Generator Set Overcurrent Protection Options

PowerHour webinar series for consulting engineers

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Nov 12 - 2:00 Eastern Time / 11:00 Pacific Time
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Cummins instructors:

Obinna Igwe
Senior Product Application Engineer
Cummins Inc.

Rich Scroggins
Technical Advisor – Data Center Market Team
Cummins Inc.

Makesi Sule
Senior Product Application Engineer
Cummins Inc.

Cummins facilitator:

Mark Taylor
Technical Marketing Specialist
Cummins Inc.

Your local Cummins contacts:

- AZ, ID, NM, NV: Carl Knapp (carl.knapp@cummins.com)
- CO, MT, ND, UT, WY: Christopher Scott (christopher.l.scott@cummins.com)
- CA, WA, OR, AK, HI: Brian Pumphrey (brian.pumphrey@cummins.com)
- MA, ME, NH, RI, VT: Jim Howard (james.howard@cummins.com)
- CT, MD, NJ, NY : Charles Attisani (charles.attisani@cummins.com)
- Northern IL, MI : John Kilinskis (john.a.kilinskis@cummins.com)
- NE, SD, KS: Earnest Glaser (earnest.a.glaser@cummins.com)
- IL, IN, KY, MO: Jeff Yates (jeffrey.yates@cummins.com)
- IA, MO: Kirby Holden (kirby.holden@cummins.com)
- DE, MD, MN, ND, OH, PA, WI, WV: Michael Munson (michael.s.munson@cummins.com)
- TX: Scott Thomas (m.scott.thomas@cummins.com)
- OK, AR: Wes Ruebman (wes.ruebman@cummins.com)
- LA, MS, AL: Trina Casbon (trina.casbon@cummins.com)
- TN, GA: Mariano Rojas (mariano.rojas@cummins.com)
- FL: Bob Kelly (robert.kelly@cummins.com)
- NC, SC, VA: Bill Morris (william.morris@cummins.com)
- Canada: Ian Lindquist (ian.lindquist@cummins.com)

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Course Objectives

Generator Set Overcurrent Protection Options

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.

Agenda

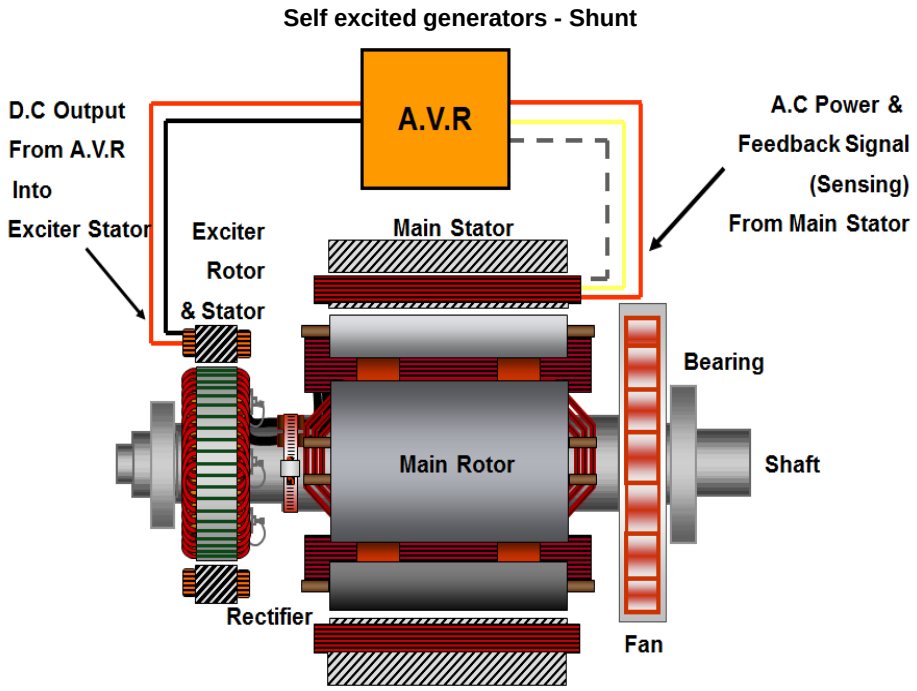
Generator performance under overcurrent conditions

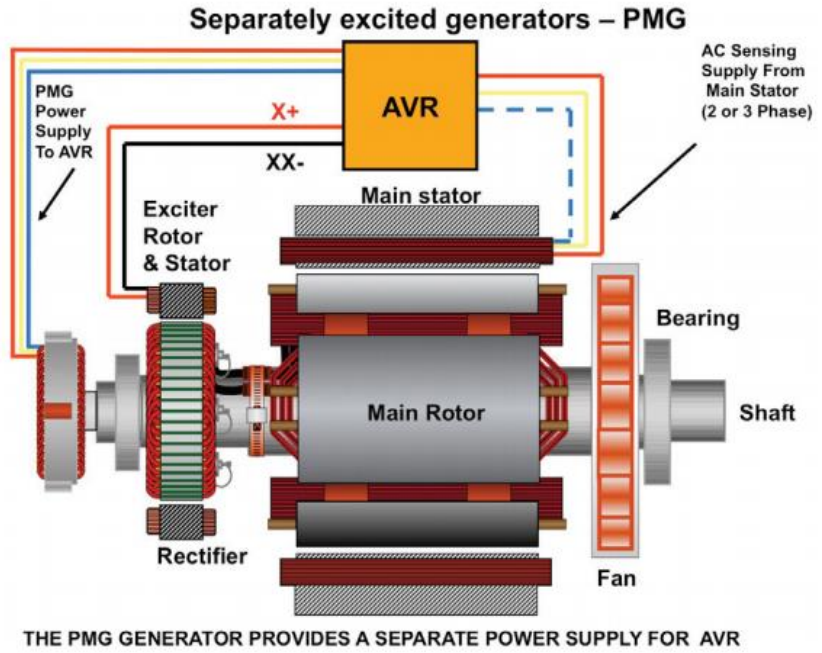
- Review of generator excitation systems
- Alternator Decrement Curves
- PowerCommand AmpSentry functionality

Describe NEC requirements for

- Overload Protection
- Selective coordination
- Arc Energy Reduction
- Generator disconnect requirements
- Separation of circuits requirements

Generator Excitation Systems



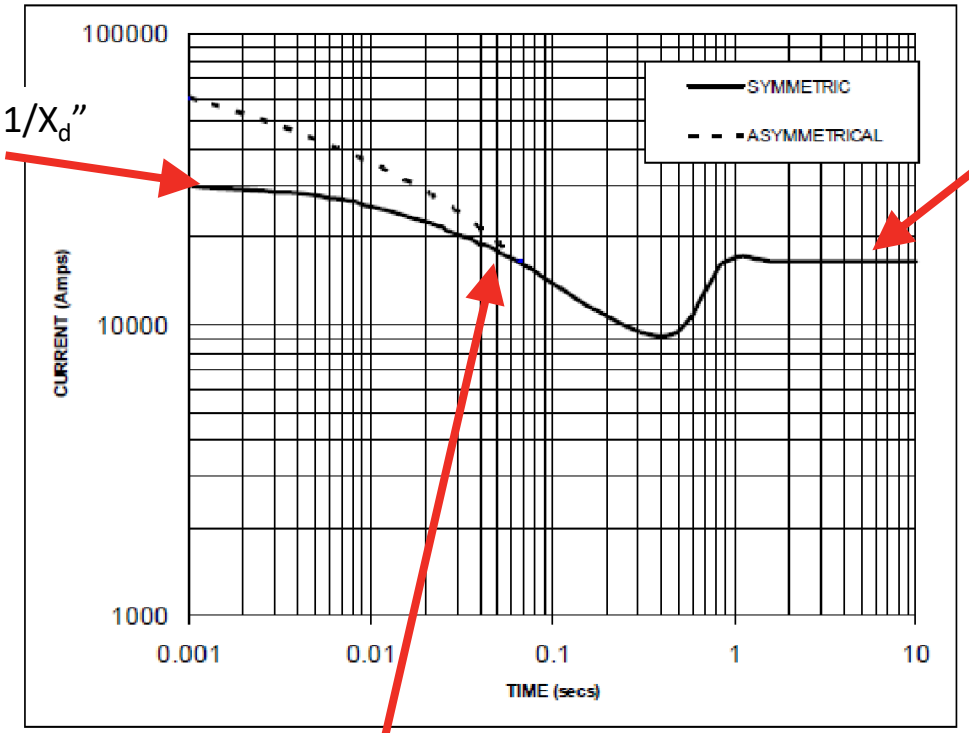


<u>Key Point:</u>
AVR may not have the capability to support the fault current long enough to clear downstream faults as the main field in the alternator may collapse.

