IEEE/IAS
Luncheon Meeting

Topic: Grounding 101
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Schneider Electric

Applicable Codes and Standards Pertaining to Bonding and Grounding Systems (General)

- IEEE Standard 142™ -2007, "IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems",
- IEEE Standard 80™ - 2000 "IEEE Guide for Safety in AC Substation Grounding"
- IEEE Standard 81™ -1983 "IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System",
- IEEE Standard 1100™-2005 – "IEEE Recommended Practice for Powering and Grounding Electronic Equipment",
- IEEE Standard 446™ -1995 "IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications" (Chapter 7).

Applicable Codes and Standards Pertaining to Bonding and Grounding Systems (General)

- NFPA 70, 2014 Edition - National Electrical Code® (NEC®) [Articles 250, 690, & 702]

- IEEE Standard 2012™ - National Electrical Safety Code (NESC)

- NFPA 780, 2011 Edition – Standard for the Installation of Lightning Protection System

- UL 96A – Installation Requirements for Lightning Protection Systems

- UL 467 – Bonding and Grounding Equipment

Applicable Codes and Standards Pertaining to Bonding and Grounding Systems (General)

- IEEE Standard 837 ™- 2002, "IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding"

- 3003.1 – 2014, "Recommended Practice for the **System** Grounding of Industrial and Commercial Power Systems"

  (Drafted to replace IEEE Standard 142™ -2007)

- 3003.2 – 2014, "IEEE Draft Recommended Practice for **Equipment** Grounding and Bonding in Industrial and Commercial Power Systems"

  (Drafted to replace IEEE Standard 142™ -2007)

Applicable Codes and Standards Pertaining To Bonding and Grounding Systems in Healthcare Facilities

- NFPA 70 , (NEC Article 250 & NEC Article 517)
- NFPA 99 , (Chapter 6 and Chapter 10)
- IEEE Standard 80 (IEEE Guide for Safety in AC Substation Grounding)
- IEEE Standard 81 (IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and earth Surface Potentials of a Ground System)
- IEEE Standard 142 (IEEE Recommended Practices for Grounding of Industrial and Commercial Power Systems)
- IEEE Standard 446, Chapter 7 (IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications)
- IEEE Standard 601, Clause 3.6 and Chapter 6 (IEEE Recommended Practice for Electrical Systems in Healthcare Facilities)
- IEEE Standard 1100 (IEEE Recommended Practice for Powering and Grounding Electronic Equipment)

Applicable Codes and Standards Pertaining to the Testing of Bonding and Grounding Systems

- NEC Article 250 **(Contrary to popular belief, there are no testing or maintenance requirements in Article 250.)**
- NFPA 99 - 2012, Chapter 6, – Electrical System Requirements (Paragraph 6.3.3– "Performance Criteria and Testing")
- NFPA 99 - 2012, Chapter 10 – Electrical Equipment (Paragraph 10.3 – "Testing Requirement – Fixed and Portable") [The 2012 Edition has more focus on "Leakage Currents" and "Touch Currents"]
- IEEE Standard 81 (IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and earth Surface Potentials of a Ground System)
- IEEE Standard 142, Chapter 4 (IEEE Recommended Practices for Grounding of Industrial and Commercial Power Systems)
- IEEE Standard 601, Clause 6.8.6.e – Field inspection procedure (This clause recommends testing, but does not mandate testing or provided for specific testing methods.)
- NFPA 70B - 2010, Chapter 11, – Grounding Systems(Very brief general information provided on testing of "grounded conductor' and 'grounding electrode'.)
- **If a bonding or grounding system is not routinely inspected or tested, how do you know if it is adequate or effective for the needs of the specific facility or installation???????**

Applicable American Codes and Standards Pertaining to Bonding and Grounding Systems as it Relates to Lightning Protection

- NFPA 70, 2014 Edition - National Electrical Code® (NEC®) [Articles 250, 285, 500, 502, 505, 694, 800]
- IEEE Standard 2012™ - National Electrical Safety Code (NESC)
- NFPA 77 – Recommended Practice on Static Electricity
- NFPA 780 – Standard for the Installation of Lightning Protection System
- UL 96A – Installation Requirements for Lightning Protection Systems
- API RP [American Petroleum Institute (Recommended Practice)] -Protection Against Ignitions Arising Out of Static Lightning and Stray Currents
- UL 467 – Bonding and Grounding Equipment
- IEEE Std. 998 - *IEEE Guide for Direct Lightning Stoke Shielding of Substations*
- DoD, DoE, NASA, and FAA Lightning Protection Requirements

Applicable European Codes and Standards Pertaining to Bonding and Grounding Systems and Lightning Protection

- IEC Standard 10234-1
- IEC Standard 61364-S
- IEC Standard 62305
- ENV 61024-1

Applicable British Codes and Standards Pertaining to Bonding and Grounding Systems and Lightning Protection

- BS 1400
- BS 6651
- BS 7430

Applicable Canadian and Australian Codes and Standards Pertaining to Bonding and Grounding Systems and Lightning Protection

- CSA C22.12 (2012) (aka; The Canadian Electrical Code)
- AS1768
- AS2307
- AS3000

Contrary to popular illusions and misconceptions, ‘GOLFERS’ are nothing more than ‘ambulatory or portable lightning abatement systems’!

Differences Between Bonding and Grounding

- **Is a green vinyl covered copper conductor (some times green vinyl with yellow stripe) located within a power circuit conduit along with the three ‘phase’ conductors**

  a.) a “grounding conductor”,

  b.) a “ground wire”,

  c.) a “bonding conductor”

