

# Grounding of AC generators and switching the neutral in emergency and standby power systems

## > White paper

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This is the first part of a two part white paper. Part one addresses system grounding arrangements for AC generators used in emergency and standby systems. The methods of system grounding covered include solid grounding and high-resistance grounding, with additional discussion of systems that are ungrounded. The second part addresses switching the neutral conductor with 4-pole transfer switches where ground fault protection systems are provided on the normal power source and where ground fault indication is provided on the emergency/standby generator.

## System and equipment grounding

Careful consideration of the grounding arrangements of AC generators used in emergency and standby power systems is essential for optimum continuity of power for critical loads and for the safety of personnel. Specific considerations for emergency and standby systems include selection of a system grounding method for the generator, when to use four pole transfer switch equipment, requirements for indication only of a ground fault on the generator, and the methods used in transfer equipment for switching the neutral pole.

The term “grounding” describes and encompasses both systems grounding and equipment grounding. The basic difference between system and equipment grounding is that system grounding involves grounding circuit conductors that are current carrying under normal operation, where equipment grounding involves grounding of all non-current carrying metallic parts that

enclose the circuit conductors. A grounding electrode or several grounding electrodes tied together as a system provides the reference ground and the means for connection to earth.

System grounding refers to the intentional connection between a conductor of an AC power system and ground. The source of normal power for the system is typically a utility supplied transformer and the source of emergency or standby power is typically an owner-supplied on-site generator set. The power system conductor connected to ground becomes the grounded conductor, which is typically the neutral circuit conductor

### UTILITY SERVICE

#### System and Equipment Grounding Connections

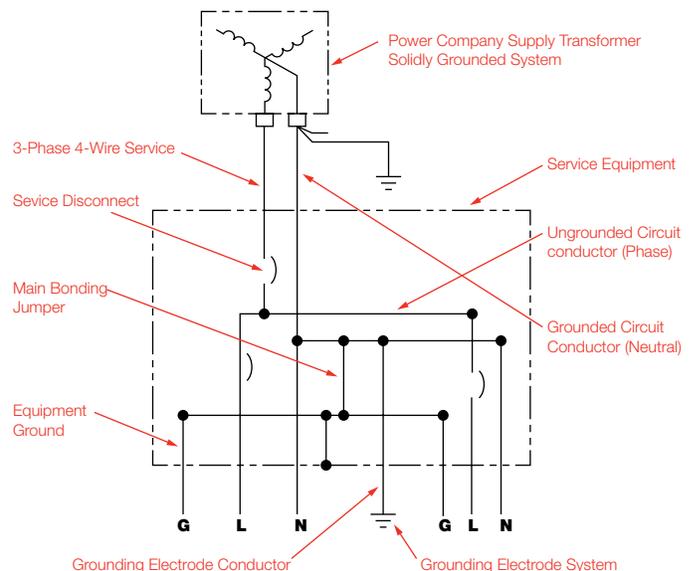


FIGURE 1

on a 3-phase 4-wire system. System grounding, in other words, describes the practice of grounding one conductor of an AC power system.

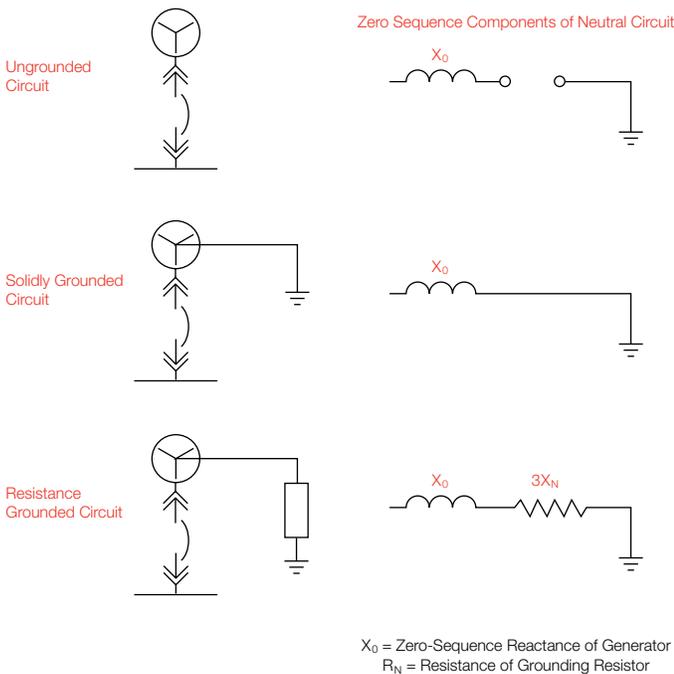
Equipment grounding refers to the bonding and grounding of all non-current carrying (during normal operation) metal conduit, equipment enclosures, supports, frames, etc. for current carrying circuit conductors and equipment. Equipment grounding contributes to personnel safety by limiting the voltage to ground on these metallic parts and reduces the hazard of electric shock. All of those metallic parts are bonded together to make an equal potential conductor. This provides a sufficiently low impedance path for ground fault current to flow back to the system power source, through a bonding jumper to the grounded circuit conductor (neutral) located at the service equipment. FIGURE 1 shows a solidly grounded utility service and identifies the grounded circuit conductor (neutral), the equipment ground, the main bonding jumper, the grounding electrode, and the grounding electrode conductor.

