GENERATING kWRx POWER PRESCRIPTIONS

Generator Protection & Disconnect Requirements

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 compliance to 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 from *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.

Overload is defined in Article 100 as:

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.*

Overcurrent is defined in Article 100 as:

Overcurrent. *Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault.*

The difference between the two terms is that excess current flowing in a normal current path is an overload, while excess current flowing in a normal or abnormal current path is an overcurrent condition. For example, a motor starting might cause an overload condition, but a short circuit would be an overcurrent condition.

This distinction is important. Because generators are required to be protected only against overloads, the generator and the conductors connected to a downstream protective device do not require short circuit protection. So, the overcurrent function in a downstream device can provide all the necessary protection for conductors from a generator because the conductors from a generator to the first downstream protective device need not be protected against a short circuit or ground fault condition between the alternator and the first overcurrent device. This allows the generator protection to be located remote from the generator set (within 25 feet in a building, and with no code-based limitation for outdoor generators).

It is not surprising that 445.12 causes confusion and it even appears to conflict with other sections of the NEC that definitively require conductor protection from short circuits. However, the structure of the NEC is such that basic requirements that are described in Chapters 1-3 are "modified" by special provisions in later sections of the NEC. Chapter 4 (for generator installations) provides special requirements due to the different nature of generator applications versus utility-powered systems. (NEC 90.3)

It's worth considering why this is reasonable: 445.12 is one section of the NEC that has not been modified for far more than 25 years. When it was written external excitation support systems like permanent magnet generators (PMG) and series boost systems did not exist for standby generators. When a fault hit a generator (particularly a 3-phase fault) the generator would quickly collapse and could not provide enough current to damage downstream conductors. As added protection, the NEC required conductors installed without overcurrent protection to be sized at 115% of rated generator output. (445.13)

This is also consistent with the requirements of section 240.21 (B)(5) (for outdoor installations) which states:

(5) ***Outside Taps of Unlimited Length****. Where the conductors are located outside of a building or structure, except at the point of load termination, and comply with all of the following conditions:*

(1) The tap conductors are protected from physical damage…

(2) The tap conductors terminate at a single circuit breaker or a single set of fuses that limits the load to the ampacity of the tap conductors. This single overcurrent device shall be permitted to supply any number of additional overcurrent devices on its load side.

(3) The overcurrent device for the tap conductors is an integral part of the disconnecting means…

(4) The disconnecting means for the tap conductors is located in a readily accessible location complying with one of the following:

> *a. Outside of a building or structure*
> *b. Inside, nearest the point of entrance of the tap conductors*
> *c. Where installed in accordance with 230.6, nearest the point of entrance of the tap conductors*

With the advent and common usage of external excitation support systems one could argue that it would be more important to require overcurrent protection at the alternator when excitation support is used—but the NEC does not require it. This is consistent with the way that the NEC treats conductors from a utility service. When overcurrent protection is used and located to protect the conductors from a generator, the conductors can be sized at 100% of the generator set rating (445.12, exception).

Finally, it is clear from the term “overload” that generators are not required to be protected against internal fault conditions because current sensing can be downstream from the generator set.

Effective Generator Protection

Generators are required to be protected, but there are serious misconceptions about how to accomplish that. The most common misconception is the idea that generator protection must be done with breakers or fuses. As is obvious from the text in 445.12, any device listed as a protective device can be used for the required protection[1]. However, it is critical that a designer verify that protection provided actually protects the alternator.

- Alternators are much more susceptible to failure than equally rated conductors. Breakers that are designed to protect conductors nearly never provide effective protection across the entire range of potential failure conditions.
- In particular, molded case breakers with thermal magnetic trips—by far the most commonly used protective device for generator sets—will never protect a generator unless they are rated at considerably lower current levels than the generator set. Use of multiple smaller devices can make the situation worse unless the aggregate ratings of the breakers are less than the rating of the generator set.
- A breaker with electronic trip may be sufficiently adjustable to protect an alternator, but it is still critical that equipment provided is set to properly protect the generator. Of course, another issue is that if a breaker does trip for no apparent reason, an operator can reset it so protection is no longer effective.