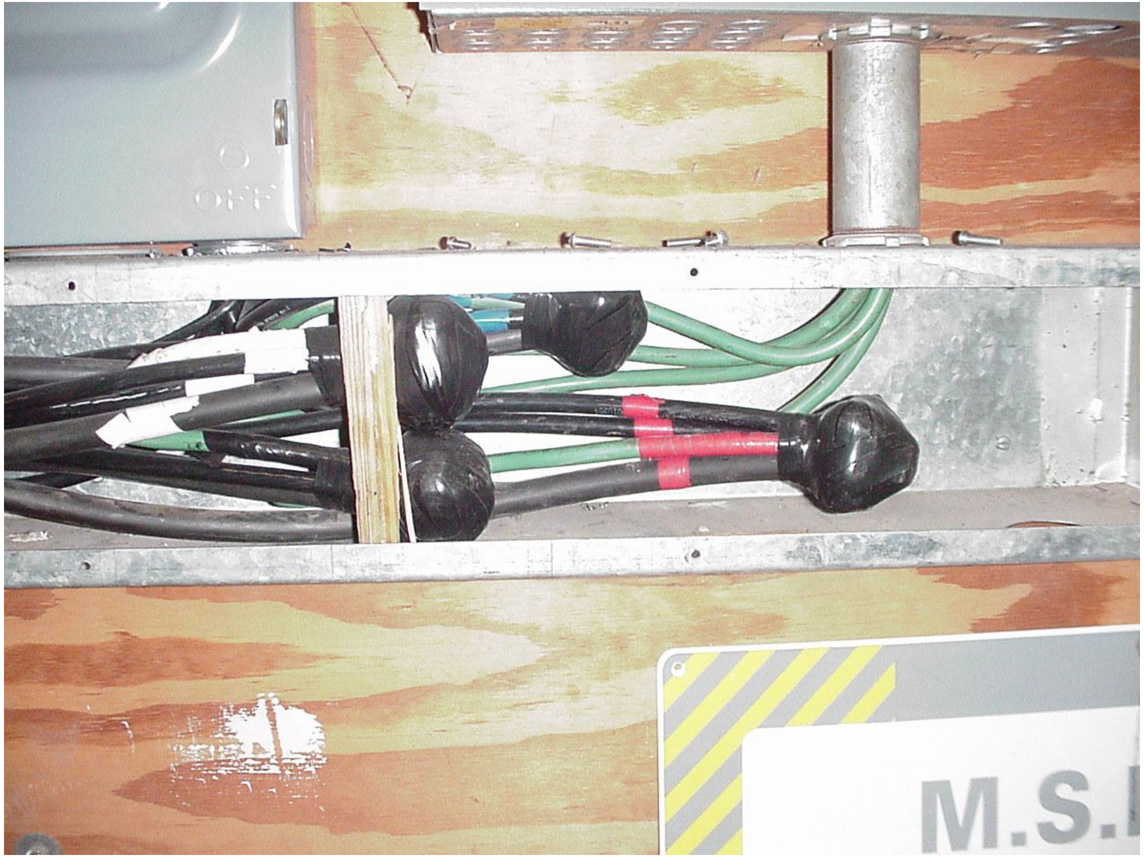
- **Exactly what is the intended purpose of the typical green vinyl covered copper conductor located within a power circuit conduit?**

Differences Between Bonding and Grounding

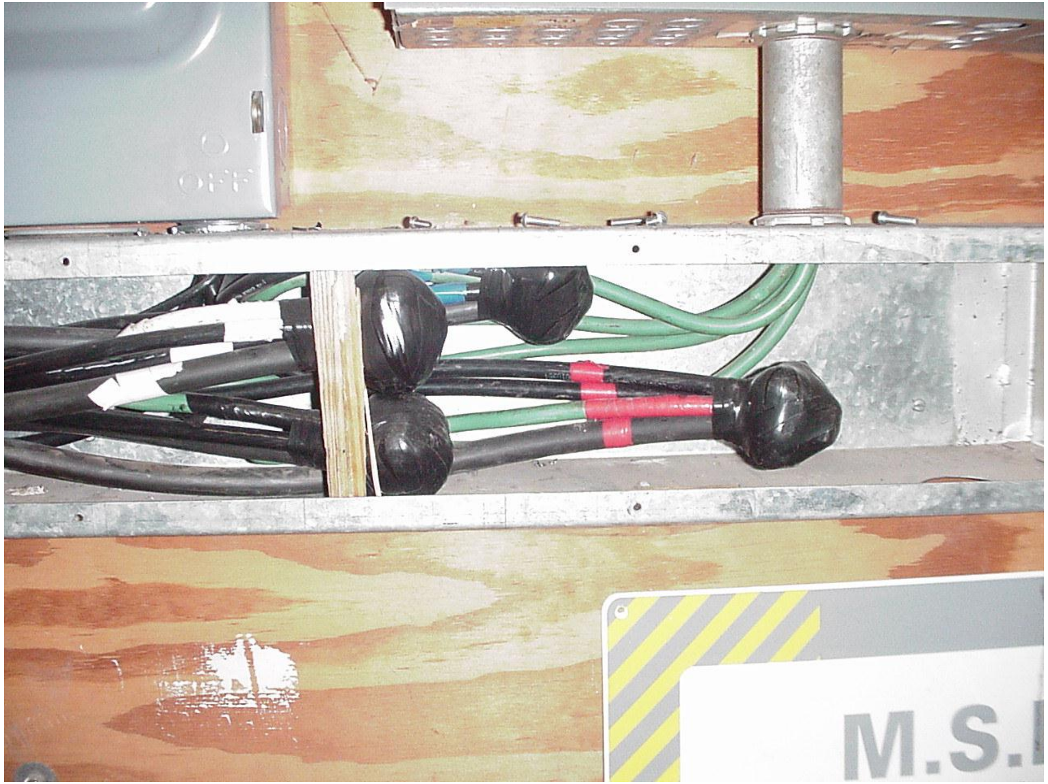
- **Is a green vinyl covered copper conductor (some times green vinyl with yellow stripe) located within a power circuit conduit along with the three ‘phase’ conductors**
  - **a.) a “grounding conductor”,**
  - **b.) a “ground wire”,**
  - **c.) a “bonding conductor”**

Exactly what is the intended purpose of the typical green vinyl covered copper conductor located within a power circuit conduit? To provide for an equipment bond to effective maintain an equal-potential between all metallic parts and equipment and to provide for an effective ground fault return path between the point of the fault and the source of electrical power.

Which conductor is the “Grounding Conductor” in this 3 phase feeder circuit?



This 'feeder circuit' consist of 3 phase conductors + 1 neutral conductor. There is NO actual "Grounding Conductor" associated with this 3 phase feeder circuit.



Differences Between Bonding and Grounding

- **The terms “bonding” and “grounding” are often employed interchangeably as general terms in the electrical industry to imply or mean that a specific piece of electrical equipment, structure, or enclosure is somehow referenced to earth.**

- **In fact, “bonding” and “grounding” have completely different meaning and employ different electrical installation methodologies.**

Bonding

“Bonding” is a method by which all electrically conductive materials and metallic surfaces of equipment and structures, not normally intended to be energized, are effectively interconnected together via a low impedance conductive means and path in order to avoid any appreciable potential difference between any separate points.

The bonded interconnections of any specific electrically conductive materials, metallic surfaces. The **bonding** of any metallic enclosures, electrical equipment, pipes, tubes, or structures via a low impedance path **is completely independent and unrelated to any intended contact or connection to the Planet Earth.**

For example, airplanes do not have any connection to the planet Earth when they are airborne. It is extremely important for the safety and welfare of passengers, crew, and aircraft the all metallic parts and structures of an airplane are effectively bonded together to avoid difference of potential between structures and parts when traveling at high rates of speed or when the frame of the aircraft is struck by lightning.

Bonding

The laboratories and satellites orbiting in space above the planet Earth obviously have no direct connection with the surface of our planet.

However, all of the conductive surfaces of these orbiting laboratories and satellites must be effectively bonded together in order to avoid differences of potential from being induced across their surfaces from the countless charged particles, magnetic energy fields, and solar produced magnetic waves traveling through space.