<u>Key Point:</u>
Ability to provide sustained short circuit current during fault conditions which prevent the field from collapsing and allows for faults downstream to clear

Alternator Performance Under a Fault - Decrement Curve (Separately Excited)

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



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

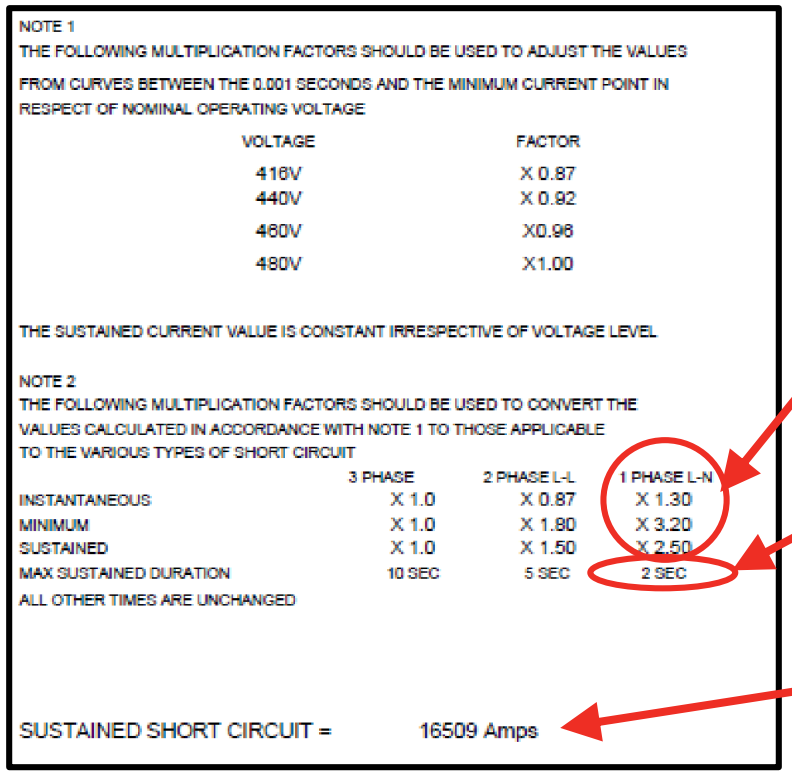
Key points:

- Alternator fault current decays, not constant like fault current from a transformer
- Conventional AVRs *increase* excitation in response to fault

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

Three phase fault characteristics

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

SUSTAINED SHORT CIRCUIT = 16509 Amps

Single phase faults result in higher levels of fault current

Unbalanced faults stress alternator rotor damper windings

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

Instantaneous Fault Current

$I_{3ph,\ p.u} = 1/X_d"$

$I_{SLG,\ p.u} = 3/(X_d" + X_2 + X_0 + 3R_f)$

$I_{LL,\ p.u} = 1.732/(X_d" + X_2)$

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.”

Per Unit Reactances

- 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

$$\frac{X_{alt}}{X_{genset}} = \frac{kVA_{alt}}{kVA_{genset}}$$

- AmpSentry uses the genset standby kVA rating as a base

Example:
Generator Set: 2500kW DQKAN,
Alternator LVSI804X, 60Hz, 480V

Generator Set kVA = 3125
Alternator kVA = 4464

$X''d_{genset}$ = 0.119/4464*3125 = 0.083

Power Generation

ALTERNATOR DATA SHEET **Frame Size LVSI804X**

CHARACTERISTICS	**No of Bearings**	2	
WEIGHTS:	Stator Assembly:	10120 lb	4600 kg
	Rotor Assembly:	6032 lb	2742 kg
	Complete Assembly:	16152 lb	7342 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) (Based on specific temperature rise at 40°C ambient temperature)		**60 Hz Voltage** (winding no) 440 (12)	480 (12)	600 (07)
163°C Rise Ratings @27°C	kW	3592	3920	3920
	kVA	4490	4900	4900
150°C Rise Ratings	kW	3496	3816	3816
	kVA	4370	4770	4770
125°C Rise Ratings	kW	3272	3571	3571
	kVA	4090	4464	4464
105°C Rise Ratings	kW	3056	3338	3338
	kVA	3820	4172	4172
80°C Rise Ratings	kW	2640	2900	2900
	kVA	3300	3625	3625
REACTANCES (per unit ± 30%) (Based on full load at 125°C Rise Rating)		440 (12)	480 (12)	600 (07)
Synchronous		2.508	2.300	2.000
Transient		0.176	0.161	0.148
Subtransient		0.130	0.119	0.108
Negative Sequence		0.186	0.171	0.156
Zero Sequence		0.025	0.023	0.021

Concept Check

Generator Set: DQKAN → 60Hz, 480V, Rated kVA = 3125

Alternator: LVSI804X → 60Hz, 480V, Rated kVA = 4464

$X''d_{alternator\_p.u} = 0.119 \rightarrow I_{3ph,\ alternator\_p.u} = 1/0.119 = 8.40$

$X''d_{genset\_p.u} = 0.083 \rightarrow I_{3ph,\ genset\_p.u} = 1/0.083 = 12.04$

$$I_{3ph,\ amps} = I_{3ph,\ p.u} \times I_{rated}$$

Which subtransient should be used to calculate actual fault current in Amps ($I_{3ph,\ amps}$)?

a) X”d alternator

b) X”d genset

c) Either one

Concept Check

Generator Set: DQKAN → 60Hz, 480V, Rated kVA = 3125

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c) Either one

Typical Genset Response to a Fault

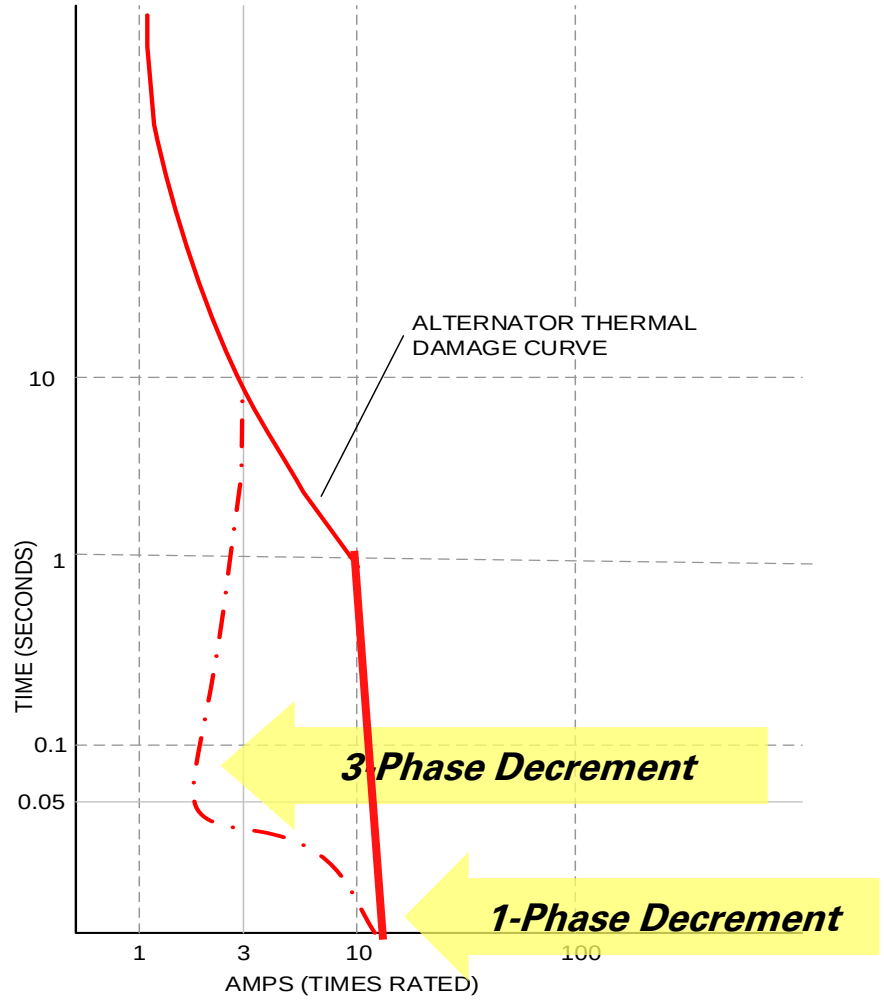
3-Phase Fault (conventional AVR)