There are several types of system grounding typically in use for low voltage (600 volts and below) AC power systems. Three-phase electrical systems may be solidly grounded, impedance grounded, or ungrounded as shown schematically in FIGURE 2. Systems are solidly

grounded to limit the voltage to ground during normal operation and to prevent excessive voltages due to lightning, line surges, or unintentional contact with higher voltage lines. Solid system grounding also facilitates the automatic clearing of ground faults by circuit protective equipment (fuses and circuit breakers). The National Electrical Code, Article 250.20, requires AC power systems of 50-1000 V to be solidly grounded where the maximum voltage to ground on the ungrounded conductors will exceed 150 V. Systems that supply phase-to-neutral loads are also required to be solidly grounded. AC power systems that are not required to be solidly grounded may be solidly grounded, impedance grounded, or ungrounded. Systems are impedance grounded or ungrounded if it is desirable to limit the magnitude of ground fault current or minimize the interruption of power due to ground faults.

The National Electrical Code Article 250 defines the type of AC power systems to be grounded and the system grounding methods permitted, the circuit conductor to ground for various systems, the location of grounding connections, types and sizes of grounding conductors and electrodes, and methods of equipment grounding and bonding. The IEEE Green Book, Standard 142, contains useful reference information on system grounding factors in selecting a system grounding method and equipment grounding and methods. The IEEE Orange Book, Standard 446, contains a chapter of recommended practice that is specific to grounding of emergency and standby generator systems.

**SYSTEM GROUNDING METHODS**



**Solid system grounding**

The National Electrical Code requires commonly used low voltage (600 V and below) AC power systems that supply line to neutral loads to be solidly grounded including emergency standby generator, as follows:

- 120/240 volts, single phase, three wire;
- 208Y/120 volts, three phase, four wire;
- 480Y/277 volts, three phase, four wire;
- 120/240 volts, three phase, four wire delta and
- 347/600 volts, three phase, four wire.

A system is solidly grounded when the connection between the neutral and ground has been made without inserting any intentional impedance in the connection. In other words, a conductor specifically referred to as the grounding electrode conductor, sized according to 250.66 of the NEC™, connects the neutral or grounded circuit conductor of the system to a grounding electrode system, with only the negligible impedance of the grounding electrode conductor itself (and its terminations).

FIGURE 2



Solid grounding facilitates the automatic clearing of ground faults by circuit protective equipment (fuses and circuit breakers) because solid grounding results in the highest magnitude of ground fault current. The higher the fault current, the higher the probability that fuses and circuit breakers will operate in the “instantaneous” range. Note that in FIGURE 2 the generator reactance shown in series with ground is the zero sequence reactance. The zero sequence reactance is included with the positive and negative sequence reactance in calculations of the amount of ground fault current to flow. Reactance data is used because it should be readily available and will closely approximate the results from using the actual machine impedances. The zero sequence reactance is typically lower than the positive and negative sequence generator reactance which determine three phase and line to line fault currents. The first cycle (symmetrical) line to ground bolted fault current at the terminals of a solidly grounded generator is given by the equation:

$$I_g = \frac{3E_{LN}}{X_1 + X_2 + X_0}$$

- $X_1$  is the Direct Axis Subtransient Reactance.
- $X_2$  is the Negative Sequence Reactance.
- $X_0$  is the Zero Sequence Reactance.

For example, using typical generator reactance, a bolted three phase fault near the generator terminals may result in an initial symmetrical current of 11.6 times the generator rated current, where a bolted L-G fault on a solidly grounded system may result in 12.6 times rated current initially due to the zero sequence reactance term in the equation.

### Impedance grounding (high resistance)

In addition to solid grounding, there are several types of impedance grounding where an intentional impedance, resistance or reactance, is inserted in the ground circuit. The most common impedance ground used, 600VAC and below, is high resistance grounding. A system is high resistance grounded when the connection between the neutral and ground has been made with intentional impedance (grounding resistor) in the connection. The neutral resistance is selected to limit the ground fault current that can flow to a level sufficient to pick up ground fault detection relays. One of the reasons for using a high resistance grounding system is that no trip is required on the first ground fault. The ground fault current, being limited by the resistor to a low value can be tolerated for some time, so that continuity of power to the critical load may be maintained until such time as the first ground fault can

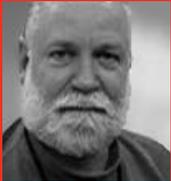
be corrected in a planned manner. High resistance grounding permits continuity of power with the first ground fault, but subsequent ground faults will result in a high magnitude phase to phase fault current that will operate the phase over current devices and power would be lost. Other reasons for high resistance system grounding are that system overvoltages are held to acceptable levels during ground faults, and the potentially destructive effects of arcing ground faults that occur in high capacity, solidly grounded systems are reduced or eliminated.