Bonding

The common means to effectively bond different metallic surfaces of enclosures, electrical equipment, pipes, tubes or structures together are with copper conductors, rated lugs, and the appropriate bolts, fasteners, or screws.

- Other effectively bonding means between different metallic parts and pieces might employ brackets, clamps, exothermic bonds, or welds to make an effectively connections.

- In addition to preventing potential differences that may result in hazards, effectively bonded equipment can also be employed to adequately and safely conduct phase-to-ground fault current, induced currents, surge currents, lightning currents, or transient currents during such abnormal conditions. .

Is the connected load equipment “effectively bonded” to the supplying system?

Are these two pieces of equipment “effectively bonded” together?

Are these two pieces of Equipment “effectively bonded” together?

Grounding

- **"Grounding"** is a term used rather exclusively in North American to indicate a direct or indirect connection to the planet Earth or to some conducting body that serves in place of the Earth.
- The connections to Earth can be intentional or unintentional by an assortment of metallic means intended to be employed as a designated grounding electrode.
- A designated "grounding electrode" is the device that is intended to establish the direct electrical connection to the earth.
- A common designated grounding electrode is often a copper clad (0.008") or copper flashed (0.004") coated steel rod.
- The designated "grounding electrode" might also be a copper or black iron water pipe, steel columns of a building or structure, concrete encased steel reinforcement rods, buried copper bus, buried copper tubing, galvanized coated steel rods or plates, or semi conductive neoprene rubber blankets. **Gas pipes and aluminum rods can not be employed as grounding electrode. FOR UNDERSTANDABLE REASONS!**
- The grounding electrode conductor is the designed conductor that is employed to connect the designated grounding electrode to other equipment grounding conductors, grounded conductor, and structures.

Earthing or Earthed

- **“Earthing” and “Earthed”** is a term developed by the United Kingdom and part of the British Electrical Code and is employed in Europe or other countries that employs International Electric Commission (IEC) standards.

- The term **“earthing”** in European or IEC countries is synonymous with the term “grounding” in North America.

- The term **“earthed”** in European or IEC countries is synonymous with the term “grounded” in North America

This tank was determined to be ‘effectively bonded and grounded. However, one might be amazed at what is commonly mixed into popular beers.

Is this electrical service “effectively grounded” or “Earthed”?

The Five Principal Purposes of Bonding & Grounding Systems

The principle purposes for an “effectively bonded grounding system via a low impedance path to earth” are intended to provide for the following.

1. Provide for an applicable reference to earth to stabilize the system voltage of a power distribution system during normal operations.
2. Create a very low impedance path for ground fault current to flow in a **relatively** controlled path.
3. Create a very low impedance path for ground fault current to flow in order for overcurrent protective devices and any ground fault protection systems to operate effectively as designed and intended.
4. Limit differences of potential, potential rise, or step gradients between equipment and personnel, personnel and earth, equipment and earth, or equipment to equipment.
5. Limit voltage rise or potential differences imposed on a power distribution system from lightning, a surge event, any phase-to-ground fault conditions, or the inadvertent commingling of or the unintentional contact with different voltage system.

Principal Purposes of Bonding and Grounding Systems

The principal purposes for an "effectively bonded grounding system via a low impedance path to earth" are intended to provide for the following.

- ***1. Provide for an applicable reference to earth to stabilize the system voltage of a power distribution system during normal operations.***

The system voltage is determine by how the secondary winding of any power class or distribution class transformer is actually configured as well as how the windings are referenced to ground or earth.

The primary function or purpose of the system bonding jumper is to provide for an applicable reference to earth for the system voltage at the origins of the specific and separately derived system to stabilize the voltage. (i.e., 600Y/347V, 480Y/277V, or 208Y/120V, 3 Phase, 4 Wire, Solidly Grounded, "WYE" Systems)

The system bonding jumper is employed as a direct connection between the Xo terminal of a supplying transformer, generator, or UPS output terminals and earth.

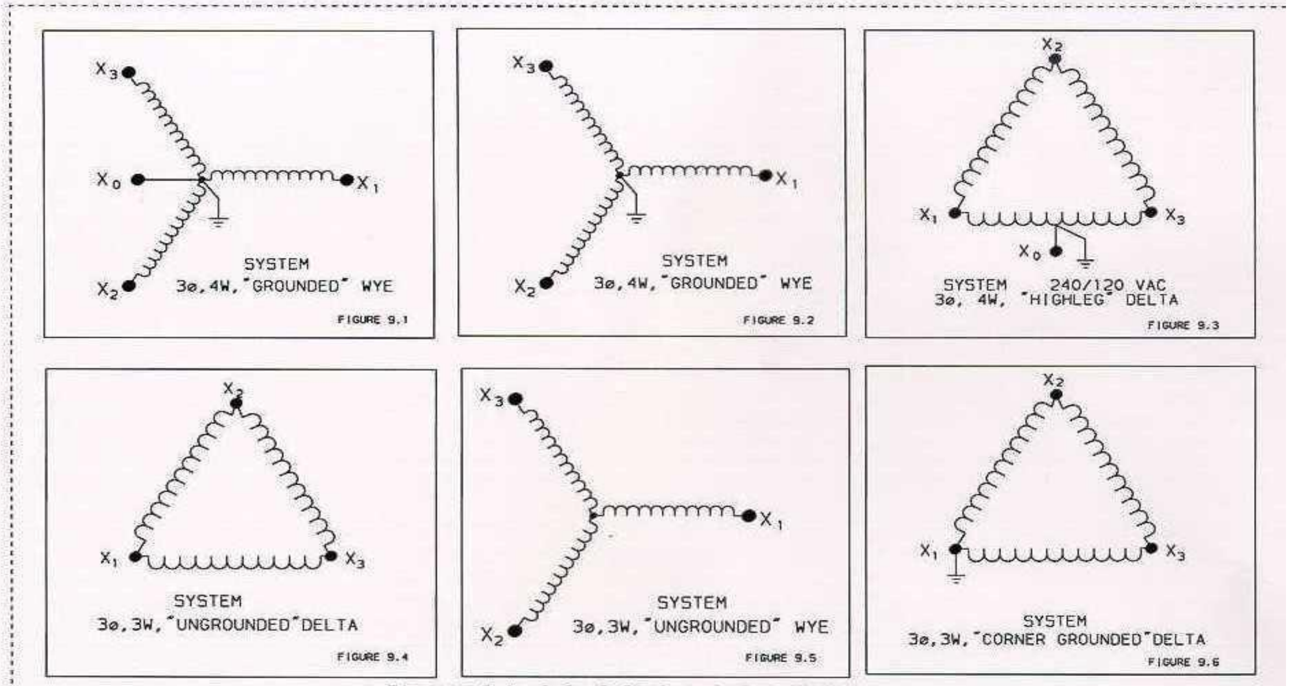
The system bonding jumper is usually connected within the same enclosure as the power supply terminals and the jumper is not normally sized to carry large magnitudes of phase-to-ground fault current.