- 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
- High volts on non-fault phases

1-Phase fault in Genset results in a higher level of fault current because it takes less excitation to maintain a single phase fault



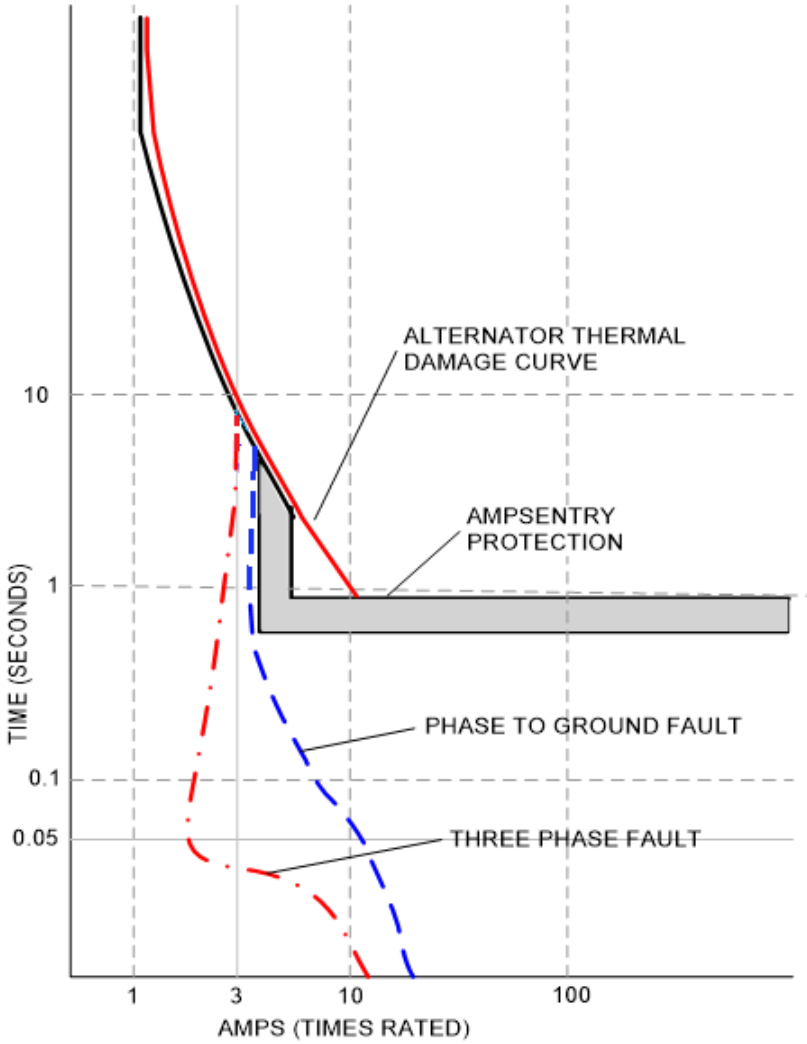
Fault Current Characteristics with AmpSentry

Instead of maximizing excitation, fault current is regulated

- Amps peak on faulted Phase
- Voltage on faulted phase collapses
- Excitation is reduced to maintain 3X rated current output
- Overvoltage avoided, coordination maintained

Overcurrent protection

- Shuts down genset down
  - Based on i^2t curve for 3 phase overcurrent
    - Indicative of a locked motor
    - Allows maximum time for coordination
  - In shorter time for LL or LG overcurrent
    - Indicative of a fault condition



AmpSentry and Neutral Grounding Resistors

- Neutral Grounding Resistors are not required to protect generator sets that are equipped with the AmpSentry protective relay
- NGR’s may still be necessary as part of the overall grounding and protection scheme
- AmpSentry will not limit instantaneous ground fault current
- In the event of a L-G fault AmpSentry will regulate current in the faulted phase at 300% of rated current for 2 seconds at which time the generator set will shut down (or until some protective device clears the fault)

NEC 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)

Generator Overload Protection

Code Requirement (NFPA 70 445.12(A))

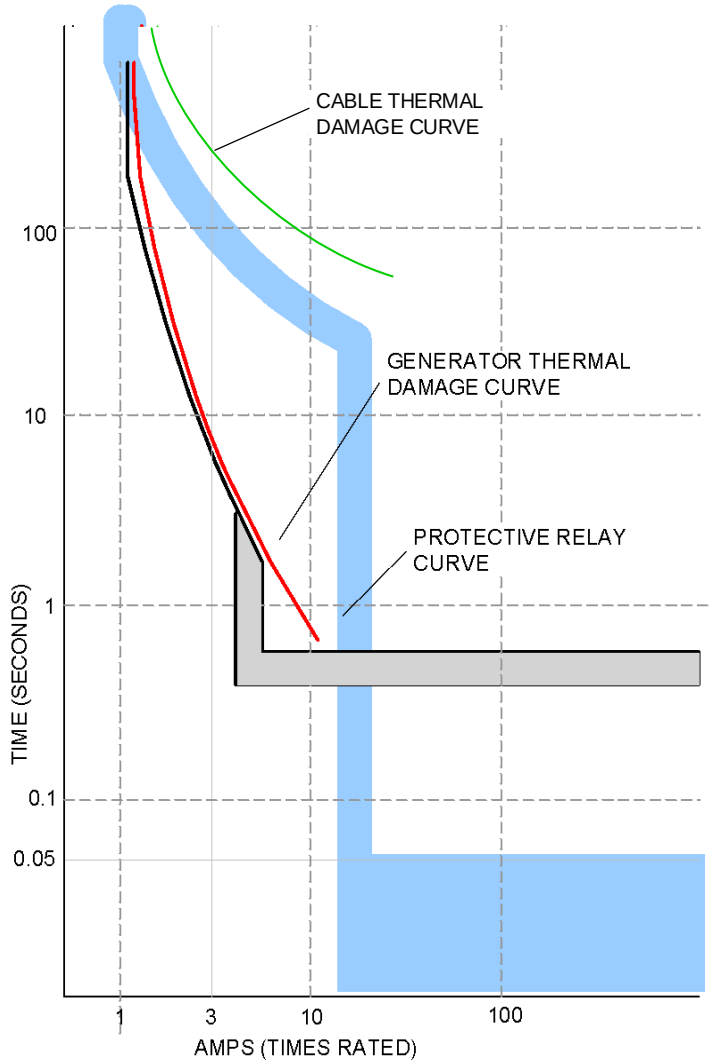
- “Generators, except AC generator exciters, shall be protected from overloads by inherent design, circuit breakers, fuses, protective relays or other identified overcurrent protective means suitable for the conditions of use.”

Generator and cable is required to be protected

- Thermal damage isn’t total failure

Conventional wisdom is not correct

- Most common protection is molded case breaker(s) with thermal/magnetic trip
- Fully rated breakers don’t protect generator
- Need fully adjustable electronic trip on the MCCB or other listed protective device



Any breaker used is susceptible to some level of nuisance trips due to instantaneous function

Cable Overload Protection

- Conductors from generator, if fully rated, are assumed protected by same device (NEC - 240.21(G))

- Article 445.13: The ampacity of the conductors from the generator terminals to the first distribution device(s) containing overcurrent protection shall be not less than 115% of the nameplate current rating of the generator.

- 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.

Concept Check

The alternator thermal damage curve is a useful tool to evaluate if adequate thermal overload protection has been provided for the generator set. In what way?

a) It defines how much current the alternator can accommodate and for how long without thermally damaging the insulation on a log-log curve.

b) It defines how much current will be generated in the event of a fault condition (current available vs. time) on a log-log curve.

