Grounding & Bonding; Temporary Power Generation and Electrical Distribution

Based on the 2017 National Electrical Code

> *"Grounding, bonding and the creation of an effective ground fault current path is the backbone of electrical safety and shock prevention in temporary power generation and electrical distribution system installations"*

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By: Steven S. Gibson, CESCP

MULTIQUIP

Table of Contents

Abstract

The subject of grounding and bonding can be confusing this is especially true for portable and vehicle (trailer) mounted generators used in the field to supply temporary/emergency power for applications such as construction, industrial, special events and emergency power during disasters. The terms ***Grounding***, ***Ground***, ***Grounded, Bonding***, and **Ground Fault Current Path** and their respective purpose within the electrical system are frequently intertwined and used incorrectly**.** Many field technicians and electricians mistakenly interchange these terms which further confuses the concept which can lead to improper and unsafe installation of temporary electrical systems.

The main reason for the grounding and bonding system is safety of personnel and property. Improper installation of the grounding and bonding system can result in accidental injury or death from electrocution, improper operation of the overcurrent protective devices, electrical equipment, and extensive equipment damage and possibly fires.

This paper using simple terms and examples will discuss the grounding and bonding system as it relates to both permanent and temporary electrical system installations, specific components of the system, there function and the requirements of the National Electrical Code (NEC). This paper will also discuss NEC terminology, relationship between effective low impedance ground fault current path and the operation of the overcurrent protection device, separately derived systems, available short-circuit current, the relationship of the grounding & bonding system to safety, and hopefully clear-up any misunderstandings or confusion surrounding grounding and bonding of generators.

The Grounding & Bonding System

The term ground and grounding are frequently misapplied. Some refer to ground as a common reference point within the electrical system or as the return path for current flow to operate the overcurrent protection device if a fault current event should occur which is not what the ground is intended for. The terms ground, grounding and grounded as defined by the National Electrical Code refer to earth or a connection to earth.

The purpose of system grounding is to intentionally connect the neutral point of an electrical system and the equipment grounding conductor to earth in a manner that controls voltage with respect to earth to within predictable limits. [1] Grounding (connecting) to earth through an approved grounding electrode system (example; ground rod) as outlined in NEC 250.52(A)(2) through (A)(8) serves an important function within the electrical system. The electrical system is intentionally grounded (connected) to earth in a specific manner to limit the voltage imposed by direct or indirect lightning strikes, line surges, or unintentional contact with higher voltage lines and the earth connection is also used to stabilize the voltage to earth during normal operations 250.4(A)(1).

For practical electrical systems the earth or ground potential is usually considered zero or near zero. When there is a potential difference in charges between two points in an electrical circuit expressed in volts current flow in the circuit can occur. Connecting to earth and creating a zero reference or zero potential difference eliminates touch potential between conductive surfaces and the earth in theory but is still based on the contact resistance of the earth. [2]

Earthing or grounding (connecting) to earth is not intended to be used as a ground- fault current path for fault detection and/or as a means of operating the overcurrent protection device (circuit breaker or fuse) to clear faults. Earth is conductive to a certain extent but because of soil resistivity it should never be considered as an effective path for ground-fault current to effectively operate or trigger an

[1] IEEE Std 142 (2007) IEEE Green Book

[2] ProSpex (2006) Electrical System Bonding and Grounding

overcurrent protective device (OCPD) if a short-circuit or line-to-ground should occur 250.4(A)(5).

The purpose of **bonding** is to join metallic parts together to form a conductive path that ensures electrical continuity and has the capacity to conduct safely any current likely to be imposed. Bonding metallic parts together equalizes any potential difference or touch potential between metal surfaces to eliminate the flow of current and it eliminates any buildup of static charges that have the potential to cause damage to sensitive equipment. All metal surfaces, enclosures, metal structures that are likely to come in contact with or become energized if a fault occurs should be bonded together and to the grounded (neutral) conductor and equipment grounding conductor to form a path for fault current to travel back to source. The bonding of metal components is not designed nor intended to carry current under normal operating conditions, but it must be able to safely do so in the event of a short circuit or ground-fault current is imposed on it. [3]

Since all metal parts are bonded together to create conductivity and continuity in the event of a ground-fault the current will try to flow back to earth or supply source though the least path of resistance. The **equipment grounding conductor** is a wire specifically sized that connects non-current carrying metal parts such as enclosures, metal frames of equipment, appliances, motors, etc. back to the grounded (neutral) conductor and/or grounding electrode conductor or both. The function of the equipment grounding conductor is to intentionally create an effective low impedance path to allow fault current to travel back to the electrical source to properly operate the overcurrent protective device to clear the fault without causing major damage to the system. According to informational note 1# Article 100 of the NEC the equipment grounding conductor can also perform the function of bonding.[4]

Figure 1

Safety

Often installation of power generation and temporary power distribution equipment (Figure 1) on construction sites, industrial facilities and special event venues are viewed by electricians and technician as “Anything Goes”. Temporary electrical installations on construction sites are commonly the most cited by OSHA during routine and focused inspections. Three of the 10 most cited violations in building construction are related to electrical requirements: *1926.451 General Requirements*, *1926.405 Wiring Methods, Components and Equipment for General Use*, and *1926.404 Wiring Design and Protection*.[5] See figure 1-A for an example of temporary electrical system.

Figure 1-A

Electricity doesn’t distinguish between permanent or temporary installations that is why the same installation practices and workmanship apply to

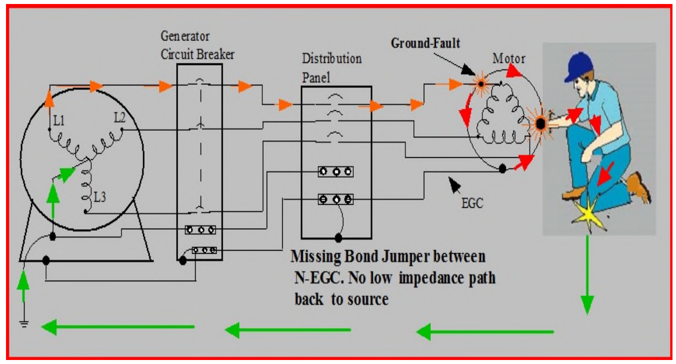
[3] ProSpex (2006) Electrical System Bonding and Grounding
[4] Article 100 (2017) National Electrical Code
[5] Wheeler, W.L. (2016) Temporary Electrical Power, Keeping it Safe!

both with a heavy emphasis on temporary because the electrical system is more exposed to the public. Grounding, bonding and the creation of an effective ground fault current path are critical aspects of the electrical protective system. Bonding of metallic parts, enclosures and the equipment grounding conductor (which also serves as a means of bonding) create an effective ground fault current path coupled with the overcurrent protection system clears potentially dangerous shorts circuits and ground-faults which can prevent and/or minimize the potential for shock, electrocution and fires from unintentional dangerous voltages on metallic parts in contact with the temporary electrical system.

All metallic components and parts that can come in contact with or are part of the temporary electrical system are bonded together to create conductivity and continuity. The equipment grounding conductor is connected between the equipment enclosures, frames, appliance, motors etc. back to the grounded conductor (neutral) to intentionally create a low impedance fault current path to promptly operate the overcurrent protection device in the event a ground fault should occur.

The proper operation of the overcurrent protection device when a fault occurs is dependent on the current in the circuit rising quickly and have a high enough value to be detected by the OCPD so that it can properly operate and promptly open to remove the voltage in the circuit.

When considering system short-circuit protection it is important to understand the maximum available fault current that can flow in a circuit to properly operate the overcurrent device. Generally, the amount of fault current available in the circuit of a temporary electrical system is based on the impedance of the supplying transformer and/or the reactance of the generator. [6] Please note; higher available fault current also means higher arcing current which has a direct impact on the level of PPE required by personel working near or on energized temporary electrical systems.



