Generator Set Overcurrent Protection

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September 24 11:00 PDT / 13:00 CDT
(1PDH issued by Cummins)
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Participants are encouraged to refer to the entire text of all referenced documents. In addition, when in 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.

AVR: Automatic voltage regulator
PMG: Permanent magnet generator

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.
Alternator Fault Performance
Decrement Curve (Separately Excited)

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

Three phase fault characteristics

\[ I_{3ph, \, pu} = \frac{1}{X_d''} \]

\[ I_{3ph, \, pu} = \left( \frac{1}{X_d''} - \frac{1}{X_d'} \right) e^{\left(\frac{-t}{T_d''}\right)} + \left( \frac{1}{X_d'} - \frac{1}{X_d} \right) e^{\left(\frac{-t}{T_d'}\right)} + \frac{1}{X_d} \]
Alternator Fault Performance

Decrement Curve Multipliers

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 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 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
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
Concept Check

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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

“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
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. 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
Arc energy reduction 240.87

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Arc Energy Reduction 240.87

Energy reduction maintenance setting (ERMS)
Arc Energy Reduction 240.87

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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
Concept check

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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

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

AmpSentry Overcurrent Protection and Arc Energy Reduction

In the interest of worker safety arc energy reduction has become a common require-ment in emergency power systems. Manufacturers of circuit breakers and protective devices have responded by adding various arc energy reducing functions to their products. One of the most commonly used energy reduction methods is energy reducing maintenance switching or “maintenance mode.” When maintenance mode is enabled anytime delays configured for selective coordination are extended in the event of a fault so the fault is cleaned in maintenance mode. 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 curve is reduced when the technician switches to maintenance mode. This allows the technician to work safely in the vicinity of live electrical equipment. In the AmpSentry overcurrent protection device (OCPD) the time delays are extended to allow the technician to safely switch to maintenance mode which inactivates the OCPD’s 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 a UL listed as a protective relay. In 2014 Cummins added a maintenance mode function to AmpSentry by PowerCommand C2.2 and SE-HF-1A. In this paper we will discuss AmpSentry and its new maintenance mode, how it enables maintenance mode and how it meets NEC energy reduction requirements.

AmpSentry

When PowerCommand controls measures current in any phase at exceeding 100% of the generator set standing rating a current running in a phase will be actuated so that the generator set will shut down based on the AmpSentry time-current curve. The green line in Figure 1 is the AmpSentry time-current. 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 fault load current rating of the generator. AmpSentry also has a fault current regulation feature. When the control measures current in any phase at exceeding 150% of the generator set standing rating the control recognizes that this is a fault condition and triggers to regulate current in the phase with the highest level of current to 100% of rated current. This bypass of this is to be achieved by demand (DOD) to clear the fault maintaining a coordinated system. AmpSentry’s current protection functions 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. We will publish consolidated FAQ along with presentation and webinar recording on powersuite.cummins.com

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