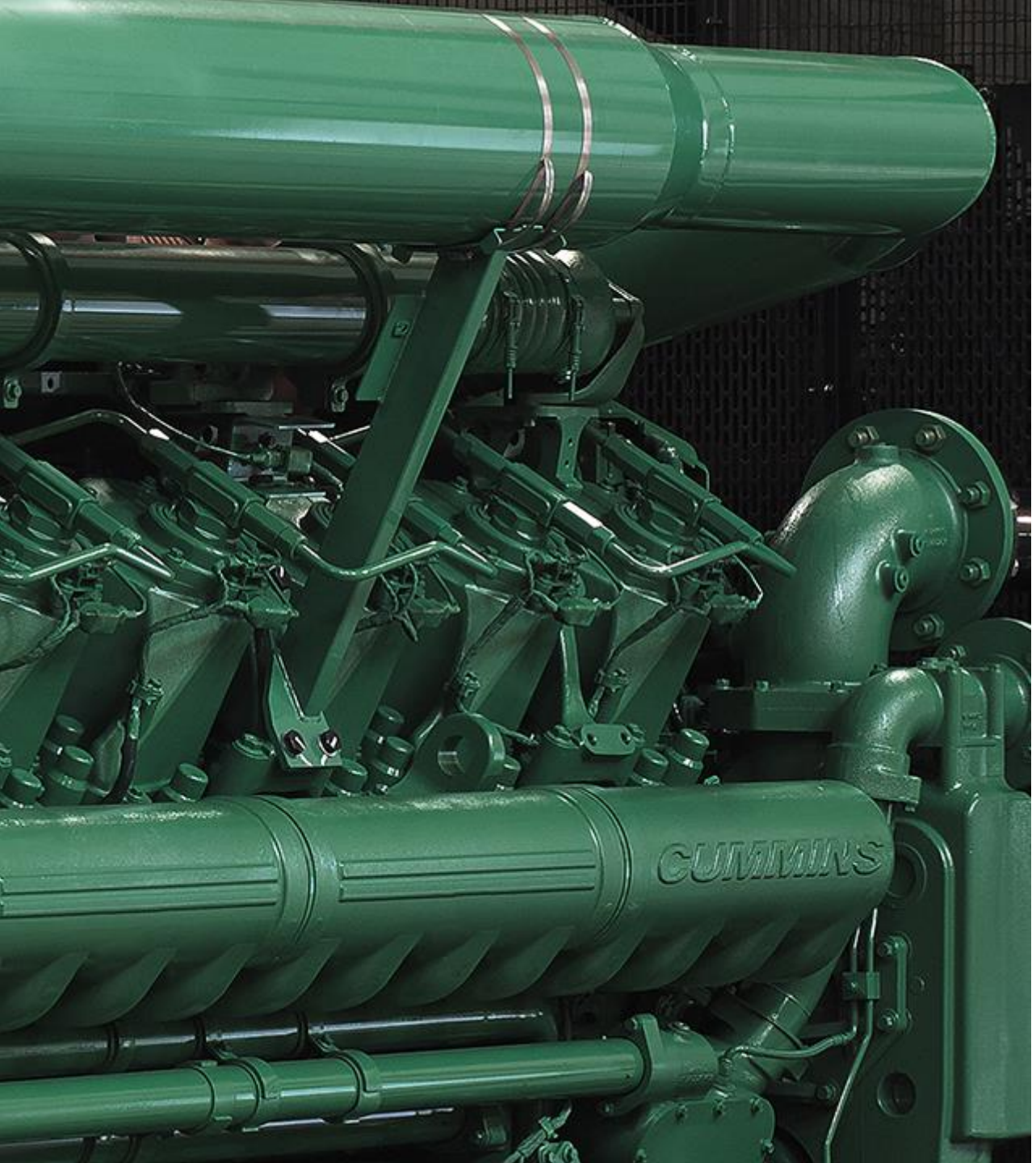

Generator Set Overcurrent Protection

PowerHour webinar series for consulting engineers

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September 24 11:00 PDT / 13:00 CDT

(1PDH issued by Cummins)

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The views and opinions expressed in this course shall not be considered the official position of any regulatory organization and shall not be considered to be, nor be relied upon as, a Formal Interpretation.

Participants are encouraged to refer to the entire text of all referenced documents. In addition, when it doubt, reach out to the Authority Having Jurisdiction.

Course Objectives

Generator Set Overcurrent Protection

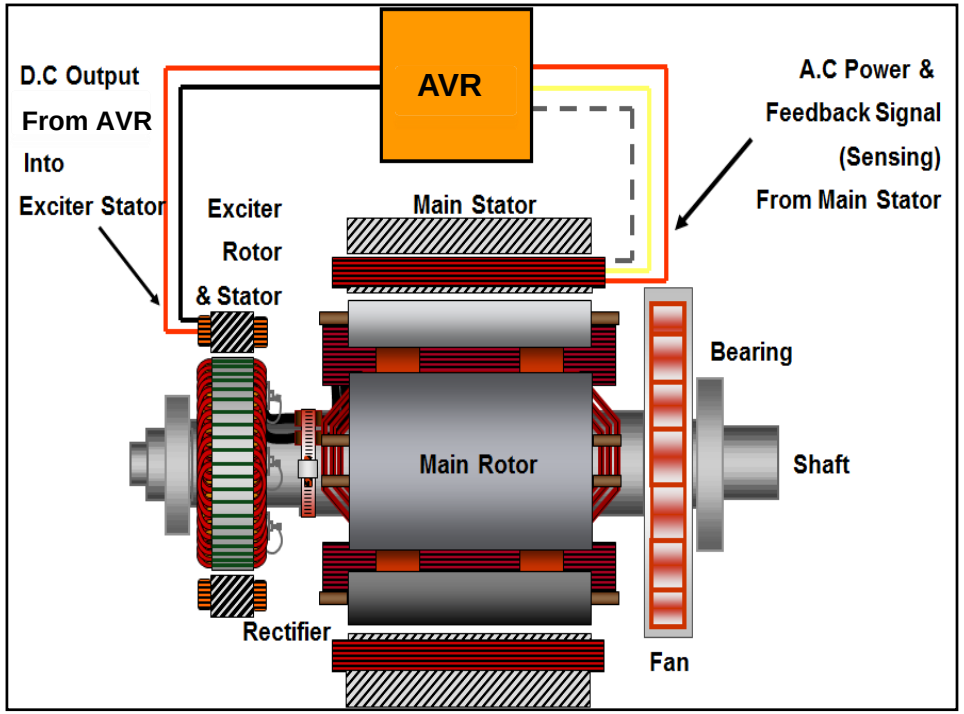
While much attention has been placed in recent years on selective coordination and protection requirements for facilities, the premise of these requirements has been protection of the cabling and distribution system. There are unique characteristics of generator sets which can impact the design of a truly reliable system which should be taken into account. This module looks to explore and explain some of these properties.

After completing this course, participants will be able to:

- Define generator excitation systems and their effect on fault current performance.
- Identify basic generator set overcurrent protection requirements in order to specify the correct protection equipment.
- Describe the NEC requirements for selective coordination, generator disconnect, arc flash energy reduction and separation of circuits in order to evaluate different means for achieving code compliance.
- Identify recent important codes changes to NFPA70, NEC 2017 and impact on Generator set protection

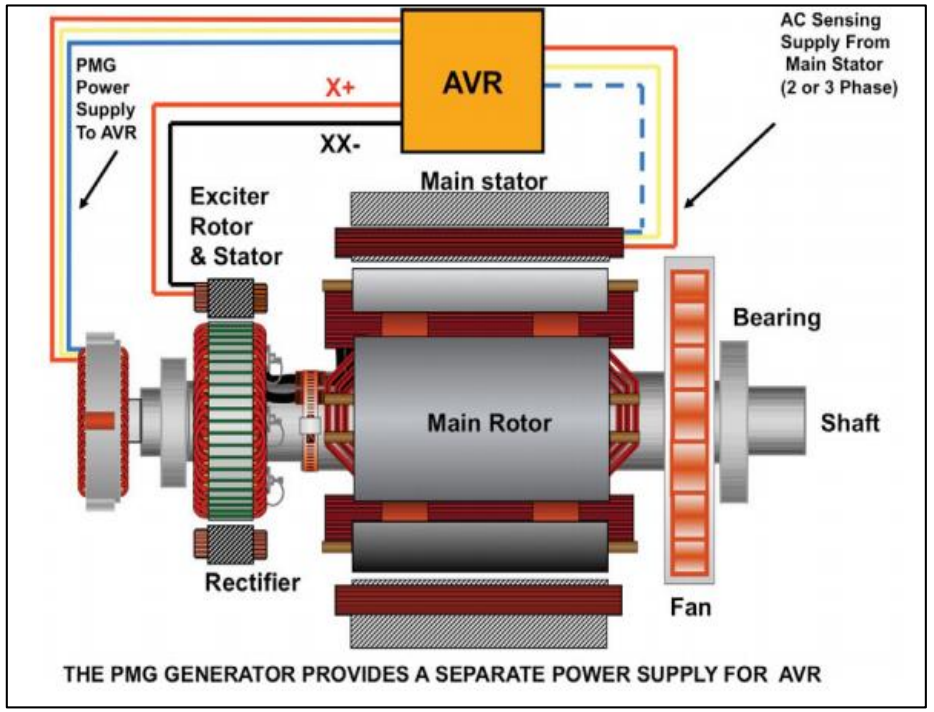
Generator Set Excitation Systems

Self excited generator set - Shunt



Key point:
AVR may not have the capability to support the fault current long enough to clear downstream faults as the main field in the alternator may collapse.