Example Figure 1-B

The preceding diagram demonstrates a short occurring between a phase conductor and the frame of the motor. The grounding system was improperly installed, the neutral is grounded to earth but it is not connected to the equipment grounding conductor (missing system bonding jumper). There is not an effective low resistance path back to source to clear the fault, the frame remains energized since earth is not an effective ground fault-current path. The worker touches the frame and completes the path when his knee touches the ground (earth) which causes current to flow though the worker due to the potential difference. The current flowing through the worker to earth, back to the ground rod, and then to source is not high enough to operate the overcurrent device. In this example improper installation of the bonding jumper causes a shock and possibly electrocution to the worker.

Conductor Identification;

Major Aspect of Safety

A very important safety aspect of the installation of temporary electrical distribution systems is the proper identification of conductors. Improper conductor identification can lead to metal frames and enclosures becoming energized, Line to ground or line to line shorts which create the potential for shock, electrocution, arc flash and extensive damage to equipment.

[6] Pfeiffer, J. (2001) Principles of Electrical Grounding

Per 200.6(A) the insulated grounded (neutral) conductor 6awg or smaller shall be identified by one of the following means;

(1) Continuous white outer finish

(2) Continuous grey outer finish

Per 200.6 (B) the grounded conductor (Neutral) Sizes 4 AWG or larger shall be identified by one of the following means;[7]

(1) Continuous white outer finish

(2) Continuous grey outer finish

(3) Three continuous white or grey stripes along the conductor entire length

(4) At time of installation, grey or white marking at its termination. Marking shall encircle the conductor or insulation.

Grounded conductor of different systems such as one system rated at 480V suppling power to temporary high voltage lighting equipment and another system rated at 208V suppling temporary low voltage distribution installed in proximity of each other, bundled together or in the same cable ramp shall have the grounded conductor identified and distinguishable by system 200.6(D).[8] Example: 480V system the neutral marked with grey phase tape and the neutral of the 208V system marked with white phase tape.

Equipment grounding conductor 6awg or smaller must have a continuous outer finish either green or green with one or more yellow stripes per 250.119.[9] Insulated equipment grounding conductor 4 AWG or larger can be permanently reidentified with green marking tape at the time of installation at every point where the conductor is accessible and at the conductor ends per 250.119(A).[10]

Per 215.12 (C) **Ungrounded (Phase) Conductors** shall be identified by one of the following means;

(1) Feeders supplied from more than one voltage system, each ungrounded conductor at all termination, connection and splice point must be identified by phase or line and system, in accordance with (a) and (b)

(a) Identified by color coding, marking tape, tagging, or other means approved by the authority having jurisdiction.

(b) Such identification must be documented in a manner that is readily available.

Using marking tape, each conductor should be taped 3” to 6” for greater visibility.

Industry best practice color code system for power and lighting conductor identification:

- 120/240V single-phase — black, red, and white
- 120/208V, 3-phase — black, red, blue, and white
- 120/240V, 3-phase — black, orange, blue, and white
- 277/480V, 3-phase — brown, orange, yellow, and gray; or, brown, purple, yellow, and gray.

When installing temporary conductors in the field it is important to clearly mark the conductors prior to installation to eliminate incorrectly marking the ends of the conductors after installation which can cause a short circuit when system is energized. Example: 50’ - 4/0, one end marked green and the other marked orange.

Comment: Inspectors view flexible cords and cable with Camlok connectors with caution because they are not attachment plugs or receptacles.[11] These types of single cables are required to be 2AWG or larger and rated for extra-hard usage see Article 400 for flexible cords and cable. When using Camlok

[7] Article 200 (2017) National Electrical Code
[8] Article 200 (2017) National Electrical Code
[9] Article 250(2017) National Electrical Code
[10] Article 250 (2017) National Electrical Code
[11] Sampson, Marcus (2012) Electrical Inspections for Carnivals, Fairs and Traveling Shows

cable pay special attention to Article 525.22(D) and the rules of 530.22. [12] Installation and use of these types of cords and cable as a temporary wiring method require protection from physical damage such as the use of cable ramps per 525.20(G).

When using temporary wiring methods that include the use of flexible cords and cable it is a requirement upon completion of the installation that the continuity of the equipment grounding conductor be verified per 525.32 to provide assurance of conductivity and continuity between the source and equipment, frames, enclosures and metal surfaces to ensure touch potential is eliminated and a complete path back to source is established for fault current to travel, rise quickly and properly operate the overcurrent protection device if a fault should occur. This is especially important since most of these types of venues and temporary electrical systems installations are exposed to the public.

Prior to any installation of electrical equipment supplies power to special event venues and similar events it is highly recommended the technician(s), electricians or project management become familiar with the NEC, grounding, bonding and especially Article 525 to ensure proper installation of equipment while always keeping public safety in mind.

Coming to terms with NEC Article 250

Grounding & Bonding

Bonded. *Non-electrical metallic parts* connected to establish electrical continuity and conductivity.[13] The joining of metallic parts together to form an electrically conductive path.

Bonding**.** Is a method which all electrically conductive materials and metallic surfaces of equipment and structures not normally intended to be energized are effectively interconnected together normally through a conductor to provide a low impedance path back to source, to avoid any appreciable potential difference between any separate points (250.4(A)(3).[14] Bonding should be designed in a way that provides a low impedance path for fault current to travel back to source to properly operate the OCPD.

The safety aspect of effective bonding is to minimize or eliminate potential difference between non-current carrying metallic surfaces within the electrical system. Bond provides zero reference to eliminate touch potential in case a fault should occur.

Bonding Jumper, System**.** A conductor installed between the grounded (neutral) conductor and the equipment grounding conductor at a separately derived system (generator or transformer) to ensure electrical continuity and has the capacity to conduct safely any fault current likely to be imposed. The system bonding jumper is sized per Table 250.102(C)(1) and based on the largest ungrounded phase conductor. Pay close attention to the notes listed at the bottom of the table.

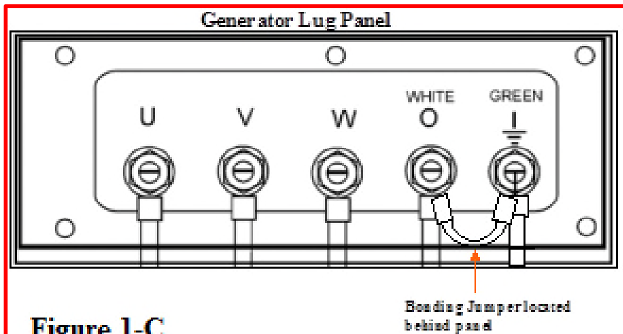


Figure 1-C

Comment; The primary function of the system bonding jumper is to complete the connection (path) between the source grounded conductor and the equipment grounding conductor at the separately derive system so phase-to-ground fault current can travel back to source to properly operate the OCPD and clear the fault .[15] In temporary power distribution projects supplied by a

[12] Sampson, Marcus (2012) Electrical Inspections for Carnivals, Fairs and Traveling Shows
[13] Article 100 (2017) National Electrical Code
[14] Waterer, F. (2012) Effective bonding, grounding: The backbone of electrical safety
[15] EP Editorial Staff (2011) Bonding and Grounding Issues in Power Distribution Systems

portable or vehicle (trailer) mounted generator the bonding jumper connecting the neutral to the equipment grounding conductor and to frame and/or earth is typically located in the generator enclosure at the output lug panel. The bonding jumper is part of the effective ground-fault current path to allow fault current travel back to source to properly operate the overcurrent protection device to clear the fault (refer to figure 1-C#). The bonding jumper should be installed in one location such as the main distribution panel or at the power source (generator or transformer secondary). It should never be located at both locations or on the load side of the distribution panel. Multiple neutral to equipment grounding conductor bonds can creates a parallel path for fault current to travel which may not properly operate the OCPD and may subject the system to objectionable current.