Concept Check

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AmpSentry™ UL Label

Power Generation

PowerCommand 3.3
Generator Set Protective
Relay with AmpSentry™
Current Monitoring and Control

c UL US LISTED Industrial Control Equipment 15VV

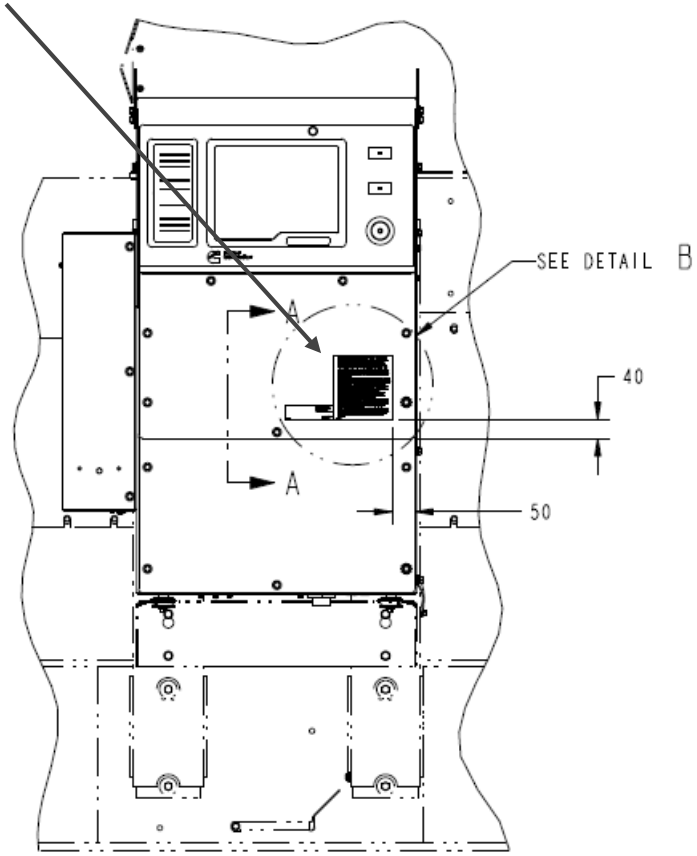
A041U104

PowerCommand Generator Set Protective Relay with AmpSentry™ Current Monitoring and Control

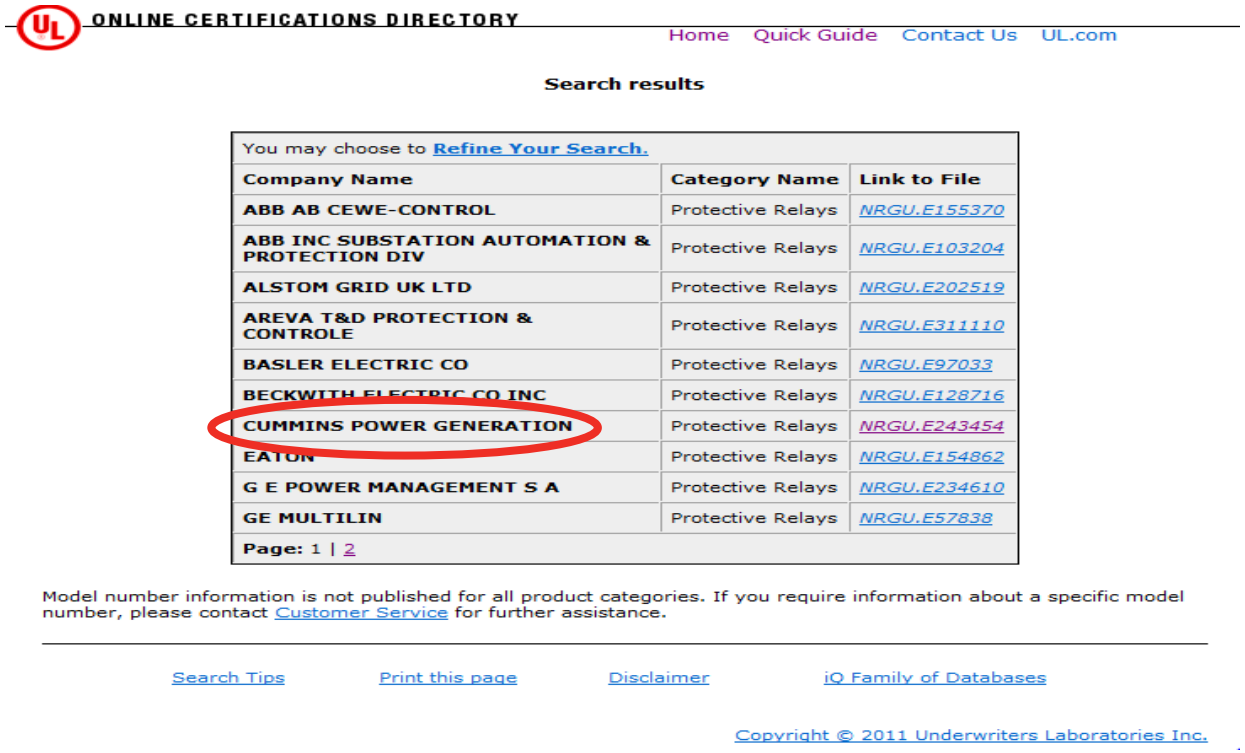
PowerCommand Protective Relay with AmpSentry current monitoring and control provides overload and overcurrent protection of generator and feeder conductors at generator terminals in accordance with the requirements of 2011 NFPA 70: National Electric code®, Articles 240.15(A) , 240.21(G), 445.12(A), 445.13 and Canadian Electrical Co de, part I, C22.1-09, Section 28-902 without the use of an additional protective device.

A disconnect for the generator set is required per 2011 NFPA 70: National Electrical Code®, Articles 225.31, 225.32, and 445.18 and Canadian Electrical Code, Part I, C22.1-09, Section 28-900 unless the driving means for the generator set can be readily shutdown and the generator is not arranged to operate in parallel with another generator or source of voltage. This engine-generator includes an emergency stop switch with lockout/tagout capability that meets this requirement.

PowerCommand Protective Relay with AmpSentry current monitoring and control allows selective coordination of generator with a downstream instantaneous trip overcurrent prot ective device in accordance with the requirements of 2011 NFPA 70: National Electrical Code®,Articles 700.27, 701.27,708.54 and Canadian Electrical Code, Part I, C22.1-09, Section 46-206. Verification of generator set electrical system coordination must be achieved by a coordination study.



Online Certification



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- AmpSentry is UL Listed as a protective relay

http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/index.htm

What is Selective Coordination?

