Breaker-Free Generator Sets With Code-Compliant ALTERNATOR OVERCURRENT PROTECTION

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INTRODUCTION

The purpose of this white paper is to determine the code compliance by AC output generator sets without unit-mounted circuit breakers from the alternator overcurrent protection perspective. In the end, this white paper discusses the application and cost benefits of breaker-free generator sets.

It is an undisputed fact that no part of the electrical power distribution system must be left unprotected. Historically, the generator set mounted circuit breaker(s) has been used primarily because, in addition to providing overcurrent protection, it has helped us comply with the relevant code requirements. Technology advancements in power generation controls have allowed manufacturers to consider alternate protection methods.

The idea of having a circuit breaker-free generator set is not comforting to us, and that is understandable.

A note regarding circuit breaker-free generator sets:

We know that in the case of Medium Voltage (MV) or High Voltage (HV) generator sets, high fault current and arc-flash hazard can be more concerning than in the case of Low Voltage (LV) generator sets. Ironically, it is interesting to note that still many MV and HV generator set installations are “breaker-free”!

(On such installations it is ensured that the alternator and load cables originating from the alternator are still protected via other forms of protections, e.g., differential protection.)

Note: All references to NEC and UL standards referenced in this white paper are based on 2020 published documents.

UNIT-MOUNTED CIRCUIT BREAKERS ARE CUSTOMARY

Traditionally, generator-mounted circuit breakers with E-stop have been widely used to meet National Electric Codes (NEC) and UL requirements.

NFPA 70 (NEC) COMPLIANCE

NFPA 70 states, “The purpose of the NFPA 70 (NEC) code is the practical safeguarding of persons and property from hazards arising from the use of electricity.” Accordingly, when it comes to generator set assemblies:

- The alternator must be protected from an overcurrent condition.
- The conductors originating from the alternator terminals must be protected.
- Arc-energy reduction calls for a reduced clearing time while maintenance personnel could be working within an arc flash boundary.
- It is required that selective coordination must be achieved for the NEC article 700, 701, and 708 loads.

NEC 445.12 (A) calls for the overcurrent protection of constant voltage alternators by various devices or methods. One of the protective devices listed in this code section is a circuit breaker.

Generator-mounted circuit breakers simultaneously open all associated ungrounded conductors (e.g., feeder cables to the load), and they can be padlocked in the open position in accordance with NEC 110.25. They also offer compliance with NEC 445.18 (A) for disconnecting means.

Circuit breakers with an arc-energy reduction maintenance feature are readily available in the market to comply with the arc energy reduction requirement stated in NEC 240.87 for circuit breakers with a trip setting range of 1200 A or higher.

NEC 110.25 Lockable Disconnection Means.

If a disconnection 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.

Exception: Locking provisions for a cord-and-plug connection shall not be required to remain in place without the lock installed.

An E-stop push button helps in compliance with NEC 445.18 (B) (1) and (2) Shutdown of Prime Mover. Additionally, the short circuit selective coordination is achieved by appropriately adjusting the trip settings on circuit breaker trip units.

UL 2200 COMPLIANCE

The UL standard for safety for stationary engine generator assemblies is UL 2200. Note that the UL 2200 standards published in September 2020 include generator sets with greater than 1000 V output as well. Accordingly, when it comes to UL 2200 listed generator set assemblies:

- UL 2200 33.3 describes the need for overcurrent protection for alternating current (AC) output power circuits, e.g., feeder cables originating from the alternator terminals to the load.
- UL 2200 14 states that an output power disconnection device must be provided.

As we know, a generator-mounted circuit breaker complies with the above-mentioned UL 2200 requirements as well.

CODE COMPLIANCE WITH BREAKER-FREE GENERATOR SETS

For ease of explanation, the KOHLER® generator set controller APM603 with UL 6200-listed integral alternator overcurrent protection is referenced in this white paper. *See Figure 1.*

Please note that the principles discussed in this white paper can be applied to other manufacturers’ generator sets as well, provided their controllers have the required capabilities and applicable features.

Let’s analyze how a breaker-free generator set can still offer the code-compliant alternator overcurrent protection as well as the feeder cables (originating from the alternator output terminals) protection.

Figure 1

COMPLIANCE WITH NEC 445.12(A) FOR OVERCURRENT PROTECTION

NEC 445.12 (A) requires protection from overload by circuit breakers, fuses, protective relays, inherent design, or other identified overcurrent protective means.