Effective Ground - Fault Current Path*.* Electrical equipment, wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low impedance circuit that facilitates the proper operation of the overcurrent device. The low impedance path shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where the ground fault may occur back to the electrical supply source. 250.4(A)(5).[16] *See Figure 2#.*

An intentionally constructed, low-impedance path designed to carry ground-fault current from the point of the line to ground (frame) fault on the wiring system back to the supply source. This low impedance path based on ohm law, when a fault occurs will create a high enough current surge in the system to be detected and facilitate the operation of the overcurrent protection device. ***The "earth" shall not be considered as an effective ground-fault current path 250.4(A)(5)***

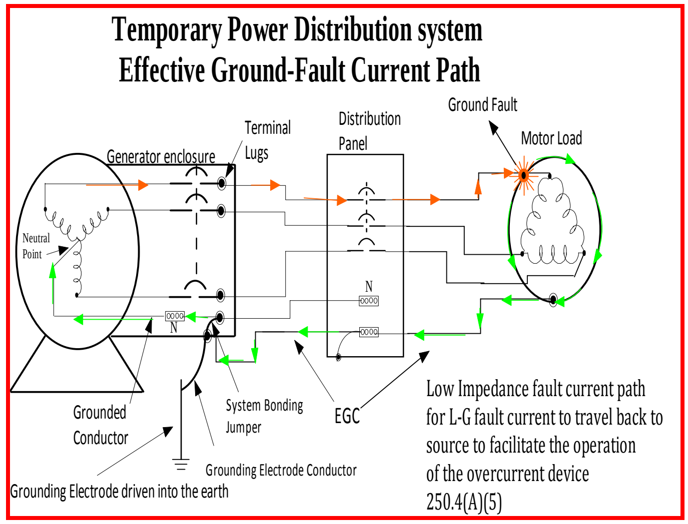


Figure 2

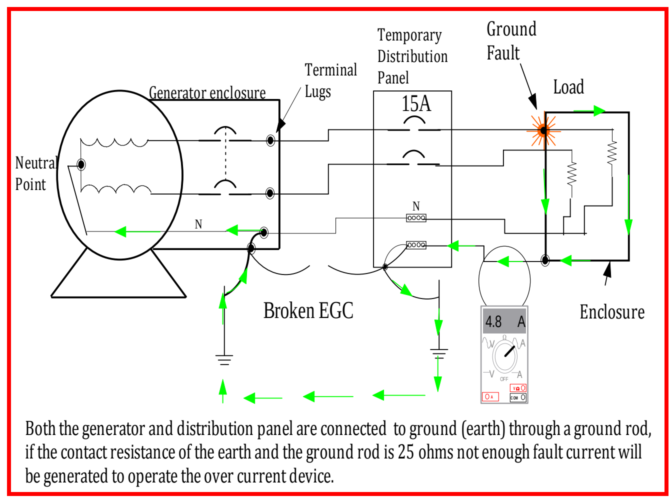


Figure 2-A

Example; *Figure 2-A the energized conductor is shorted to the enclosure unfortunately, the equipment grounding conductor is broke so the only return path for fault current to travel back to source is through earth. If the contact resistance through earth to the grounding electrodes is 25 ohms, then mathematically the fault current generated is not high enough to properly operate the 20A overcurrent device.* Contact resistance of the grounding electrode to earth is 25Ω ohms. Ohms law (I = E/R) 120V / 25Ω = 4.8 amps.

[16] Article 250 (2017) National Electrical Code, page 70-104

The amount of ground fault current generated is not enough magnitude to operate the 20-amp circuit breaker located in the distribution panel.

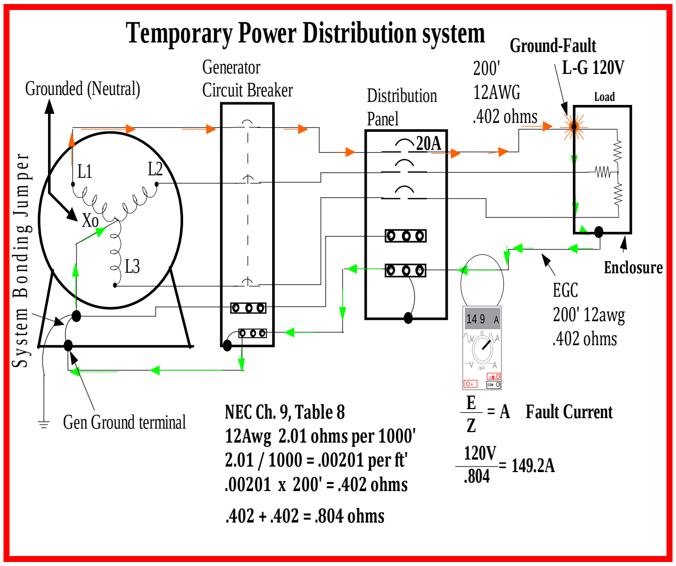


Figure 2-B (Example Only)

Figure 2-A demonstrates mathematically earth is not an effective ground- fault current path. Figure 2-B demonstrates the effectiveness of creating a low impedance fault current path back to source. Based on the impedance of the circuit 149 amps of fault current is generated when the ground-fault occurs which is enough to operate the 20A single pole breaker.

The illustration is an example, for a more detail method of calculating system short-circuit current refer to; Bulletin EDP-1 (2004) Engineering Dependable Protection For an Electrical Distribution System, Part 1, A Simple Approach to Short- Circuit Calculations. Cooper-Bussmann.

Ground. NEC defines ground as the earth.[17] IEEE 142 defines ground as a conducting connection intentional or accidental between an electrical circuit or equipment and the earth, or to some other body that serves in place of the earth.[18]

Comment: A good example of a conductive body that serves in place of the earth is a portable or vehicle (trailer) mounted generator. Under specific condition of uses NEC 250.34 permits the generator frame to be used in place of earth.

Ground Fault. An unintentional electrically conductive connection between an ungrounded (phase) conductor and the normally non-current carrying conductors, metal parts of enclosures, equipment, or earth.[19]

Ground-Fault Circuit Interrupter (GFCI) A device intended for the protection of personnel that functions to deenergize a circuit within an established period when a current to ground exceeds the value established for a Class A device. A Class A device trips when the current to ground exceed 5ma or higher. For information of GFCI see UL 943, Standard for Ground-Fault Circuit Interrupters.

Comment: All 125-volt, single-phase 15-, 20-, and 30-ampere receptacles that are not part of the permanent wiring of a building or structure and are in use by personnel shall have ground-fault circuit interrupter protection 590.6(A)(1). All receptacles in used for outdoor use by personnel shall be GFCI protected. If the GFCI and the branch circuit supplying the receptacle utilize a portable cord the GFCI shall be listed, labeled and identified for portable use 525.23(D).

Grounded (Grounding) Connected to ground (earth) or to a conductive body that extends the ground connection.[20]

Grounded Conductor. A system or circuit conductor (normally the neutral) that is intentionally grounded (Connected to Earth).[21] The grounded conductor is sized in accordance with Table 250.102(C)(1).

[17] Article 100 (2017) National Electrical Code
[18] IEEE Std 142 (2007) IEEE Green Book
[19] Article 100 (2017) National Electrical Code
[20] Article 100 (2017) National Electrical Code
[21] Article 100 (2017) National Electrical Code

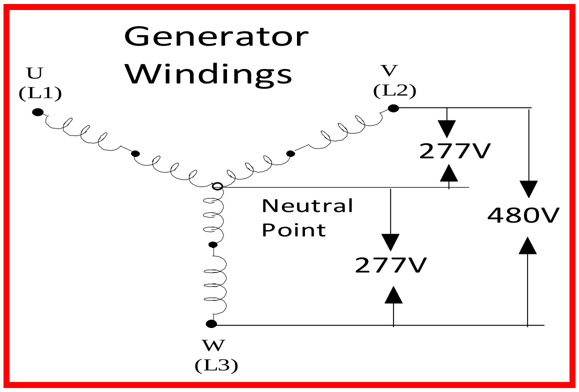


Figure 3

Neutral Conductor. The conductor connected to the neutral point of a system that's intended to carry current under normal conditions.[22] See Figure 3#.