Separately excited generator set - PMG



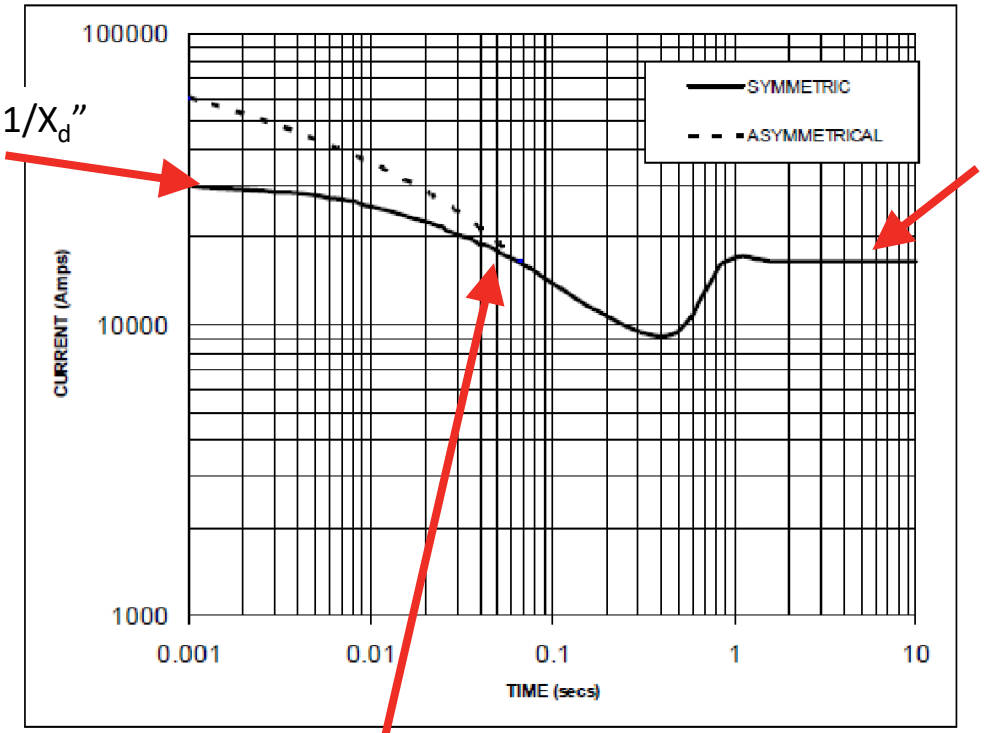
Key point:
Ability to provide sustained short circuit current during fault conditions which prevent the field from collapsing and allows for faults downstream to clear.

AVR: Automatic voltage regulator
PMG: Permanent magnet generator

Alternator Fault Performance

Decrement Curve (Separately Excited)

$I_{3ph,\,pu} = 1/X_d''$



$$I_{3ph,\,pu} = (1/X_d'' - 1/X_d')*e^{(-t/Td'')} + (1/X_d' - 1/X_d)*e^{(-t/Td')} + 1/X_d$$

Three phase fault characteristics

Current is a function of the AVR, Excitation System and alternator electro-magnetic design.

Key points:

- Alternator fault current decays, not constant like fault current from a transformer

- Conventional AVRs *increase* excitation in response to fault

Alternator Fault Performance

Decrement Curve Multipliers

NOTE 1
THE FOLLOWING MULTIPLICATION FACTORS SHOULD BE USED TO ADJUST THE VALUES FROM CURVES BETWEEN THE 0.001 SECONDS AND THE MINIMUM CURRENT POINT IN RESPECT OF NOMINAL OPERATING VOLTAGE

VOLTAGE	FACTOR
416V	X 0.87
440V	X 0.92
460V	X0.96
480V	X1.00

THE SUSTAINED CURRENT VALUE IS CONSTANT IRRESPECTIVE OF VOLTAGE LEVEL

NOTE 2
THE FOLLOWING MULTIPLICATION FACTORS SHOULD BE USED TO CONVERT THE VALUES CALCULATED IN ACCORDANCE WITH NOTE 1 TO THOSE APPLICABLE TO THE VARIOUS TYPES OF SHORT CIRCUIT

	3 PHASE	2 PHASE L-L	1 PHASE L-N
INSTANTANEOUS	X 1.0	X 0.87	X 1.30
MINIMUM	X 1.0	X 1.80	X 3.20
SUSTAINED	X 1.0	X 1.50	X 2.50
MAX SUSTAINED DURATION	10 SEC	5 SEC	2 SEC

ALL OTHER TIMES ARE UNCHANGED

IEEE Std 142-2007 (Green Book)
1.7.1 “Unlike the transformer the three sequence reactances from a generator are not equal. The zero sequence reactance has the lowest value and the positive sequence reactance varies as a function of time. Thus, a generator will usually have a higher initial ground fault current than three phase fault current if the generator has a solidly grounded neutral.”

Single phase faults result in higher levels of fault current

Unbalanced faults stress alternator rotor damper windings

SUSTAINED SHORT CIRCUIT = 16509 Amps

Sustained short circuit current is determined by the AVR and excitation system

Spec Note Under single phase or multiple phase fault conditions, the protective functions calculate the fault energy over time and compares it to the alternator's thermal limits. When the thermal energy limit is exceeded, it shall switch off alternator excitation and shut down generator-set at the appropriate time to prevent damage to the alternator.

Alternator data sheet

Alternator reactances are published using the alternator kVA rating as a base

Fault current calculations need to use the same base or the reactances need to be converted to the genset kW rating base

Engineers will use software packages such as SKM to demonstrate coordination on their projects

-Cummins Power Command control protective relay "**AmpSentry" is included in the latest version of SKM and EasyPower**

Alternator Data Sheet
Frame Size: LVSI804X

Characteristics				
	No of Bearings:	**1-bearing**	**2-bearing**	
Weights:	Stator assembly:	N/A	10141 lb	4600 kg
	Rotor assembly:	N/A	6060 lb	2749 kg
	Complete assembly:	N/A	17954 lb	8144 kg
Maximum speed:		2250 rpm		
Excitation current:	Full load:	3.94 Amps		
	No load:	0.88 Amps		
Insulation system:	Class H throughout			

3 Ø Ratings (0.8 power factor)			**60 Hz** (winding no)			
			416 (12)	440 (12)	480 (12)	600 (07)
163° C rise ratings	@ 27° C	kW	3680	3592	3920	3920
		kVA	4600	4490	4900	4900
150° C rise ratings	@ 40° C	kW	3304	3496	3816	3816
		kVA	4130	4370	4770	4770
125° C rise ratings	@ 40° C	kW	3096	3272	3571	3571
		kVA	3870	4090	4464	4464
105° C rise ratings	@ 40° C	kW	2892	3056	3338	3338
		kVA	3615	3820	4172	4172
80° C rise ratings	@ 40° C	kW	2512	2640	2900	2900
		kVA	3140	3300	3625	3625
3 Ø Reactances (Based on full load at 125° C rise rating)			416 (12)	440 (12)	480 (12)	600 (07)
Synchronous			2.655	2.508	2.300	2.000
Transient			0.186	0.176	0.161	0.148
Subtransient			0.137	0.130	0.119	0.108
Negative sequence			0.197	0.186	0.171	0.156
Zero sequence			0.027	0.025	0.023	0.021

Concept Check

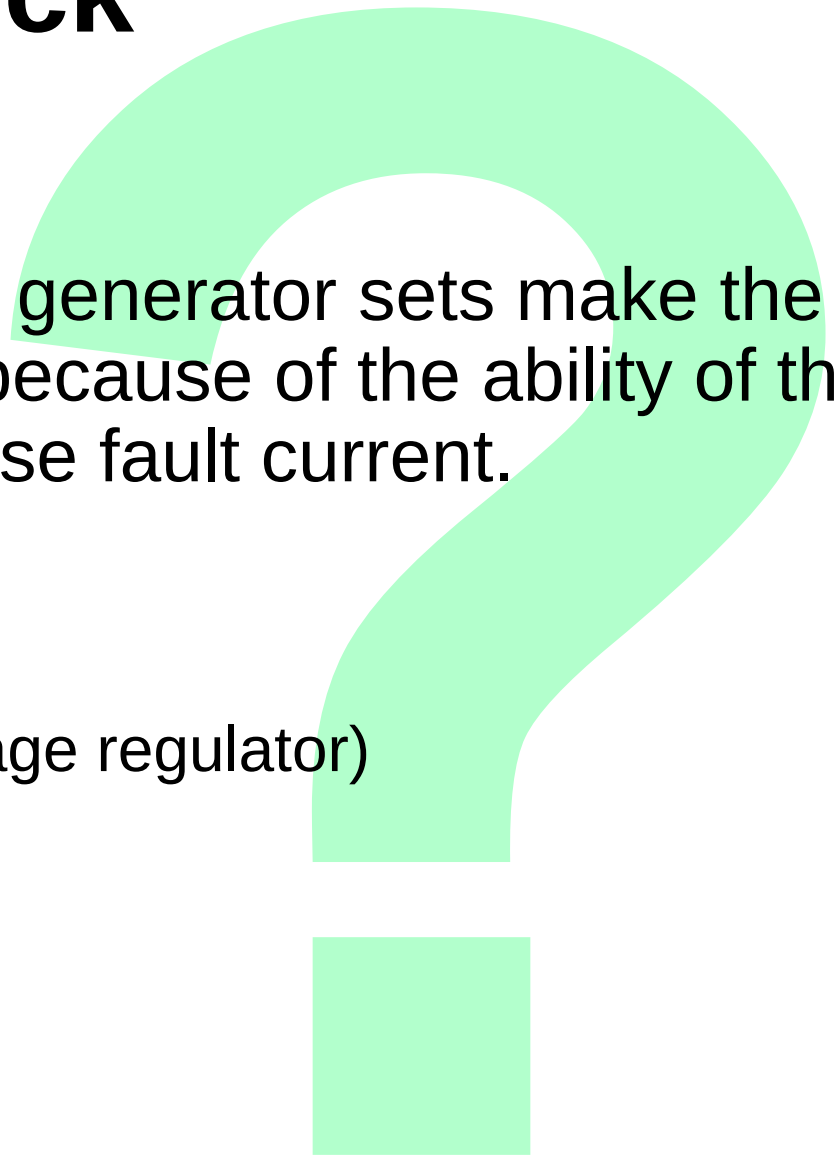
_____ excited generator sets make the task of selective coordination simpler because of the ability of the excitation system to sustain a three phase fault current.

