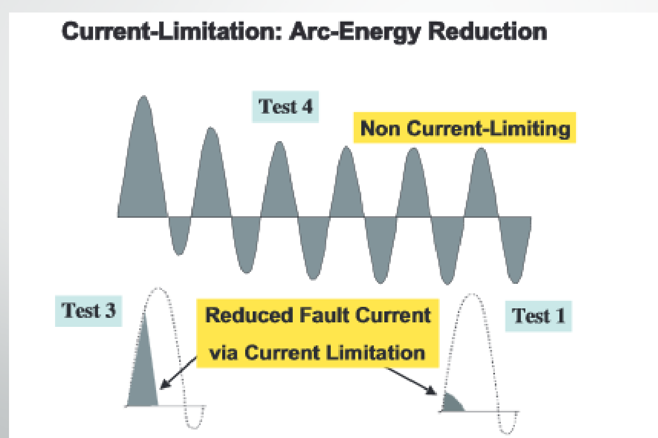
Current limiting Vs Non current limiting



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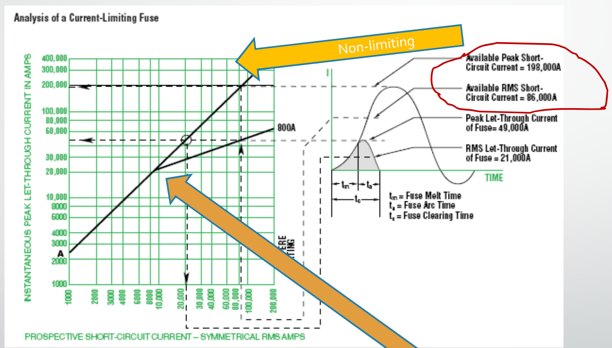
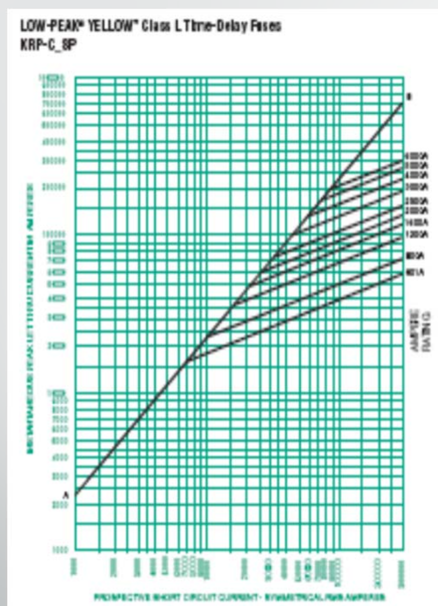
800A Fuse



21kA RMS limited
49kA peak



KRP-C_SP Fuse – RMS Let-Through Currents (kA)

Prosp. Short C.C.	Fuse Size									
	601	800	1200	1600	2000	2500	3000	4000	5000	6000
	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}	I_{RMS}
5,000	5	5	5	5	5	5	5	5	5	5
10,000	8	10	10	10	10	10	10	10	10	10
15,000	9	12	15	15	15	15	15	15	15	15
20,000	10	13	17	20	20	20	20	20	20	20
25,000	11	14	19	22	25	25	25	25	25	25
30,000	11	14	20	24	27	30	30	30	30	30
35,000	12	15	21	25	29	35	35	35	35	35
40,000	13	16	22	26	30	35	40	40	40	40
50,000	14	17	23	28	32	37	50	50	50	50
60,000	15	18	25	30	34	40	49	60	60	60
70,000	15	19	26	32	36	42	52	62	70	70
80,000	16	20	27	33	38	44	54	65	76	80
90,000	17	21	29	34	39	45	56	67	79	90
100,000	17	22	30	36	41	47	58	70	81	100
150,000	20	25	34	41	47	54	67	80	93	104
200,000	22	27	37	45	51	59	73	87	102	114
250,000	24	29	40	49	55	64	79	94	110	123
300,000	25	31	43	52	59	68	84	100	117	130

Note: For I_{RMS} value at 300,000 amperes, consult Factory.

Class CC Rejection-Type Fuses

FNQ-R Time-Delay, Rejection Type
Branch Circuit Fuse
Class CC
Physical Size:13/32 X 11/2"
Construction: Melamine Tube
Ampere Ratings:1/4 - 30 Amps.
Voltage Rating: 600V AC or less
Interrupting Rating: 200,000A RMS Sym.

- LP-CC Low-Peak® Fuse
- Time-Delay Current Limiting,
- Class CC - Rejection Type
- Physical Size: 13/32 X 1-1/2"
- Ampere Ratings: 1/4 - 30 Amps.
- Voltage Rating: 600 Volts AC (or less), (300V DC & 20-30A), 150V DC (3-15A)
- Interrupting Rating: 200,000A RMS Sym; 20,000A DC
- Construction: Melamine Tube

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Quick Acting, Class J Fuses

Quick Acting
Ampere Ratings: 1-600 Amps.
Voltage Rating: 600 Volts AC (or less)
Current Limiting
Interrupting Rating: 200,000A RMS Sym.

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Dual element -- time delay fuses

FRS-R 600V Knife blade

FRN-R 250V ferrule end

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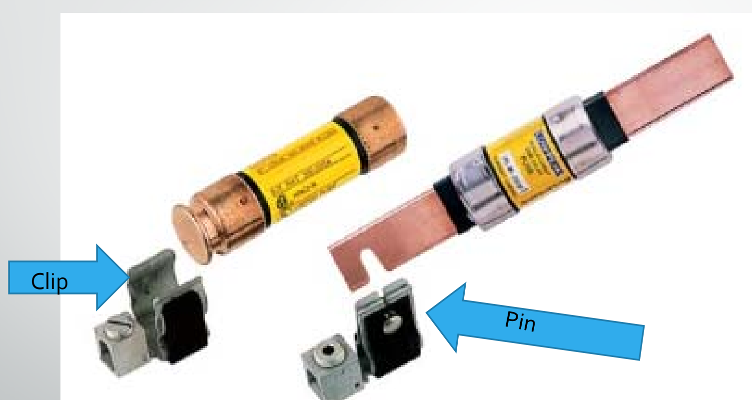
Rejection fuseholders



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Time-Delay Class G Fuses

SC
Fast Acting (1/2-6A), Class G
Time-Delay (7-60A), Class G
Construction: Melamine Tube
Ampere Ratings: **½** - 60A
Voltage Rating:1/2 -20A: 600V AC/170V DC or less
25-60A: 480V AC/300V DC or less
Interrupting Rating: 100,000A RMS Sym., 10,000A DC