Figure 1 illustrates a typical generator damage curve, typical molded case breaker trip characteristics, and typical fully-rated conductor

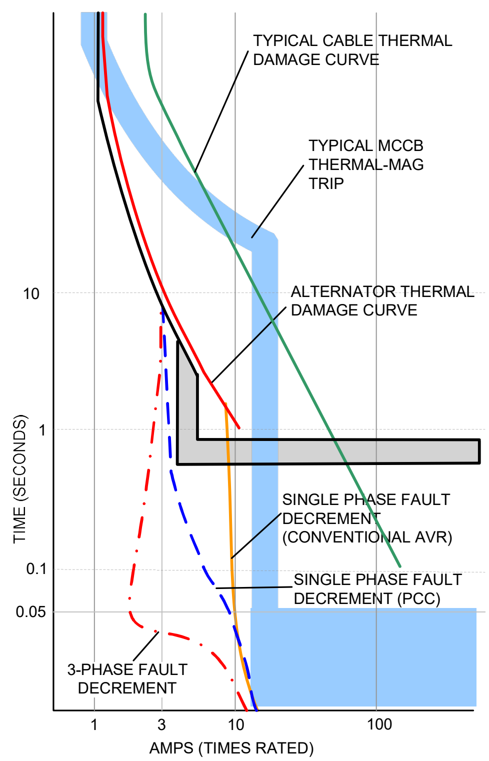

Figure 1: Typical generator and conductor damage curves with molded case breaker protection and relay-based protection.

[1] The 2017 NEC includes new paragraph *445.13(B)* ***Overcurrent Protection Provided****. Where the generator set is protected with a listed overcurrent protective device or a combination of a current transformer and protective relay, conductors shall be permitted to be tapped from the load side of the protected terminals in accordance with 240.21(B).* This statement reinforces the requirements in 445.12.

damage characteristics. Notice that while the molded case breaker trip characteristic provides good protection for the fully rated cables, it provides no protection to the generator, and also can nuisance trip at high current levels or with low level overload conditions. Thermal magnetic trips are particularly susceptible to nuisance trip under high ambient conditions. Breakers are commonly rated at maximum temperature of 40 degrees centigrade. So, whenever they are exposed to higher ambient conditions which are common in generator applications in most of North America, it is not uncommon for them to fail or nuisance trip.

Note also that all AC generators have similar damage curves. NEMA MG-1, the North American standard for alternator design, states that unless testing has been done to determine otherwise, the alternator thermal damage characteristic should be based on an $I^2t=40$ curve. In spite of this, most designers do not require documentation to verify protection—simply assuming that any breaker similarly rated to the generator protects the generator and conductors. Note also that standard UL 2200 test procedures do not validate the thermal limits of a generator or require documentation of those limits.

Damage curves from various alternators are also different in that the end point of the damage curve is defined by the subtransient reactance of the generator. In Figure 1, with peak current level of about 10 times rated current, a subtransient reactance of approximately ten percent can be deduced. At higher subtransient current levels the curve would be shorter (not extend as far to the right), indicating that the alternator has lower peak fault current capability.

Inspection of the decrement curve of the generator also shows that the alternator (even with PMG) cannot produce sufficient current in less than approximately one second to damage the generator (or fully rated conductors). So, instantaneous trips are never necessary for generator or fully rated conductor protection. While the alternator provides a relatively high inrush current, even with a PMG the machine can only provide three times rated current on a sustained fault.

If a generator is provided with a conventional excitation system, a single phase fault will result in over excitation of the machine and the machine will produce close to peak current until it is either damaged or switched off. The un-faulted phases will exhibit very high voltage levels on the un-faulted phases. With fault current regulation functions in the excitation control system (commonly a voltage regulator) the single phase decrement will look more similar to a 3-phase fault except that it will decay a bit more slowly and the risk due to over voltage on a fault is eliminated. The message of this characteristic is that it is a good idea to have over voltage protection in generator set applications and if you can get fault current regulation you should, even though it is not required by code.

Multiple Generator-mounted Breakers

UL 2200 includes a stipulation that the total ampacity of all breakers on a generator set must not exceed 125% of the generator current rating without other protection provided[2]. UL 2200 does not evaluate effectiveness of alternator protection (other than verifying that a protective device operates when the manufacturer says it will), and use of UL 2200 alone with its 125% limitation will generally not result in effective alternator protection. Effective overcurrent protection will only be achieved when the protection operates based on an accurate alternator thermal damage curve.

In general, use of multiple breakers on a generator for generator protection can result in even less effective protection than if a single breaker rated equally to the generator is used.

While generator-mounted circuit breakers are commonly used, it should be noted that circuit breakers are not well-suited for generator applications. Potential issues include:

- Ambient temperatures inside a generator set room/enclosure often exceed the 40 degree centigrade maximum ambient temperature for breakers. Higher ambient temperatures can impact on trip characteristics of a breaker protective device, and will definitely impact on its ability to withstand sustained high current levels.
- Circuit breakers are generally not evaluated for mounting on a vibrating machine.
- Generators have limited connection and wire bend space, and the amount of space available in any given kW-rating alternator can vary considerably between suppliers.