Grounding Conductor, Equipment (EGC). The conductive path(s) that provides a ground-fault current path and connects normally non-current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor or both. Article 100 definitions, *Informational note No.1*: It is recognized that the equipment grounding conductor also performs bonding.[23] The equipment grounding conductor is sized per Table 250.122 and is based on the size of the overcurrent device.

Example: A 6/4 SOO 50A spider box cord, the green grounding wire is actually a bond wire that bonds the metal frame of the spider box back to source to ensure there are no potential difference. The grounding wire does not carry current under normal operating conditions. Its primary purpose is to carry electrical current only under short circuit or ground-fault conditions that would be potentially dangerous. The equipment grounding wire serves as the primary path for the fault current to flow back to source to properly operate the OCPD and remove dangerous voltages from unintentional energization of metallic surfaces, frames or electrical enclosures.

Solidly Grounded System. An electrical power-supply system such as a generator that has the neutral directly connected to ground (earth) without inserting any resistors or impedance devices between the system and earth.[24]

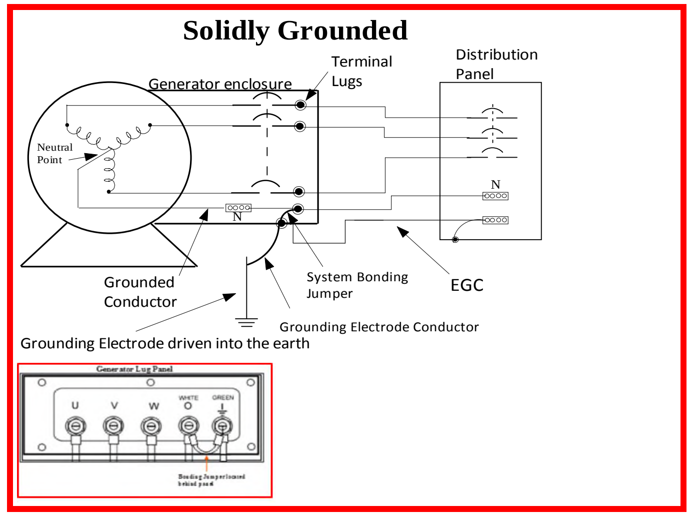


Figure 4

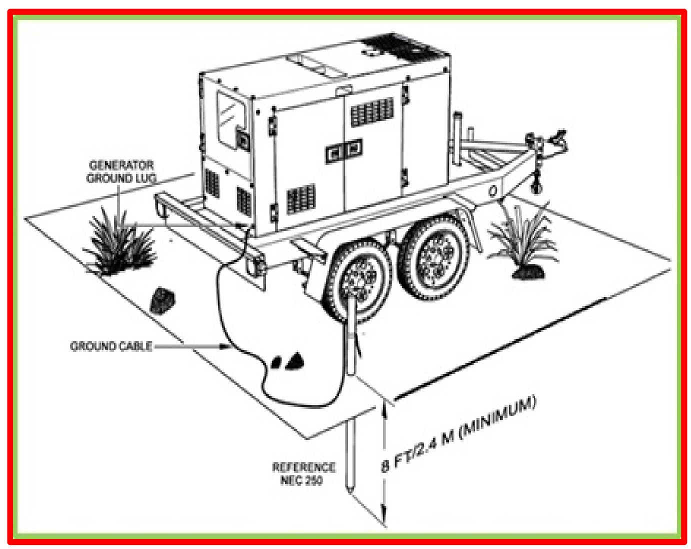


Figure 4-A

Grounding Electrode. A conducting object through which a direct connection to earth is established.[25] Example: Metal underground water pipe, concrete encased electrode (rebar), ground ring, ground plate and ground rod. Most common electrode used

[22] Article 100 (2017) National Electrical Code
[23] Article 100 (2017) National Electrical Code, p.70-37
[24] Csanyi, E. (2015) When to use a solidly grounded system?
[25] Article 100 (2017) National Electrical Code

with temporary generators is the ground rod electrode.

Ground rod installation requirements; 250.53(G) See Figure 5#

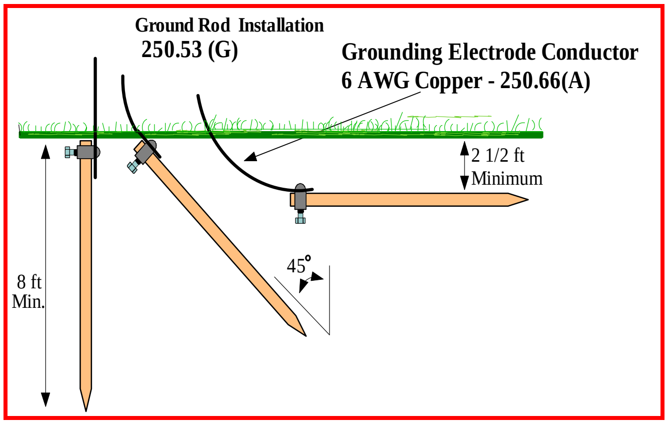


Figure 5#

Grounding Electrode Conductor. A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.[26] Grounding electrode conductor is sized in accordance with 250.66.

Comment: Pay close attention to 250.52 Grounding Electrodes, 250.53 Grounding Electrode System Installation and 250.66 Size of Alternating-Current Grounding Electrode Conductor. These articles intertwine with each other and can be misinterpeted.

Example 1#: Grounding electrode conductor is sized per table 250.66 except as permitted in 250.66(A) through (C). 250.66(A) If the grounding electrode conductor connects to a rod, pipe or plate electrode and does not extend to other types of electrodes that require larger conductors then the grounding electrode conductor shall not be required to be larger than a 6 AWG copper conductor.

Example 2#: 250.53(A)(2) a single rod, pipe, or plate electrode shall be supplemented by an additional electrode of a type specified in 250.52(A)(2) through (A)(8) which basically means when a generator is required to be grounded (connected) to earth then you have to install two or more ground rods. Please read the exception listed at the bottom of 250.53(A)(2) *"Exception: If a single rod, pipe, or plate electrode has a resistance to earth of 25 ohms or less, the supplemental electrode shall not be required."*

The complexity surounding earth grounding, what costitutes a good ground and what resistance values are exceptable has been discussed and studied for years. Ideally a ground should achieve a value of zero ohms. NFPA and IEEE have recommended a contact resistance of 5 ohms or less. [27] NEC 250.53(A)(2) Exception – if a grounding electrode has a resistance to earth of 25 ohms or less than a supplemental rod is not required. The reference to 25 ohms is what the NEC uses as it maximum resistance value, some applications such as telecommunication may require less than 10 ohms for sentitive equipment.

Establishing an effective earth grounding electrode system that has a low resistivity can be complicated and it effectiveness is depedant on soil resistivity which varries based on soil mediums, moisure content and disolved salts.

Using a standard multimeter to measure contact resistance from the grounding electrode to earth to prove the contact resistance is less than 25 ohms is not an effective means of measuring soil resistivity.

Typically, soil resistivity is measured utilizing the Wenner Four-Pin Method which uses a ground resistance meter (Figure 5-A).[28] Four metal pins are placed in contact with the ground in a straight line and equally spaced. A constant current is then injected through the ground via the meter and the outer two electrodes labeled C1 and C2. The potential drop is then measured across the inner two electrodes labeled P1 and P2. The meter

[26] Article 100 (2017) National Electrical Code
[27] Fluke (2014) Earth Grounding Resistance
[28] Lyncole (2013) Earth Grounding Fundamentals

provides a direct ohm reading that is used in the following formula to determine soil resistivity:[29]

$\rho = 2\pi RA\ \Omega m$

ρ =Soil resistivity

R = Ground resistance meter readout (ohms)

A = Distance between electrodes (feet)

The resistivity calculated is the average resistivity of the soil between the surface of the ground and a depth equal to the pin spacing.[30]

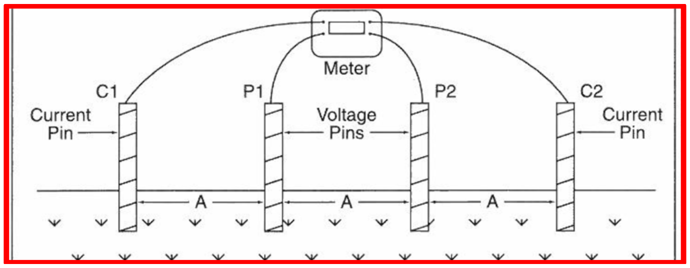


Figure 5-A

Several varables exist that can cause a change in the resistivity after installation such as time of year, temperature, moisure or a change in ground water. Multiple electrodes installed in parallel does lower the contact resistance but it is still dependant on soil medium, how many electrodes installed, dept and spacing.[31] For more information on earth grounding installation practices, soil resistivity, measurement practices I recommend reviewing the Handbook of Electrical Installation Practice ISBN 0-632-06002-6.

