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Design for safety and reliability – appropriate connection provisions for generator sets

White Paper

By Munir Kaderbhai, Sales Application Engineer

Standby electric generators provide a welcome measure of protection against a loss of power, but only if the generators are properly installed and applied. One of the most crucial installation concerns is the load conductors' connection to the generator set. The load conductors, their connection points and routing away from the generator set are the means to transfer energy from the emergency power source to the power distribution system. If the quality of these connections is jeopardized in any way, it can lead to safety hazards and make your emergency power source unreliable.

Priorities and options in generator connections

When reviewing the installation of your emergency power supply system, give top priority to proper electrical connections to the generator. You should ensure that the generator set is installed using appropriate provisions to allow a reliable, economical and safe connection.

There are several ways in which connections to the generator can be made, and several factors to keep in mind for proper connections, including alternator and conductor overload protection, disconnect requirements, conductor size and vibration. The goal of this paper is to highlight these factors and to provide recommendations for safe, durable and reliable load conductor connections.

Generator connection options

Power connections to a generator set may be made to generator-mounted circuit breakers or, when alternator and conductor overload protection is provided by a device such as AmpSentry™ Protective Relay, directly to the alternator terminals. In installations where there is no integral Underwriters Laboratory® (UL) Listed means of protection for the generator and its conductors, then connection to a circuit breaker (CB) is common. Protection requirements are detailed in National Electric Code (NEC) article 445.12.

Both molded case and insulated case CBs may be used for generator sets. Molded case breakers are typically mounted in a circuit breaker enclosure directly attached to the alternator. The CB box may house single or dual CBs depending on the application requirements. Insulated case CBs are typically larger and more sensitive to vibration. They are usually mounted in a freestanding enclosure next to the generator.

If connections are being made to the generator via a CB and if the CB does not include mechanical lugs, then the installer needs to provide lugs for customer connections. These lugs should be anti-rotational, to prevent the connections from loosening due to vibration or thermal expansion. It is important to verify that the number of conductors per phase and the conductors' size match the published lug quantities and capacities on the CBs. The lug set-screws should be tightened using torque values provided by the manufacturer, so that the cables are not damaged.

If the generator has UL Listed integral means of overload protection, oftentimes it's beneficial to remove the CB and make electrical connections directly to the generator set. Removing the breaker can make the task of selectively coordinating the overcurrent protection devices downstream less complicated, because then all of the CBs or fuses in the emergency system can be provided by a single supplier. Without a main CB on the generator, provisions to connect to the generator set are provided via an entrance box.

Top entry versus bottom entry

Conductors can be routed into the CB or entrance box through either the top or bottom surface of the box (Figure 1). If you are the system designer, you should specify on the facility drawings or in the specifications whether the intention is to top-connect or bottom-connect the generator set. Customer connection points inside the box will typically be provided to a bus bar. The bus bars must have NEMA two-hole patterns to comply with the UL connection requirements. This means that the conductors should be terminated using either compression or mechanical lugs and should be secured to the bus bars with proper fasteners.