Consequently, use of generator-mounted breakers could be considered a violation of the NEC, which states in article 110.3:

[2] Another common design mistake that is rarely caught…

***(B) Installation and Use.** Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling.*

Circuit breakers that are generator-mounted will have shorter life and as previously noted will be more prone to nuisance tripping in a generator environment. So, one could argue that use of breakers would not even comply with the requirements of 445.12 that requires "*protective means suitable for the conditions of use".* At the same time it should be understood that standby generators usually operate so few hours that this is not usually an issue.

Even without the UL issue and life/performance issues, NFPA 110 requires prototype testing of the generator set assembly, and mounting of breakers without demonstrating successful prototyping can result in mechanical failures of the structure of a machine due to the added weight and use of untested connection means. This is particularly true is seismic areas due to the additional relative movement between the conductors which are commonly constrained by the structure around them and the alternator, which moves relative to the structure when a seismic event occurs.

If circuit breakers are used in generator applications, it is good practice to mount the breakers so that they are vibration-isolated from the generator set (unless prototype testing verifies that the assembly is sound without it), and the number of breakers used should be minimized.

Use of Overcurrent Protection at the Generator Set

Generators that are installed with effective overcurrent protection at the generator set that is UL (or other recognized testing agency) listed are allowed greater flexibility in facility distribution system design.

Requirements for wiring of emergency, legally required, and optional standby circuits with a generator set at the source can be found in NEC 700.10 (B). Similar requirements are in Articles 701 and 702.

700.10 (B) Wiring. Wiring of two or more emergency circuits supplied from the same source shall be permitted in the same raceway, cable, box, or cabinet. Wiring from an emergency source or emergency source distribution overcurrent protection to emergency loads shall be kept entirely independent of all other wiring and equipment, unless otherwise permitted in 700.10(B) (1) through (5):

Critical requirements related to generator wiring are in sub-paragraph 5:

(5) Wiring from an emergency source to supply emergency and other loads in accordance with 700.10(B)(5)a, b, c, and d as follows:

a. Separate vertical switchgear sections or separate vertical switchboard sections, with or without a common bus, or individual disconnects mounted in separate enclosures shall be used to separate emergency loads from all other loads.

b. The common bus of separate sections of the switchgear, separate sections of the switchboard, or the individual enclosures shall be permitted to be supplied by single or multiple feeders without overcurrent protection at the source.

Exception to (5)b: Overcurrent protection shall be permitted at the source or for the equipment, provided that the overcurrent protection complies with the requirements of 700.28. (which requires selective coordination)

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

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

These paragraphs can be summarized as follows:

- Emergency circuit wiring must be kept entirely separate from other wiring from the point where the conductors from the generator split into the individual types of circuits. Similar requirements are in Article 695 for electric fire pump circuits.
- Wiring for the emergency circuits can terminate in any allowed connection provision or listed device. So, whether the destination is a breaker in an individual enclosure, a switchboard bus, or a breaker in an isolated section of a switchboard, it should be accepted. A single circuit that is split into different types of loads downstream, or

individual circuits to each load type is also acceptable (ref: exception to (5)b). These requirements are common for all applications as described in articles 701 and 702.

- Emergency circuits must be selectively coordinated. Care should be taken to review the system design to be sure that tripping of other load types does not cause shutdown or disconnect of the generator set when it can properly serve emergency loads.

The 2017 NEC has further clarification on allowed provisions for the connection of multiple loads to a generator set:

445.13 (B)Overcurrent Protection Provided. Where a generator set is protected with a listed overcurrent protective device or a combination of a current transformer and protective relay, conductors shall be allowed to be tapped from the load side of the protected terminals in accordance with 240.21(B).

At this point it is clear that a generator set with listed overcurrent protection can be installed using the tap rules in the NEC, which provides a great deal of flexibility to a designer, allowing for multiple system designs that are reliable and ultimately more cost effective.