System Configuration

- **The *system configuration* of any Power Distribution System is based strictly on how the secondary windings of the Distribution Class or Power Class Transformer, or generator, *supplying* the Service Entrance Main or loads, are configured.** (This includes whether or not the windings are referenced to earth.)

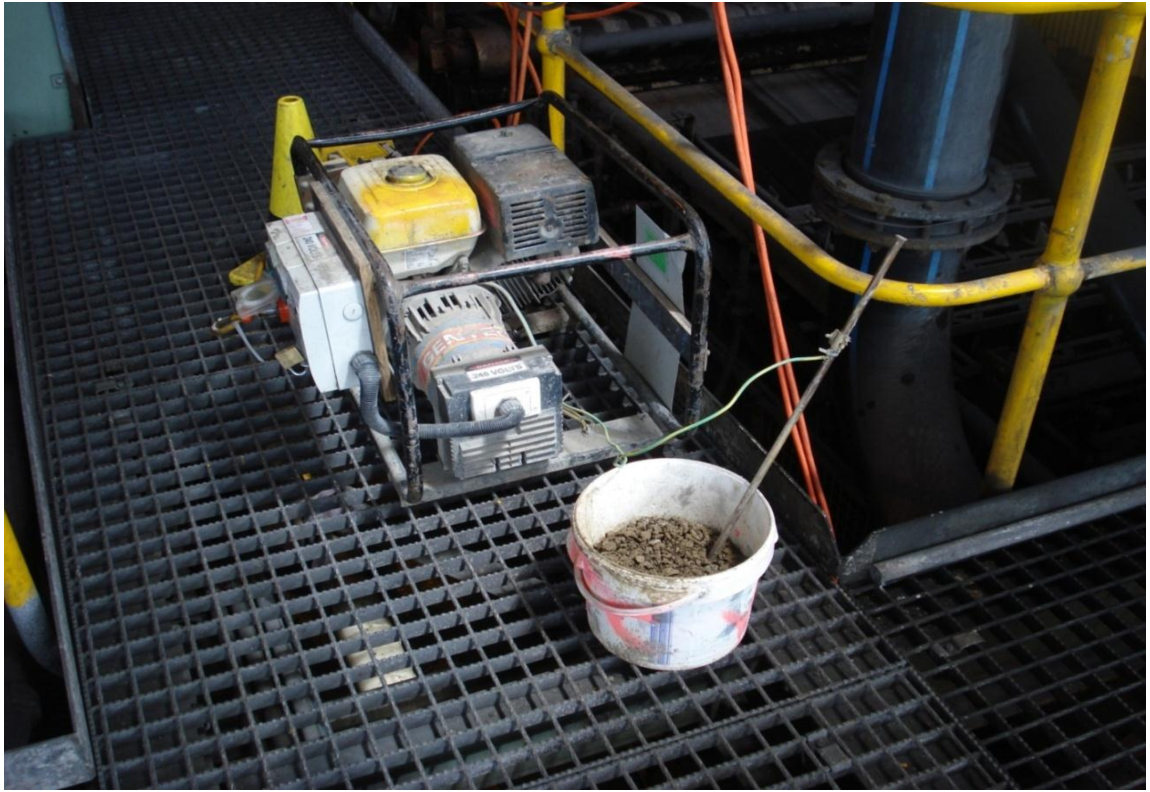
- The system configuration is ***not*** based on how any specific load or equipment is configured or connected to a particular power distribution system

Power System Configurations



Figures 9.1, 9.2, 9.3, 9.4, 9.5, and 9.6

Is the center point of the neutral of this generator "effectively referenced" to conductive Earth?



Principal Purposes of a Bonding and Grounding System

- ***2. Create a very low impedance path for ground fault current to flow in a "relatively" controlled path.***

  The exact point and time where a phase-to-ground fault might occur can not be determined. Depending on the exact point of the phase-to-ground fault within a specific power distribution system, multiple return paths are likely to occur between the point where the fault conductor makes contact with a conductive surface and the Xo terminal of the supplying transformer or local standby generator.

  It is desirable and preferred that the majority of the ground fault current flow primarily in the specific equipment bonding jumpers and equipment ground conductors directly associated with the fault circuit.

  If the impedance in the equipment bonding jumpers and equipment ground conductors associated with the faulted circuit is too high, then significant magnitudes of phase-to ground fault current will likely take various other parallel paths in order to return to the source winding of the power supply.

Principal Purposes of a Bonding and Grounding System

- ***2. Create a very low impedance path for ground fault current to flow in a "relatively" controlled path.***

The flow of 'phase-to-ground' fault current will take any and all available conductive paths from the point of the fault to the Xo terminal of the source of the electrical power supply. (transformer, generator, UPS Unit, etc…)

Other uncontrolled and unexpected return paths can subject facility personnel to dangerous touch potential differences which can cause death, injury, or permanent damage to internal organs.

Other unaffected equipment could be negatively affected or damaged by potential rises and unintended flow of current.

Principal Purposes of a Bonding and Grounding System

- ***3. Create an effective and very low impedance path for ground fault current to flow in order for overcurrent protective devices and any ground fault protection systems to operate effectively as designed and intended.***

  During the time of the phase-to-ground faulted condition the subjected equipment bonding jumpers and the equipment grounding conductors are intended to function as a very low impedance path between the point of the fault and the ground bus within the service equipment or the stand by generator equipment.

  These affect equipment bonding jumpers and the equipment grounding conductors constitute 50% of the total power circuit during the period in which phase-to-ground fault current is flowing.

  If the impedance in the ground fault return path is not effective low enough, then the overcurrent protective devices employed in the circuit as fuses and thermal-magnetic circuit breaker will be ineffective to prevent substantial equipment damage. If the impedance in the ground fault return path is too high, then the resulting flow of phase-to-ground fault current might actually be lower than the rating of the fuses and thermal-magnetic circuit breakers installed to protect the affected circuit.

Principal Purposes of a Bonding and Grounding System

- ***3. Create an effective and very low impedance path for ground fault current to flow in order for overcurrent protective devices and any ground fault protection systems to operate effectively as designed and intended*.**

  Per NEC® 250-4(A)(5) in order to meet the requirements of an effective ground-fault current path **"electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems."**

  The ground fault current path must be capable of effectively and safely carrying the maximum ground-fault current likely to be imposed on it from any point in a specific power distribution system where a ground fault may occur to the return to power supply source.

  Earth can not be considered as an effective ground-fault current path.

  Randomly inserting individual ground rods into the soil to connect to remote electrical equipment will not provide an effective return path for phase-to-ground fault current.

