NEC 2017 Requirements for Generator Set Overcurrent Protection

January 24th, 2017 11:00 PDT / 13:00 CDT
(1PDH issued by Cummins)
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Course Objectives

Participants will be able to:

- Explain 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 pertaining to the topics listed above.
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
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.
Key Point: Ability to provides sustained short circuit (SSC) 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)

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

Three phase fault characteristics

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

Key points:
- Alternator fault current decays, it doesn’t remain constant like fault current from a transformer.
- System design software tools such as SKM account for this.
Decrement Curve Multipliers

Instantaneous Fault Current

\[ I_{3\text{ph, p.u}} = \frac{1}{X_d} \]

\[ I_{\text{SLG, p.u}} = \frac{3}{(X_d + X_2 + X_0 + 3 R_f)} \]

\[ I_{\text{LL, p.u}} = \frac{1.732}{(X_d + X_2)} \]

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

\[
\frac{X_{alt}}{X_{genset}} = \frac{kVA_{alt}}{kVA_{genset}}
\]

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

- 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

\[X''_{d_{genset}} = \frac{0.119}{4464} \times 3125 = 0.083\]
NEC Requirements

- Overload protection of generator and conductors (Article 445.12 and 445.13)
- Selective coordination (Articles 700.28 & 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.

Exception: Where deemed ... vital to the operation of the electrical system...the overload sensing devices (shall) be permitted to be connected to an annunciator or alarm...

**Overload.** Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload.
Cable Overload Protection

- Article 445.13 (A): 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.*

- Article 240.21 (G): Conductors from generator terminals that meet 445.13 shall be permitted to be protected by the generator overload protective device(s) required by 445.12.
Where the generator set is equipped with a listed overcurrent protective device or a combination of a current transformer and overcurrent relay, conductors shall be permitted to be tapped from the load side of the protected terminals in accordance to 240.21(B)
Generator Set Overload Protection - 445.12 (A)

Conductor Size /Overload Protection - 445.13 (A), 240.21 (G)

Taps on main generator set feeder conductor - 445.13(B)
Is the Protection There?

- 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
Inherently Designed Overcurrent Protection - AmpSentry™ Protective Relay

- Overcurrent protection integral to the Cummins PowerCommand Control System
- UL listed device
- Provides overcurrent protection by shutting down the genset before alternator thermal damage occurs
- If current exceeds 300% of rated, AmpSentry™ decreases excitation to regulate current at 300% until:
  - Fault is cleared by a downstream breaker
  - Or generator set is shut down based on:
    • Thermal damage curve for 3 phase fault
    • 2 seconds for L-G fault
    • 5 seconds for L-L fault
AmpSentry™ Trip Curve

- Library Files available in:
  - SKM POWER*TOOLS
  - EasyPower® Suites

Link to access the trip curve - http://power.cummins.com/power-systems-analysis-equipment-library
3-Phase Fault Response with AmpSentry™ Overcurrent Relay

3 Phase L1-L2-L3 Short: AmpSentry Regulation and Shutdown

**Peak Current:** $I_{R/X''d}$

Regulates at 3X Rated
Shuts down before damage
Voltage Recovery (3-phase fault) with AmpSentry™ Overcurrent Relay

3 Phase L1-L2-L3 Short and Recovery: L-N Voltages vs. Time

- Alt L1-N Voltage (%)
- Alt L2-N Voltage (%)
- Alt L3-N Voltage (%)

Voltage Recovery (3-phase fault) with AmpSentry™ Overcurrent Relay

Overcurrent Relay

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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)
Online Certification

- AmpSentry is UL Listed as a protective relay

http://database.ul.com/cgi-bin/XYV/template/LISEXT/1FRAME/index.htm
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 Electrical Code Articles 240.15(A), 240.21(G), 445.12(A), 645.13 and Canadian Electrical Code, 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 435.18 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 protective 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.
What is Selective Coordination?

- **NEC Article 100 Definition**: 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 700.32, 701.27, and 708.54 “…power system(s) shall be selectively coordinated with all supply side OCPDs.” over-current
Selective Coordination

Without Selective Coordination

- OPENS
- NOT AFFECTED
- UNNECESSARY POWER LOSS

Fault

With Selective Coordination

- OPENS
- NOT AFFECTED

Fault
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 and EasyPower.

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.
“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
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 and EasyPower software simplifies design of coordinated systems
(N) NFPA 70 240.87 (B) Arc Energy Reduction

“Where the highest continuous current trip setting is 1200A or higher … one of the following or approved equivalent means (to reduce clearing time) shall be provided…

… Energy-reducing maintenance switching with local status indicator

… an energy reducing maintenance switch allows a worker to set a circuit breaker trip time to “no intentional delay”
Generator Set Circuit Breaker Arc Flash Protection

- Example – Square D P and H Micrologic™ solid state trip units (P and H)
- Energy Reduction Maintenance Setting (ERMS)

![Local ERMS Switch](image1)

![ERMS Label on Trip Unit](image2)

![ERMS Switch “OFF” and “ON” Mode](image3)
Generator Set Integrated Arc Flash Protection – AmpSentry™ Maintenance Mode

- AmpSentry Maintenance Mode similar to circuit breaker arc energy reducing function
- Instantaneous generator set shutdown in the event of a short circuit, bypassing all time delays
  - Can also be configured to shunt trip a downstream breaker
- Enabled by a customer input or by connecting InPower service tool
- Complies with NEC requirement for arc energy reduction
AmpSentry and NEC Arc Flash Reduction

- Arc energy calculation depends on several site specific factors
  - Available fault current, arc interrupting time, system voltage, grounding method, conductor gap, working distance
- Maintenance Mode reduces arc interrupting time
  - Shuts down genset within 50 msec
  - Configurable output can shunt trip a breaker
Generator Set Disconnect Means and Shutdown of Prime Mover

- *(N) 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
NFPA70-2014 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
NFPA70-2014 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.
Recommendations

- 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

- Based on this spec, typical equipment provided might be:
  - Molded case circuit breaker with solid state trips
  - Inherent Overcurrent protection
Generator Protection Summary

- 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
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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