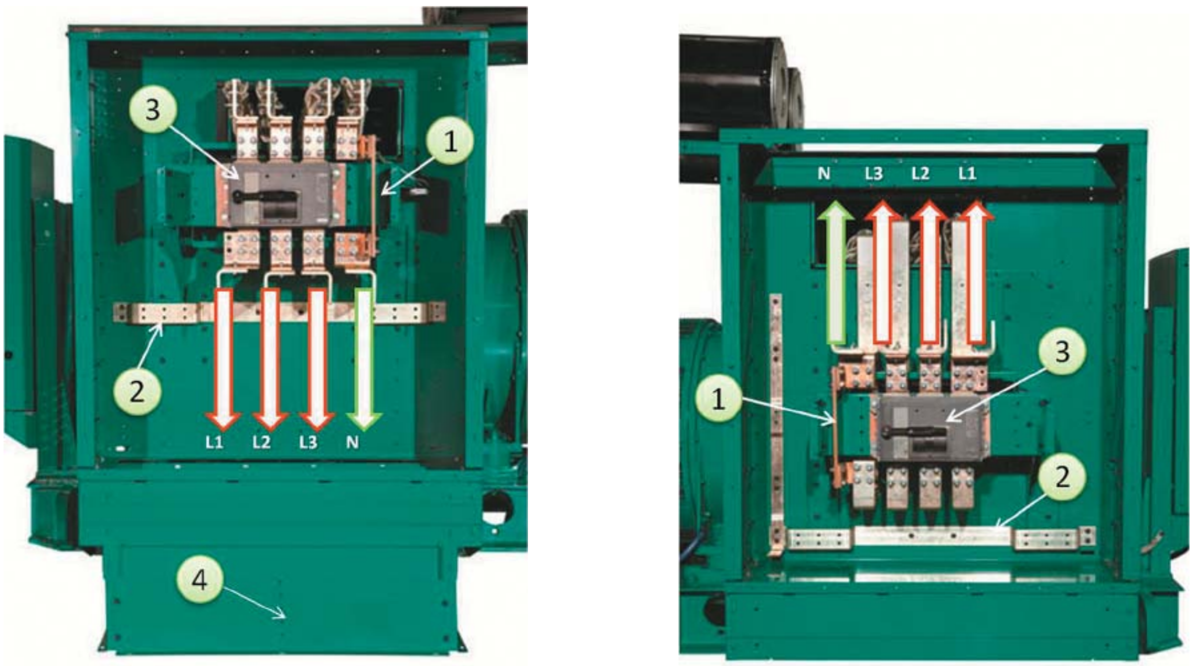

Figure 1 - Circuit breaker box (left – bottom entry; right – top entry) – 1) neutral disconnect link; 2) grounding bus; 3) circuit breaker; 4) bottom-entry chute.

UL and the NEC require mechanical protection for conductors. For top-entry installations, this protection is typically provided by conduit. These conduits must be flexible enough to handle generator set three-dimensional vibration; they typically have a 90° bend to help absorb vibration. For bottom-entry installations, conduits may be required, depending on the location of the electrical connection box. If the box is mounted on the alternator, then cables running from the stub-up area of the foundation and to the box cannot be left exposed to accidental contact by unqualified persons and must be protected with flexible conduits.

UL Listed 100% rated circuit breaker assembly

Circuit breaker manufacturers test their breakers to be able to handle 100% rated current for an unlimited time under standard test conditions per UL489. Under these test conditions, the CB is in free air and the ambient temperature is maintained at 40°C.

In typical installations, however, the CB will be housed in an enclosure, which can trap heat and increase the temperature inside the box if the enclosure is not adequately sized and ventilated. In thermomagnetic-type circuit breakers, if the temperature within the enclosure exceeds operational limits, it can cause nuisance tripping of the breaker. Therefore, for continuous loads, a typical CB assembly can be applied at only 80% of its rated current. This could mean that you will have to oversize your CB and its conductors in order to operate the generator set at or near its rated load for an extended period of time. All these factors can add cost and complexity to the installation.

The NEC has an exception to this rule, which allows CB assemblies to be rated at 100%. In contrast to standard rated (or 80% rated) CBs, 100% rated assemblies can carry 100% of the CB and conductor current rating. In order to be 100% rated, the equipment must undergo additional UL testing to ensure that the additional heat generated by running higher currents through the circuit will be safely dissipated and not cause a high temperature rise within the enclosure. UL489 specifies the minimum enclosure size and venting requirements for the CB box.

In addition to meeting these size requirements, the 100% rated assembly must also be labeled as such by the manufacturer [Figure 2 (1)]. Without this label, the assembly will be considered 80%, even if the box size and venting requirements are met.