A graphical description of some alternatives for connections is as follows:

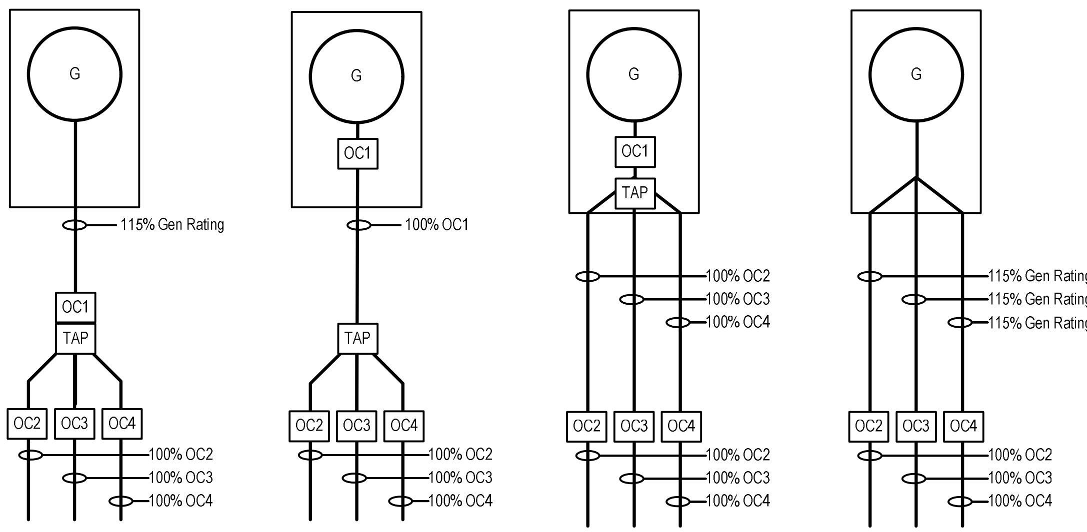

Figure 2: This illustration shows a number of acceptable alternatives for connection of conductors from a generator to multiple loads, along with indication of conductor sizing requirements. OC1 is often specified to be a circuit breaker, but is specifically allowed to be any listed protective device that will protect the alternator. TAP indicates a tapped connection per requirements of NEC 240.21. OC2, OC3, and OC4 are also typically circuit breakers, but other protective devices are also allowed by the NEC. Conductors "downstream from a tap for OC2, OC3, and OC4 are sized based on OC device rating.

In the first illustration from the left in Figure 2, a generator is provided with overload protection, and a remote breaker with downstream loads tapped per NEC requirements. Note that conductors from the generator are required to be sized at 115% of the generator rating, or the rating of overcurrent device 1 (OC1).

In the second illustration in Figure 2, the same arrangement is used, but OC1 is located at the generator and provides both required generator protection and protection for both overcurrent and generator overload. This allows a single set of 100% rated conductors connected from the generator set to a tap box (or tap bus, or main lug only switchboard). The 100% rating is acceptable assuming the overcurrent protection shown is a listed protective device.

In the third illustration the tap is moved to the generator, which allows the conductors to the downstream devices to be rated based on the tap rules and the ratings of the downstream devices.

The fourth illustration shows the same situation as the third figure, without listed overcurrent protection (just overload) at the generator set, and the installation will not meet tap rule requirements for overcurrent protection ahead of the tap.

Consequently, authorities often require[3] conductors sized based on the rating of the generator set rather than the downstream devices. This becomes a practical problem at the generator set as there may not be enough conductor space in the generator enclosure to handle the required number and size of conductors. (Generator sets are only guaranteed to have enough terminal space for cables rated at 100% of the generator set current rating.)

The big point to note here is that once you have effective, **listed** alternator protection in place beyond overload protection which is required by code, there is a lot of flexibility for connecting loads to a generator set and the difficulties presented by example 4 are eliminated.

Note also that the tap rules for use inside a building have considerably different requirements when the installation is inside a building versus a typical generator set installation which is outside of the building it serves. The biggest change being that there is no limit on the length of the tap on an outdoor generator. (NEC 240.21 (B)(5))

It is worth noting that with the trend toward use of more and more non-linear loads on generator sets, and the impedance of a generator typically being significantly higher than a utility service, voltage waveform distortion can be an issue on a generator set due to heating effects of the harmonic currents as well as sensing issues. Consequently, in order to achieve accurate sensing for proper overcurrent protection and prevent nuisance tripping, many designers are moving toward use of higher cost digital true RMS trip sensing devices, rather than the traditional thermal-magnetic trip devices. Digital trips or adjustable protective relaying are usually necessary to get trip characteristics that result in proper protection for the alternator.

Ground Fault Protection

Generator set installations rated for operation at 480VAC and 1000 amps and higher (feeder sizes) are required to have ground fault sensing. This requirement is called out in NEC section 215.10 and modified in articles in 700 and 701. Note that 230.95, which covers requirements for services, does not apply to generator sets because a generator source is not a service.