Principal Purposes of a Bonding and Grounding System

- ***3. Create an effective and very low impedance path for ground fault current to flow in order for overcurrent protective devices and any ground fault protection systems to operate effectively as designed and intended*.**

  The primary function or purpose of the main bonding jumper (or MBJ) located within the service equipment is to provide a low impedance return path for the return of phase-to-ground fault current from the ground bus in the service equipment to the respective power supply source such as service transformers, stand by generators, or the output terminals of onsite UPS via the neutral conductors.

  The MBJ must be adequately sized to effectively carry all phase-to-ground fault current likely to be imposed on it. In addition, the MBJ is another bonding jumper that is often employed to stabilize the system voltage with respect to ground or earth.

  The MBJ is only a small portion of the ground fault return path for phase-to-ground fault current to return to the Xo terminal of the respect power source.

Principal Purposes of a Bonding and Grounding System

- ***4. Limit differences of potential, potential rise, or step gradients between equipment and personnel, personnel and earth, equipment and earth, or equipment to equipment .***

  It is extremely important that all conductive surfaces and equipment enclosures associated with any power distribution system be effective bonded together via a low impedance path. Without a very low impedance path for ground fault current to flow in a relatively controlled path potential rises or step potential differences are likely to occur at other locations within the power distribution system.

  During non-faulted conditions part of the normal load current will flow through the conductive surfaces, equipment enclosures, and earth if any current carrying conductor is connected to earth at more than one location.

  If any grounded conductor (neutral) were to become connected to any conductive surface or equipment enclosure downstream of the MBJ, then part of the load current will flow through the conductive surface, equipment enclosure, or the earth because a parallel path will have been created.

Principal Purposes of a Bonding and Grounding System

- ***5. Limit voltage rise or potential differences imposed on an asset, facility, or structure from lightning strikes, a surge event impinging on the service equipment, any phase-to-ground fault conditions, or the inadvertent commingling of or the unintentional contact with different voltage system.***

  When lightning strikes an asset, facility or structure the return stroke current will divide up among all parallel conductive paths between attachment point and earth.

  The division of current will be inversely proportional to the path impedance Z, ($Z = R + XL$, resistance plus inductive reactance).

  The resistance term should be very low, assuming effectively bonded metallic conductors. The inductance and corresponding related inductive reactance presented to the total return current will be determined by the combination of all the individual inductive paths in parallel.

  The more parallel paths that exist in a bonding and grounding system will equate to lower total impedance.

Questions?

- Can remotely connected equipment **be "effective grounded"** or referenced to Earth by the installation **of only a single 'ground rod'** into the Earth near the equipment?

  If so, then how and why?

  If not, then why not?

- Can the installation of 'ground rods' be effectively utilized as any form of an "effective ground fault return path"?

  If so, then how and why?

  If not, then why not?

Questions?

- Can remotely connected equipment **be "effective grounded"** or referenced to Earth by the installation **of only a single 'ground rod'** into the Earth near the equipment?

NO!

- Can the installation of 'ground rods' be effectively utilized as any form of an "effective ground fault return path"?

NO!

Selected Clauses from IEEE 142

- Clause 2.1.4 Overcurrent Protection Operation

  "The equipment ground system is an essential part of the overcurrent protection system. The overcurrent protection system requires a low-impedance ground return path in order to operate promptly and properly. **The earth ground system is rarely of low enough impedance and is not intended to provide an adequate return path.** The impedance of the grounding conductor must be low enough that sufficient ground-fault current will flow to operate the overcurrent protective device and clear the fault rapidly."

- Clause 2.8.8 – Earth Resistivity

  "Earth is inherently a rather poor conductor whose resistivity is around one billion times that of copper."

Questions?

- Are all subterranean soils the same?

    If so, then how and why?

    If not, then why not?

- Relative to electrical installations, do soils ever require inspections and maintenance?

    If so, then how and why?

    If not, then why not?

Questions?

- Are all subterranean soils the same?

NO!

- Relative to electrical installations, do the surrounding soils ever require inspections, maintenance, or treatments?

YES!

Selected Clauses from IEEE 142

- Clause 4.1.3 - Resistivity of Soils:

  “**It is *strongly* recommended that the resistivity of the earth at the desired location of the connection be investigated**. The resistivity of soils varies with the depth from the surface, the type and concentration of soluble chemicals and minerals in the soil, the pH of the soil, the moisture content, and the soil temperature. The presence of surface water does not necessarily indicate low resistivity.”

- Clause 4.1.6 - Soil Treatments:

  “To be effective, a regular maintenance scheme must be established to ensure low resistance grounding is achieved.)

Selected Clauses from IEEE 142

- Clause 4.4.5 - Electrical Grounding and Corrosion:

  "The effect of the grounding installation on corrosion must be considered. **Systems, equipment, and lighting sometimes unknowingly contribute to galvanic corrosion of underground conductors, structures, and piping.** Galvanic corrosion is caused by electrically connected dissimilar metals which form a galvanic cell. Under these conditions the following factors determine the rate of corrosion."

Question for Consideration

When, or during what conditions, should bonding and grounding systems conduct electrical currents?

Question for Consideration

When, or during what conditions, should bonding and grounding systems conduct electrical currents?

Only during abnormal conditions as;

- **Surge events**
- **Direct lightning strikes**
- **Indirect lighhting strikes**
- **‘Phase-to-Ground’ events**

Selected Clauses from IEEE 142

ARRANGEMENT OF METALS IN GALVANIC SERIES

CORRODED END
Anodic or less noble
Magnesium
Zinc
Aluminum
Cadmium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Nickel-Copper Alloys
Stainless Steels (passive)
Silver
Gold
Platinum
PROTECTED END
Cathodic or most noble

Any one of these metals and alloys will theoretically corrode while offering protection to any other which is lower in the series, so long as both are electrically connected.

In actual practice, however, zinc is by far the most effective in this respect.

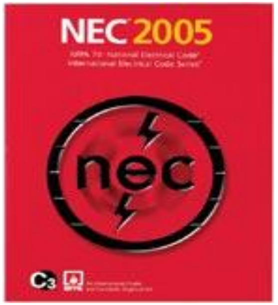
Figure 1. Summary of the "electromotive series of metals" address on corrosion.

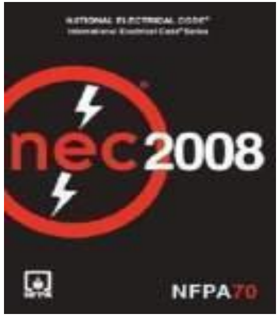
- Clause 4.4.5 - Electrical Grounding and Corrosion:

The rate of oxidation and corrosion is determined by;

- The potential difference between the two metals.
- The ratio of the exposed areas of the two metals.
- The resistance of the electrolyte.
- The resistance of the external circuit.
- Stray currents between electrodes, conductors, structures, pipes, and earth.
- **Current of one ampere flowing for one year will corrode away 20lbs of steel, 22 lbs of copper, 24 lbs of aluminum, 75 lbs of lead, or 26 lbs of zinc. With greater current flow, more metal will corrode away.**

NFPA 70 [The National Electrical Code (NEC)]





- "Article 250 in the NEC covers grounding.
  - The NEC is NOT a design document .
  - The NEC is NOT a maintenance document.
  - The NEC is NOT a performance document .
  - The NEC is NOT a testing document.
  - The NEC is ONLY a **minimum** construction and installation **'requirement'** document.
  - "Minimum requirements" are insufficient for the construction and installation of grounding systems associated with Critical, Emergency, and Life Safety Power Distribution Systems in Healthcare Facilities.