For pratical purposes, the simplest means of earth grounding to meet the installation requirements of the NEC in a field installation of temporary power system is to install two or more ground rods per 250.53(A)(2) or connect to another approved electrode type specified in 250.52(A)(2) through (A)(8). If two or more supplemental ground rod electrodes are installed they shall not be less than 6(ft) apart 250.53(A)(3). See Figure 6#.

Note: one conductor terminates at each ground clamp unless the clamp is listed for multiple conductors 110.14(A).

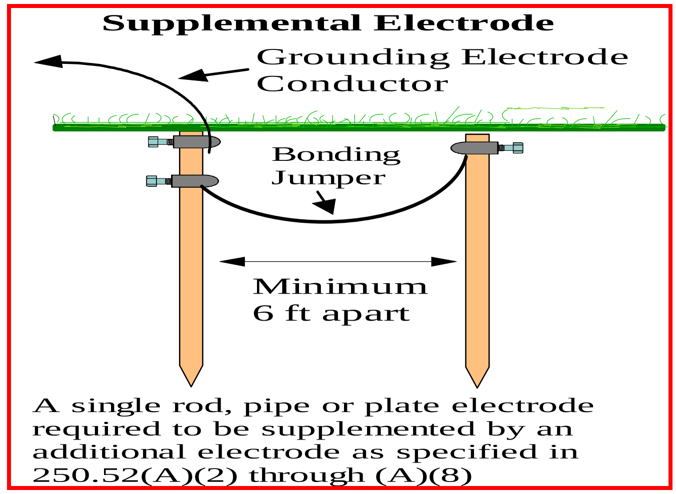


Figure 6#

Danger:Temporary electricial systems installed to power special event venues increase the need to properly install a grounding electrode system because the greater exposure to the public. The installation of grounding electrode system in a temporary electrical distribution system is critical because it can reduces arcing on metal parts, equipment, building structures, tent structures and stages from induced voltages from indirect lightning strikes and unintentional contact with higher voltages or voltages from other energized systems 250.4(A)(2).

Premise Wiring (System). The interior and exterior wiring, including power, lighting control, signal circuits, and all associated hardware, fittings, and wiring devices. This includes both permanently and temporarily installed wiring from the service point to the outlets, or where there's no service point, wiring from and including the electric power source such as a generator, transformer, or PV system to

[29] Stokes, Geoffrey (2003) Handbook of Electrical Installation Practice

[30] Lyncole (2013) Earth Grounding Fundamentals

[31] IEEE Std 142 (2007) IEEE Green Book

the outlets. This doesn't include the internal wiring of electrical equipment and appliances.[32]

Separately Derived System. An electrical source other than a service, having no direct connection(s) to circuit conductors of any other electrical source other than those established by grounding and bonding connection.[33]

Comment: The purpose of bonding the neutral to the equipment grounding conductor of a separately derived systems is to ensure that the electrical system has an established path for ground-fault current to travel back to the supply source to operate the overcurrent device if a fault should occur. Bonding the neutral to the equipment grounding conductor, frame and to earth in a separately derived system such as a generator or transformer is also used to stabilize system voltage during normal operation. Separately derived systems shall be grounded in accordance with 250.30.

DANGER- Shock Hazard: Failure to provide a low impedance ground-fault current path (no neutral-to-EGC bond) for the separately derived system (generator) can create a condition where a phase-to-ground fault cannot be removed. The result is that all metal parts of the electrical system will remain energized with dangerous line voltage if a phase-to-ground fault should occur.

⚠WARNING In a temporary electrical distribution system where the generator is the sole source of power do not bond the neutral to EGC at the first distribution panel and at the generator. Multiple neutral-to-EGC connections especially on the load side can cause power problems from elevated ground voltage and electromagnetic interference. Multiple neutral-EGC bonds create parallel fault current paths which may not generate the necessary fault current to properly and promptly operate the overcurrent protection device(s).

If a temporary generator is used as an alternate energy source suppling power to a building service then how the neutral conductor is connected and bonded will determine if the generator is considered a separately derived system or not. If the transfer switch is designed to switch the neutral conductor in addition to the phase conductors it would make the generator a separately derived system. The generator would require a system bonding jumper be connected between the neutral, equipment grounding conductor, and the grounding electrode conductor per 250.30. The generator is required to be field marked to indicate whether or not the neutral is bonded per 445.11. See figure 7# for an example of a separately derived system.

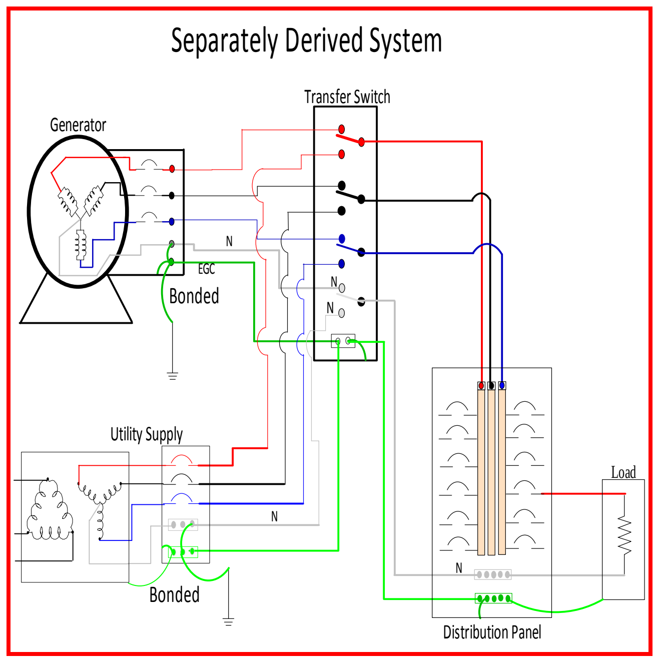


Figure 7#.

Most generators temporary installed to supply power to a building service though a preexisting transfer switch during disasters are normally not seperately derived systems. Electrician must verify how the neutral conductor is connected in the transfer switch and/or the service panel prior to installation of the temporary generator.

[32] Article 100 (2017) National Electrical Code, p.70-40

[33] Article 100 (2017) National Electrical Code, p.70-41

If the neutral conductor is not switched in the transfer switch and it is connected directly to the service neutral grounded conductor which is bonded then the generator is not a seperately derived system and the requirements of 250.30 will not apply. The neutral at the generator is not permitted to be grounded (bonded) to the grounding electrode conductor and the EGC. The generator would have to be field marked per 445.11 to indicate that the neutral is not bonded. See figure 8# for an example of a generator connected as a non-seprately derived system.