a) Shunt (self)

b) PMG (Separately)

c) AVR (Automatic voltage regulator)

d) DC



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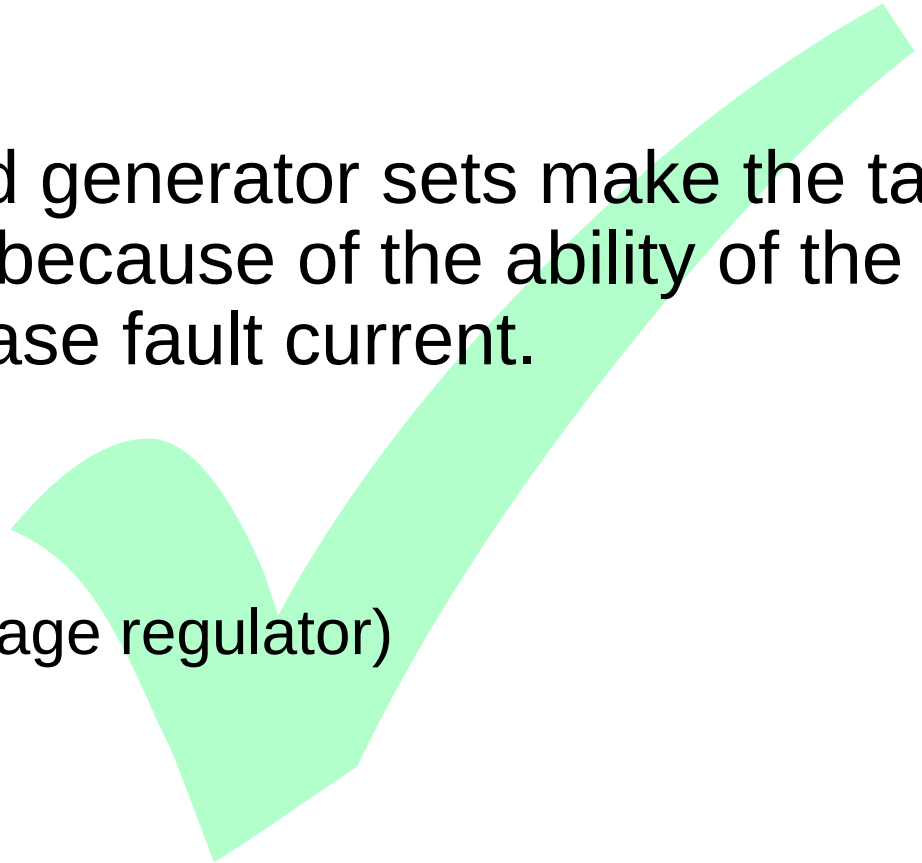


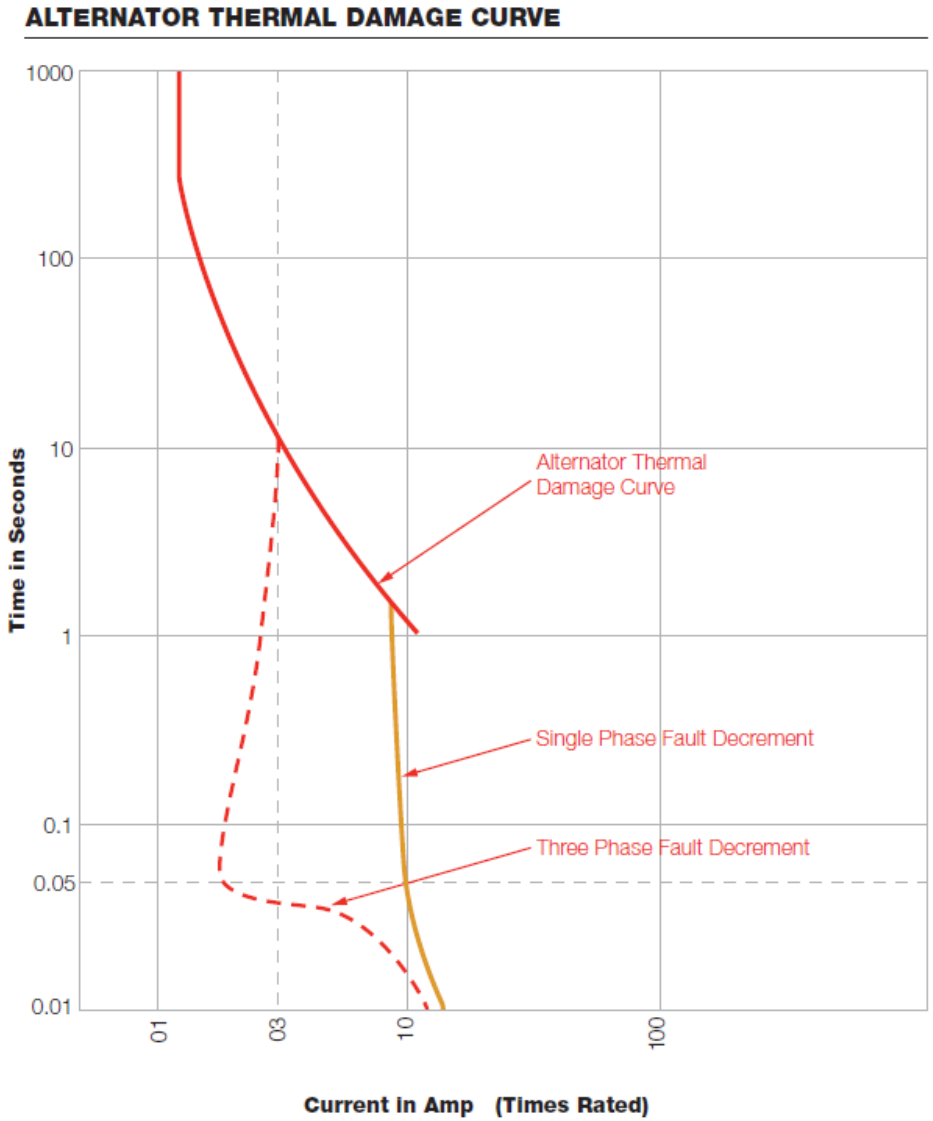
Generator Set Response to a Fault

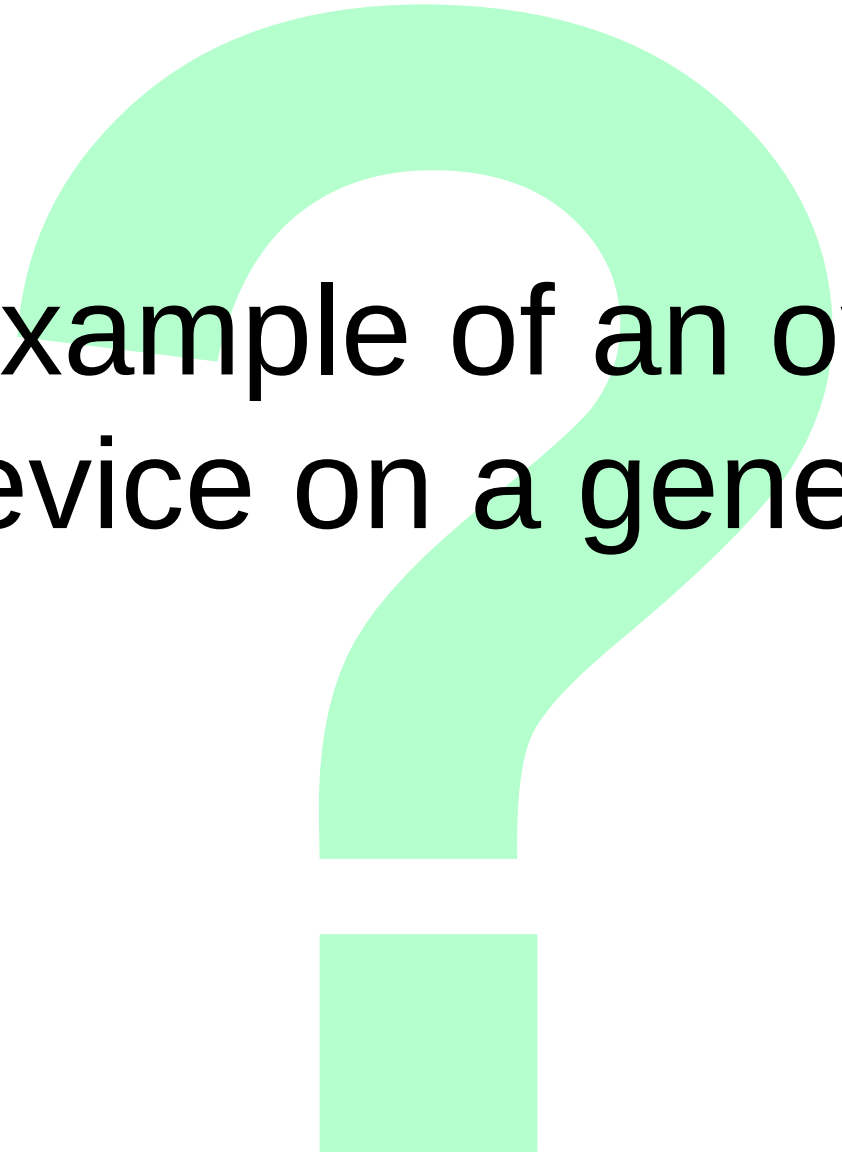
3-Phase fault (conventional AVR)