Definitions in the 2005/2008/2011/2014 Edition of the NEC

- What is “Effectively Grounded”?

  The 2005/2008/2011/2014 National Electrical Code defines effectively grounded as: “Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltage that may result in undue hazards to connected equipment of persons."

- What is “Grounded”?

  The 2005 NEC defines “Grounded” as: “Connected to earth or to some conducting body that serves in place of the earth."

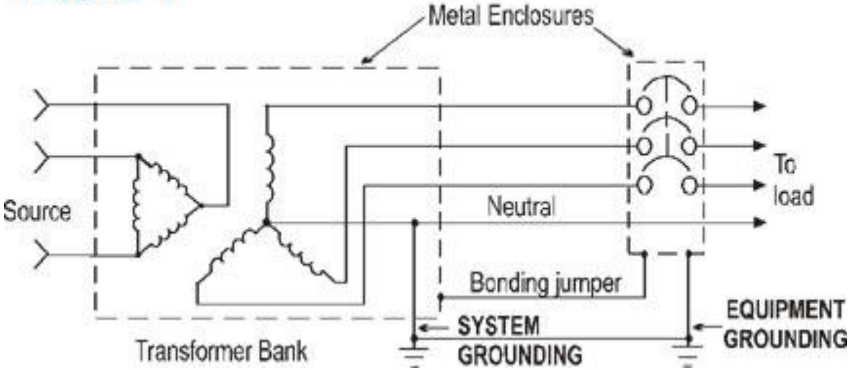
  The 2008 NEC defines “Grounded” as: “Connected to earth.”

  The 2011 and 2014 NEC defines “Grounded” as: “Connected (connecting) to ground or to a conductive body that extends the ground connection.”

- What is “Solidly Grounded”?

Definitions in the 2005/2008/2011/2014 Edition of the NEC

FIGURE 1



- What is "Solidly Grounded"?

  "Connected to ground without inserting any resistor or impedance device."

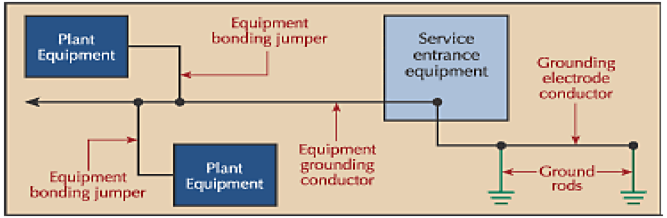
- What is "Grounded Conductor"?

  "A system or circuit conductor that is intentionally grounded."

  A "grounded conductor" carries current during "normal" operations of the power distribution system.

  (The "grounded conductor" is commonly referred to as the neutral conductor.)

Definitions in the 2005/2008/2011/2014 Edition of the NEC



- What is “Grounding Conductor”?

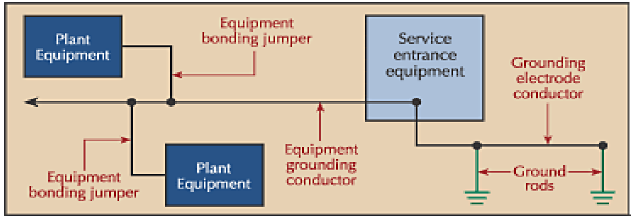
  “A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes."

  A “grounding conductor” is intended to only carry current during an “abnormal” operation of the power distribution system or a faulted condition.

- What is the “Equipment Grounding Conductor”?

  “The conductor used to connect the non-current carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both at the service equipment or at the source of a separately derived system." .

Definitions in the 2005/2008/2011/2014 Edition of the NEC



- What is “Grounding Electrode”?

  “A device that establishes an electrical connection to the earth.“

- What is a “Grounding Electrode Conductor”?

  “The conductor used to connect the grounding electrode(s) to the equipment grounding conductor, to the grounded conductor, or to both, at the service, at the building or structure where supplied by a feeder(s) or branch circuit(s), or at the source of a separately derived system.”

Definitions in the 2005/2008/2011/2014 Edition of the NEC

- What is “Main Bonding Jumper (MBJ)”?

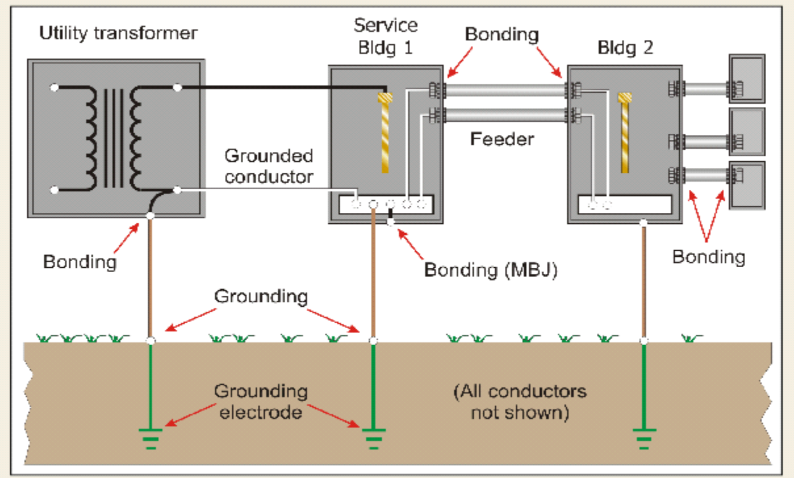


Figure 1. Grounding and bonding functions

“The connection between the grounded circuit conductor and the equipment grounding conductor at the service.”

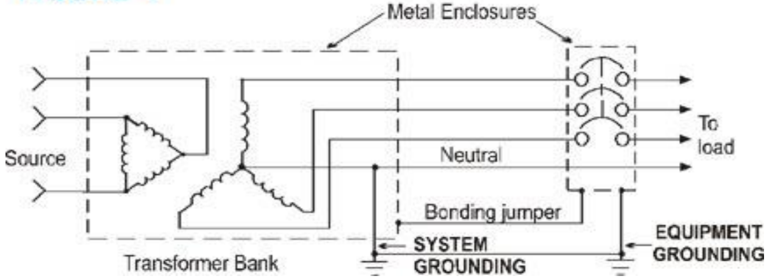
The primary function or purpose of the MBJ is to provide a low impedance return path for the return of phase-to-ground fault current from the ground bus in the service equipment to the power supply source (transformer, generator, or output terminals of an UPS).