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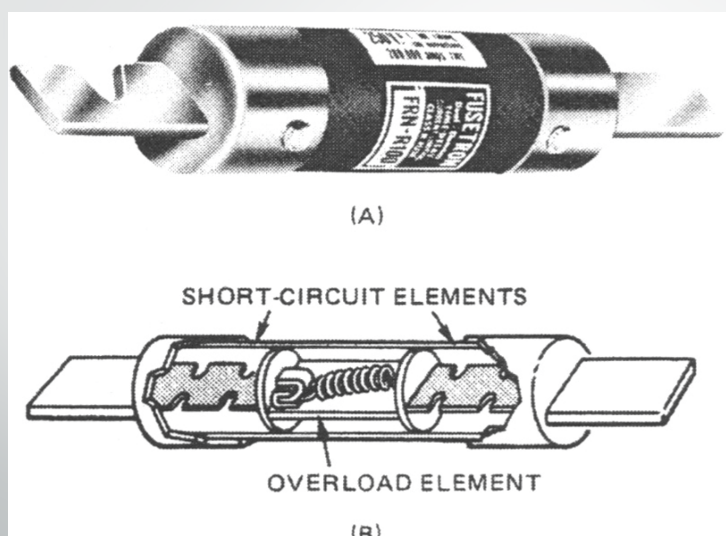
Dual Element Time Delay Fuses



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Dual-Element, Time-Delay Fuses

Overload

Or short ckt

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One-Time General Purpose Fuses - NON and NOS

General Purpose Application
Non-Current Limiting
Ampere Ratings: 1/8-600 Amps.
Voltage Rating: NON: 250 Volts AC, 125 Volts DC (0-100A); NOS: 600 Volts AC
Interrupting Rating: 50,000A RMS Sym. (1-60A), 10,000A RMS Sym. (65-600A)
10,000A @ 125V DC (NON 0-100A)

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E-Rated Medium Volt for Potential & Small Power Transformers

JCD, JCW, JCE, JCQ, JCI & JCT
Current Limiting
Indicating/Non-Indicating
Plated Ferrules
Voltage Rating: (Max. Design) 2475, 2750, 5500, 8300, 15,500
Current Ratings: 1/4E through 10E

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NEW 240.67 Arc Energy Reduction

Effective on Jan. 1,2020 - where fuses are 1200 A or more- follow parts A and B below

(A) Documentation needs to be available as to the location of the fuses

(B) Either the fuse must clear the overcurrent in .07 seconds or other methods as referenced in 240.67 (B) 1-4 (below) shall be used.

1. Differential relaying
2. Energy reduction maintenance switching
3. Active arc mitigation system
4. An approve d equivalent means

Part VII Circuit Breakers
240.80 Method of Operation

- Circuit breakers shall be trip free and capable of being closed and opened by manual operation.
- Normal method of operation by other than manual means, such as electrical or pneumatic, shall be permitted if means for manual operation are also provided.

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240.81 Indicating

- Circuit breakers shall clearly indicate whether they are in the open "off" or closed "on" position.
- Where circuit breaker handles are operated vertically rather than rotationally or horizontally, the "up" position of the handle shall be the "on" position.

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240.83 Marking.

(A) Durable and Visible. Circuit breakers shall be marked with the ampere rating that will be visible after installation. Such marking shall be permitted to be made visible by removal of a trim or cover.

(B) Location. Circuit breakers rated 100 amperes or less and 1000 volts or less shall have the ampere rating molded, stamped, etched, into their handles or escutcheon areas.

(C) Interrupting Rating. Every circuit breaker having an interrupting rating **other than 5000 amperes shall have its interrupting rating shown** on the circuit breaker.

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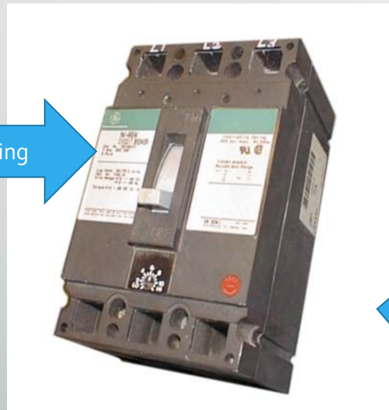
Labeling



After cover is removed

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240.83 Marking

(D) Used as Switches.

- CB used as switches in 120 V and 277 V fluorescent lighting circuits shall be listed and shall be marked SWD or HID.
- Circuit breakers used as switches in high-intensity discharge lighting circuits shall be listed and shall be marked as HID.

(E) Voltage Marking. Circuit breakers shall be marked with a voltage rating not less than the nominal system voltage that is indicative of their capability to interrupt fault currents between phases or phase to ground.

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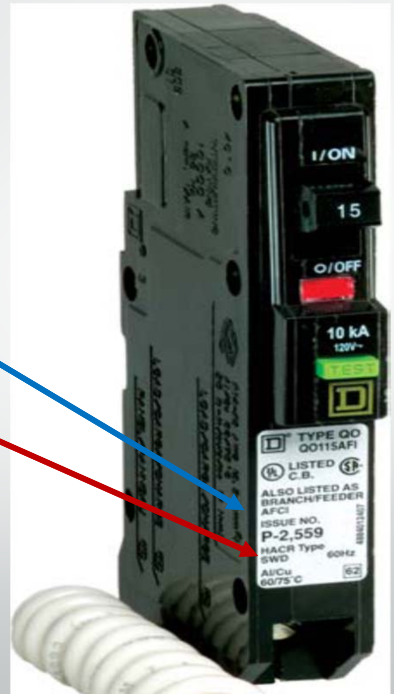
AFCI breaker
SWD



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GFCI 1 pole and 2 pole

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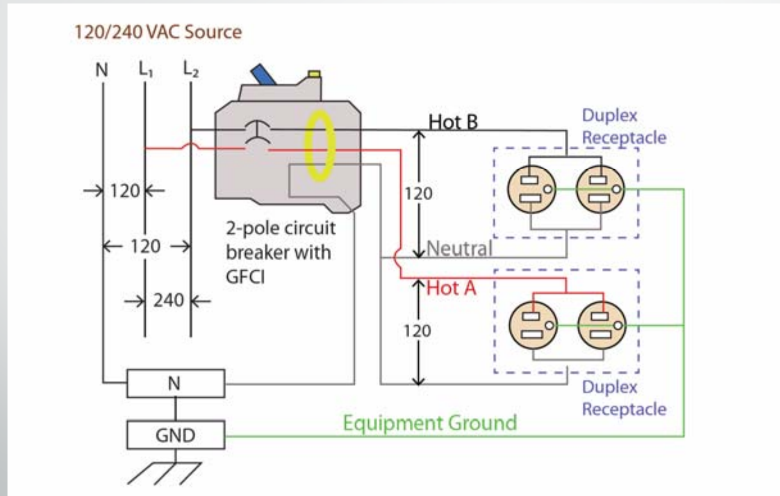
GFCI 2 pole 120/240V with shared neutral



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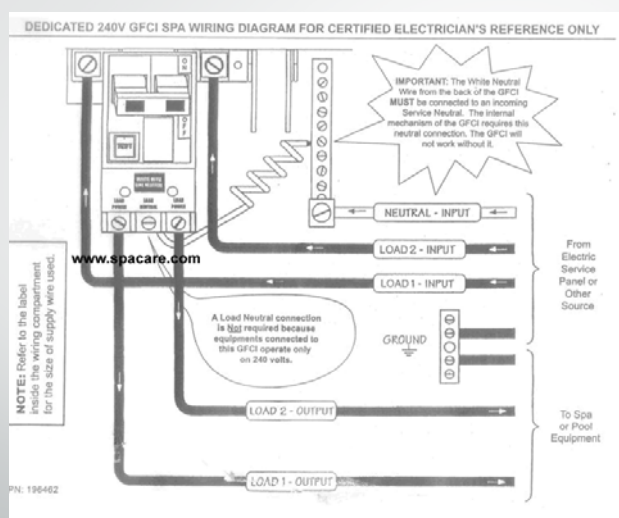
GFCI 2 pole/ 240V – without neutral