700.27 Ground-Fault Protection of Equipment. The alternate source for emergency systems shall not be required to have ground-fault protection of equipment with automatic disconnecting means. Ground-fault indication of the emergency source shall be provided in accordance with 700.6(D) if ground-fault protection of equipment with automatic disconnecting means is not provided. (701.26 has identical requirements)

The text of the NEC is sometimes understood to mean that ground fault protection is required for the generator set. However, as can be seen by the thermal damage curve for a typical generator set in Figure 1, a generator set cannot be damaged by an external ground fault when properly protected, and no ground fault protection is required by Article 445. Ground fault protection is prescribed for the protection of the distribution system and other connected hardware.

The reference to "*without disconnecting means*" should be interpreted to mean that only an alarm is required at the generator set, not a shutdown of the generator set or tripping of a breaker or other disconnect device. Article 702 does not have a paragraph analogous to those in 700 and 701, so those applications must have ground fault protection as described in NEC 215.10 and 230.95.

Ground fault protection on a generator main breaker may be required to coordinate with downstream branch ground fault devices, which are required as of the 2014 NEC. While coordination is not specifically stated for ground fault equipment, it could be interpreted to be required as ground fault equipment is an overcurrent protective device:

210.13 Ground Fault Protection of Equipment. Each branch circuit disconnect rated at 1000 amps and more and installed on a solidly grounded wye electrical system of more than 150 volts to ground, but not exceeding 600V phase-to-phase, shall be provided with ground fault protection of equipment in accordance with the provisions of 230.95.

Note that a generator set rated at 1000 amps or more could be provided with two or more breakers rated less than 1000A, thus eliminating the need for ground fault protection in the generator system. In it also important to recognize that if ground fault alarm or protection is required, for that protection to be functional the generator system must be properly grounded and bonded. Two things are required:

[3] Be aware that there is considerable disparity in the interpretation and enforcement of protection requirements with this design—so it's better to use one of the other designs where possible.

- For all applications, the generator or generator parallel bus must have a **single** neutral to ground bond as per NEC 250.30.A (1). This means that if the system incorporates 4-wire loads, 4-pole (switched neutral) transfer switches must be used in the system; and if multiple generators are paralleled on a common bus, the bonding point will be in the switchgear rather than at each individual generator set.
- The bonding point must be located (electrically) between the generator source and the ground fault sensor. This allows ground fault current to bypass the sensor when returning to the source, so that a ground fault can be accurately sensed[4].

Generator Disconnect Rules

Disconnects are generally required in electrical systems to allow safe service of downstream electrical equipment, and also to allow firemen to disconnect power to a facility to avoid the hazards of fighting a fire around energized electrical equipment.

Generator applications are different from utility-powered systems in that a since a generator is most safe to work on when it is prevented from operating there are two acceptable alternatives for disconnects: a disconnect means such as would be used on a utility-powered system, or shutting down and locking out the generator set.

Figure 4: Disconnect requirements for a non-paralleled generator set can be often be met using an emergency stop switch with lock-out/tag-out provisions.

Of those two alternatives, by far the safest alternative is to prevent the generator set from running, because it makes the generator unable to operate or energize the system. So, the generator is both safe to work on electrically and mechanically when transfer switches with mechanical interlocks between sources are used. Further, anything electrically connected to the generator set is safe to work on when these requirements are met.

The NEC requires compliance to these objectives via the following sections for all generator installations:

445.18[5] Generators shall be equipped with a disconnect(s), lockable in the open position by means of which the generator and all protective devices and control apparatus are able to be disconnected entirely from the circuits supplied by the generator except where the following conditions apply:

(1) Portable generators are cord- and plug-connected, or (2) Both of the following conditions apply:
a. The driving means for the generator can be readily shut down, is rendered incapable of restarting, and is lockable in the OFF position in accordance with 110.25.

b. The generator is not arranged to operate in parallel with another generator or other source of voltage.

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[4] The 2017 NEC has added a provision added in article 700.6 (D) that notes that the bonding point for a paralleled generator system may be at a location other than the generator set itself in order to meet this physical requirement.

[5] The 2017 NEC has significant changes that attempt to further clarify these requirements. 445.18 is changing to:
445.18 ***Disconnecting Means and Shutdown of Prime Mover****.*
(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 ungrounded conductors. Each disconnecting means shall be lockable in the open position in accordance with 110.25.*
(B) Shutdown of Prime Mover*. Generators 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 15kW 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 meet the requirements of 445.18 (B)(1) and (B)(2).