The MBJ must be adequately sized to effectively carry all phase-to-ground fault current likely to be imposed on it.

Definitions in the 2005/2008/2011/2014 Edition of the NEC

- What is “Bonding Jumper”?

FIGURE 1



“A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.”

The primary function or purpose of a bonding jumper is to provide a low impedance electrically conductive connection between separate enclosures, conduits, raceways, structures, or equipment frames.

Must be properly sized to effectively carry any and all current likely to be imposed on it.

Definitions in the 2005/2008/2011/2014 Edition of the NEC

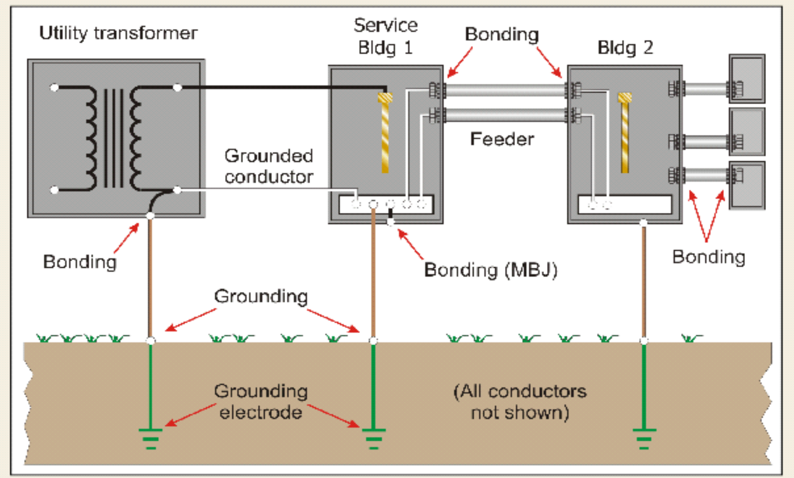


Figure 1. Grounding and bonding functions

- What is "System Bonding Jumper"?

"The connection between the grounded circuit conductor and the equipment grounding conductor at a separately derived system." (New definition introduced into the 2005 NEC.)

"The connection between the grounded circuit conductor and the supply-side bonding jumper, or the equipment grounding conductor, or both, at a separately derived system." (As revised in the 2011 NEC.)

The primary function or purpose of the system bonding jumper is to provide for an applicable reference to earth for the system voltage at the origins of the specific and separately derived system. The system bonding jumper is a connection between the Xo terminal of a transformer, generator, or UPS output terminals and earth. This jumper is not normally sized to carry ground fault current.

(i.e. 600Y/347V, 480Y/277V, or 208Y/120V, 3 Phase, 4 Wire, Solidly Grounded, "WYE" Systems)

General Requirements for Bonding and Grounding

Article 250.4 of the 2014 National Electrical Code identifies what general requirements relating to the grounding and bonding of electrical systems are required to be accomplished. The prescriptive methods contained in this article shall be followed to the comply with the performance requirements of this section.

- Article 250.4 (A)(3) “Bonding of Electrical Equipment”

“Normally non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to the electrical supply source in a manner that establishes **an effective ground-fault current path**.”

- Article 250.4 (A)(4) “Bonding of Electrically Conductive Materials and Other Equipment”

“Normally non-current carrying electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes **an effective ground-fault current path**.”

General Requirements for Bonding and Grounding

Article 250.4 of the 2014 National Electrical Code identifies what general requirements relating to the grounding and bonding of electrical systems are required to be accomplished. The prescriptive methods contained in this article shall be followed to the comply with the performance requirements of this section.

- Article 250.4 (A)(5) "Effective Ground-Fault Current Path"

"Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a, *low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. **It 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 a ground fault may occur to the electrical supply source. **The earth shall not be considered as an effective ground-fault current path.**" (*The word "permanent" in the 2005 NEC was removed in the 2008 NEC)

Maximum Impedance in a Ground Fault Return Loop

- Phase-to-Ground fault are the most common type of faulted condition in any power distribution system (95% - 98%).
- During the period of any phase-to-ground fault, the ground fault return path (bonding and grounding system) is 50% of the power circuit.
- In order for fuses or thermal/magnetic circuit breakers to effectively open during a phase-to-ground fault in a 480Y/277V power distribution system, the maximum %Z in the ground fault return path is calculated below.

Fuse Size (a)	CB Size (b)	Maximum %Z in Ground Return Loop*
5A	10A	18.48 OHMS
10A	20A	9.23 OHMS
15A	30A	6.12 OHMS
20A	40A	4.62 OHMS
30A	60A	3.08 OHMS

Maximum Impedance in a Ground Fault Return Loop

Fuse Size (a)	CB Size (b)	Maximum %Z in Ground Return Loop*
40A	80A	2.31 OHMS
50A	100A	1.75 OHMS
75A	150A	1.23 OHMS
100A	200A	0.924 OHMS
125A	250A	0.739 OHMS
150A	300A	0.616 OHMS
175A	350A	0.528 OHMS
200A	400A	0.462 OHMS
250A	500A	0.370 OHMS
300A	600A	0.308 OHMS

Maximum Impedance in a Ground Fault Return Loop

Fuse Size (a)	CB Size (b)	Maximum %Z in Ground Return Loop*
400A	800A	0.231 OHMS
500A	1000A	0.185 OHMS
600A	1200A	0.154 OHMS
800A	1600A	0.116 OHMS
1000A	2000A	0.093 OHMS
	2500A	0.074 OHMS
1500A	3000A	0.062 OHMS
2000A	4000A	0.047 OHMS

Common Issues Found with Bonding and Grounding Systems

- **All utilities are not effectively bonded together.**
- **All structures are not effectively bonded together**
- **EMT conduits with set screw couplings employed as the ground fault return path.**
- **No grounding bushings employed**
- **Improper or loose connections. Undersized grounding conductors**
- **Oxidization and reduction of mechanical grounding connections**
- **Lightning abatement system directing lightning currents into the building via connections to building steel**
- **No access to external ground grid system**
- **Deterioration of external ground grid system over time**
- **No records of initial ground grid testing.**
- **No records of regular inspections and maintenance of grounding systems.**
- **Excessive impedance in the ground fault return path**
- **No drawings or records available for the facility’s grounding system**
- **Bonding and Grounding System never inspected or tested**

Grounding 101

- **It is an illusion to ‘feel’ or ‘think’ that bonding and grounding systems do or should last forever**

- **Can, or do, lightning strikes deteriorate the grounding system of a building, structure, or a facilities?**

Grounding 101

- **Can, or do, lightning strikes deteriorate the grounding system of a building, structure, or a facilities?**

- **Yes! The available frequency, energy, and duration of lightning strikes can cause appreciable and significant mechanical, molecular, thermal stresses, and deformities on connections and conductors resulting in deteriorations that may not be readily apparent.**