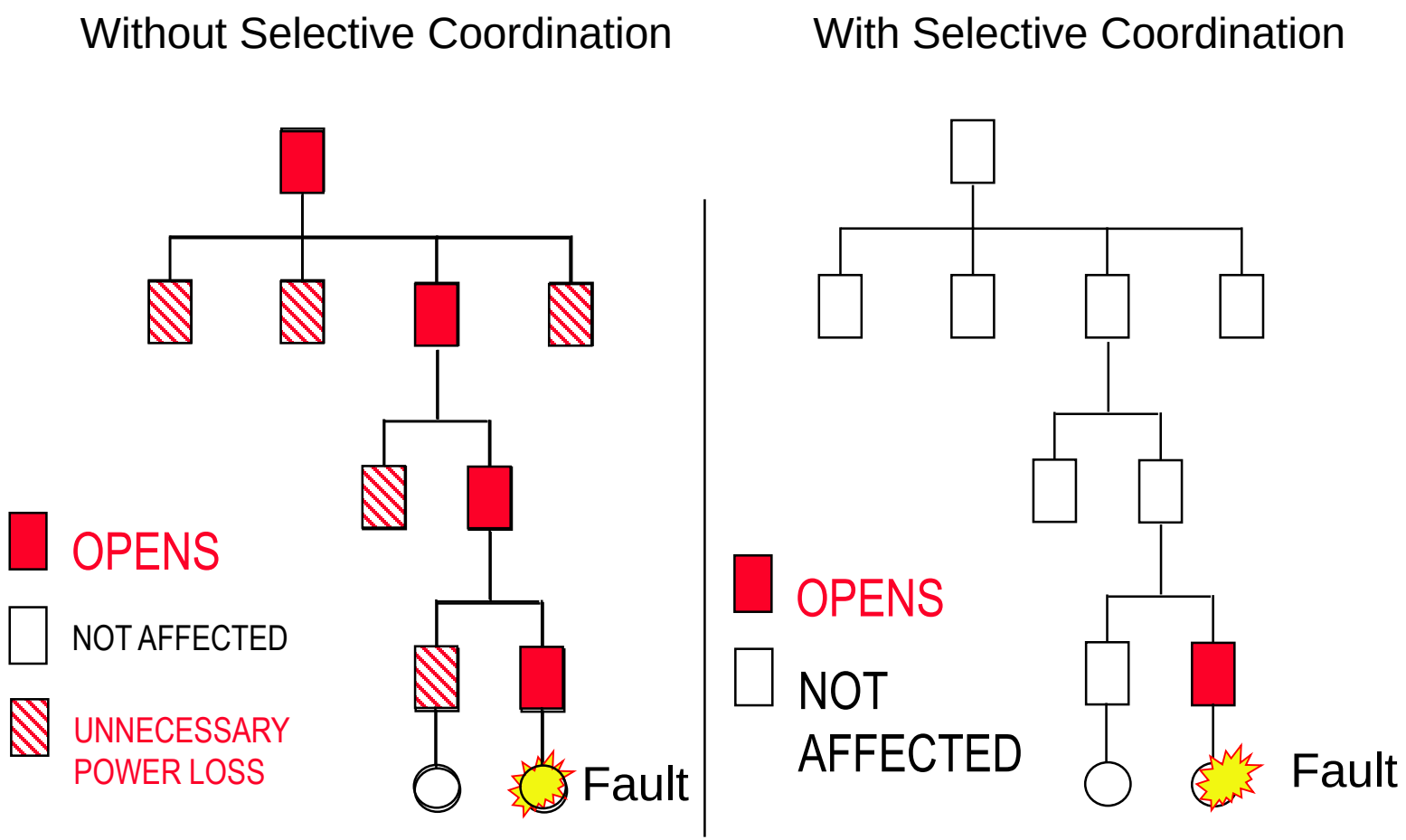
NEC Article 100 Definition

- **Selective Coordination:** Localization of an over-current condition to restrict outages to the circuit or equipment affected, accomplished by the choice of over-current protective devices and their ratings or settings

Selective Coordination is required for emergency, legally required standby and critical operations power systems circuits

- NEC-2017, 700.32, 701.27, and 708.54 "…over-current devices shall be selectively coordinated…"
- Selective coordination required except between transformer primary/secondary and same sized over-current devices in series

Selective Coordination



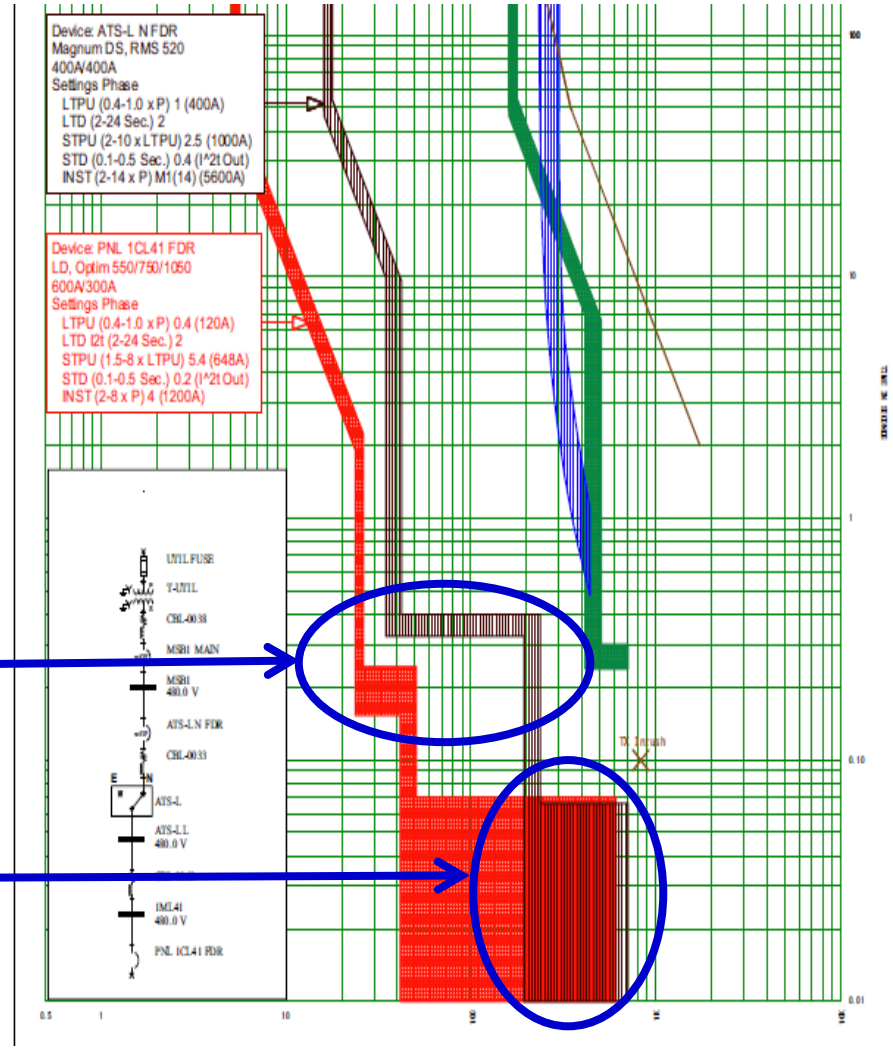
Demonstrating Selective Coordination

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

- AmpSentry is included in the latest version of SKM

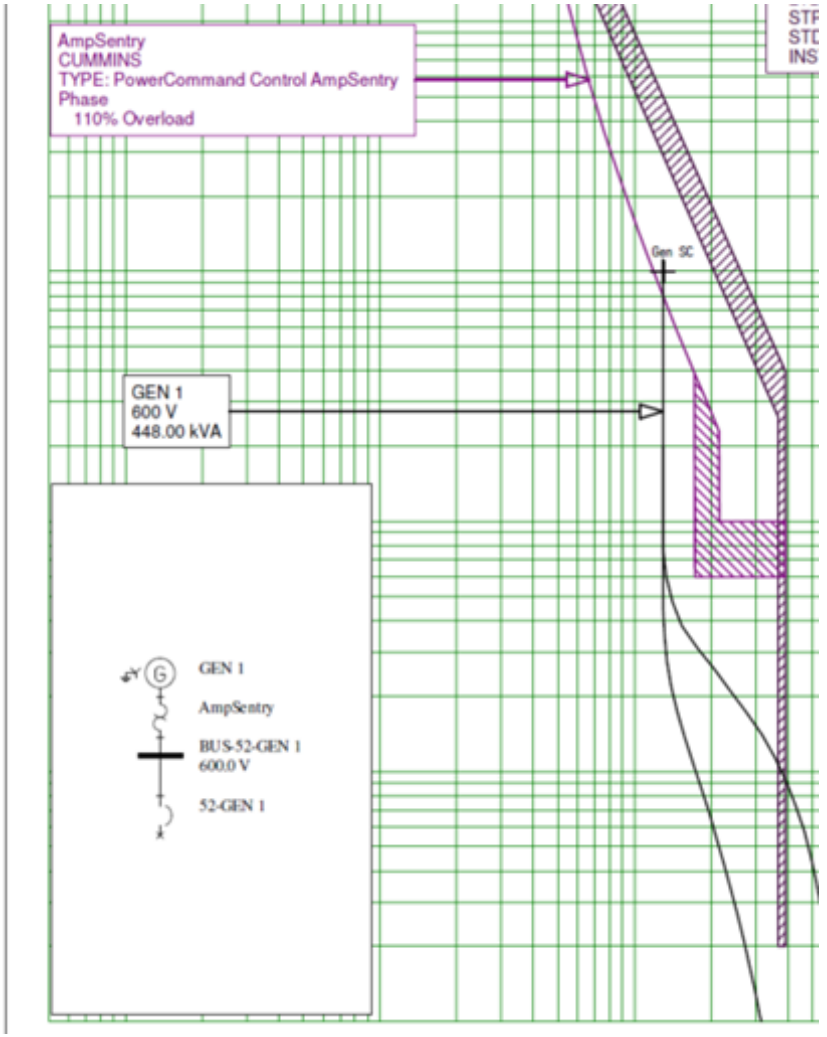
No overlap - breakers are coordinated in this region of the curve

Trip curves overlap – these breakers are not coordinated for high levels of fault current