The KOHLER generator set controller APM603 has integral alternator overcurrent protection that is certified as Over Current Protection (OCP) and Engine Generator Controls (EGC) under the UL 6200 listing.

NEC 445.12 Overcurrent Protection.

445.12(A) Constant-Voltage Generators.

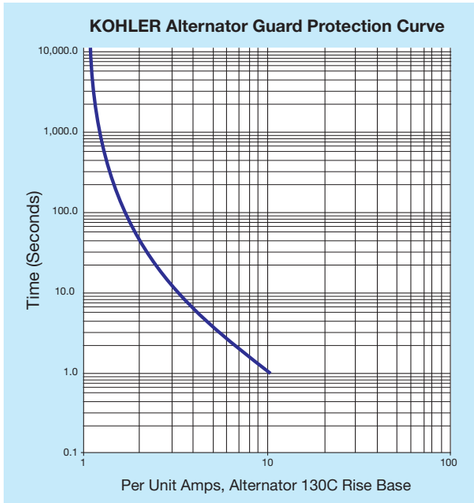
Constant-voltage generators, except ac generator exciters, shall be protected from overload by inherent design, circuit breakers, fuses, protective relays, or other identified overcurrent protective means suitable for the conditions of use.

The APM603 controller’s integral alternator overcurrent protection curve is published in the short-circuit selective coordination software SKM. The curve is labeled as “Kohler Alternator Guard” in *Figure 2*.

Thus, the APM603 controller with UL 6200-listed integral alternator overcurrent protection does qualify as the “identified overcurrent protective means” in compliance with NEC 445.12(A).

As we know, UL 6200 is the standard for controllers for use in power production, e.g., generator sets. For more information, read the Kohler technical white paper #127: Comparing UL 6200 and UL 508 for Generator Controllers.

Figure 2



NEC 445.18 (B) FOR EMERGENCY SHUTDOWN OF PRIME MOVER

A mechanically resettable local E-stop push button mounted adjacent to APM603 controller, satisfies paragraphs (1) & (2) in this section.

An activation of E-stop triggers the following events in a generator set with APM603 controller:

- It takes away the ignition signal to the ECU. Thus, shutting down the fuel supply to the prime move. (As we know, the ECU controls fuel to the engine.)
- It takes away power to the engine crank relay.
- It also signals the APM603 to stop its run signal and provides an alarm.

NEC 445.18 (A) FOR DISCONNECTING MEANS

NEC445.18 (B) states that the provision 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 NEC 110.25. The mechanically resettable local E-stop push button with a padlock accessory satisfies this requirement. See *Figure 3*.

Figure 3

NEC 445.18 (C) FOR REMOTE EMERGENCY SHUTDOWN

NEC 445.18 (C) states that generator sets with greater than 15 kW rating (regardless of the type of system or installation) shall be provided with an additional requirement to shut down the prime mover. A standard remote-mounted E-stop push-button station, mounted outside the equipment room or generator enclosure satisfies this requirement.

NEC 445.18 Disconnection Means and Emergency Shutdown.

445.18(A) Disconnecting Means.
Generators other than cord-and-lag-connected portable generators shall have one of more disconnecting means. Each disconnecting means shall simultaneously open all associated ungrounded conductors. Each disconnection means shall be lockable open in accordance with 110.25.

445.18(B) Emergency 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 shutdown 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.

NEC 445.18 (E) FOR GENERATORS INSTALLED IN PARALLEL

It would be remiss to not investigate the validity of NEC 445.18 (A) Disconnecting Means and NEC 445.18 (B) Emergency Shutdown of Prime Mover with reference to paralleled generator sets. NEC 445.18 (E) states that the provision of 445.18 (A) for Disconnecting Means shall be capable of isolating the generator output terminal for the paralleling equipment. So, let's analyze how "breaker-free" paralleled generator sets meet the NEC 445.18 (A) requirement for Disconnecting Means.

The NEC 445.18 (E) code for paralleled generator sets clearly states that the disconnecting means shall not be required to be located at the generator. This means that paralleled generator set's emergency power system can be designed with paralleling breakers located in the paralleling switchgear- (or switchboard) and the generator sets can be still breaker-free.

NEC 445.18(E) Generator Installed in Parallel.
Where a generator is installed in parallel with other generators, the provisions of 445.18(A) shall be capable of isolating the generator output terminals from the paralleling equipment. The disconnecting means shall not be required to be located at the generator.