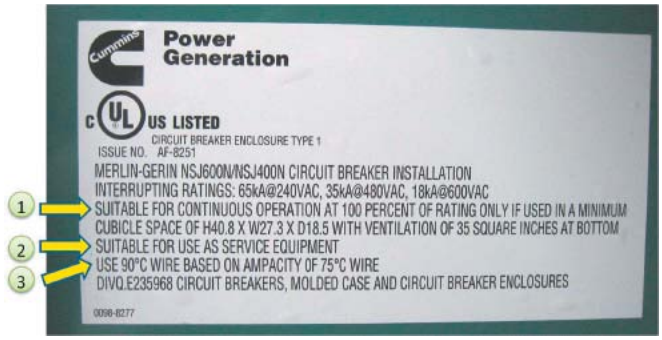

Figure 2 - (1) The 100% CB assembly must be labeled by the manufacturer as being 100% rated; (2) Equipment has to bear the marking "suitable for use as service equipment"; (3) Use 90°C rated conductors but size based on ampacity of 75°C.

Using a 100% rated CB assembly can allow the full rating of the breaker to be utilized, and may allow the use of a smaller CB frame size. This practice can help reduce the cost of the breaker and also reduce the amount of space occupied by the CB in the enclosure. The total required cable size may also be reduced, providing more room in the enclosure for the cables and making it easier to connect to the bus bars.

Outdoor generator compliance — service-rated equipment

NEC Article 225.31 requires a disconnect means for conductors that supply or pass through the building or structure. Article 225.36 states that the disconnect means referred to in 225.31 shall be suitable for use as service equipment. This requirement means that if you have an outdoor generator set, there has to be a service disconnect where the conductors enter the building, and the disconnect has to be a service entrance device. The NEC also requires each disconnecting means that is installed and used as a service disconnecting means to be identified as a service disconnecting means [See Figure 2(2)].

Where an outdoor-housed generator is equipped with readily accessible disconnection means located within the site of the building or structure supplied, an additional disconnecting means is not required where ungrounded conductors pass through the building [NEC Articles 700.12(B)(6), 701.12(B)(5), 702.11]. Note that the disconnection means must be suitable for use as service equipment and labeled as such.

Conduit and cable size

Conductors connected to the generator set's alternating current (AC) output should be sized as required by the load currents, the application and local electrical codes. The generator set manufacturer will typically specify line-line ampere ratings of a specific generator set for the specific voltage selected.

The NEC handbook provides guidelines for the ampacity of phase and neutral conductors connected to the generator set. Article 445.13 requires that the ampacity of conductors from the generator terminals to the first distribution device(s) containing overcurrent protection shall not be less than 115% of the nameplate rating of the generator set. The exception is for generator designs that have inherent means for preventing an overload condition. For that case, conductors can be rated at 100% of the nameplate current rating. NEC Article 310 covers general requirements for conductors and provides tables that can be used to help determine minimum conductor size.

In larger generator set applications, both the size and the number of the cables and conduits can get very large, so it is important to ensure that electrical connection boxes are sized appropriately, not only to accommodate the cables/conduits but also to provide adequate space for easy entry into the box. Most likely, you will have more than one cable/conduit per phase, so there should also be provisions in the entrance box for multiple conduits. For example, multiple punch-outs and liquid tight strain relief connectors are recommended. NEC Article 445.16 also requires that cables that pass though the opening in the enclosures be protected by bushings from openings with sharp edges.

As an example, consider a 2MW generator set that is rated at about 3000A at 480V. For a type RHW copper cable with temperature rating of 75°C and an ambient temperature of 30°C (86°F), the ampacity of a 750 kcmil given by Table 310.15(B)(16) in the NEC handbook is 475A. A total of eight cables will give a total current rating of 3800A. It is good practice to design for at least an ambient temperature of 40°C, which requires the use of a 0.88 correction factor from Table 310.15(B)(2)(a). This reduces the current rating to 3344A. An additional correction factor of 0.7 from Table 310.15(B)(3)(a) also must be applied if there are more than three cables bundled together per raceway/ conduit, dropping the capacity and current rating of the eight cables to 2340A.