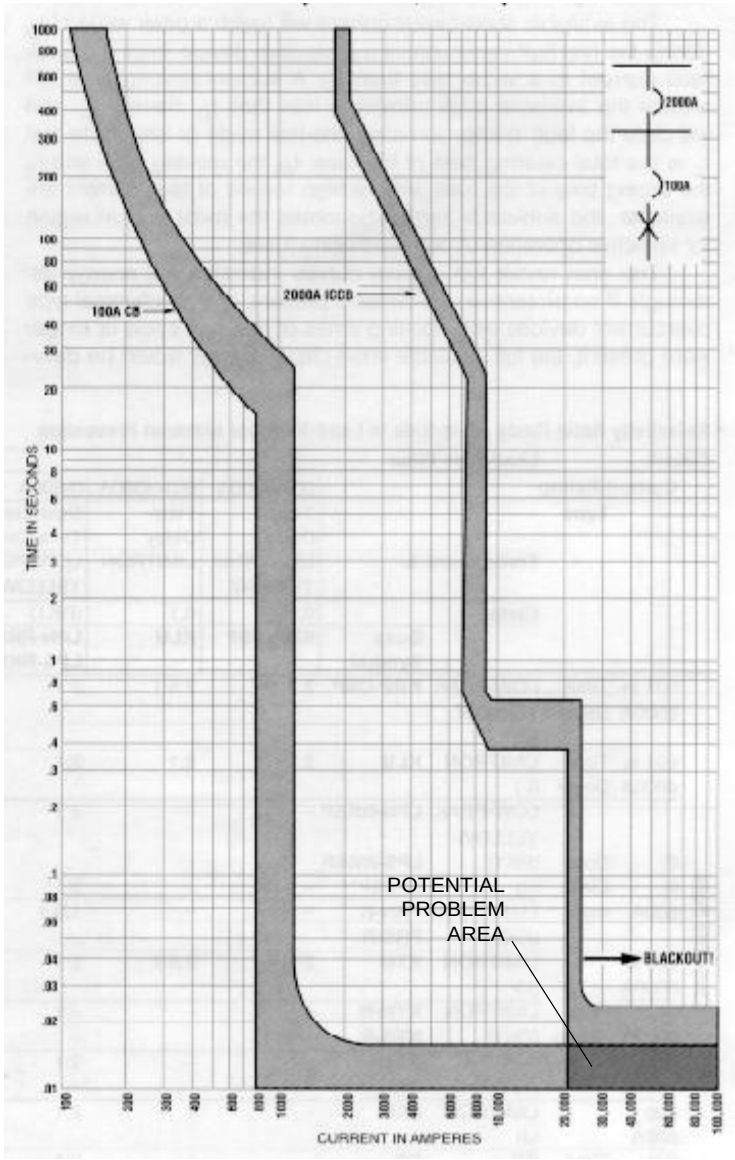
AmpSentry and Selective Coordination

- Amp Sentry simplifies coordination by regulating fault current until the downstream breaker clears
- Genset mounted molded case circuit breaker present challenges in coordinating with downstream breakers
- The inclusion of AmpSentry in SKM software simplifies design of coordinated systems



“Overlap Exception”

- Circuit breaker manufacturers can demonstrate coordination with their own products
- Published coordination charts
- Drives project to use consistent devices through the entire project



NFPA 70 240.87 Arc Energy Reduction

"Where the highest continuous current trip setting is 1200A or higher … one of the following means shall be provided

Seven clearing time reduction means are listed:

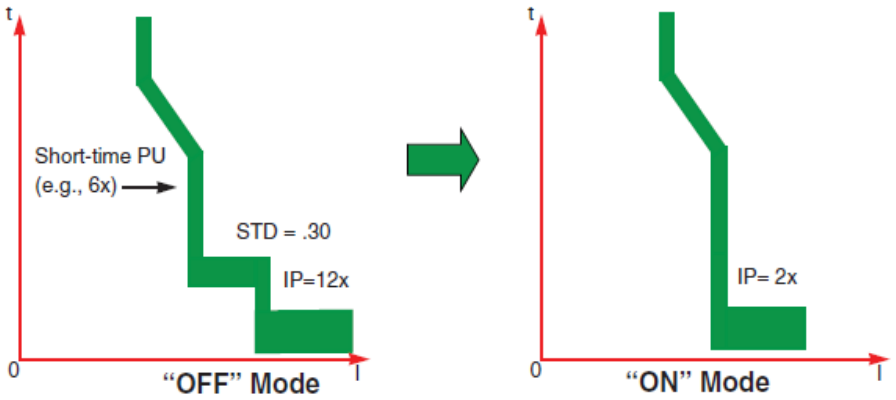
(1) Zone selective interlocking
(2) Differential relaying
(3) Energy-reducing maintenance switching with local status indicator
(4) Energy-reducing active arc flash mitigation system
(5) An instantaneous trip setting that is less than the available arcing current
(6) An instantaneous override that is less than the available arcing current
(7) An approved equivalent means

Allows a worker to set a circuit breaker electronic trip unit or protective relay to operate faster should an arc fault occur while the worker is working within the protected zone

Energy Reducing Maintenance Switching

Energy Reduction Maintenance Setting (ERMS)

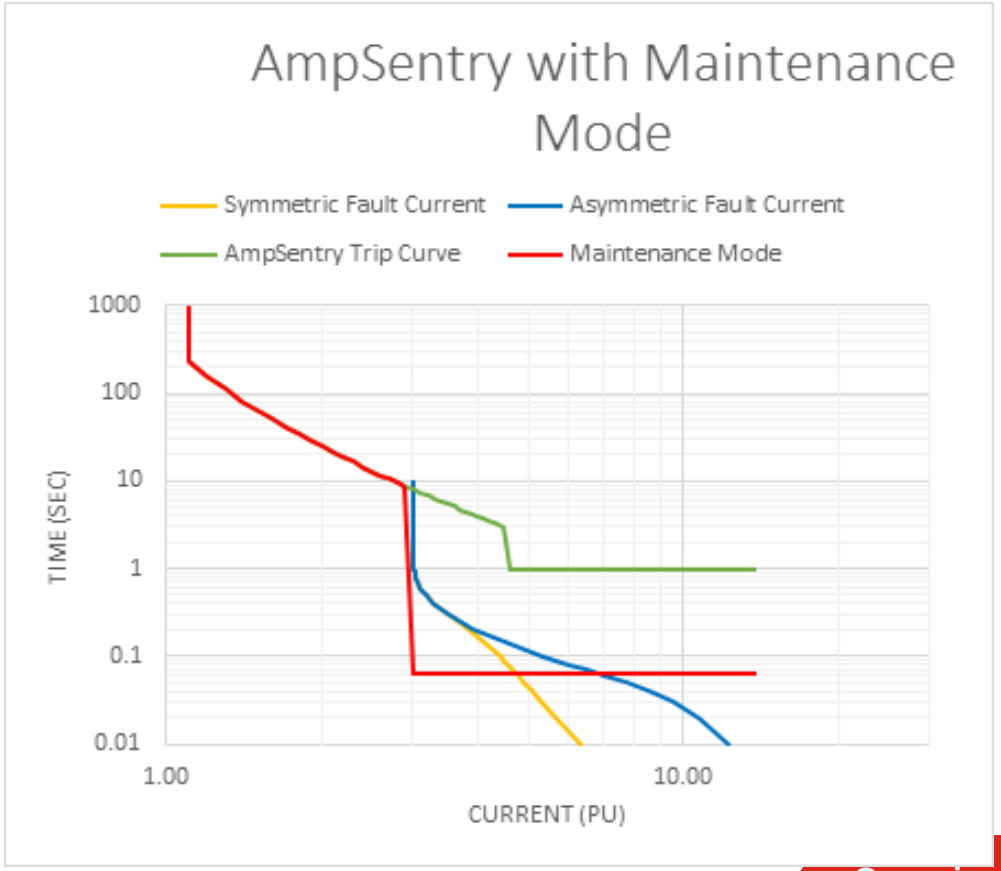
Local ERMS Switch



ERMS Switch "OFF" and "ON" Mode

AmpSentry Maintenance Mode

- Generator shuts down within 50 msec
- Running the genset in maintenance mode during testing reduces arc flash



What about the disconnect requirements?