- Volts collapse, amps peak
- Amps collapse
- AVR on full
- Approximately 3X rated

1-Phase fault (conventional AVR)

- Volts collapse on faulted phase, amps peak
- AVR on full
- Amps don’t collapse on faulted phase
- Genset results in a higher level of fault current
- High volts on non-fault phases





What is an example of an overcurrent protection device on a generator set?

Generator Set Response to a Fault

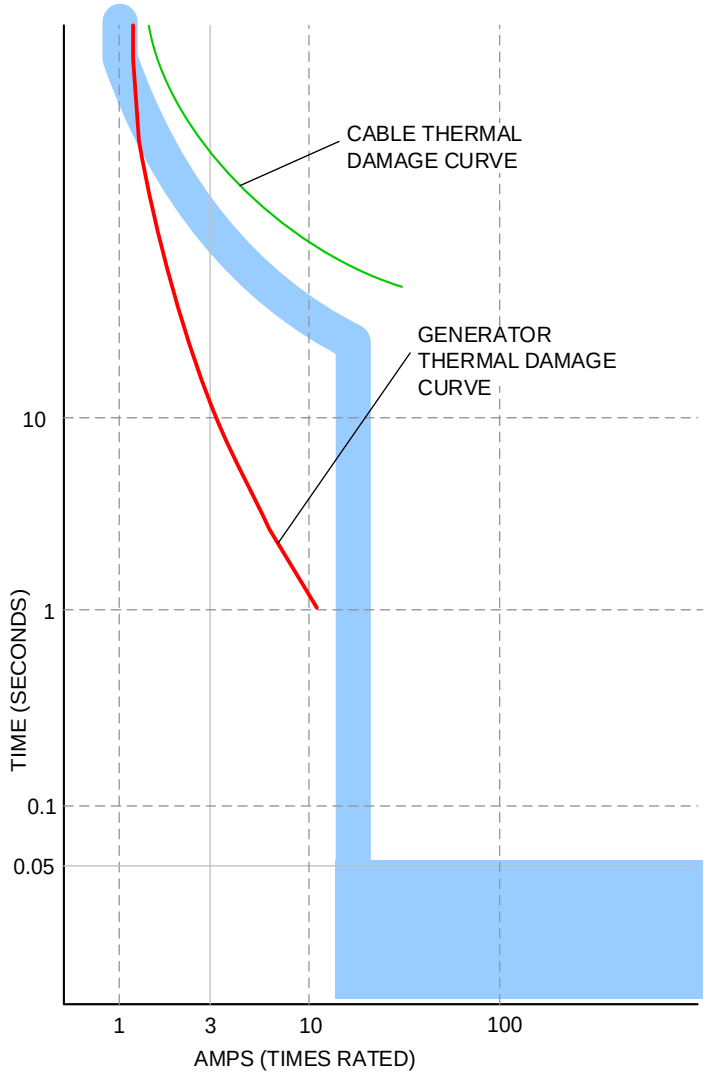
With Overcurrent Protection

Code Requirement (NFPA 70 (2017) 445.12(A))

“Constant-voltage generators, except ac generator exciters, shall be protected from overload by inherent design, circuit breakers, fuses, protective relays, or other identified overcurrent protective means suitable for the conditions of use”.

Concerns raised:

- Common practice using fully rated molded case breaker(s) with thermal/magnetic trip may not protect generator
- Molded case circuit breaker with fully adjustable electronic trip unit or other UL listed protective device may be needed to protect generator as required

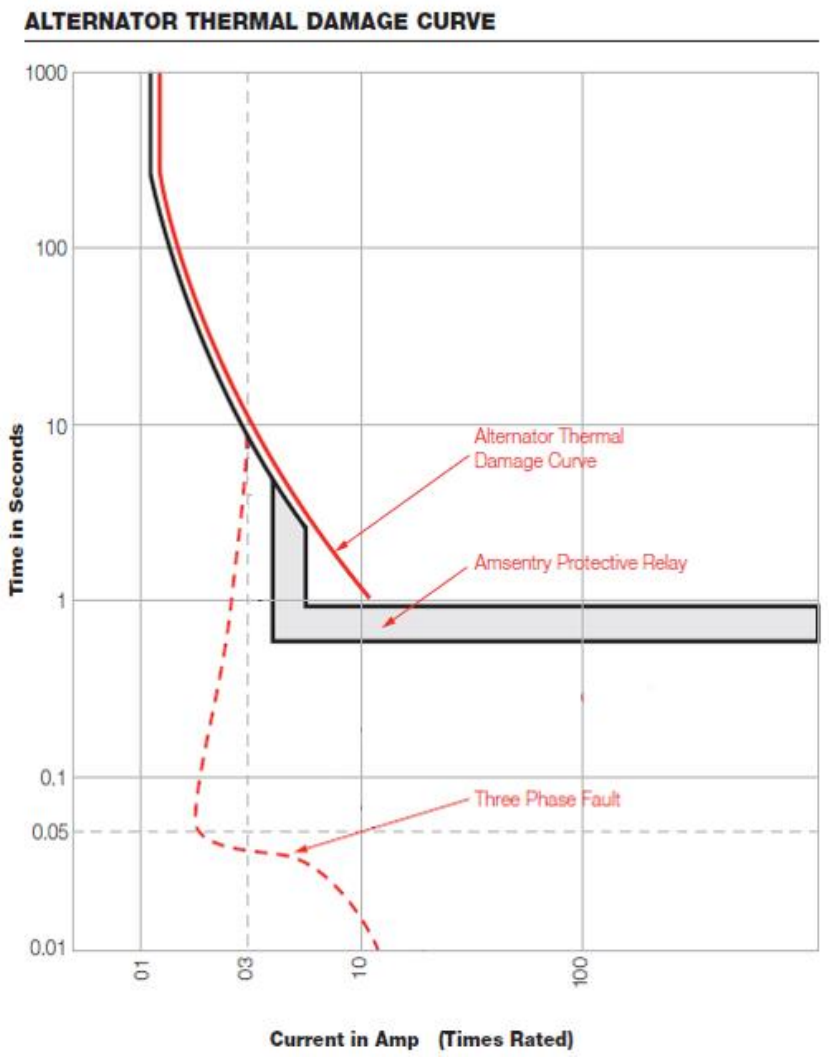


Fault Current Characteristics

With Inherent Overcurrent Protection Relay

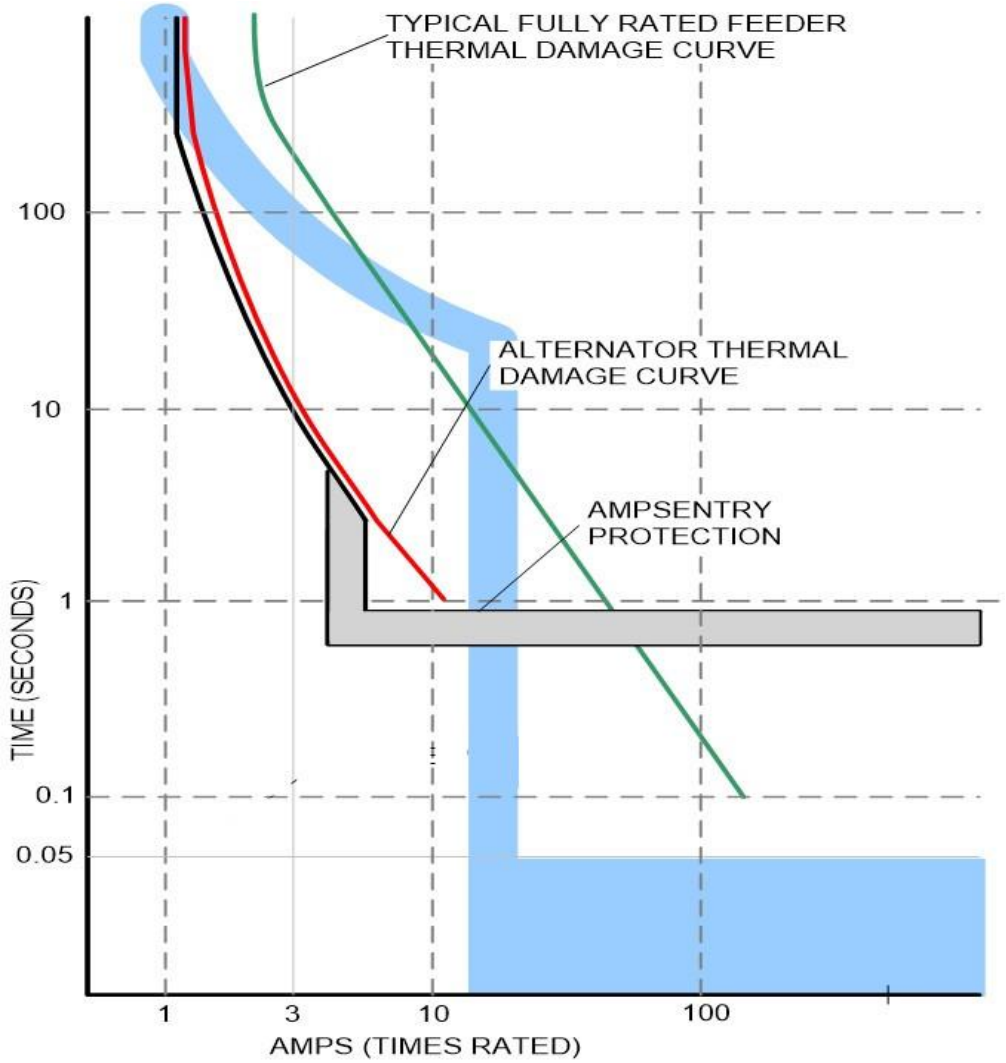
Provided by most generator set manufacturers (based on generator set model and configuration)