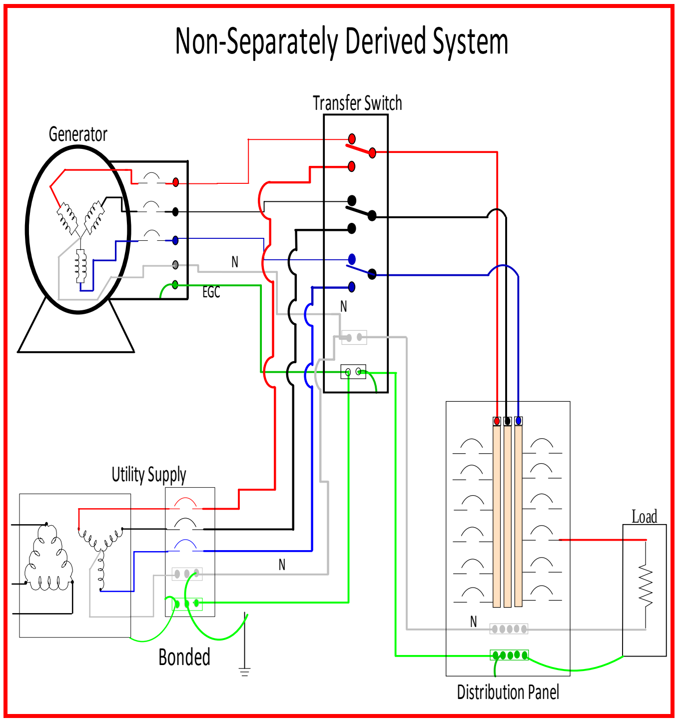


Figure 8#

Note; Improper neutral to case connection such as load side bonding and/or if both the transfer switch has a solidly connected neutral and the generator neutral is bonded to the EGC potential objectionable current can flow on metal parts and the equipment grounding conductor. 250.142

Grounding Portable and Vechicle Mounted Generators

250.34 (A) & (B) Portable and vechicle mounted generators are not required to be connected to earth as long as the neutral point is connected to the equipment grounding conductor and to the frame of the generator and the generator only supplies equipment or receptacles mounted on the generator (Frame serves in place of earth).

There are some controversy concerning single Camlok connectors permanenly mounted on the generator and if they are considered single receptacles, see figure 9-A. I believe most would agree they are considered as receptacles. However, camlok pigtails hardwired into the lugs on the generator are not receptacles. Power suplied by these pigtails do not meet the requirements of 250.34 (A) or (B) therefore if used the generator is required to be grounded to a grounding electrode in accordance with 250.

Figure 9-A#

OSHA construction standard for the most part follows the same rule as NEC 250.34. OSHA 29 CFR 1926.404(f)(3)(i) directs that the frame of a portable generator need not be grounded (connected to earth) and that the frame may serve as the ground (in place of the earth) if the following condition are met:

- The generator supplies only equipment mounted on the generator and/or cord and plug-connected equipment through receptacles mounted on the generator, 1926.404(f)(3)(i)(A), and
- The noncurrent-carrying metal parts of generator (such as the fuel tank, the internal combustion engine, and the generator's housing) are bonded to the generator frame, and the equipment grounding conductor

terminals (of the power receptacles that are a part of [mounted on] the generator) are bonded to the generator frame, 1926.404(f)(3)(i)(B).[36]

If these conditions do not exist, a grounding electrode, such as a ground rod, is required to be installed per Article 250 of the National Electrical Code.[37]

If the generator supplies power to a struture via a transfer switch (home, office, shop, trailer, or similar), it must be connected to a grounding electrode system, such as a driven ground rod.[38]

Inspectors commonly treat vechicle (trailer) mounted generators suppling power to HVAC equipment, temporary low voltage distribution systems for tents, stages and other structures such as buildings or trailers as a single source derived system and the fact that the feeder conductors are generally hardwire to the generator terminal lugs the generator is required to be grounded to the earth through an approved grounding electrode in accordance with NEC Article 250.

Example; Article 525.31 all equipment to be grounded shall be connected to an equipment grounding conductor of a type specified by 250.118. The equipment grounding conductor shall be connected to the system grounded conductor at the service disconnecting means or in the case of a separately derived system such as a generator it shall be connected to the grounded conductor at the generator but not at both. The connection between the equipment grounding conductor and the grounded (neutral) conductor shall never be made on the load side.

250.34 addresses the use of the generator frame in place of earth as the reference point, the requirements for bonding all metal noncurrent carrying parts and components of the electrical system back to the grounded conductor and the equipment grounding conductor at the power source are still required to form an effective ground-fault current path [250.4].

The (AHJ) auhority having jurisdiction (electrical inspector) can still require a single and supplemental ground-rod(s) be driven at the generator, please consult your local AHJ prior to the start of a project to determine if they require earthing, if they do require a ground rod please have the earth (ground) checked for lines, cable or any other obstructions before driving any electrodes into the earth or damage can occur. “Call before you dig”

Multiple Sources of Supply.

Where multiple power sources or separately derived systems or both supply power to portable structures (tents) and are separated by less than 12ft the equipment grounding conductor of all power sources that serve the structure shall be bonded together at the portable structure. Bonding all the equipment grounding conductors at the structure eliminates the possibility of a potential difference created by the different power sources. The conductor used to bond the different power sources together at the structure shall be copper and sized in accordance with Table 250.122 based on the largest overcurrent device supplying the structure and not smaller than 6AWG (525.11).[39]

Ground-Fault Current & Overcurrent Protection

Special consideration has to be given to the magnitude of ground-fault current that can be generated within an electrical system to insure the intended ground-fault current path can handle the current imposed safely without damage and distress.

[36] OSHA Fact Sheet (2005) Grounding Requirements for Portable Generators
[37] OSHA Fact Sheet (2005) Grounding Requirements for Portable Generators
[38] OSHA Fact Sheet (2005) Grounding Requirements for Portable Generators
[39] Article 525 (2017) National Electrical Code

The removal of dangerous voltages on metal parts and enclosures from a ground-fault is dependant on the low impedance path back to the source so current can rise quickly and to a magnatude suffient to open the branch or system overcurrent protective device.[40] See figure 9# for an example of calculated fault current on a wire.

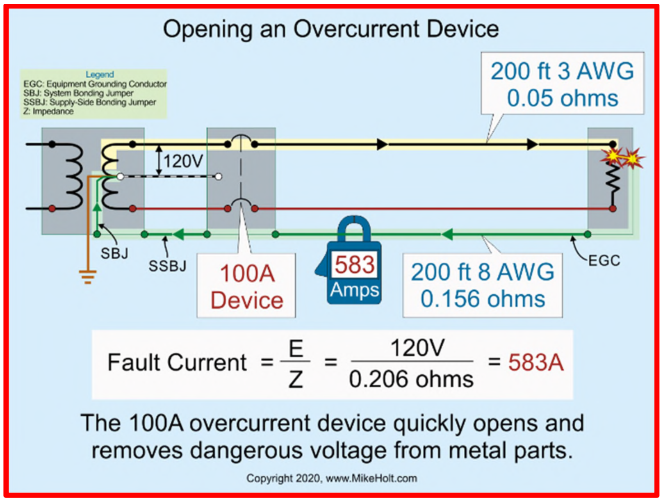


Illustration provided coustey of Mike Holt Enterprise

Figure 9#

The time it takes for an overcurrent protective device to open is dependant on the magnitude of the fault current. A higher fault current value will result in a shorter clearing time. Example: A 20 amp overcurrent protection device with an overload of 40 amps takes about 25 to 150 seconds to open. The same device with a fault current of 150 amps trips and opens the circuit in 2 to 8 seconds. See figure 10# for example of 20 amp time-current curve.[41]