The 2017 NEC has also added a requirement to provide emergency illumination at a disconnect for emergency (Article 700) loads:
700.16 Emergency Illumination. *…Where an emergency system is installed, emergency illumination shall be provided in the area of the disconnecting means required by 225.31 and 230.70, as applicable, where the disconnecting means are installed indoors.*

Since the generator is required to be lockable, the following requirements also apply:

110.25 Lockable Disconnecting Means. Where a disconnecting means is required to be lockable open elsewhere in this Code, it shall be capable of being locked in the open position. The provisions for locking shall remain in place with or without the lock installed.

When a physical disconnect is not used per 445.18 (2)(b), one should interpret the rule to mean “shall be incapable of operating or attempting to operate.”

Rules in articles 700, 701, and 702 add additional requirements for generators installed outdoors. Section 700.12 (B) (6) states:

(6) Outdoor Generator Sets. Where an outdoor housed generator set is equipped with a readily accessible disconnecting means in accordance with 445.18, and the disconnecting means is located within sight of the building or structure supplied, an additional disconnecting means shall not be required where ungrounded conductors serve or pass through the building or structure. Where the generator supply conductors terminate at a disconnecting means in or on a building or structure, the disconnecting means shall meet the requirements of 225.36.

Exception: For installations under single management, where conditions of maintenance and supervision ensure that only qualified persons will monitor and service the installation and where documented safe switching procedures are established and maintained for disconnection, the generator set disconnecting means shall not be required to be located within sight of the building or structure served.

Identical requirements are found in articles 701 and 702.

The term “within sight” is a defined term in Article 100 of the NEC:

In Sight From (Within Sight From, Within Sight). *Where this Code specifies that one equipment shall be “in sight from,” “within sight from,” or “within sight of,” and so forth, another equipment, the specified equipment is to be visible and not more than 15 m (50 ft) distant from the other.*

Summarizing:

- An installation utilizing a non-paralleled generator with an integral lock-out/tag-out provision (such as an emergency stop switch) does not require a traditional disconnect which actually interrupts the current flow with contacts that physically open. The emergency stop switch with lock-out/tag-out provisions provides a means to both safely work on downstream equipment, and also to work safely on the generator set.
- When the generator is outside of the structure being served by the generator, the disconnect generally must be visible and within 50 feet of the building.
- For an outdoor generator, if the disconnect is not visible and within 50 feet of the building or structure, an additional disconnect (or disconnects) will be required where the conductors from the generator enter the building. When the disconnect is used at the building, generally must be suitable for use as service equipment per 225.36.

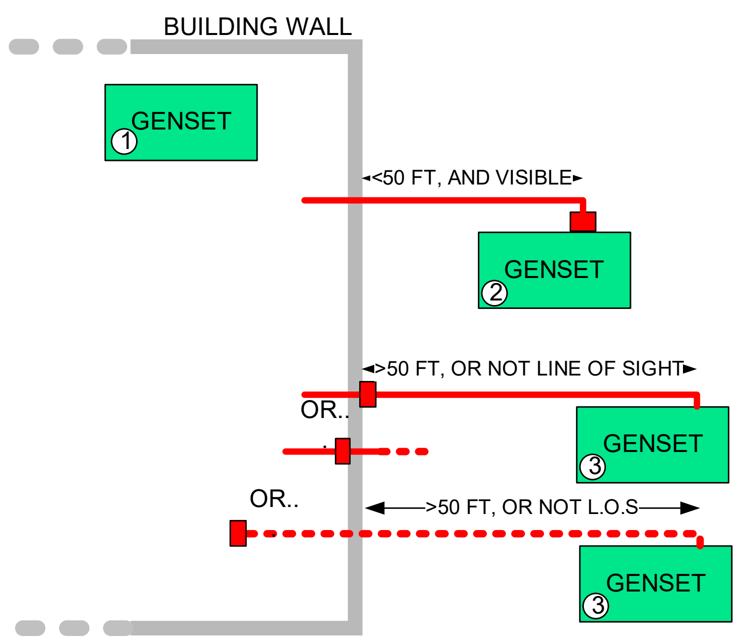

Figure 5: For an outdoor generator there generally must be a disconnect that is visible and within 50 feet of where “the conductors enter the building”. If the disconnect is located at the building it must be suitable for use as service equipment.