- Example of inherent generator set overcurrent protective relay:
  - Cummins Power Command Controls (PCC) "**AmpSentry"**
    -PCC regulates fault current in order to simplify selective coordination.
    -Fault current is regulated until downstream Over Current Protective device (OCPD) clears fault.
    -Current regulation instead of voltage means controls does not increase excitation and no over voltage on single phase fault.



Generator Set Response to a Fault

With Inherent Overcurrent Protection



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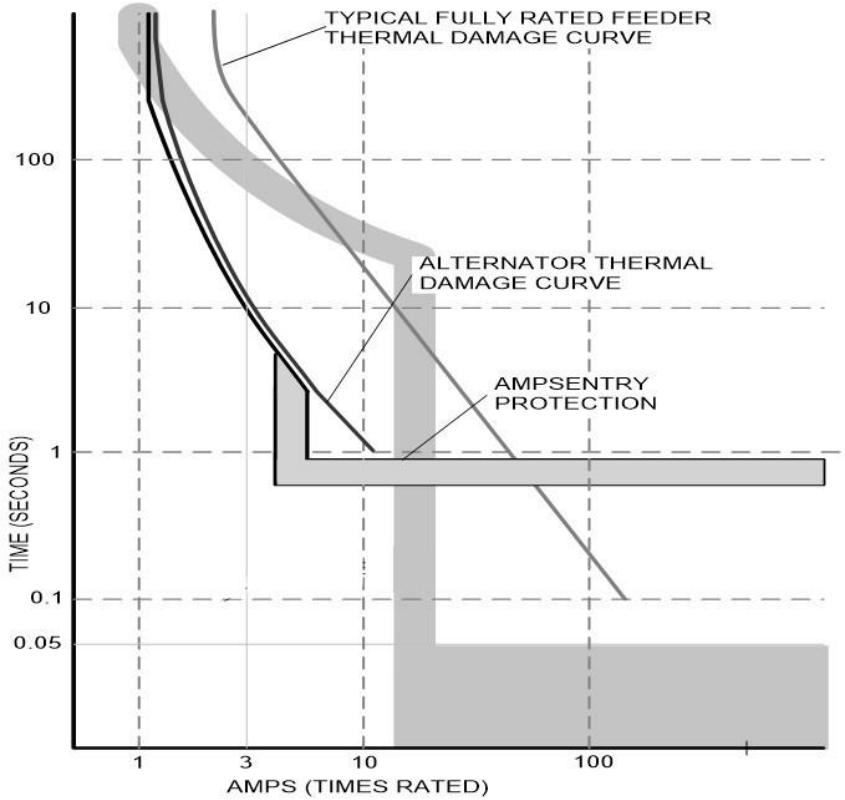
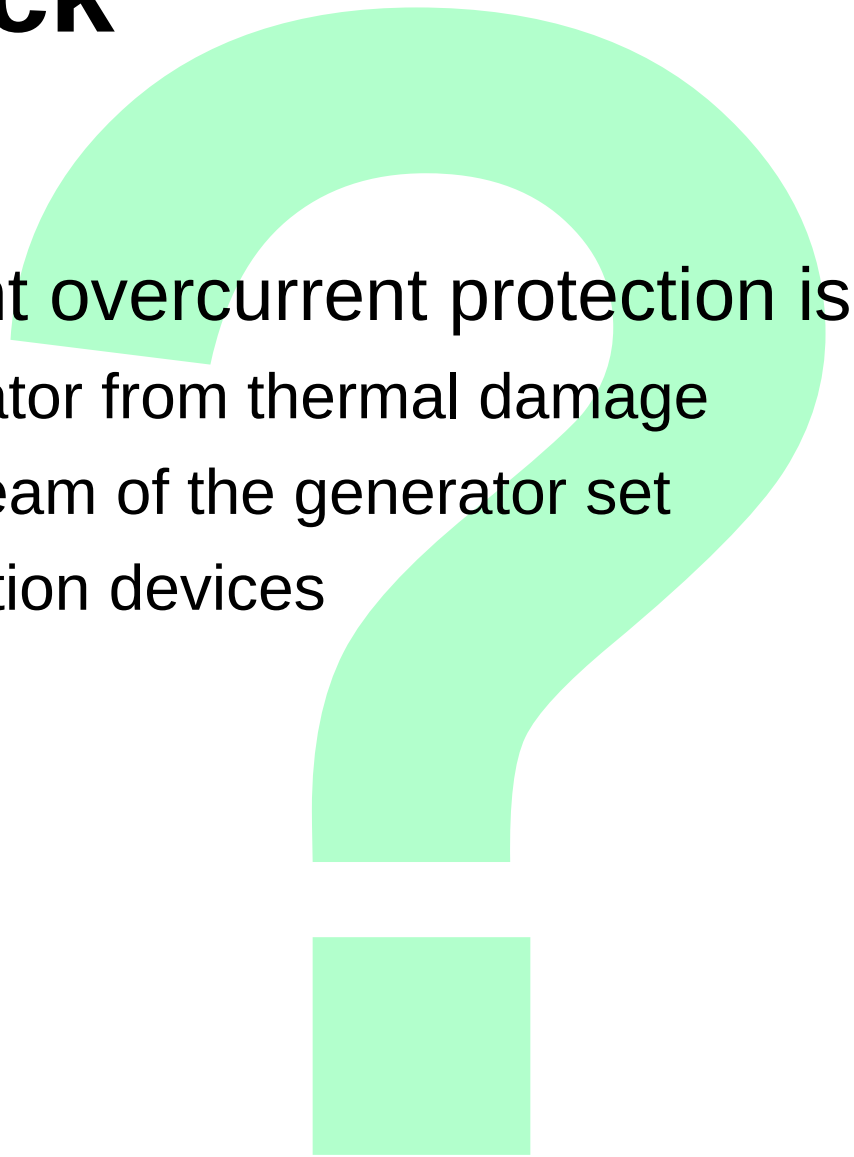


Spec Note The generator set shall be provided with an overcurrent protective device that is coordinated with the alternator to prevent damage on any possible overload or overcurrent condition external to the machine. The protective device shall be listed as a utility grade protective device under UL category NRGU. The control system shall be subject to UL follow-up service at the manufacturing location to verify that the protective system is fully operational as manufactured.

Concept check

Generator set inherent overcurrent protection is capable to protect

a) Generator set alternator from thermal damage
b) Conductors downstream of the generator set
c) Downstream distribution devices
d) All of the above



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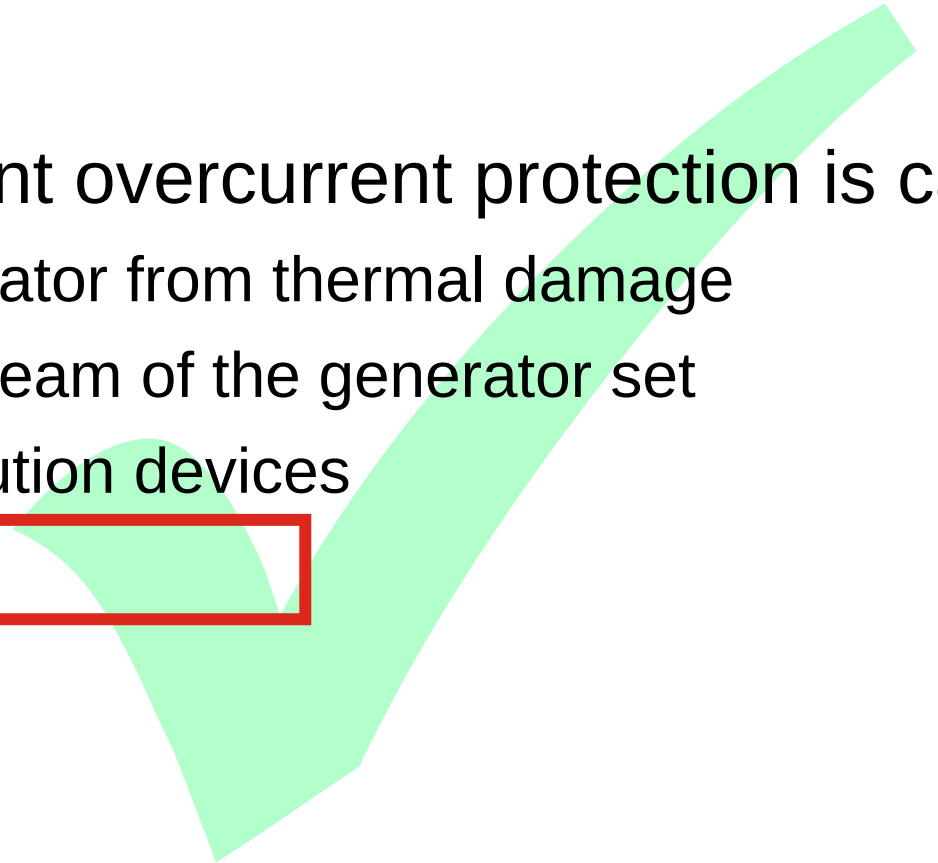