With a switchgear or switchboard-mounted mounted paralleling circuit breaker, compliance with NEC 445.18 (A) is still required with respect to the circuit breaker or switch being capable of being lockable in the open position. The E-stop push button with a padlock accessory fulfills this requirement. As described in the handbook, with a padlocked (activated) E-stop, the paralleling controls are designed to not close the paralleling circuit breaker. *"This protects a worker servicing a generator that is taken out of the parallel line-up from being exposed to a back feed at the output terminals of the generator set."* In another scenario of paralleled generator sets, when this E-stop is pressed it will shut down the generator set and signal the paralleling controls to open the corresponding paralleling circuit breaker. The same padlockable E-stop achieves compliance with NEC 445.18 (B) Emergency Shutdown of Prime Mover requirement installations as well.

NEC 240.21 (G) FOR CONDUCTORS FROM GENERATOR TERMINALS

NEC 240.21 (G) states that load cables originating from the generator set terminals that meet the size requirements in NEC 445.13 shall be permitted to protect against overload by the alternator overload protective device(s) required by NEC 445.12.

NEC 240.21(G) Conductors from Generator Terminals.
Conductors from generator terminals that meet the size requirement in 445.13 shall be permitted to be protected against overload by the generator overload protective devices(S) required by 445.12.

This means that the UL 6200-listed alternator overcurrent protection that is integral to the APM603 generator controller will protect load cables originating from the generator set terminals provided the load cables are sized per the NEC 445.13 guidelines.

NEC 445.13 Ampacity of Conductors.

445.13 (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 percent of the nameplate current rating of the generator.

NEC 240.87 FOR ARC-ENERGY REDUCTION

NEC 240.87 states various means to reduce the clearing time of circuit breakers that are rated or can be adjusted to 1200 A or higher.

The APM603 controller is certified under UL 6200 to be switched to the Arc-Energy-Reduction Maintenance mode. When a user activates this mode, the APM603 controller also offers a local status indicator.

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

240.87(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).
Documentation shall also be provided to demonstrate that the method chosen to reduce clearing time is set to operate at a value below the available arcing current.

240.87(B) Method to Reduce Clearing Time.
One of the following means shall be provided and shall be set to operate at less than the available current.

(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. Temporary adjustment of the instantaneous trip setting to achieve arc energy reduction shall not be permitted.
(6) An instantaneous override
(7) An approved equivalent means

UL 2200 SECTION 14 FOR OUTPUT POWER DISCONNECTION DEVICE

This section states that the generator set assembly shall be provided with *"an output disconnect device or a lockout switch that electrically isolates the generator assembly from other electrical energy sources and also prevents motoring."* It further states that *"the disconnect device may be a separate device that is installed with the generator or it may be integral to the generator."*

Among the numerous protections provided by the APM603 controller, the Reverse Power (32R) and the Overspeed (12) protections prevent motoring. In such scenarios with breaker-free generator sets, the paralleling circuit breaker located in the switchgear can be tripped open.

When one of the paralleled generator sets is out of service, the generator-mounted mechanically resettable E-stop can be activated to address the caution stated in the note of section 14.3. As required in section 14.3, a signal contact is also available through the APM603 controller to indicate that the generator set is out of service. As long as the E-stop of the generator set is active, the paralleling controls will prevent the switchgear-mounted corresponding paralleling circuit breaker from closing.

UL2200 Section 14 Output Power Disconnection Device

14.1 The generator assembly shall provide the following:

a) An output power disconnection device or a lockout switch that electrically isolates the generator assembly from other electrical energy sources and also prevents motoring and

b) Installation instructions that a disconnect shall be installed with the generator

NOTE: A disconnect means is required to be provided for an installed generator. The disconnect device may be a separate device that is installed with the generator or may be integral to the generator.

14.2 When a disconnect device is provided it shall:

a) Open all ground conductors;

b) Consist of either a manually or electrically operated switch or circuit breaker;

c) Employ an operating handle that is either accessible from outside of the enclosure or located under a door or hinged cover, and

d) Be marked in accordance with 93.15.

14.3 A signal contact shall be available to indicate that the generator assembly is out of service then the lockout switch is operated.

NOTE: A stationary engine generator assembly may operate be operated when the output disconnect is open therefore the generator assembly may not be out of service.

UL 2200 SECTION 33.3 FOR ALTERNATING CURRENT (AC) OUTPUT CIRCUITS PROTECTION

Section 33.3 states that the overcurrent protection device shall be a circuit breaker, fuse, or equivalent means.