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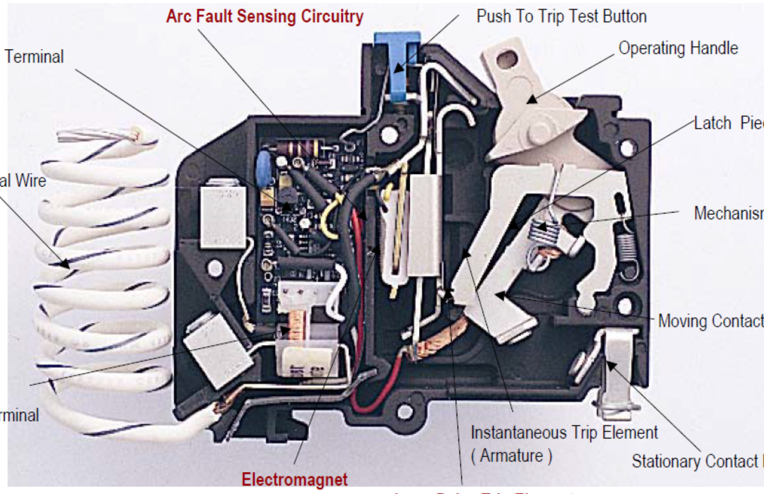
A Look Inside an AFCI Breaker



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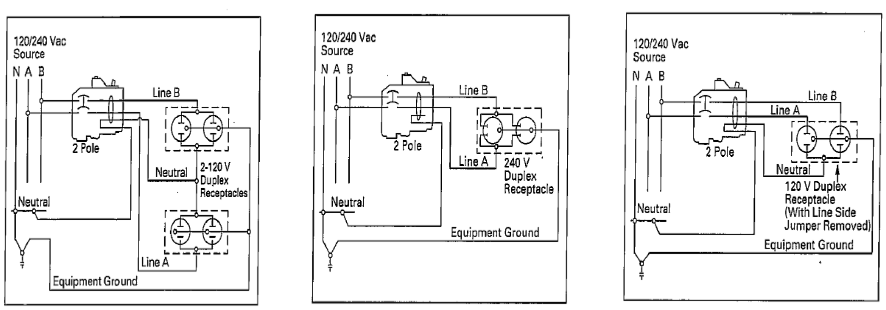
Combination 2 Pole Arc Fault Configurations



2-Pole Shared Neutral with
Multi-Duplex Receptacle Application

2-Pole 240 Volt Load Application
Sourced by 120/240 Vac

2-Pole Shared Neutral with
Duplex Receptacle Application

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Standard Features and Benefits:

- Enhanced electronics to reduce unwanted tripping from non-compliant devices
- Standard LED indicates one of seven trip codes to simplify circuit diagnostics
- Trip codes are stored permanently into the breaker's memory, to help identify "trip" history
- Meets areas requiring AFCI protection under the 2008 and 2011 NEC®
- Exclusive "Trip to OFF" and simple 1-Step breaker reset
- Branch overvoltage protection for sensitive electronics
- Limited lifetime warranty

Optional Plug-on Neutral Features and Benefits:

- Time savings up to 25% per AFCI and GFCI installation
- Eliminates unwanted tripping due to loose pigtail connections
- Improved wireway access
- Easier troubleshooting due to less wiring

CH Trip codes on AFCI BKR

Next Generation Trip Codes

- **Thermal trip/manual disconnect** - The breaker has detected an overload, short circuit or was manually turned off
- **Series arc** - A low current arc has been detected within one of the current pathways
- **Parallel arc** - A high current arc has been detected between two conductors
- **Short delay** - An electronic backup to the short-circuit mechanism
- **Overvoltage** - Voltage of 160V rms or greater
- **Ground fault** - Current has found an alternate path to ground
- **Self test failure** - The breaker continually tests the internal electronics and software to ensure that the arc fault detection technology is working properly

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Dual function AFCI/GFCI

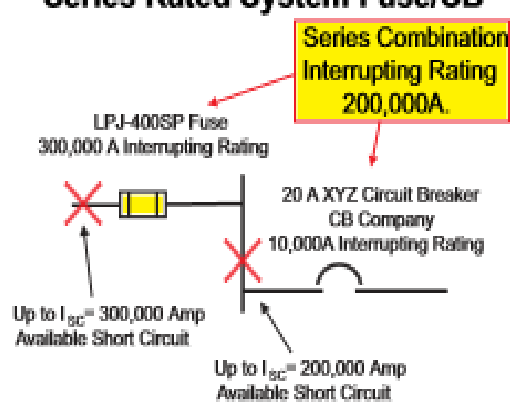
Breakers can be both Class A GFCI and "Combination" - series and parallel fault –AFCI breakers as well as inverse time overcurrent protection

240.86 Series Ratings

Where a circuit breaker is used on a circuit having an available fault current higher than the marked interrupting rating by being connected on the load side of an acceptable overcurrent protective device having a higher rating, the circuit breaker shall meet the requirements specified in (A) or (B), and (C).

***CAUTION:** A series rated combination allows a load side (protected) circuit breaker to be applied where the available short circuit current exceeds the interrupting rating marked on that circuit breaker.*

Series Rated System Fuse/CB



240.86(A) Series Ratings

Selected Under Engineering Supervision in Existing Installations.

- The series rated combination devices shall be selected by a licensed professional engineer engaged in the design or maintenance of electrical installations. The selection shall be documented and stamped by the professional engineer. This series combination rating, including identification of the upstream device, shall be field marked on the end use equipment.

- For calculated applications, the engineer shall ensure that the downstream circuit breaker(s) that are part of the series combination remain passive during the interruption period of the line side fully rated, current-limiting device.

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240.87 Arc Energy Reduction

Where the highest continuous current trip setting for which the actual overcurrent device installed in a circuit breaker is rated or can be adjusted is 1200 A or higher, 240.87(A) and (B) shall apply. (below)

(A) Documentation. Documentation shall be available to those authorized to design, install, operate, or inspect the installation as to the location of the circuit breaker(s).

(B) Method to Reduce Clearing Time. One of the following or approved equivalent means shall be provided:

(1) Zone-selective interlocking

(2) Differential relaying

(3) Energy-reducing maintenance switching with local status indicator

(4) Energy-reducing active arc flash

(5) An instantaneous trip setting at less than fault current

(6) An instantaneous override that is less than fault current

(7) An approved equivalent means

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- LSI breaker with energy reducing maintenance switch- Used to reduce Arc fault energy when working downstream- by using "no intentional delay" mode.
- When using "an energy reducing active arc mitigation system", no change in the circuit breaker setting is required.