Grounding 101

- **Can, or do, ‘phase-to-ground’ fault deteriorate the bonding systems associated with the power distribution systems of a building, structure, or a facilities?**

Grounding 101

- **Can, or do, ‘phase-to-ground’ fault deteriorate the bonding systems associated with the power distribution systems of a building, structure, or a facilities?**
- **Yes! The available frequency, energy, and duration of ‘phase-to-ground’ event can cause appreciable and significant mechanical, molecular, thermal stresses, and deformities on connections and conductors resulting in deteriorations that may not be readily apparent.**

Grounding 101

- **If a bonding or grounding system is not routinely inspected or tested, how do you know if it is adequate or effective for the needs of a specific facility?**
- **The weakest link in any facilities electrical power distribution system, lightning abatement system, or lightning protection system are always the grounding systems which are buried and out of sight and out of mind and begin to deteriorate at varying rates as soon as they are installed in the Earth.**
- Rational people have no doubts that when large humans are buried (hopefully after their death) that their respective bodies will quickly breakdown and return to base elements if placed in direct contact with Earth. However, a 5/8' diameter x 10' rod of cheap recycled steel, coated with a very thin layer of copper, that is driven into the ground with considerable force is suppose to last forever.
- Grounding Electrode Systems "don't last forever"??? "I'm Shocked! Shocked!"

The Four Principal **Functions** of Bonding & Grounding Systems

The four principle **function** or **resulting benefits** for an "effectively bonded grounding system via a low impedance path to earth" are intended to provide for the following.

1. Personnel safety to avoid hazardous of "step and touch" potentials that can result in shocks, injuries, and death
2. Protection of structures (building and facilities) and equipment by quickly dissipating the energy from a lightning strike or 'phase-to-ground' fault thus limiting the potential rises that can create hazardous voltages
3. Reducing the potential and risk for fires and explosions
4. Provide a path for claimed or diverted surge and transient energy to be directed and dissipated

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

The effectiveness and reliability of any grounding system is dependent on the following

1. The Grounding Electrode (GE) is the conductive device(s) or material(s) specifically intended to make the direct contact(s) with Planet Earth and is the point(s) where fault currents or surge energy is distributed and dissipated into Earth. The effectiveness of any GE is a function of;

- Material(s) of construction
- Cross section area as a function of diameter
- Cross section area as a function of Length
- Depth in Soil
- Area(s) of actual contact with conductive soil(s)

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

The effectiveness and reliability of any grounding system is dependent on the following

There are two categories of Grounding Electrodes (GE)

- **Intrinsic** electrodes

a.) Metal frame of a building or structure

b.) Underground metallic water pipes (i.e.; black iron & copper)

c.) Embedded reinforcement rods as part of foundation or floor slabs (must be intentionally bonded and accessible for inspections)

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

The effectiveness and reliability of any grounding system is dependent on the following

There are two categories of Grounding Electrodes (GE)

- **Intended** electrodes

a.) Ground Rod(s)

b.) Ground Plate(s)

c.) Ground Mess

d.) Bare copper conductors

e.) Semi-conductive neoprene blankets

f.) Ground Pipes & Tubes (copper and galvanized steel)

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

The effectiveness and reliability of any grounding system is dependent on the following

2. The Grounding Electrode Conductor (GEC) is the conductive conductor(s), device(s) or material(s) specifically intended to make the direct contact(s) with the Grounding Electrode (GE) for the conduction of fault current or surge energy. The effectiveness of any GEC is a function of;

- Material(s) of construction (copper, aluminum, copper clad steel, steel rods)
- Cross section area as a function of diameter
- Must be able to effectively and repetitively conductor and withstand **ALL** of the available fault or surge energy likely to be imposed on it from all sources without disfiguring or melting

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

3. **The Grounding Electrode Connector(s)** is/are the conductive means by the Grounding Electrode Conductor(s) [GEC] is/are effective bonded to Grounding Electrode(s) [GE]. Often not given necessary attention. There three types.

- **Mechanical**
  - a.) Least expense material
  - b.) Less Labor
  - c.) Requires maintenance
- **Compression**
  - a.) Requires a specific type of crimpable copper clamp or fitting
  - b.) Requires a special tool for fitting and crimping
  - c.) Can corrode if used on dissimilar metals
- **Exothermic Bonding (aka; Cadweld)**
  - a.) Most expensive
  - b.) Requires more labor
  - c.) Requires special molds and powder
  - d.) Is maintenance free if the performed properly

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

The effectiveness and reliability of any grounding system is dependent on the following

4. Resistance between Grounding Electrode (GE) and surrounding soil

- Diameter of grounding electrode (GE) **is not as important** as length of ‘GE’
- Doubling the diameter of a round ground rod only reduces contact resistance by approximately 10%
- Doubling the length of the ‘GE’ can ‘theoretically reduce the contact resistance by up to 40%
- Best application is the insertion or burial of multiple grounding electrodes that are symmetrically arranged and spaced in a square or rectangular pattern

The Five Items that Determine the Effectiveness and Reliability of any Grounding System

The effectiveness and reliability of any grounding system is dependent on the following

5. **Soil Resistivity** as measured in ohm-centimeters or in ohm-meters. (Ohm-meters is the most common measurement.)

- Is the most important variable in the successful functionality of any grounding system.
- The soil resistivity of a specific site must be known **BEFORE** construction begins. However, it is rarely considered until after construction and operations begin when anomalies, fathom events, and damaged electrical equipment begins to occur
- The soil resistivity can change dramatically overtime.
- **Rarely tested** after construction and operations begin

Design Considerations for a Grounding System

- What is the intended purpose of the building, facility, plant, or process operation?
- What is the desired or stated 'use-life' of the building, facility, plant, or process operation?
- Upon what type of fill, soil, gravel, rocks, or materials will the building, facility, or plant be erected? What is the composition of the subterranean materials or soil?
- What is average moisture content of the subterranean materials or soil? What are the water tables per year, per decade, per 50 years?
- What is the intended construction methodology? Subterranean I-Beams and footers, erected I-Beams, poured slab, pre-cast walls, subterranean structures a low parking decks, or below grade floors and basements?
- What is the soil resistivity of a specific site?
- What is the natural pH of the soil?
- Are there any chemicals, waste, or intentional buried debris in the soil?

Design Considerations for a Grounding System

- What is the elevation of the site?
- What is the sites potential for flooding?
- What are the average or expected variations in moisture content and temperatures for the proposed site?
- What are the local isokeraunic levels?
- Are there any existing building or structures associated with the new building of facility? If so, how old are they and what is the arrangement, design, and age of any existing grounding systems?
- What will be the shape or configuration of the intended building, facility, or plant?
- Are there any existing subterranean utilities about the intended new site?
- Are there any known buried structures or buried objects?
- Are there any plans for future additions, expansions, electrical equipment, or power supplies?

Additional Topic References and Resources

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Questions?

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