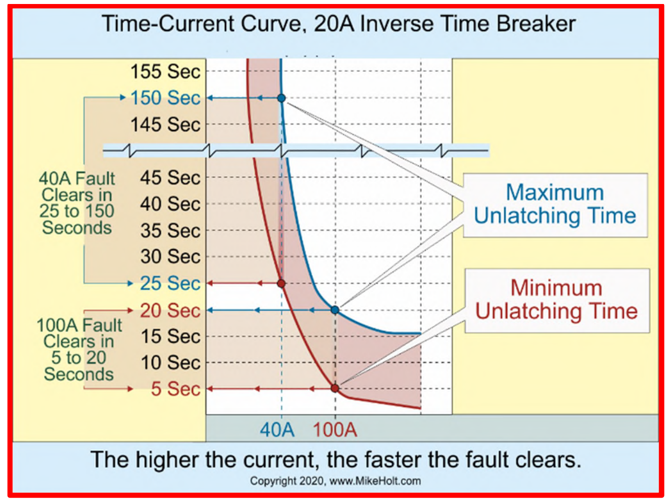


Illustration provided coustey of Mike Holt Enterprise

Figure 10#

Available Short-Circuit Current

The available short-circuit current depends on the impedance of the circuit. The lower the impedance the higher the short circuit current. The factors that affect the available short-circuit current at a transformer include system voltage, KVA rating, and transformer impedance expressed in a percentage. Factors that influence the short-circuit current of a generator are the system voltage, generator size in KVA, and the different reactances of the windings. Other factors that influence short-circuit current in a system is conductor material, size, length, motor operated equipment and other connected equipment.[42] For a better understanding of how available short-circuit current is calculated in an electrical system I recommend reading;

Bulletin EDP-1 (2004) Engineering Dependable Protection For an Electrical Distribution System, Part 1, A Simple Approach to Short- Circuit Calculations. Cooper-Bussmann. Retrieved from; http://www1.cooperbussmann.com/library/docs/EDP-1.pdf

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[40] Holt, M. (2017) Bonding and Grounding
[41] Holt, M. (2017) Bonding and Grounding
[42] Holt, M. (2017) Understanding the National Electrical Code, Vol. 1

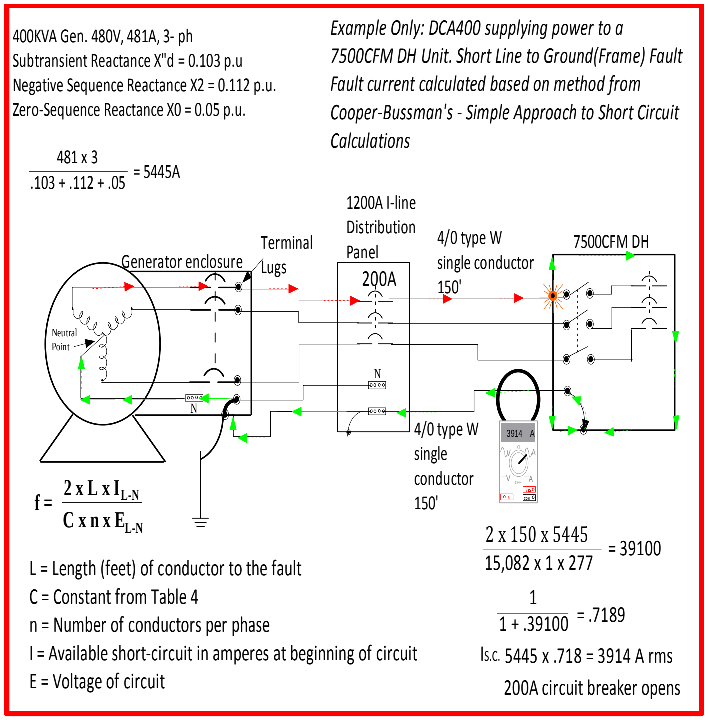

Figure 10-A

Figure 10-A is an example of a 400KVA generator running a 7500cfm dehumindification unit which is protected by a 200A breaker located in the 1200A I-line panel. One of the phase conductors short to the frame of the DH unit. The amount of fault current generated is suffient to open the 200A breaker and clear the fault. The fault current in the circuit was calculated based on the methods and formulas listed in Cooper-Bussmann's. "A Simple Approach to Short Circuit Calculations ".

Please Note: Compared to utility or a transformer the fault current available from a generator is relativity low but high enough to damage the windings if the fault is not cleared in an appropiate amount of time. It is important when reviewing breaker settings to ensure the instanous set point are set based on the available fault current in the circuit. If the set points are to high the breaker may not clear the fault before it causes damage to generator windings.

Interrupting Protection Rating

(Ampere Interrupting Capacity)

Circuit breakers have an general interrupting rating of 5,000 amperes (5KA) unless marked otherwise 110.9.[43] See figure 11#. Fault current rating (AIC) is very important when designing circuit protection for equipment. Overcurrent devices must have an interrupting rating not less than the nominal circuit voltage and the short circuit current that's available at the line terminals of the equipment.[44] The calculated fault current of a circuit or equipment should never exceed the interrupting rating of the overcurrent device or fire and/or an explosion is possible. See example listed in Figure 12#.[45]

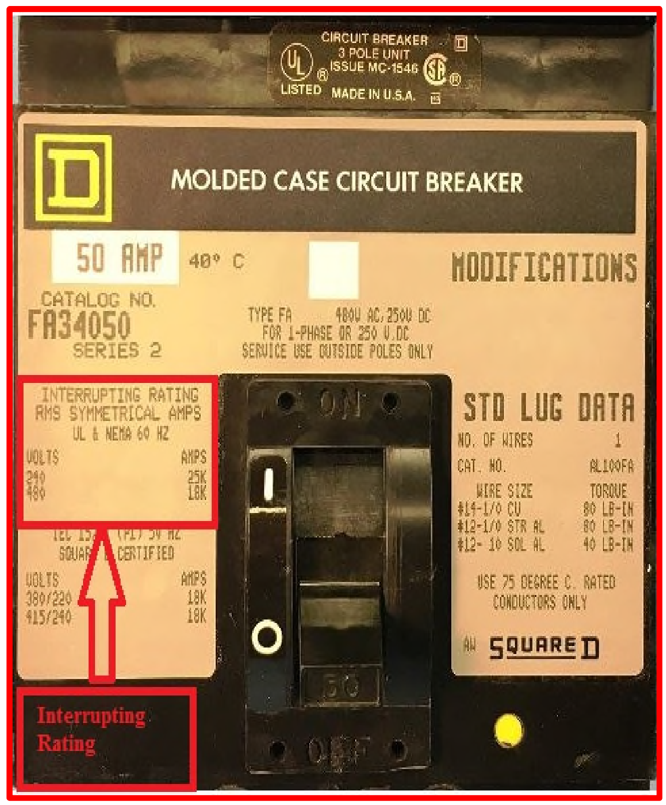

Figure 11#

[43] Art. 110 (2017) National Electrical Code
[44] Holt, M. (2017) Bonding and Grounding
[45] Holt, M. (2017) Bonding and Grounding

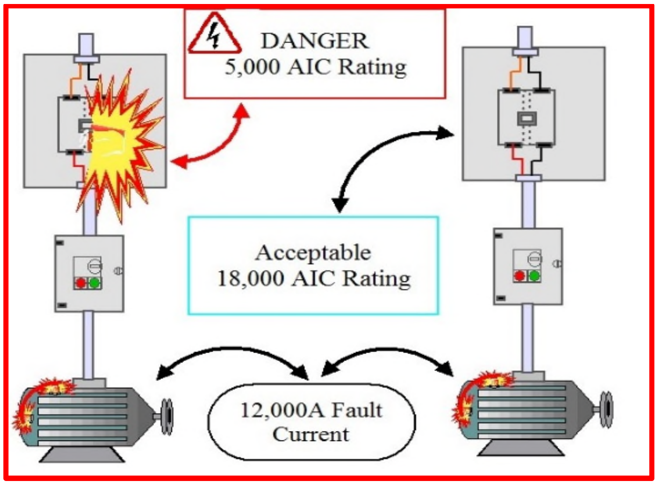

Figure 12#

Danger: Based on the circuit and/or equipment charateristic extreamly high values of current flow caused by short-circuit or ground-faults can produce destructive thermal and magnetics forces on conductors, motors, generator and transformers. Overcurrent protection devices not rated to interupt the current at the available fault current values at it listed voltage rating can explode while attempting to open the circuit overcurrent protection device from a short-circuit or ground-fault, which can cause serious injury or death, as well as property damage.[46] This is why NEC Article 110.10 requires the overcurrent protective devices, the total impedance, the equipment short-circuit ratings, and other characteristics of the circuit to be protected shall be calculated, selected and coordinated to permit the circuit protective devices to clear the fault without extensive damage to the electrical system or equipment.[47]