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VIII. Supervised Industrial Installations
240.90 General

- Overcurrent protection in areas of supervised industrial installations shall comply with all of the other applicable provisions of this article, except as provided in Part VIII.
- The provisions of Part VIII shall be permitted only to apply to those portions of the electrical system in the supervised industrial installation used exclusively for manufacturing or process control activities.

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240.91 Protection of Conductors

Conductors shall be protected in accordance with 240.91(A) or (B).

(A) General. Conductors shall be protected in accordance with 240.4.

(B) Devices Rated Over 800 Amperes. Where the overcurrent device is rated over 800 amperes, the ampacity of the conductors it protects shall be equal to or greater than 95 percent of the rating of the overcurrent device specified in 240.6 in accordance with (B)(1) and (2).

(1) The conductors are protected within recognized time vs. current limits for short-circuit currents

(2) All equipment in which the conductors terminate is listed and marked for the application

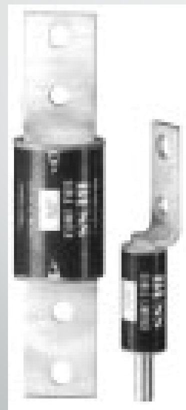
IX. Overcurrent Protection over 1000 Volts, Nominal

240.100 Feeders and Branch Circuits

(A) Location and Type of Protection. Feeder and branch circuit conductors shall have overcurrent protection in each ungrounded conductor located at the point where the conductor receives its supply, or at an alternative location in the circuit when designed under engineering supervision that includes, but is not limited to, considering the appropriate fault studies and time–current coordination analysis of the protective devices, and the conductor damage curves. The overcurrent protection shall be permitted to be provided by either 240.100(A)(1) or (A)(2).

Cable Limiters

Interrupting Rating: 200,000 Amps., 600 Volts AC RMS Symmetrical
UL Listing: KDM, KDR, KDP and KFM

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240.100 A-1 & 2

(1) Overcurrent Relays and Current Transformers. Circuit breakers used for overcurrent protection of 3-phase circuits shall have a minimum of three overcurrent relay elements operated from three current transformers. The separate overcurrent relay elements (or protective functions) shall be permitted to be part of a single electronic protective relay unit.

On 3-phase, 3-wire circuits, an overcurrent relay element in the residual circuit of the current transformers shall be permitted to replace one of the phase relay elements. An overcurrent relay element, operated from a current transformer that links all phases of a 3-phase, 3-wire circuit, shall be permitted to replace the residual relay element and one of the phase-conductor current transformers. Where the neutral conductor is not re-grounded on the load side of the circuit as permitted in 250.184(B), the current transformer shall be permitted to link all 3-phase conductors and the grounded circuit conductor (neutral).

(2) Fuses. A fuse shall be connected in series with each ungrounded conductor.

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Branch circuits and feeders
240.100 (B) & (C)

(B) Protective Devices. The protective device(s) shall be capable of detecting and interrupting all values of current that can occur at their location in excess of their trip-setting or melting point.

(C) Conductor Protection. The operating time of the protective device, the available short-circuit current, and the conductor used shall be coordinated to prevent damage or dangerous temperatures in conductors or conductor insulation under short circuit conditions.

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Medium Voltage Fuse Links

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Dummy Fuse "Neutrals" These are not fuses, Listed Product

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Fault Current Calculations

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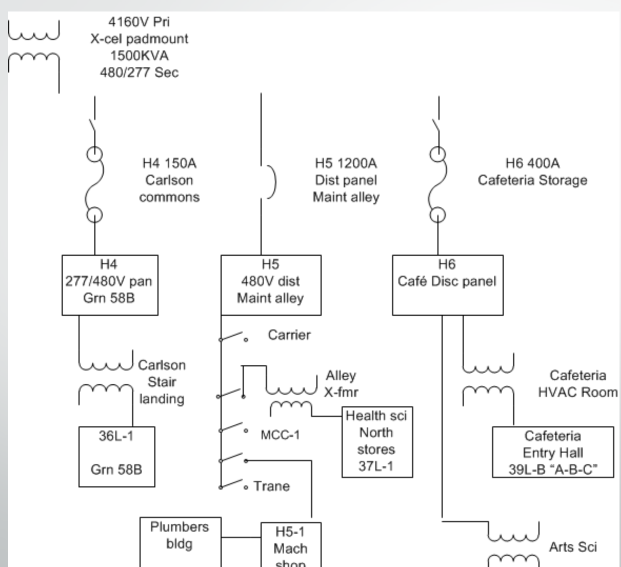
Procedure

To determine the fault current at any point in the system, first draw a one line diagram showing all of the sources, as well as the impedances of the circuit components. To begin, all system components including the utility should be shown.

One line diagram



Procedure

It must be understood that the short circuit calculations are done without considering current limiting devices in the system.

3-phase fault current

Basic Point-to-Point Calculation Procedure

Step 1. Determine the transformer full load amperes from either the nameplate or the following formulas:

3Ø Transformer $I_{f.l.} = \frac{KVA \times 1000}{E_{L-L} \times 1.732}$

1Ø Transformer $I_{f.l.} = \frac{KVA \times 1000}{E_{L-L}}$

Step 2. Find the transformer multiplier.

Multiplier $= \frac{100}{*\%Z_{trans}}$

* **Note.** Transformer impedance (Z) helps to determine what the short circuit current will be at the transformer secondary. Transformer impedance is determined as follows: The transformer secondary is short circuited. Voltage is applied to the primary which causes full load current to flow in the secondary. This applied voltage divided by the rated primary voltage is the impedance of the transformer.

Example: For a 480 volt rated primary, if 9.6 volts causes secondary full load current to flow through the shorted secondary, the transformer impedance is 9.6/480 = .02 = 2%Z.

In addition, U.L. listed transformer 25KVA and larger have a ± 10% impedance tolerance. Short circuit amperes can be affected by this tolerance.

Step 3. Determine the transformer let-through short-circuit current**.

$$I_{S.C.} = I_{f.l.} \times \text{Multiplier}$$

***Note.** Motor short-circuit contribution, if significant, may be added at all fault locations throughout the system. A practical estimate of motor short-circuit contribution is to multiply the total motor current in amperes by 4. Values of 4 to 6 are commonly accepted.

Step 4. Calculate the "f" factor.

3Ø Faults

$$f = \frac{1.732 \times L \times I_{3\emptyset}}{C \times E_{L-L}}$$

1Ø Line-to-Line (L-L) Faults on 1Ø Center Tapped Transformer

$$f = \frac{2 \times L \times I_{L-L}}{C \times E_{L-L}}$$

1Ø Line-to-Neutral (L-N) Faults on 1Ø Center Tapped Transformer

$$f = \frac{2 \times L \times I_{L-N}^{\dagger}}{C \times E_{L-N}}$$

Where:

L = length (feet) of conductor to the fault.

C = constant from Table of "C" values for conductors and busway. For parallel runs, multiply C values by the number of conductors per phase.

I = available short-circuit current in amperes at beginning of circuit.