The 1987 NEC was the first edition to include a change the: permits use of high resistance grounding of three phase AC systems of 480 volts to 1000 volts that do not serve L-N loads, and where several other conditions are also met. These conditions include: only qualified personnel will service the system, continuity of power is required, and ground fault detection is installed. High resistance grounded systems are commonly found in industrial facilities supplying power to critical processes. Most typical low voltage emergency standby systems are required to serve line to neutral loads. The generator windings are wye connected and the neutral is brought out for use as a circuit conductor. In this case the generator would not be permitted to be high resistance grounded. However, where line to neutral loads need not be served, or where delta-wye isolation transformers are used to derive a neutral for L-N loads, a 480 volt 3-phase 3-wire generator may be high resistance grounded. In such applications meeting the conditions set down by the NEC, the advantages of high resistance grounding would be gained in terms of continuity of service with a single ground fault.

### Ungrounded

A power system not having any intentional connection to ground is referred to as an ungrounded system. However, because of the capacitive coupling between the phase conductors and ground, an ungrounded system is in reality grounded through the distributed capacitance of the system conductors to ground. A line to ground fault on an ungrounded system cause a very small ground fault current to flow through the capacitance of cables, transformers, and other electrical equipment on the system. Thus, ungrounded systems are designed to operate such that phase overcurrent devices do not trip for the first phase to ground fault. If a second ground fault occurs on another phase, the result is a line to line fault with high fault current. The relatively high current of the L-L fault should trip phase overcurrent devices, as it would with the high resistance grounded system.

### About the author



Lawrence A. Bey is a Senior Sales Engineer and a 1978 University of Minnesota graduate. Larry has been a Cummins Power Generation employee and a CPG Distributor Sales Engineer for a total of 29 years. Larry represents Cummins Power Generation on Technical Committees of the National Fire Protection Association for NFPA 110 Emergency and Standby Power Systems, NFPA 99

Essential Electrical Systems for Health Care Facilities, and CMP 20 of the National Electrical Code. Larry also represents Cummins Power Generation on the Canadian Standards Association for Emergency Power Supply Systems. Larry is active with the National Electrical Manufacturers Association (NEMA) on the Automatic Transfer Switch Subcommittee. He has written articles for industry publications on grounding of generators, overload protection of generators, as well as starting motors from generators.

### UNGROUNDED SYSTEM

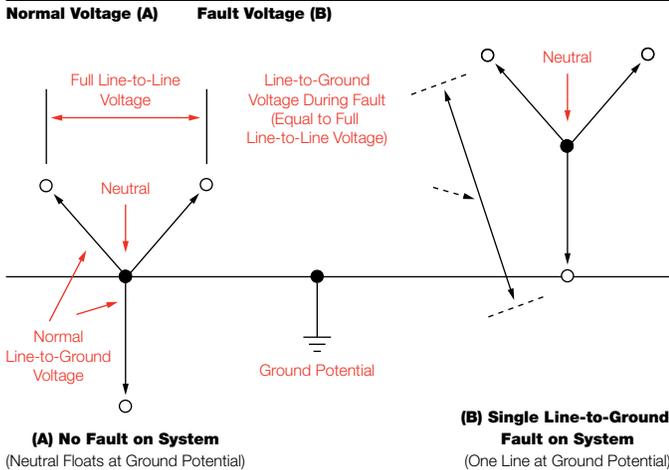


FIGURE 3

When the neutral of a system is not grounded, a ground fault on one line causes full line to line voltage throughout the system, between ground and the two unfaulted phases. This voltage is 73% higher than normal as shown in FIGURE 3. Usually the insulation between each line and ground is adequate to withstand full line to line voltage. However, if the insulation has deteriorated and the overvoltage is sustained sufficiently long, a second ground fault may occur due to insulation failure. In spite of these considerations, ungrounded systems may be used to gain an additional degree of service continuity.

### Summary

The method of system grounding used has a significant effect on the continuity of power to critical loads under ground fault conditions. Solidly grounded systems provide the highest ground fault current to facilitate clearing of circuit protective devices. A line to ground fault generally results in an immediate operation of the circuit breaker or fuse and continuity of power to the load is lost. Most low voltage power systems are required by the National Electrical Code to be solidly grounded. High resistance or ungrounded systems may be used where permitted and continuity of power to the load with a single ground fault is desired.

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