- An installation that utilizes generators operating in parallel on a common bus requires an additional disconnecting means to prevent generators operating on a paralleling bus from energizing conductors of a generator being serviced. Again, there is no requirement for this disconnecting means to be visible from the generator.
- Where a generator installation incorporates a disconnect means for a fire pump, it must be lockable in the closed position. Other disconnects are required to be lockable in the open (disabling power flow) position.
- The exception to 700.12 (B) (6) allows a generator disconnect to be "not within sight" as long as there is trained, qualified staff to operate the disconnect (presumably always available) and documented processes are established and maintained. The intent of this exception was that for situations where, for example, a generator was installed in a "campus" environment or industrial environment with controlled access to the facility, there is normally a staff trained to manage the site, and formal documentation and procedures are maintained to keep the system safe and reliable. A typical generator site in a commercial building typically would not meet these requirements, but it will up to the local authorities to judge whether or not a specific site qualifies under this exception.
- It's worth noting that the "within sight" requirement is often not enforced, but the risk of not complying is a potential rejection which will result in delays and unnecessary costs.

Generator Disconnects for Paralleling Applications

In order for paralleled generator sets to be safe to work on a generator requires both the means to prevent the generator set from mechanically operating and electrically energizing the load, and must also have a second disconnect means whose purpose is to prevent the alternator conductors from being energized from the paralleling bus. (NEC 445.18(b)) Note that operation of either the primary disconnect means at the generator set (control lock out "CLO" such as an emergency stop switch) or a remote device alone provide the necessary mechanism for rendering the downstream distribution system safe for servicing.

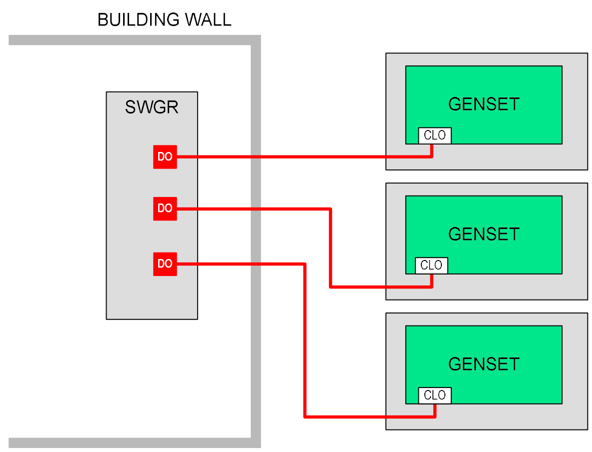

Figure 6: Outdoor paralleled generators with disconnect requirements shown.

Many paralleling applications utilize draw-out power circuit breakers in a switchboard line-up for the paralleling device. When this is done, the draw-out mechanism not only provides a convenient mechanism for service of the breaker while the balance of the system is in service, it also provides an ideal disconnect mechanism for the secondary generator set disconnect, because it allows visible verification that it is disconnected, and can be disconnected while the balance of equipment is in service.

Paralleled generators that are installed inside a building can be designed in a similar fashion to outdoor machines. Note that there is no requirement for generator disconnects to be visible from the generator, or conversely, that the generator is visible from the disconnect. (The illustration assumes that the draw-out mechanism location meets the requirements of "where the conductors enter the building or structure" in the NEC.)

Coordination requirements

Circuits from generator sets that serve emergency and legally required loads are required to be selectively coordinated:

700.28 Selective Coordination.

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

Selective coordination shall be selected by a licensed professional engineer or other qualified persons engaged primarily in the design, installation, or maintenance of electrical systems. The selection shall be documented and made available to those authorized to design, install, inspect, maintain, and operate the system.

Exception: Selective coordination shall not be required between two overcurrent devices located in series if no loads are connected in parallel with the downstream device.

Nearly identical text is found in 701.27.

Generator sets pose particular challenges for selective coordination due to limited fault current that is available, and the need for protection of the alternator[6]. Referring back to Figure 1, it can be seen that peak fault current is rarely more than ten times rated current, and often is substantially less. Because an alternator is more susceptible to damage than conductors, the alternator damage curve falls far to the left of a typical damage curve for 100% rated conductors. Consequently, typical breakers serving loads downstream from the generator protective device must often be 50% or less in steady state rating than the generator rating in order to coordinate with required generator protection.

These factors will mitigate toward the use of relatively larger numbers of smaller devices downstream from the generator set, and relatively few levels of downstream devices. It also makes it more critical for a designer to specify (and get) generators that can produce acceptable levels of fault current so that coordination can be achieved.

There is, however, a greater practical challenge. If circuit breakers with instantaneous trips are used in the generator distribution system and the generator protection is a circuit breaker with instantaneous trip, all the breakers that require coordination will effectively *be required to be sourced from the same manufacturer and have coordinated trip units* in order to demonstrate selective coordination of the system as a whole.