†**Note.** The L-N fault current is higher than the L-L fault current at the secondary terminals of a single-phase center-tapped transformer. The short-circuit current available (I) for this case in Step 4 should be adjusted at the transformer terminals as follows: At L-N center tapped transformer terminals, $I_{L-N} = 1.5 \times I_{L-L}$ **at Transformer Terminals.**

3-phase fault current

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"C" Values for Conductors and Busway

Copper												
AWG or kcmil	Three Single Conductors						Three-Conductor Cable					
	Conduit						Conduit					
	Steel			Nonmagnetic			Steel			Nonmagnetic		
	600V	5KV	15KV	600V	5KV	15KV	600V	5KV	15KV	600V	5KV	15KV
14	389	389	389	389	389	389	389	389	389	389	389	389
12	617	617	617	617	617	617	617	617	617	617	617	617
10	981	981	981	981	981	981	981	981	981	981	981	981
8	1557	1551	1557	1558	1555	1558	1559	1557	1559	1559	1558	1559
6	2425	2406	2389	2430	2417	2406	2431	2424	2414	2433	2428	2420
4	3806	3750	3695	3825	3789	3752	3830	3811	3778	3837	3823	3798
3	4760	4760	4760	4802	4802	4802	4760	4790	4760	4802	4802	4802
2	5906	5736	5574	6044	5926	5809	5989	5929	5827	6087	6022	5957
1	7292	7029	6758	7493	7306	7108	7454	7364	7188	7579	7507	7364
1/0	8924	8543	7973	9317	9033	8590	9209	9086	8707	9472	9372	9052
2/0	10755	10061	9389	11423	10877	10318	11244	11045	10500	11703	11528	11052
3/0	12843	11804	11021	13923	13048	12360	13656	13333	12613	14410	14118	13461
4/0	15082	13605	12542	16673	15351	14347	16391	15890	14813	17482	17019	16012
250	16483	14924	13643	18593	17120	15865	18310	17850	16465	19779	19352	18001
300	18176	16292	14768	20867	18975	17408	20617	20051	18318	22524	21938	20163
350	19703	17385	15678	22736	20526	18672	22646	21914	19821	24904	24126	21982
400	20565	18235	16365	24296	21786	19731	24253	23371	21042	26915	26044	23517
500	22185	19172	17492	26706	23277	21329	26980	25449	23125	30028	28712	25916
600	22965	20567	17962	28033	25203	22097	28752	27974	24896	32236	31258	27766
750	24136	21386	18888	28303	25430	22690	31050	30024	26932	32404	31338	28303
1000	25278	22539	19923	31490	28083	24887	33864	32688	29320	37197	35748	31959
Aluminum												
14	236	236	236	236	236	236	236	236	236	236	236	236
12	375	375	375	375	375	375	375	375	375	375	375	375
10	598	598	598	598	598	598	598	598	598	598	598	598
8	951	950	951	951	950	951	951	951	951	951	951	951
6	1480	1476	1472	1481	1478	1476	1481	1480	1478	1482	1481	1479
4	2345	2332	2319	2350	2341	2333	2351	2347	2339	2353	2349	2344
3	2948	2948	2948	2958	2958	2958	2948	2956	2948	2958	2958	2958
2	3713	3669	3626	3729	3701	3672	3733	3719	3693	3739	3724	3709
1	4645	4574	4497	4678	4631	4580	4686	4663	4617	4699	4681	4646
1/0	5777	5669	5493	5838	5766	5645	5852	5820	5717	5875	5851	5771
2/0	7186	6968	6733	7301	7152	6986	7327	7271	7109	7372	7328	7201
3/0	8826	8466	8163	9110	8851	8627	9077	8980	8750	9242	9164	8977
4/0	10740	10167	9700	11174	10749	10386	11184	11021	10642	11408	11277	10968
250	12122	11460	10848	12862	12343	11847	12796	12636	12115	13236	13105	12661
300	13909	13009	12192	14922	14182	13491	14916	14698	13973	15494	15299	14658
350	15484	14280	13288	16812	15857	14954	15413	16490	15540	17635	17351	16500
400	16670	15355	14188	18505	17321	16233	18461	18063	16921	19587	19243	18154
500	18755	16827	15657	21390	19503	18314	21394	20606	19314	22987	22381	20978
600	20093	18427	16484	23451	21718	19635	23633	23195	21348	25750	25243	23294
750	21766	19685	17686	25976	23701	20934	26431	25789	23750	29036	28262	25976
1000	23477	21235	19005	28778	26109	23482	29864	29049	26608	32938	31919	29135

Note: These values are equal to one over the impedance per foot for impedances found in IEEE std. 241-1990, IEEE Recommended Practice for Commercial Building Power Systems.

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Step 5. Calculate "M" (multiplier).

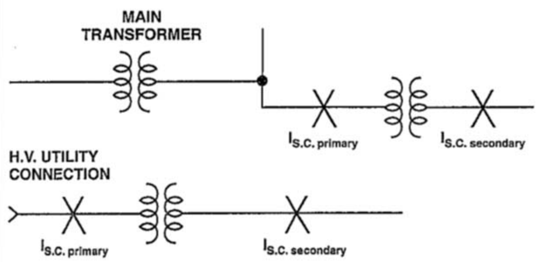
$$M = \frac{1}{1+f}$$

Step 6. Calculate the available short-circuit symmetrical RMS current at the point of fault.

$$I_{S.C.\ sym\ RMS} = I_{S.C.} \times M$$

Calculation of Short-Circuit Currents at Second Transformer in System

Use the following procedure to calculate the level of fault current at the secondary of a second, downstream transformer in a system when the level of fault current at the transformer primary is known.



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Procedure for Second Transformer in System

Step A. Calculate the "f" factor ($I_{S.C.\ primary}$ known)

3Ø Transformer
($I_{S.C.\ primary}$ and $I_{S.C.\ secondary}$ are 3Ø fault values)

$$f = \frac{I_{S.C.\ primary} \times V_{primary} \times 1.73\ (\%Z)}{100{,}000 \times KVA_{trans}}$$

1Ø Transformer
($I_{S.C.\ primary}$ and $I_{S.C.\ secondary}$ are 1Ø fault values: $I_{S.C.\ secondary}$ is L-L)

$$f = \frac{I_{S.C.\ primary} \times V_{primary} \times (\%Z)}{100{,}000 \times KVA_{trans}}$$

Step B. Calculate "M" (multiplier).

$$M = \frac{1}{1+f}$$

Step C. Calculate the short-circuit current at the secondary of the transformer. (See Note under Step 3 of "Basic Point-to-Point Calculation Procedure".)

$$I_{S.C.\ secondary} = \frac{V_{primary}}{V_{secondary}} \times M \times I_{S.C.\ primary}$$

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Eg: 3-Phase Fault Current Calculation