This example demonstrates the fact that many large cables can be required to be able to use the full rated current output of the generator set. It also demonstrates the importance of ensuring that the electrical connection box not only allows entry for multiple cables but also has sufficient space and sufficiently large entrance holes to accommodate all these large cables. Having an adequately sized electrical connection box is important, because it provides adequate bend space for very large conductors and allows ease of installation for the electrician.

Bus bar temperature rise

Per UL2200 requirements, the temperature of a bus bar can be as high as 90°C over a 40°C ambient temperature. Therefore, it is sometimes recommended that the conductors connecting to the bus bars be 90°C rated. However, the conductors must still be sized using the 75°C column in 310.15(B)(16) in the NEC. This is because the terminations of electrical utilization equipment, such as CBs, panelboards and transfer switches, are rated for a maximum temperature of 75°C.

Regarding temperatures, note that there are two “flavors” of 100% rated CBs, which are defined by the temperature limits at the wire terminal connection. The temperature can either rise to a maximum temperature of 50°C at a 40°C ambient, or it may rise to a temperature of 60°C at the wire terminal connection at a 40°C ambient. If the temperature rise is below 50°C, then you may use a 75°C rated conductor sized to the 75°C chart. If the temperature rise is over 50°C but below 60°C, then you have to use a 90°C rated conductor sized to the 75°C chart. The manufacturer may specify that you use 90°C rated wire-based ampacity of 75°C wire [Figure 2(3)].

Bracing requirements

It is essential to have bracing and conductor spacing supports that are physically and electrically able to withstand expected mechanical forces and voltages. Short circuit currents can induce tremendous magnetic forces between conductors. If conductor bracing and supports are not adequate, there could be enough force to bend metals, to break insulators and to disconnect any connector terminations that are not securely fastened.

Generator sets are required by NFPA 110 to be short circuit tested, and one part of that testing is to validate the design of the electrical connection box. NFPA 110 section 5.2.3 (1) requires generators for Level 1 systems to be specifically designed, assembled and tested to ensure system operation under short circuits. Prototype tests must be performed by the manufacturer to verify that the generator can safely withstand the forces associated with short circuit conditions.

Proper entrance box design for handling generator set vibration

All generator sets vibrate during normal operation. Greater movement can also occur upon sudden load changes, fault events and/or during startup and shutdown. In most generators the engine and alternator — the main sources of vibration on the generator set — are mounted on the generator set skid. In some generator set designs, the electrical connection box will be mounted directly on the alternator, which means that electrical connections made within the box will also be subjected to these vibrations. If these forces of vibration are not mitigated, not only may rigid electrical connections fail, but vibration forces can also be transmitted by the stiff connections and cause damage to the generator set components. Electrical connection points on the generator — bushings, bus bars, terminal blocks, etc. — are not designed to absorb these stresses. Therefore, all electrical connections to the generator must be able to absorb the vibration movement and startup/shutdown movements.

The required solution is to use flexible interconnections for generator set AC power cables and conduits, so they are able to handle the vibration in all three dimensions, and the relative movement between the generator set and its foundation.[1] However, situations may arise where following such recommendations can add complexity and cost to the overall design.

For example, in high-range (1 MW and above), low-voltage (below 600V L-L) generator sets with large current outputs, the size of the conduits can become quite significant, making it more difficult to achieve the S-shaped bends required to handle the three-dimensional vibrations. This problem may be exacerbated if there is limited space available for bending the conduit. Limited space will make it difficult to fit, maneuver and bend the thick conduits, despite their flexibility.[2]

In some generator sets the electrical connection box is mounted directly onto the generator skid (Figure 3). This can be beneficial, especially if in-skid anti-vibration mounts (AVMs) are used between the engine/alternator and the skid. With in-skid AVMs, an electrical connection box connected directly to the skid will be isolated from the majority of the vibration generated by the engine/alternator. This, in turn, will help reduce vibration stresses at the electrical connection points, which are common points of failure. This approach may help make the generator more reliable. Note that generator sets with in-skid AVMs may still need under-skid isolation mounts, depending on local seismic requirements.