NEC (2017) Requirements

Overload protection of generator and conductors (Article 445.12 and 445.13)

Selective coordination (Articles 700.32 & 701.27 & 708.54)

Arc Energy Reduction (Article 240.87)

Disconnecting Means for Generators (Article 445.18)

Separation of Emergency Circuits (Article 700.10)

Overload protection of generator set and conductors

240.21(G) Conductors from generator terminals. Conductors from generator terminals that meet the size requirements in 445.13 shall be permitted to be protected against overload by the generator overload protective device(s) required by 445.12.

445.12 Constant voltage generators: Constant-voltage generators, except ac generator exciters, shall be protected from overload by inherent design, circuit breakers, fuses, protective relays, or other identified overcurrent protective means suitable for the conditions of use.

445.13 Ampacity of conductors (A) general. The ampacity of the conductors from the generator output terminals to the first distribution device(s) containing overcurrent protection shall not be less than 115 percent of the nameplate current rating of the generator. It shall be permitted to size the neutral conductors in accordance with 220.61. Conductors that must carry ground-fault currents shall not be smaller than required by 250.30(A). Neutral conductors of dc generators that must carry ground-fault currents shall not be smaller than the minimum required size of the largest conductor.

Exception: Where the design and operation of the generator prevent overloading, the ampacity of the conductors shall not be less than 100% of the nameplate current rating of the generator.

Selective coordination

Selective coordination. Localization of an overcurrent condition to restrict outages to the circuit or equipment affected, accomplished by the selection and installation of overcurrent protective devices and their ratings or settings for the full range of available overcurrents, from overload to the maximum available fault current, and for the full range of overcurrent protective device opening times associated with those overcurrents.

700.32 Selective coordination. Emergency system(s) overcurrent devices shall be selectively coordinated with all supply-side overcurrent protective devices.

701.27 Selective coordination. Legally required standby system(s) overcurrent devise shall be selectively coordinated with all supply-side overcurrent protective devices.

708.54 Selective coordination. Critical operations power system(s) overcurrent devices shall be selectively coordinated with all supply-side overcurrent protective devices.

Arc energy reduction 240.87

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

(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 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 mitigation system

(5) An instantaneous trip setting that is less than the available arcing current

(6) An instantaneous override that is less than the available arcing current

(7) An approved equivalent means

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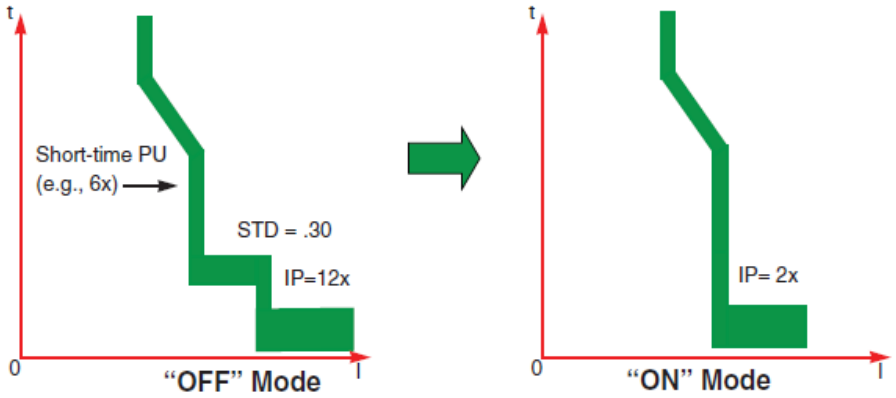
Arc Energy Reduction 240.87

Energy reduction maintenance setting (ERMS)



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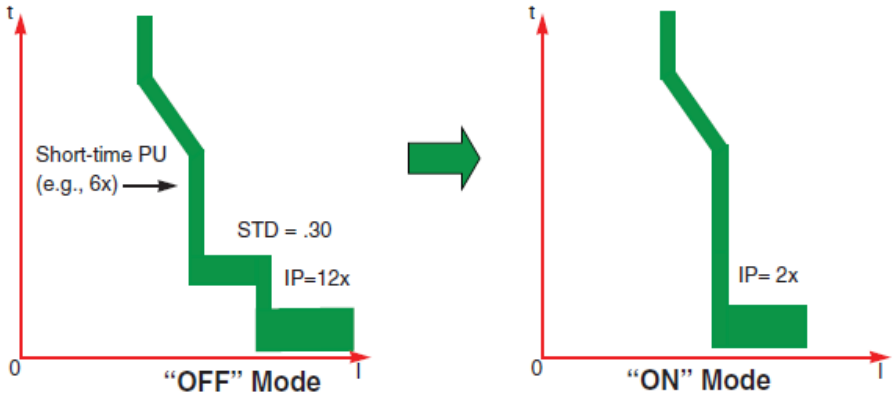
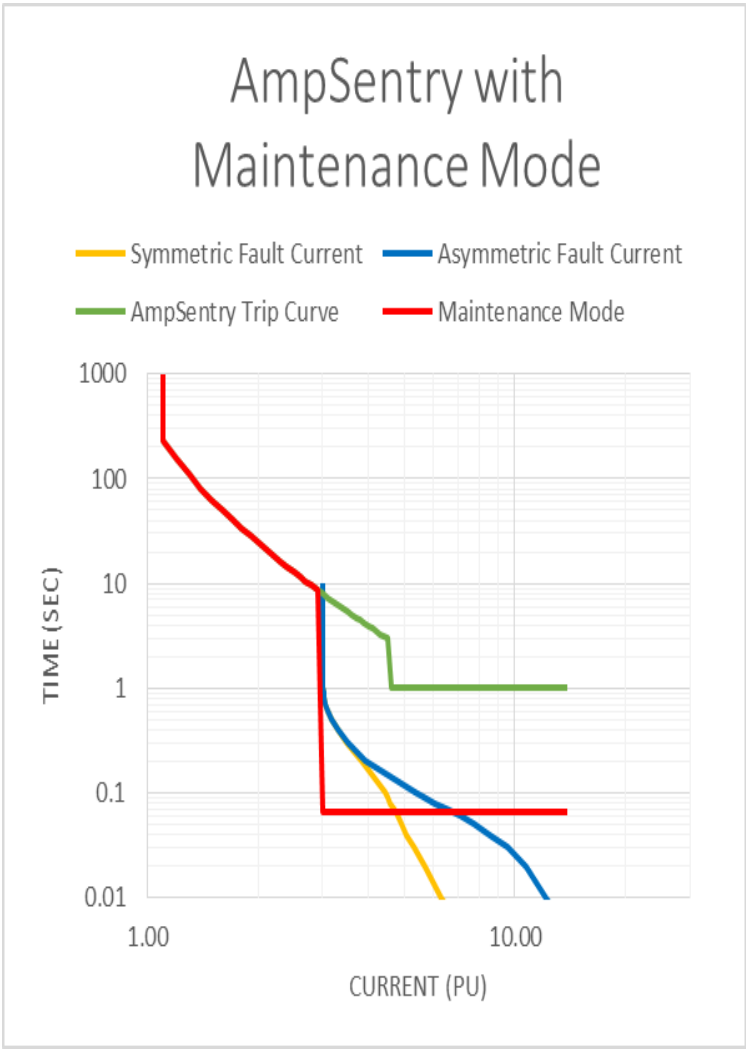




Spec Note The protective system provided shall not include an instantaneous trip function unless the system is operating in arc flash reducing maintenance mode per NEC 240.87 (2017)