System A

Available Utility
Infinite Assumption

1500 KVA Transformer,
480V, 3Ø, 3.5%Z,
3.45%X, 56%R

$I_{f.l.}$ =1804A

25' - 500kcmil
6 Per Phase
Service Entrance
Conductors in Steel Conduit

2000A Switch

KRP-C-2000SP Fuse

Fault X_1

400A Switch

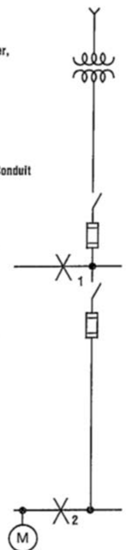
LPS-RK-400SP Fuse

50' - 500 kcmil
Feeder Cable
In Steel Conduit

Fault X_2

Motor Contribution

One-Line Diagram



Fault X_1

Step 1. $I_{f.l.} = \frac{1500 \times 1000}{480 \times 1.732} = 1804A$

Step 2. $\text{Multiplier} = \frac{100}{3.5} = 28.57$

Step 3. $I_{S.C.} = 1804 \times 28.57 = 51{,}540A$

$I_{S.C.\ motor\ contrib} = 4 \times 1{,}804^* = 7{,}216A$

$I_{total\ S.C.\ sym\ RMS} = 51{,}504 + 7{,}216 = 58{,}720A$

Step 4. $f = \frac{1.732 \times 25 \times 51{,}540}{6 \times 22{,}185 \times 480} = 0.0349$

Step 5. $M = \frac{1}{1 + .0349} = .9663$

Step 6. $I_{S.C.sym\ RMS} = 51{,}540 \times .9663 = 49{,}803A$

$I_{S.C.motor\ contrib} = 4 \times 1{,}804^* = 7{,}216A$

$I_{total S.C.\ sym\ RMS\ (fault\ X_1)} = 49{,}803 + 7{,}216 = 57{,}019A$

Fault X_2

Step 4. Use $I_{S.C.sym\ RMS}$ @ Fault X_1 to calculate "f"

$f = \frac{1.732 \times 50 \times 49{,}803}{22{,}185 \times 480} = .4050$

Step 5. $M = \frac{1}{1 + .4050} = .7117$

Step 6. $I_{S.C.sym\ RMS} = 49{,}803 \times .7117 = 35{,}445A$

$I_{sym\ motor\ contrib} = 4 \times 1{,}804^* = 7{,}216A$

$I_{total\ S.C.\ sym\ RMS\ (fault\ X_2)} = 35{,}445 + 7{,}216 = 42{,}661A$

*Assumes 100% motor load. If 50% of this load was from motors, $I_{S.C.\ motor\ contrib.} = 4 \times 1{,}804 \times .5 = 3608A$

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3-Phase Fault Current Calculation

System B

Available Utility
Infinite Assumption

1000 KVA Transformer,
480V, 3Ø,
3.5%Z

$I_{f.l.}$= 1203A

30' - 500 kcmil
4 Per Phase
Copper in PVC Conduit

1600A Switch

KRP-C-1500SP Fuse

Fault X_1

400A Switch

LPS-RK-350SP Fuse

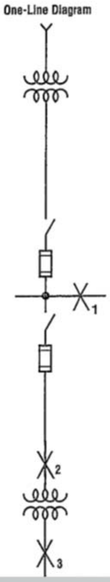
20' - 2/0
2 Per Phase
Copper in PVC Conduit

Fault X_2

225 KVA transformer,
208V, 3Ø
1.2%Z

Fault X_3

One-Line Diagram



Fault X_1

Step 1. $I_{f.l.} = \frac{1000 \times 1000}{480 \times 1.732} = 1203A$

Step 2. $\text{Multiplier} = \frac{100}{3.5} = 28.57$

Step 3. $I_{S.C.} = 1203 \times 28.57 = 34{,}370A$

Step 4. $f = \frac{1.732 \times 30 \times 34{,}370}{4 \times 26{,}706 \times 480} = .0348$

Step 5. $M = \frac{1}{1 + .0348} = .9664$

Step 6. $I_{S.C.sym\ RMS} = 34{,}370 \times .9664 = 33{,}215A$

Fault X_2

Step 4. $f = \frac{1.732 \times 20 \times 33{,}215}{2 \times 11{,}423 \times 480} = .1049$

Step 5. $M = \frac{1}{1 + .1049} = .905$

Step 6. $I_{S.C.sym\ RMS} = 33{,}215 \times .905 = 30{,}059A$

Fault X_3

Step A. $f = \frac{30{,}059 \times 480 \times 1.732 \times 1.2}{100{,}000 \times 225} = 1.333$

Step B. $M = \frac{1}{1 + 1.333} = .4286$

Step C. $I_{S.C.\ sym\ RMS} = \frac{480 \times .4286 \times 30{,}059}{208} = 29{,}731A$

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1- Phase Fault Current Calculation

1-Phase Fault Calculation

1. It is necessary that the proper impedance be used to represent the primary system. For 3Ø fault calculations, a single primary conductor impedance is only considered from the source to the transformer connection. This is compensated for in the 3Ø short-circuit formula by multiplying the single conductor or single-phase impedance by 1.73.

However, for single-phase faults, a primary conductor impedance is considered from the source to the transformer and back to the source. This is compensated in the calculations by multiplying the 3Ø primary source impedance by two.

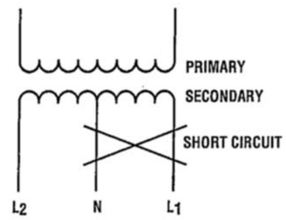
1-Phase Fault Calculation

2. The impedance of the center-tapped transformer must be adjusted for the half-winding (generally line-to-neutral) fault condition.

The diagram at the right illustrates that during line-to-neutral faults, the full primary winding is involved but, only the half-winding on the secondary is involved. Therefore, the actual transformer reactance and resistance of the half-winding condition is different than the actual transformer reactance and resistance of the full winding condition. Thus, adjustment to the %X and %R must be made when considering line-to-neutral faults. The adjustment multipliers generally used for this condition are as follows:

1.5 times full winding %R on full winding basis.

1.2 times full winding %X on full winding basis.



Note: %R and %X multipliers given in "Impedance Data for Single Phase Transformers" Table may be used, however, calculations must be adjusted to indicate transformer KVA/2.

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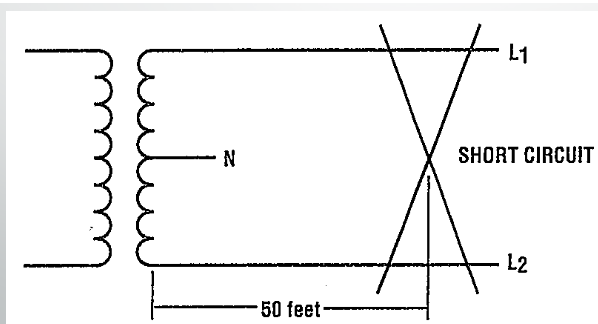
3. The impedance of the cable and two-pole switches on the system must be considered "both-ways" since the current flows to the fault and then returns to the source. For instance, if a line-to-line fault occurs 50 feet from a transformer, then 100 feet of cable impedance must be included in the calculation.

The calculations on the following pages illustrate 1Ø fault calculations on a single-phase transformer system. Both line-to-line and line-to-neutral faults are considered.