Disconnects are intended to:

- Prevent energizing of downstream circuits
- In a generator application, to make it safe to work on the generator
- *Can be met with genset e-stop*

Problem: the term “disconnect” implies opening circuit to prevent current flow.

- 445.18 (2) (a) is intended to allow use of a device such as an emergency stop switch

Generator Set Disconnect Means and Shutdown of Prime Mover

Changes in the 2017 NEC Rules

NFPA 70-2014, 445.18

- *(A) Disconnecting Means - Generators shall be equipped with disconnect(s), lockable in the open position*

- *(B)* Shutdown of Prime Mover
  - (1) Provisions to disable all prime mover start control circuits
  - (2) Initiate a shutdown mechanism that requires a mechanical reset
  - Provisions for (B) permitted to satisfy requirements for (A) if capable of being locked out.

- (C) Generator Installed in Parallel
  - Provisions of 445.18(A) shall be capable of isolation the generator output terminals from the paralleling equipment.
  - Disconnect means shall not be required to located at the generator.

Generator Set Disconnect Means and Shutdown of Prime Mover (cont.)

E-stop switch with lockable shroud

Disconnect starter battery and lockout

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

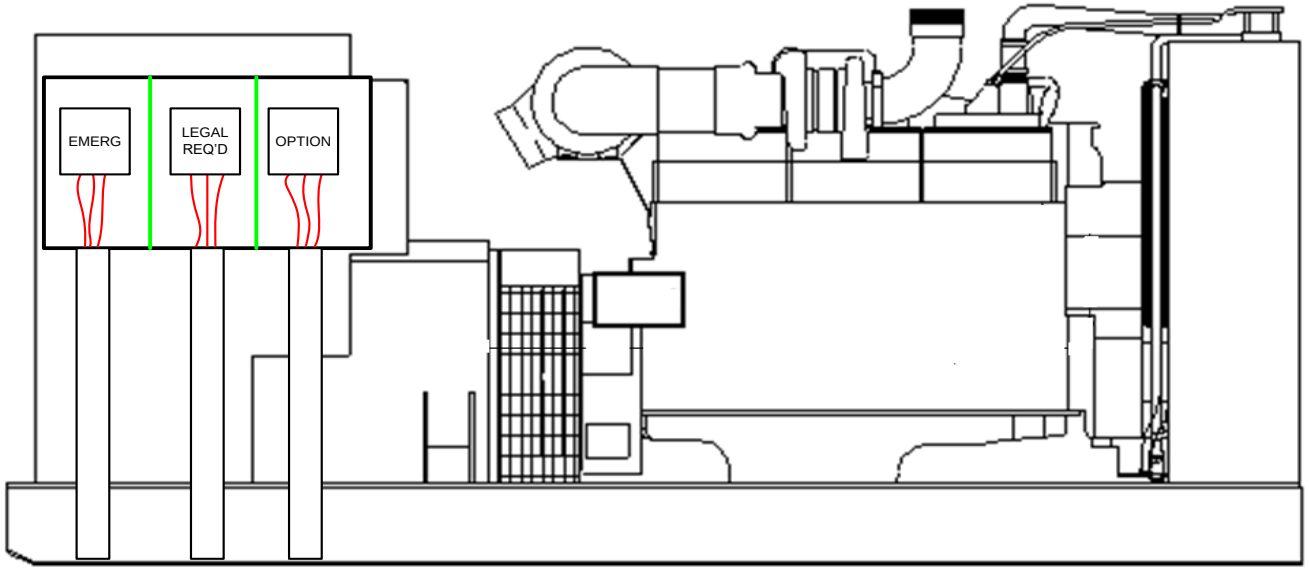
Genset has two sources of electrical supply

- 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

Separation of Emergency Circuits



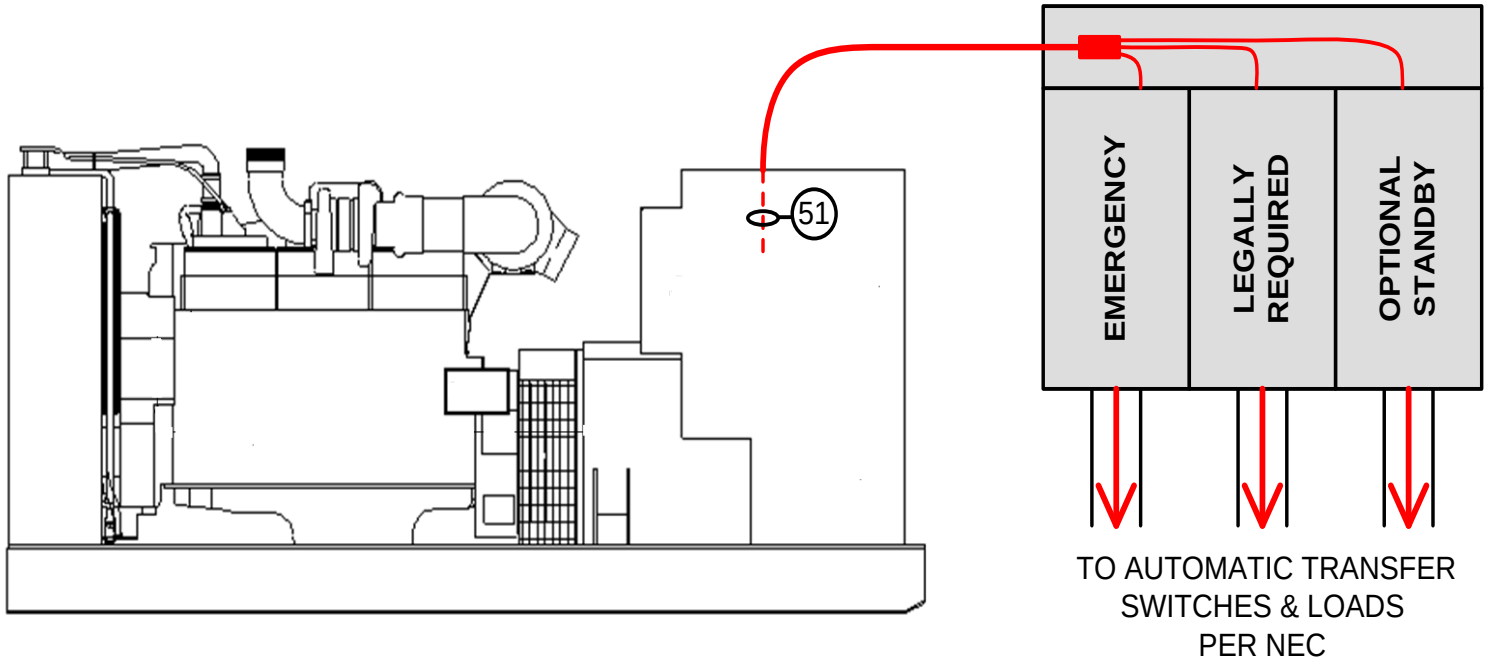
NFPA70-2017 700.10 (B)(5)(c):

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 Circuits

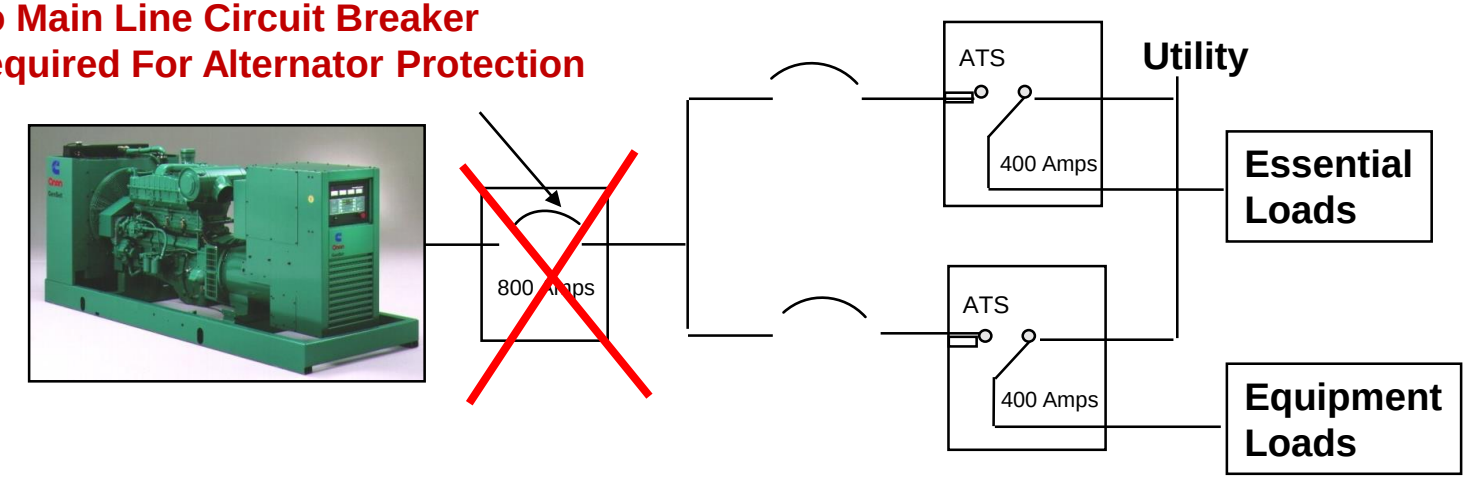


NFPA70-2017 700.10 (B)(5)(d):