The exception rule states that the overcurrent protection is not required to be provided with the generator set when the installation instructions specify the required overcurrent protection for the generator set.

Nonetheless, the KOHLER® APM603 generator set controller qualifies as the "equivalent means" as it is UL 6200-listed under two certified functions: EGC (Engine Generator Controls) and OCP (Overcurrent Protection).

UL2200 Section 33.3 Output Alternating Current Power Circuits:

33.3 1 An output circuit shall be provided with overcurrent protection for all ungrounded conductors as described in 33.3.3. The voltage rating of the overcurrent protection shall not be less than the rating of the circuit with which it is used. The overcurrent protection device shall be a circuit breaker, fuse or equivalent means intended for use as branch circuit protection and located within 7.62 meters (25 feet) of the generator output terminals.

Exception: The overcurrent protections is not required to be provided with the generator when the installation instructions specify the required overcurrent protection for the output power circuit.

33.3 2 The voltage rating specified in 33.3.1 for a 3-phase circuit shall be based on the phase-to-phase voltage.

33.3 3 The rating of the overcurrent protection shall not exceed the ampacity of the conductors intended to be connected to the generator as determined in accordance with 17.1.8.

BENEFITS OF BREAKER-FREE GENERATOR SETS

We learned that breaker-free generator sets can be code-compliant. What are the benefits of considering breaker-free generator sets on the project?

- The alternator overcurrent protection curve that is integral to the generator controller is meticulously aligned by the generator set manufacturer to protect the thermal damage curve of the alternator.
- The ready availability of this protection curve (e.g., KOHLER® Alternator Guard) in the widely used software programs, such as SKM, facilitates the engineer in the short circuit selective coordination study.
- The absence of the "instantaneous" region in the controller's alternator overcurrent protection curve allows the downstream breakers to trip, thus facilitating the selective coordination study by the engineer. Also, with the breaker-free generator set, the issue of a mismatch between the generator circuit breaker manufacturer and the downstream distribution switchgear manufacturer will not occur.
- Eliminating redundant generator set circuit breakers, particularly on large kW size generator sets (LV, MV, and HV applications) results in substantial cost savings.
- For large kW size generator set installations, the circuit breaker is mounted inside a freestanding switchgear that is placed adjacent to the generator set. Eliminating this freestanding and bulky switchgear results in a generator enclosure with a smaller footprint, which results in further cost savings. Even for indoor installations, where the real estate is tight, it can result in important space savings.

SUMMARY OF FEATURES AND ACCESSORIES REQUIRED ON BREAKER-FREE GENERATOR SETS

For breaker-free standalone or paralleled generator sets to be code-compliant, the recommended features and accessories that we discussed in this white paper are summarized below.

- The generator set controller with integral alternator overcurrent protection that is UL-listed.
- The generator set controller with an ERMS feature and a local status indication.
- A mechanically resettable E-stop push button with a padlock accessory.
- An output signal contact on the generator set controller to indicate that the generator set is out of service when the mechanically resettable E-stop is activated.
- For all stationary and portable (over 15 kW) generator sets, a marking on the nameplate that the generator is protected against the overload by inherent design (reference NEC 445.11 (4)).
- An E-stop push-button station mounted remotely i.e., outside the equipment room or generator enclosure.
- In the case of paralleled generator sets, the switchgear/switchboard-mounted generator paralleling circuit breakers will be electrically operated. When the E-stop is activated, it will signal the paralleling controls to prevent the closing of the paralleling circuit breaker.

NEC 445.11 Marking.

Each generator shall be provided with a nameplate giving the manufacturer's name, the rated frequency, the number of phases if ac, the rating in kilowatts or kilovolt-amperes, the power factor, the normal volts and amperes corresponding to the rating, the rated ambient temperature, and the rated temperature rise.

Nameplates or manufacturer's instructions shall provide the following information for all stationary generators and portable generators rated at more than 15 kW:

(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 generators, in lieu of the synchronous, subtransient, and transient reactances..

CONCLUSION

The idea of a circuit breaker-free generator set is not reassuring to everyone. However, with appropriate features and accessories, a breaker-free AC output generator set is not only code-compliant but it also offers necessary alternator overcurrent protection.

Ultimately one needs to analyze the benefits of a breaker-free generator set applicable to the project and make an informed decision with an open mind. As always, the downstream distribution system should be designed in compliance with the applicable code requirement and by following appropriate electrical system design principles.

Please contact your nearest KOHLER distributor if you are interested in further discussion on this topic.

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