Another advantage of having the electrical connection box directly on the skid is that it will be closer to the foundation. Bottom-entry installations can cover exposed power leads rising through the stub-up area using either sheet metal ducts or chutes, which provide protection from potentially hazardous contact with power leads. This method allows cables to be run directly from the stub-up area into the entrance box,

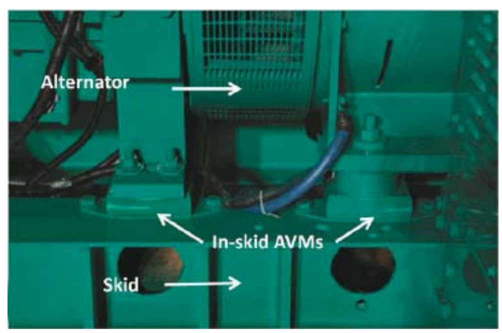

Figure 3 - Left: Generator set with skid-mounted circuit breaker box. Right: Detail showing in-skid anti-vibration mounts (AVMs).

[1]Refer to Power Topic #6011: Flexible interconnections for generator set AC power cables and conduits.
[2]For systems of 600V and above, NEC bending requirements outlined in Article 300.31 have to be considered.

About the author

Munir Kaderbhai, sales application engineering, joined Cummins Power Generation in 2010 as a point of contact for generator set sizing, codes and standards, transfer switches and general standby power systems application considerations. Munir has an M.S. in electrical engineering from North Dakota State University (Fargo, ND) and a dual B.A. degree in physics and mathematics from Concordia College (Moorhead, MN). Prior to joining Cummins, he held electronic design internships with a couple of construction and agricultural equipment manufacturers and also worked in R&D at the NDSU Center for Nanoscale Science & Engineering.

and cables are much easier to bend than conduits. Additionally, the metal plate at the bottom of the electrical connection box can be removed, making it even easier to route cables into the box. This approach reduces the cost and complexity of the installation while increasing reliability.

Conclusion

There are several options in making connections to the generator set, and several factors to keep in mind for proper cable termination:

- Power cable connections to a generator set may be terminated at the generator-mounted circuit breaker or made directly to the alternator terminals.
- If the generator has other means of overcurrent protection, then removing the circuit breaker altogether can be beneficial. However, it's important to ensure that the installation complies with all applicable NEC rules.
- Customers and system designers should work closely with the Authority Having Jurisdiction (AHJ) to ensure compliance with local codes.
- The generator electrical connection box should be large enough to accommodate large cables and provide cable-bending space if required.
- All electrical connections to the generator must be able to absorb vibration movements. Selecting a generator with a skid-mounted electrical connection box may help reduce vibration stresses at the electrical connection points and may also reduce cable-bending requirements.
- Proper design of the bracing and conductor spacing supports is essential, and therefore prototype test reports furnished by the generator set manufacturer should be carefully reviewed.
- The AC power supply interconnection to the generator set must be designed and validated to withstand damage due to forces of vibration induced by seismic forces. Some local authorities require third-party testing or certification of generator set design to validate seismic performance. These tests are performed to verify the generator set's electrical and mechanical system integrity.

Having a UL2200 Listed generator set is required by most AHJs and for good reason: It ensures that you are buying a product certified to meet stringent safety standards set by a nationally recognized testing agency and approved third party.

References

- ANSI/NFPA 70, National Electrical Code, 2011
- ANSI/NFPA 110, Generator Sets for Emergency and Standby Power Applications
- ANSI/NFPA 99, Health Care Facilities

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