Concept check

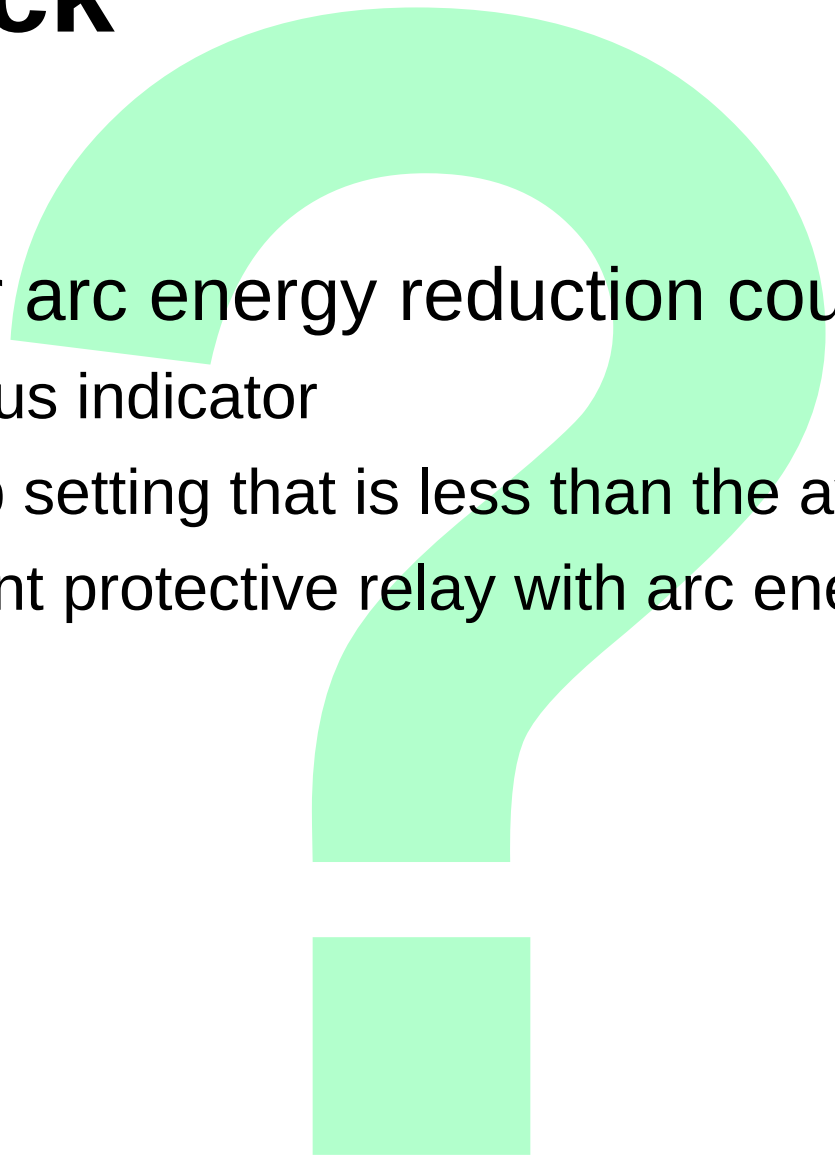
NEC requirements for arc energy reduction could be met with

a) ERMS with local status indicator

b) An instantaneous trip setting that is less than the available arcing current

c) Generator set inherent protective relay with arc energy reduction functionality.

d) All of the above



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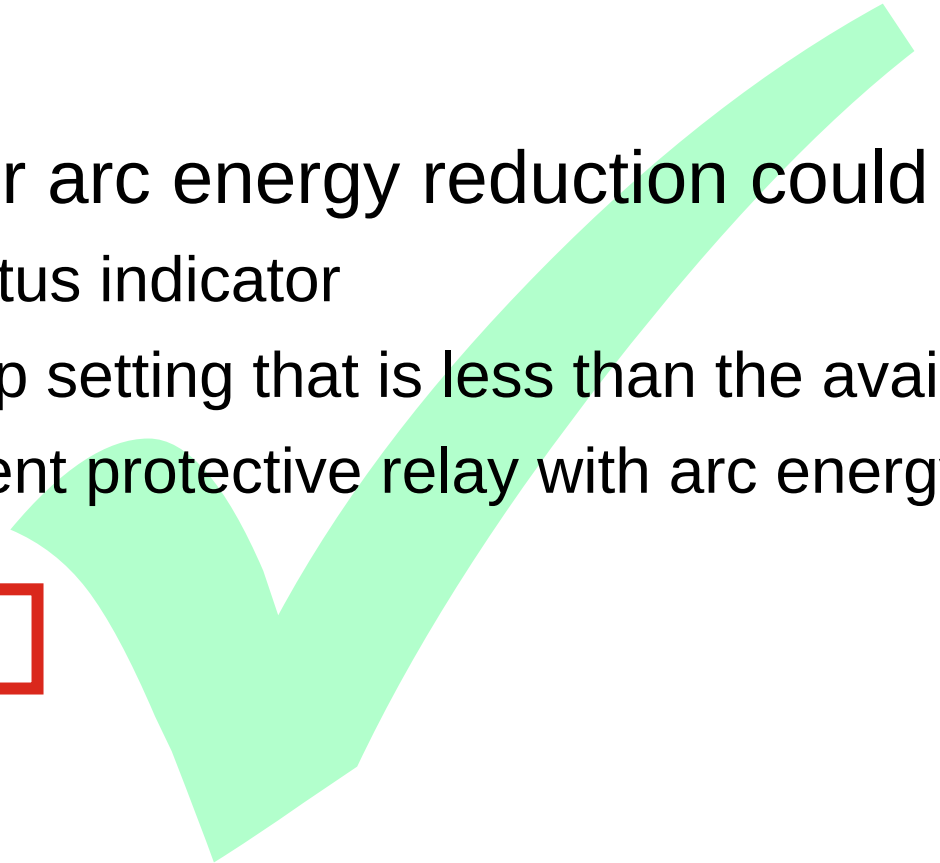

Disconnecting means and shutdown of prime mover 445.18

(A) Disconnecting means. Generators other than cord-and-plug-connected portable shall have one or more disconnecting means. Each disconnecting means shall simultaneously open all associated ungrounded conductors. Each disconnecting means shall be lockable in the open position in accordance with 110.25.

(B) Shutdown of prime mover. Generator shall have provisions to shut down the prime mover. The means of shutdown shall comply with all of the following:

(1) Be equipped with provisions to disable all prime mover start control circuits to render the prime mover incapable of starting.

(2) Initiate a shutdown mechanism that requires a mechanical reset.

The provisions to shut down the prime mover shall be permitted to satisfy the requirements of 445.18(A) where it is capable of being locked in the open position in accordance with 110.25.

Generators with greater than 15 kW rating shall be provided with an additional requirement to shut down the prime mover. This additional shutdown means shall be located outside the equipment room or generator enclosure and shall also meet the requirements of 445.18(B)(1) and (B)(2).

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Lock out tag out

NFPA 70E requires that equipment must be disconnected from all sources of electrical supply

- Neither the e-stop switch or a genset mounted breaker is sufficient to meet LOTO requirements

Genset has two sources of electrical supply

- Battery + charging system
- Utility or paralleled genset

LOTO procedure should include

- Removing and locking out battery cable
- Locking out breaker that feeds charging system
- Locking out paralleling breaker that connects utility or paralleled genset

Disconnecting means and shutdown of prime mover 445.18

E-stop switch with lockable shroud

Disconnect starter battery and lockout

Spec Note Emergency stop switch shall be a red “mushroom head” pushbutton device complete with lock-out/tag-out provisions. Depressing switch shall cause the generator set to immediately stop the generator set and prevent it from operating.

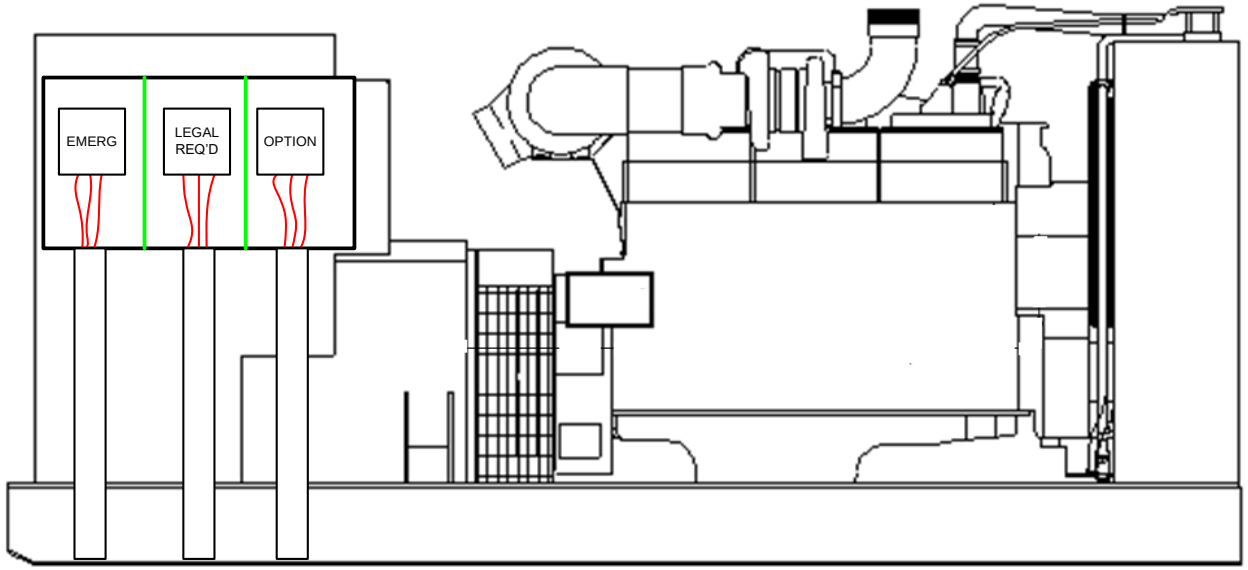
Separation of emergency circuits

NFPA70-2017 700.10 (B)(5)(c):