While easy to achieve in concept, in a practical sense the circuit breaker(s) used for the alternator protection are often sourced early in the construction process and by a different supplier relative to the other breakers in the distribution system. If the breaker(s) on the generator set are required to be coordinated with downstream devices and are not "compatible" with the balance of the distribution system, they will be generally be required to be changed in order to be in compliance with NEC requirements.

While it may seem physically straightforward to change breakers on a generator set, there are complications.

If the generator is a listed assembly and the breakers are provided in a separate listed assembly, then the breakers can be replaced without complication (other than significant added cost and delay in finishing a project), as long as they are installed in compliance to the generator and breaker assembly manufacturers' instructions (including connection and bend space requirements). If, however, the generator set incorporates breakers as a component of a single listed assembly, a change to the assembly requires re-inspection by the agency that provides the listing.

If the coordination study reveals that a larger breaker must be located on the generator to allow downstream coordination, the modification work is more complicated. This could include major modifications to the physical construction of the load connection box and generator load connection provisions due to physical characteristics of the alternator connection box and connection provisions. Since every alternator is limited to some degree in terms of connection space, it is possible that the required conductors will not fit in the available space.

Obviously, if this work must be completed after the generator set is installed costs and delays can sky-rocket. Further, it should be remembered that adding hardware that is not prototype-tested with the generator set leaves the door open for unexpected failures due to vibration that is present in all generator set applications.

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[6] The 2017 NEC includes new requirements for labeling so that a designer or inspector can verify that protection and coordination are based on the supplied machine characteristics:
445.11 Marking….Nameplates or manufacturer's instructions shall provide the following information for all stationary generators and portable generators rated more than 15kW:
(1) Subtransient, transient, synchronous, and zero sequence reactances
(2) Power rating category
(3) Insulation system class
(4) Indication if the generator is protected against overload by inherent design, an overcurrent protective relay, circuit breaker, or fuse.
(5) Maximum short circuit current for inverter-based generator set, in lieu of synchronous, transient, and subtransient reactances.

Recommended Practices

Over the past several code cycles several critical changes in the NEC have occurred with respect to protection of generator sets, distribution equipment, and the provisions required for disconnects on generator sets. These have been primarily directed at clarifying the requirements of the code and in some cases specifically allowing reasonable and justifiable relaxation of some requirements that are required for utility-powered systems but not critical in generator-powered systems.

In spite of these changes, generators continue to utilize commonly misapplied protection and installed in violation of NEC requirements. The result: more expensive, less reliable, and even less safe installations. To avoid these problems, designers should take the following steps:

- Generator set submittals should always include an alternator thermal damage curve and evidence that the alternator protection provided actually protects the machine via specific settings using a listed protective device. This allows a designer to verify that a machine not only meets NEC requirements, but also will also be as reliable and safe to operate as critical systems demand. Some suppliers have made provisions for display of integral protection and generator set decrement curves within engineering tools from companies like SKM and Easypower that enable convenient verification and coordination of coordination.
- The alternator thermal damage curve and protection device curve will become an integral part of a coordination study when that becomes necessary. Alternator reactance data is also necessary for this work.
- The combination of all the requirements for protection and disconnects along with requirements for selective coordination of some circuits make it impractical to use circuit breakers mounted on a generator as the means of disconnect and alternator protection. Where available from generator suppliers as a listed option, protective relaying is a reasonable option since it does not have required instantaneous protection and is generally flexible enough to adjust to properly protect the alternator. Where breakers are used for alternator protection and must be coordinated with downstream devices, make provisions for verifying that the generator breaker(s) coordinate with other breakers in the system.
- It’s also worth noting that the NEC requires only overload protection for generator sets (usually achieved with an overcurrent device). Addition of additional protective devices and unnecessary protective functions (other than overvoltage) will negatively impact on generator set reliability. Since most generator set controls now offer these functions as standard, there is no good justification for addition of other protective devices for the generator set.
- For generator sets installed in outdoor enclosures and where the disconnect is not “within sight”, the facility will require a service entrance listed disconnect where the conductors from the generator enter the facility. Note that when a disconnect means is provided remote from the generator set, an additional disconnect is not required on the generator set.

This all being said, since the recommendations represent a “new” way of doing things, it’s important to clear a proposed design with electrical inspection authorities prior to finalizing system design.

Gary Olson is a graduate engineer and a 40-year veteran of the on-site power generation industry. He is a Senior Member of IEEE and a past member of NFPA 70 Panel 13, the industry group that writes and manages changes to NEC articles 445, 700, 701, and 702. He is a current member on the working group for NFPA 110 and works as an independent consultant providing clients with initial design assistance and resolution of on-site technical issues, as well as optimization of on-site power systems.