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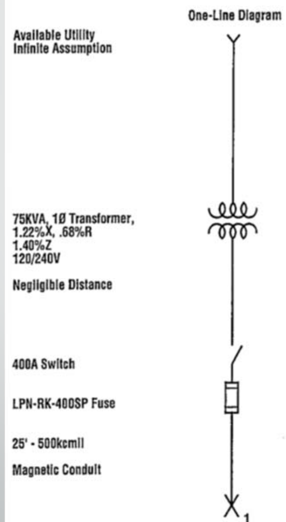
Line-to-Line Fault @ 240V — Fault X_1



Fault X_1

Step 1. $I_{f.l.} = \frac{75 \times 1000}{240} = 312.5A$

Step 2. $\text{Multiplier} = \frac{100}{1.40} = 71.43$

Step 3. $I_{S.C.} = 312.5 \times 71.43 = 22{,}322A$

Step 4. $f = \frac{2 \times 25 \times 22{,}322}{22{,}185 \times 240} = .2096$

Step 5. $M = \frac{1}{1 + .2096} = .8267$

Step 6. $I_{S.C.\ L\text{-}L\ (X_1)} = 22{,}322 \times .8267 = 18{,}453A$

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"C" Values for Conductors and Busway

AWG or kcmil	Three Single Conductors, Conduit, Steel 600V	Steel 5KV	Steel 15KV	Nonmagnetic 600V	Nonmagnetic 5KV	Nonmagnetic 15KV	Three-Conductor Cable, Conduit, Steel 600V	Steel 5KV	Steel 15KV	Nonmagnetic 600V	Nonmagnetic 5KV	Nonmagnetic 15KV
Copper												
14	389	389	389	389	389	389	389	389	389	389	389	389
12	617	617	617	617	617	617	617	617	617	617	617	617
10	981	981	981	981	981	981	981	981	981	981	981	981
8	1557	1551	1557	1558	1555	1558	1559	1557	1559	1559	1558	1559
6	2425	2406	2389	2430	2417	2406	2431	2424	2414	2433	2428	2420
4	3806	3750	3695	3825	3789	3752	3830	3811	3778	3837	3823	3798
3	4760	4760	4760	4802	4802	4802	4760	4790	4760	4802	4802	4802
2	5906	5736	5574	6044	5926	5809	5989	5929	5827	6087	6022	5957
1	7292	7029	6758	7493	7306	7108	7454	7364	7188	7579	7507	7364
1/0	8924	8543	7973	9317	9033	8590	9209	9086	8707	9472	9372	9052
2/0	10755	10061	9389	11423	10877	10318	11244	11045	10500	11703	11528	11052
3/0	12843	11804	11021	13923	13048	12360	13656	13333	12613	14410	14118	13461
4/0	15082	13605	12542	16673	15351	14347	16391	15890	14813	17482	17019	16012
250	16483	14924	13643	18593	17120	15865	18310	17850	16465	19779	19352	18001
300	18176	16292	14768	20867	18975	17408	20617	20051	18318	22524	21938	20163
350	19703	17385	15678	22736	20526	18672	22646	21914	19821	24904	24126	21982
400	20565	18235	16365	24296	21786	19731	24253	23371	21042	26915	26044	23517
500	22185	19172	17492	26706	23277	21329	26980	25449	23125	30028	28712	25916
600	22965	20567	17962	28033	25203	22097	28752	27974	24896	32236	31258	27766
750	24136	21386	18888	28303	25430	22690	31050	30024	26932	32404	31338	28303
1000	25278	22539	19923	31490	28083	24887	33864	32688	29320	37197	35748	31959
Aluminum												
14	236	236	236	236	236	236	236	236	236	236	236	236
12	375	375	375	375	375	375	375	375	375	375	375	375
10	598	598	598	598	598	598	598	598	598	598	598	598
8	951	950	951	951	950	951	951	951	951	951	951	951
6	1480	1476	1472	1481	1478	1476	1481	1480	1478	1482	1481	1479
4	2345	2332	2319	2350	2341	2333	2351	2347	2339	2353	2349	2344
3	2948	2948	2948	2958	2958	2958	2948	2956	2948	2958	2958	2958
2	3713	3669	3626	3729	3701	3672	3733	3719	3693	3739	3724	3709
1	4645	4574	4497	4678	4631	4580	4686	4663	4617	4699	4681	4646
1/0	5777	5669	5493	5838	5766	5645	5852	5820	5717	5875	5851	5771
2/0	7186	6968	6733	7301	7152	6986	7327	7271	7109	7372	7328	7201
3/0	8826	8466	8163	9110	8851	8627	9077	8980	8750	9242	9164	8977
4/0	10740	10167	9700	11174	10749	10386	11184	11021	10642	11408	11277	10968
250	12122	11460	10848	12862	12343	11847	12796	12636	12115	13236	13105	12661
300	13909	13009	12192	14922	14182	13491	14916	14698	13973	15494	15299	14658
350	15484	14280	13288	16812	15857	14954	15413	16490	15540	17635	17351	16500
400	16670	15355	14188	18505	17321	16233	18461	18063	16921	19587	19243	18154
500	18755	16827	15657	21390	19503	18314	21394	20606	19314	22987	22381	20978
600	20093	18427	16484	23451	21718	19635	23633	23195	21348	25750	25243	23294
750	21766	19685	17686	25976	23701	20934	26431	25789	23750	29036	28262	25976
1000	23477	21235	19005	28778	26109	23482	29864	29049	26608	32938	31919	29135

Note: These values are equal to one over the impedance per foot for impedances found in IEEE std. 241-1990, IEEE Recommended Practice for Commercial Building Power Systems.

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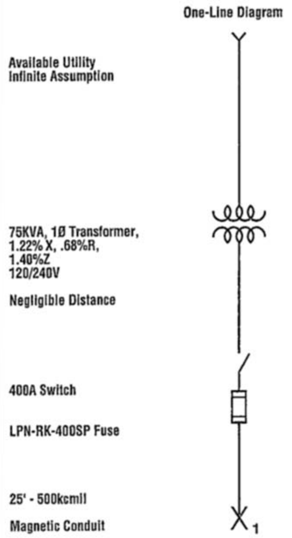
Line-to-Neutral Fault @ 120V — Fault X_1



Fault X_1

Step 1. $I_{f.l.} = \frac{75 \times 1000}{240} = 312.5A$

Step 2. Multiplier $= \frac{100}{1.40} = 71.43$

Step 3. $I_{S.C.\,(L\text{-}L)} = 312.5 \times 71.43 = 22{,}322A$

$I_{S.C.\,(L\text{-}N)} = 22{,}322 \times 1.5 = 33{,}483A$

Step 4. $f = \frac{2^{*} \times 25 \times 22{,}322 \times 1.5}{22{,}185 \times 120} = .6288$

Step 5. $M = \frac{1}{1 + .6288} = .6139$

Step 6. $I_{S.C.\,L\text{-}N\,(X_1)} = 33{,}483 \times .6139 = 20{,}555A$

* Assumes the neutral conductor and the line conductor are the same size.