Emergency circuits shall not originate from the same vertical switchgear section, vertical switchboard section, panelboard enclosure or individual disconnect enclosure as other circuits

Could meet the requirement with individual enclosures for each breaker

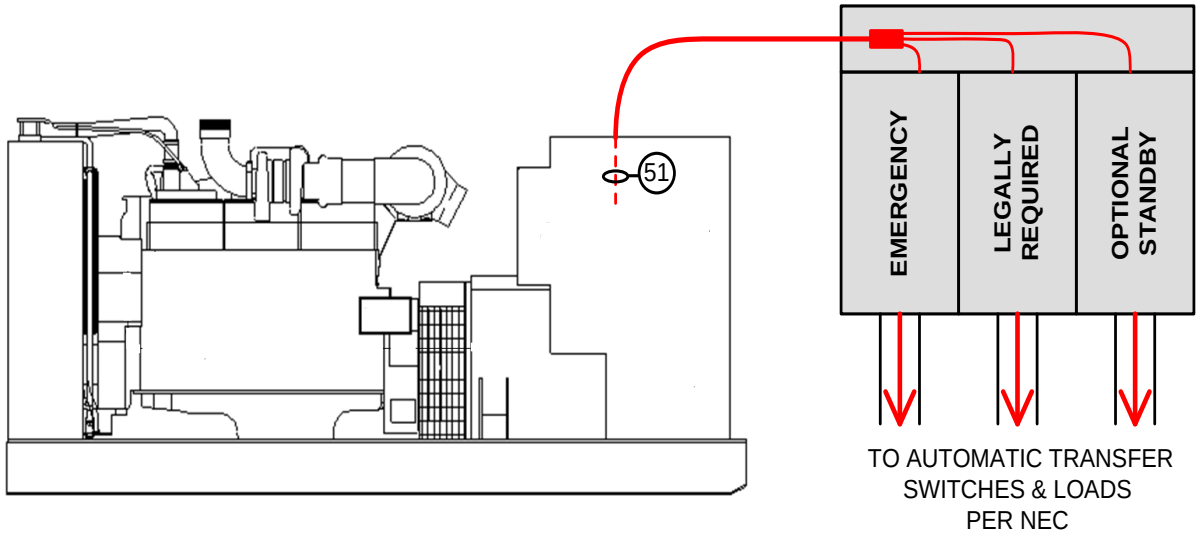
- Selective coordination requires breaker selection as a *system*



Separation of emergency Circuits

NFPA70-2017 700.10 (B)(5)(d):

It shall be permissible to utilize single or multiple feeders to supply distribution equipment between an emergency source and the point where the combination of emergency loads are separated from all other loads



Course Summary

Generator Set Overcurrent Protection

- Define generator excitation systems and their effect on fault current performance.
- Identify basic generator set overcurrent protection requirements in order to specify the correct protection equipment.
- Describe the NEC requirements for selective coordination, generator disconnect, arc flash energy reduction and separation of circuits in order to evaluate different means for achieving code compliance.
- Identify recent important codes changes to NFPA70, NEC 2017 and impact on Generator set protection

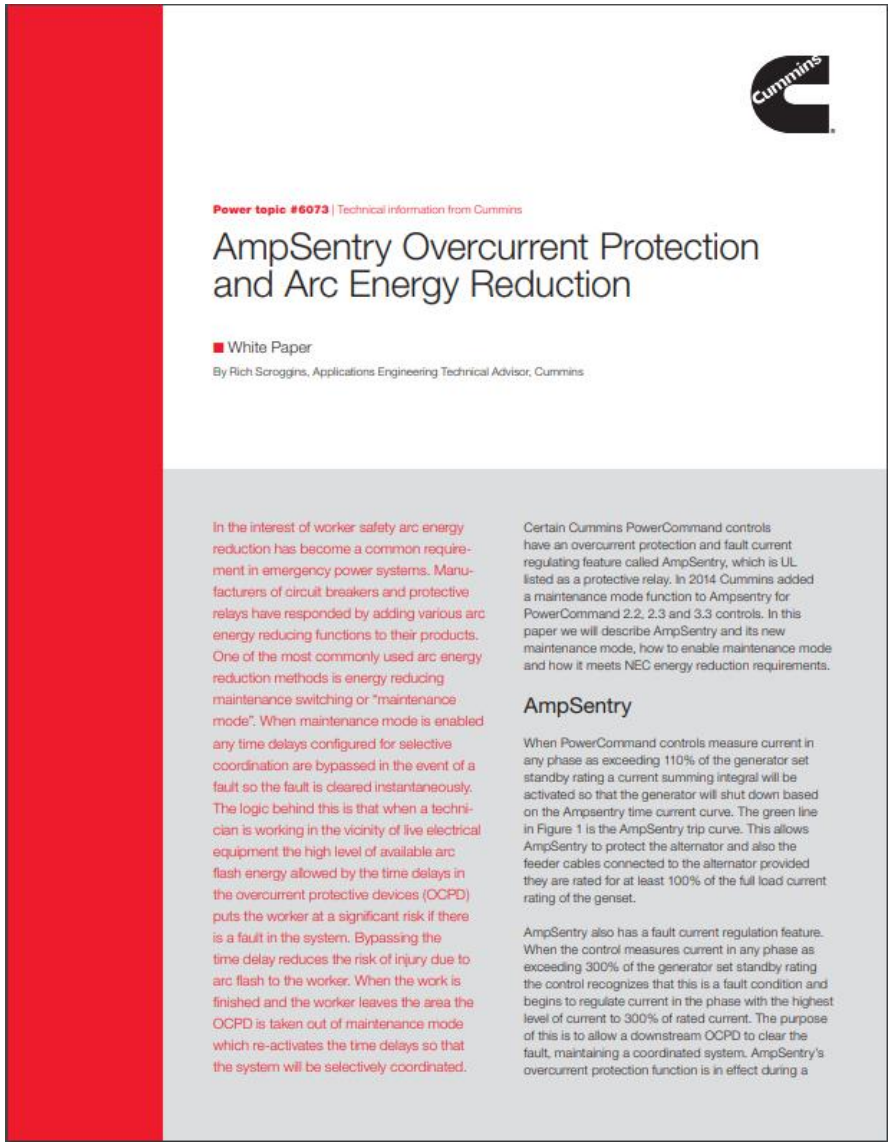
Consider

- Generator set mounted thermal magnetic breakers may not protect the generator set and could be difficult to coordinate with downstream devices.
- Generator set inherent overcurrent protection, when listed and labeled appropriately, is suitable for generator set overcurrent protection.
- Generator set emergency stop with lock out and battery/charging system with lock out satisfy NEC disconnect requirements.
- Arc energy reduction strategies may be included in the generator set control eliminating the need for an external device.
- Based on this, typical equipment provided might be:
  -Molded case circuit breaker with solid state trips
  -Inherent Overcurrent protection such as **AmpSentry** which is an UL listed overcurrent protective relay integral to cummins generator.

Additional Resources

Cummins White Papers

- A Comparison of Generator Excitation Systems
- Alternator Protection
- Generator Protection And Disconnect Requirements
- AmpSentry Overcurrent Protection and Arc Energy Reduction
- Selective Coordination Standards and Design Challenges
- Short Circuit and Arc Flash Evaluations using AmpSentry Capability



Power topic #6073 | Technical information from Cummins

AmpSentry Overcurrent Protection and Arc Energy Reduction

White Paper

By Rich Scroggins, Applications Engineering Technical Advisor, Cummins

In the interest of worker safety arc energy reduction has become a common requirement in emergency power systems. Manufacturers of circuit breakers and protective relays have responded by adding various arc energy reducing functions to their products. One of the most commonly used arc energy reduction methods is energy reducing maintenance switching or "maintenance mode". When maintenance mode is enabled any time delays configured for selective coordination are bypassed in the event of a fault so the fault is cleared instantaneously. The logic behind this is that when a technician is working in the vicinity of live electrical equipment the high level of available arc flash energy allowed by the time delays in the overcurrent protective devices (OCPD) puts the worker at a significant risk if there is a fault in the system. Bypassing the time delay reduces the risk of injury due to arc flash to the worker. When the work is finished and the worker leaves the area the OCPD is taken out of maintenance mode which re-activates the time delays so that the system will be selectively coordinated.

Certain Cummins PowerCommand controls have an overcurrent protection and fault current regulating feature called AmpSentry, which is UL listed as a protective relay. In 2014 Cummins added a maintenance mode function to Ampsentry for PowerCommand 2.2, 2.3 and 3.3 controls. In this paper we will describe AmpSentry and its new maintenance mode, how to enable maintenance mode and how it meets NEC energy reduction requirements.

AmpSentry

When PowerCommand controls measure current in any phase as exceeding 110% of the generator set standby rating a current summing integral will be activated so that the generator will shut down based on the Ampsentry time current curve. The green line in Figure 1 is the AmpSentry trip curve. This allows AmpSentry to protect the alternator and also the feeder cables connected to the alternator provided they are rated for at least 100% of the full load current rating of the genset.

AmpSentry also has a fault current regulation feature. When the control measures current in any phase as exceeding 300% of the generator set standby rating the control recognizes that this is a fault condition and begins to regulate current in the phase with the highest level of current to 300% of rated current. The purpose of this is to allow a downstream OCPD to clear the fault, maintaining a coordinated system. AmpSentry's overcurrent protection function is in effect during a

Q&A

Type your questions, comments, feedback in the **WebEx Q&A box**. We will get to as many questions as we can

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