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

Summary and Recommendations

No Main Line Circuit Breaker
Required For Alternator Protection



- Generator set mounted thermal magnetic breakers may not protect the generator and will be difficult to coordinate with downstream devices
- AmpSentry is a UL listed overcurrent protective relay integral to Cummins generator controls
  - Included in SKM and EasyPower software
  - Meets NFPA 70 240.87 requirements for arc energy reducing maintenance switching
- The generator E-stop switch meets NEC disconnect requirements
- Mounting breakers off of the generator simplifies separation of circuits requirements
- Based on this spec, typical equipment provided might be:
  - Molded case circuit breaker with solid state trips
  - Inherent Overcurrent protection

Course Summary

Generator Set Overcurrent Protection Options

- 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.

Specify:

- Alternator shall be protected per the requirements of NFPA70 section 445.12.
- The protection provided shall be coordinated with the thermal damage curve of the alternator. Damage curve and protection curve shall be submitted to verify performance.
- The protection shall allow operation of the generator set continuously at its rated output.
- The protection equipment provided shall be 3rd party certified to verify performance.
- The protection shall include arc energy reducing maintenance switching

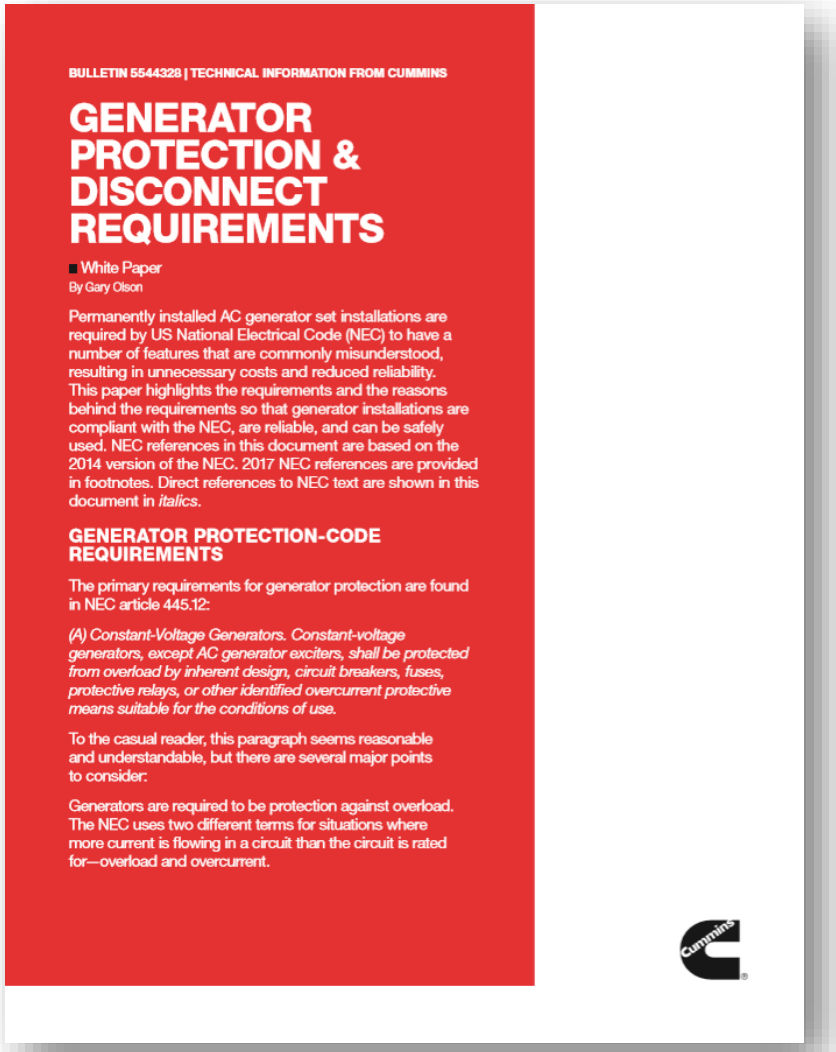
Additional Resources

Cummins White Papers

- AmpSentry Overcurrent Protection and Arc Energy Reduction
- Generator Protection & Disconnect Requirements
- Short Circuit and Arc Flash Evaluations using AmpSentry Capability - Part 1
- Short Circuit and Arc Flash Evaluations using AmpSentry Capability - Part 2

Cummins PowerHour On-Demand Webinars

- NEC 2017 Code Changes for Emergency Power Systems
- UL 1008 Withstand Close Ratings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GENERATOR PROTECTION & DISCONNECT REQUIREMENTS

White Paper

By Gary Olson

Permanently installed AC generator set installations are required by US National Electrical Code (NEC) to have a number of features that are commonly misunderstood, resulting in unnecessary costs and reduced reliability. This paper highlights the requirements and the reasons behind the requirements so that generator installations are compliant with the NEC, are reliable, and can be safely used. NEC references in this document are based on the 2014 version of the NEC. 2017 NEC references are provided in footnotes. Direct references to NEC text are shown in this document in *italics*.

GENERATOR PROTECTION-CODE REQUIREMENTS

The primary requirements for generator protection are found in NEC article 445.12:

(A) 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.

To the casual reader, this paragraph seems reasonable and understandable, but there are several major points to consider:

Generators are required to be protection against overload. The NEC uses two different terms for situations where more current is flowing in a circuit than the circuit is rated for—overload and overcurrent.

Q&A

Please type your questions, comments and feedback in the **Zoom Q&A** window.

After the PowerHour, a complete list of questions and answers will be published on powersuite.cummins.com.

Obinna Igwe
Senior Product Application Engineer
Cummins Inc.

Rich Scroggins
Technical Advisor – Data Center Market Team
Cummins Inc.

Makesi Sule
Senior Product Application Engineer
Cummins Inc.

Mark Taylor
Technical Marketing Specialist
Cummins Inc.

Your local Cummins contacts:

- AZ, ID, NM, NV: Carl Knapp (carl.knapp@cummins.com)
- CO, MT, ND, UT, WY: Christopher Scott (christopher.l.scott@cummins.com)
- CA, WA, OR, AK, HI: Brian Pumphrey (brian.pumphrey@cummins.com)
- MA, ME, NH, RI, VT: Jim Howard (james.howard@cummins.com)
- CT, MD, NJ, NY : Charles Attisani (charles.attisani@cummins.com)
- Northern IL, MI : John Kilinskis (john.a.kilinskis@cummins.com)
- NE, SD, KS: Earnest Glaser (earnest.a.glaser@cummins.com)
- IL, IN, KY, MO: Jeff Yates (jeffrey.yates@cummins.com)
- IA, MO: Kirby Holden (kirby.holden@cummins.com)
- DE, MD, MN, ND, OH, PA, WI, WV: Michael Munson (michael.s.munson@cummins.com)
- TX: Scott Thomas (m.scott.thomas@cummins.com)
- OK, AR: Wes Ruebman (wes.ruebman@cummins.com)
- LA, MS, AL: Trina Casbon (trina.casbon@cummins.com)
- TN, GA: Mariano Rojas (mariano.rojas@cummins.com)
- FL: Bob Kelly (robert.kelly@cummins.com)
- NC, SC, VA: Bill Morris (william.morris@cummins.com)
- Canada: Ian Lindquist (ian.lindquist@cummins.com)

Closing

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