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Transformer Short Circuit Amps

TRANSFORMERS

Short-Circuit Currents Available from Various Size Transformers

Voltage And Phase	KVA	Full Load Amps	% Impedance†† (Nameplate)	Short-Circuit Amps†
120/240 1 ph.*	25	104	1.58	11,574
	37½	156	1.56	17,351
	50	209	1.54	23,122
	75	313	1.6	32,637
	100	417	1.6	42,478
	167	695	1.8	60,255
120/208 3 ph.**	25	69	1.6	4,791
	50	139	1.6	9,652
	75	208	1.11	20,821
	100	278	1.11	27,828
	150	416	1.07	43,198
	225	625	1.12	62,004
	300	833	1.11	83,383
	500	1388	1.24	124,373
	750	2082	3.5	66,095
	1000	2776	3.5	88,167
	1500	4164	3.5	132,190
	2000	5552	5.0	123,377
	2500	6950	5.0	154,444
277/480 3 ph.	112½	135	1.0	15,000
	150	181	1.2	16,759
	225	271	1.2	25,082
	300	361	1.2	33,426
	500	601	1.3	51,362
	750	902	3.5	28,410
	1000	1203	3.5	38,180
	1500	1804	3.5	57,261
	2000	2406	5.0	53,461
	2500	3007	5.0	66,822

* Single-phase values are L-N values at transformer terminals. These figures are based on change in turns ratio between primary and secondary, 100,000 KVA primary, zero feet from terminals of transformer, 1.2 (%X) and 1.5 (%R) multipliers for L-N vs. L-L reactance and resistance values and transformer X/R ratio = 3.

** Three-phase short-circuit currents based on "infinite" primary.

† U.L. listed transformers 25 KVA or greater have a ±10% impedance tolerance. Short-circuit amps reflect a "worst case" condition.

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Various Types of Short Circuit Currents as a Percent of Three Phase Bolted Faults (Typical).

Three Phase Bolted Fault	100%
Line-to-Line Bolted Fault	87%
Line-to-Ground Bolted Fault	100%*
Three Phase Arcing Fault	89% (480V) 12% (208V)
Line-to-Line Arcing Fault	74% (480V) 2% (208V)
Line-to-Ground Arcing Fault	38% (480V) 0% (208V)

*Typically much lower but can actually exceed the Three Phase Bolted Fault if it is near the transformer terminals.

Impedance Data for Single-Phase Transformers

kVA 1Ø	Suggested X/R Ratio for Calculation	Normal Range of Percent Impedance (%Z)*	Impedance Multipliers** For Line-to-Neutral Faults for %X	for %R
25.0	1.1	1.2–6.0	0.6	0.75
37.5	1.4	1.2–6.5	0.6	0.75
50.0	1.6	1.2–6.4	0.6	0.75
75.0	1.8	1.2–6.6	0.6	0.75
100.0	2.0	1.3–5.7	0.6	0.75
167.0	2.5	1.4–6.1	1.0	0.75
250.0	3.6	1.9–6.8	1.0	0.75
333.0	4.7	2.4–6.0	1.0	0.75
500.0	5.5	2.2–5.4	1.0	0.75

* National standards do not specify %Z for single-phase transformers. Consult manufacturer for values to use in calculation.

** Based on rated current of the winding (one–half nameplate kVA divided by secondary line-to-neutral voltage).

Note: U.L. Listed transformers 25 KVA and greater have a ± 10% tolerance on their impedance nameplate.

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Impedance Data for Single-Phase and Three-Phase Transformers-Supplement†

kVA 1Ø	kVA 3Ø	%Z	Suggested X/R Ratio for Calculation
10	—	1.2	1.1
15	—	1.3	1.1
	75	1.11	1.5
	150	1.07	1.5
	225	1.12	1.5
	300	1.11	1.5
333	—	1.9	4.7
	500	1.24	1.5
500	—	2.1	5.5

†These represent actual transformer nameplate ratings taken from field installations.

Note: U.L. Listed transformers 25KVA and greater have a ±10% tolerance on their impedance nameplate.

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Ampacity	Busway				
	Plug-In	Feeder		High Impedance	
	Copper	Aluminum	Copper	Aluminum	Copper
225	28700	23000	18700	12000	—
400	38900	34700	23900	21300	—
600	41000	38300	36500	31300	—
800	46100	57500	49300	44100	—
1000	69400	89300	62900	56200	15600
1200	94300	97100	76900	69900	16100
1350	119000	104200	90100	84000	17500
1600	129900	120500	101000	90900	19200
2000	142900	135100	134200	125000	20400
2500	143800	156300	180500	166700	21700
3000	144900	175400	204100	188700	23800
4000	—	—	277800	256400	—

Note: These values are equal to one over the impedance per foot for impedance in a survey of industry.

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Electrical Association

End of Over current protection information

Part 2 NEC 2017

83

Voltage Drop - Extra Material

84

Voltage Drop
Single Phase

$$VD = \frac{2 \times K \times I \times L}{CM}$$

VD = Voltage drop
K = Ohms per mil foot – copper @ 75°C is 12.8
I = Current in amperes
L = Length of wire one direction
CM = Circular mil area of conductor

85

Voltage Drop- Three Phase

$$VD = \frac{1.732 \times K \times I \times L}{CM}$$

86

Voltage Drop Problem

What size copper conductor is needed to keep voltage drop to 3% or less for a 120v, single phase circuit that is serving a load of 8 amps and is 140' in length in one direction?

Use K = 12.8

87

Voltage Drop Problem

What size copper conductor is needed to keep voltage drop to 3% or less for a 120v, single phase circuit that is serving a load of 8 amps and is 140' in length in one direction?

Use K = 12.8

3% = .03 x 120v = 3.6v

88

Voltage Drop Problem

What size copper conductor is needed to keep voltage drop to 13% or less for a 120v, single phase circuit that is serving a load of 8 amps and is 140' in length in one direction?

Use K = 12.8

1. 3% = 0.03 × 120v = 3.6v
2. 3.6VD = $\frac{2 \times 12.8 \times 8 \times 140}{CM}$

89

Voltage Drop Problem

What size copper conductor is required to keep voltage drop to 3% for a 120v, single phase circuit that has a load of 8 amps and is 140' in length in one direction?

Use K = 12.8

1. 3% = 0.03 × 120v = 3.6v
2. 3.6VD = 2 × 12.8 × 8 × 140/cm
3. cm = 2 × 12.8 × 8 / (3.6 VD)

90

Voltage Drop Problem

Use K = 12.8

1. 3% = 0.03 × 120v = 3.6v
2. $3.6VD = \frac{2 \times 12.8 \times 8 \times 140}{CM}$
3. $CM = \frac{2 \times 12.8 \times 8 \times 140}{3.6}$
4. CM = 7965

91

Voltage Drop Problem

Use K = 12.8

1. 3% = 0.03 × 120v = 3.6v
2. $3.6VD = \frac{2 \times 12.8 \times 8 \times 140}{CM}$
3. $CM = \frac{2 \times 12.8 \times 8 \times 140}{3.64}$

CM = 7965

ANSWER: 10 AWG

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End of Voltage Drop Problems

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