Special Consideration for Grounding Generators

The characteristics of generators are significantly different from transformers and other power sources. Generator have little ability to withstand the sudden heating effects and mechanical (stress) force of a short-circuit or ground-fault. Unlike a transformer, the three sequence reactances (positive, negative and zero sequence) of a generator are not equal with zero-sequence having the lowest value. Generally, if the generator has a solidly grounded neutral it will have a higher initial ground-fault current than a three-phase bolted fault current. NEMA (MG 1) only requires generators to withstand a bolted three-phase fault at the machine terminals unless otherwise specified.[48] The negative-sequence current thermal withstand limit is a product of time and with a solidly grounded neutral the ground-fault current is about eight times that of full-load current while the steady state three-phase fault current is about three times the full load current.[49] Example of the calculated line-to-ground fault current at the generator terminals;

Simple Method (Example only)

$$\text{Amperes, RMS} = \frac{\text{Rated Amperes x 3}}{X''d + X_2 + X_0}$$

X"d = Generator Subtransient reactance

X 2 = Generator negative- sequence reactance

X0 = Generator zero-sequence reactance

Using a 400kva generator as an example;

480V, 481A, Three-phase, 60 hz. (reactances listed in a per unit value)

Subtransient Reactance X"d = 0.103pu

Negative-Sequence Reactance X2 = 0.112pu

Zero-Sequence Reactance X0 = 0.05pu

$$\frac{481 \text{ x } 3}{0.103 + 0.112 + 0.05} = 5445\text{A}$$

5445A RMS effective symmetrical current

The peak symmetrical value is 5445 x √2 = 7700A

[46] Holt. M. (2017) Understanding the National Electrical Code, Volume 1, p.61
[47] Article 110.10 (2017) National Electrical Code
[48] IEEE Green Book (2007) Grounding of Industrial and Commercial Power Systems
[49] IEEE Green Book (2007) Grounding of Industrial and Commercial Power Systems

Compared to three-phase fault current calculated using subtransient reactance.

Three-phase fault current RMS effective symmetrical current is 481A / 0.103 = 4669A.

Peak symmetrical value is 4669 x √2 = 6602A.

The ground-fault current is about 16% higher than three-phase fault current.

Larger container mounted generators (ie. 500kw – 2meg) the higher level of ground-fault currents are more prevelent especially if the units are operated in parallel. If units operate in parallel the fault current is multiplied by the number of units operating in parallel at the time of the fault. When multiple generators operate in parallel special consideration must be given to the AIC rating of system overcurrent protection devices and equipment to in sure they can handle the additional fault current imposed from a ground-fault. See Figure 13.

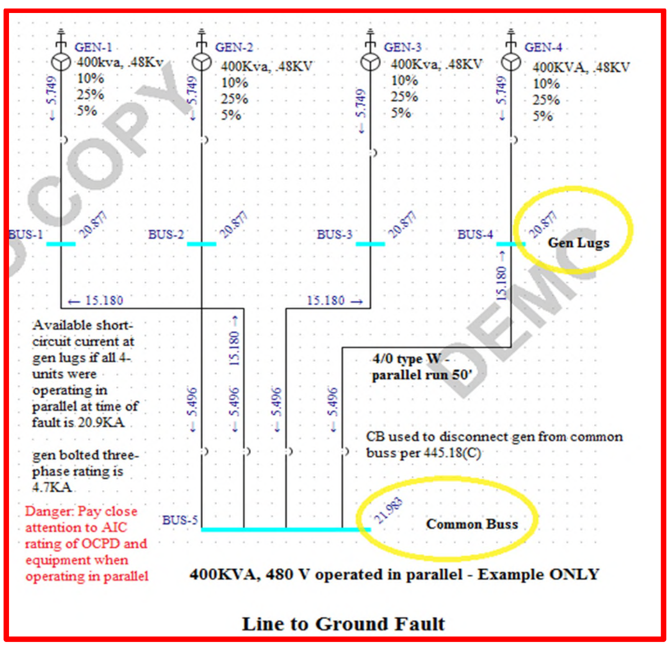

Figure 13#

Because of the damageing effects of ground-fault current on generators windings some applications require ground detection and fault limiting high impedance grounded neutral systems, usally a resistor that limits ground-fault current to a lower and safer current value. The National Electrical Code permits the use of these types of grounded neutral systems for voltages upto 1000V as long as the requirements of 250.36 are followed. For systems over 1000V see 250.187. When considering the use of fault limiting grounded neutral systems I recommend you first consult with a professional engineer who specializes in these components.

For more information on recommended practice of using fault limiting high impedance neutral grounding systems please refer to IEEE Std. 142, Green Book . For mining and tunnel applications please see (MSHA) Code fo Federal Regulations, Title 30, 18.47 (voltage limitation). Title 30, 75.814 applies to Underground Coal Mines, 77.801 applies to Surface Mines.

Please note; the magnatude of fault current based on the different reactances of the generator windings and the time current can sustain before falling to a steady state is heavly dependant on the voltage regulation system and the length of time it can sustain it output to the excitation field before it colapses or fails. For more information on the study of the voltage regulation system, diferent AC / DC components of fault current and the effects within the windings of a generator please see the following reference material:

Chapman, Stephen (2005) Electric Machinery Fundamentals, Forth Edition, published by McGraw-Hill, ISBN 0-07-246523-9

El-Hawary, M.E. (2008) Introduction to Electrical Power Systems. Published by John Wiley & Sons, Inc. ISBN 978-0470-40863-6

Wildi, Theodore (2006) Electrical Machines, Drives, and Power Systems. Sixth Edition. Pearson Education, ISBN 0-13-177691-6

Conclusion

Primary function of the grounding and bonding system is electrical safety and the prevention of dangerous touch potential of energized metal parts and/or metal surfaces when an unintentional ground fault occurs. The most important aspect is the creation of a low impedance fault current path back to source through the proper selection and installation of the bonding jumpers, equipment grounding conductor and connection to the grounded conductor which allows for the ground-fault current to rise quickly and promptly operate the overcurrent protection device to remove dangerous voltages from the system when a fault occurs.

Regardless if the generator frame or earth is used as the grounding electrode, neutral must be bonded to the ground terminal at the generator terminal board and to the generator frame to complete the creation of the effective path for fault current to travel back to source. The only exception is if the generator is installed as a non-separately derived system then the neutral to ground bond jumper located behind the terminal lugs must be removed. Electrician responsible for installation should determine if the generator is separately derived or not.

Grounding and bonding items to remember; Grounding electrode conductor is sized in accordance with Table 250.66 unless the grounding electrode is a rod, pipe or plate then the conductor does not have to be larger than a no. 6 AWG copper conductor [250.66(A)]. The bonding conductor or jumpers are sized in accordance with Table 250.102(C)(1) and the equipment grounding conductor is sized in accordance with Table 250.122. Remember to read all the articles, exceptions and informational notes that are associated with these tables to ensure proper installation.

Remember all temporary electrical system installations should be done by a qualified person and/or licensed electrician in accordance with local, state and national electrical codes and standards.

Author Biography

Steven Gibson, MS.Ed, CESCP
Senior Manager-PE Technical Support, Multiquip, Inc.
Carson, CA.

Mr. Gibson served in the US Army after high school as a power generation technician. After the military he worked in the equipment , power and HVAC rental industry for 16 years. Joined Multiquip in 2007 and has over 30 years combined experience in the electrical and power generation industry. Education includes a Master of Science in Higher Education, Graduate Certificate in Adult Learning, B.S. in Occupational Safety & Health, A.S. in Electrical Engineering Technology, and a A.A.S in Business. He is currently an NFPA Certified Electrical Safety Compliance Professional, Licensed Electrical Contractor, Master Electrician and is a former Worforce Development Adjunct Instructor - Master Electrician Exam Prep Program (TRD157).

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