Bringing *grounding and bonding* down to earth

**Current in an Electrical Circuit**

- Current will always try to return to its source
- In order for there to be current, there must be a complete circuit
- Current will take as many paths or circuits available to it to return to the source
- The amount of current in each path is directly related to the amount of opposition (impedance or resistance) of that particular path

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**Current in an Electrical Circuit (cont.)**

- The same care that is given to constructing the electrical circuits (*phase conductors and neutral conductors*) must also be given to the grounding and bonding circuits of the system
- The safety (*grounding and bonding*) circuits must operate effectively

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**Overcurrent Device Operation**

- Overcurrent devices require amperes to operate
- Lower resistance or opposition means increased amperes
- Circuits operating normally with current below the overcurrent device ratings will continue to operate normally
- Current levels in electrical circuits above the overcurrent device rating cause the overcurrent device to open
- The higher the current, the quicker the device will operate
- Inverse time as applied to overcurrent devices means the more current, the faster the device opens

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**Overcurrent Device Operation**

- Current returns to its source (applies to both normal current and fault current)
Grounded conductors (usually neutrals) are intended to carry return currents from circuits to the source in normal operation. The conductor is referred to as grounded because this is the action required at the service or separately derived system. The term "grounded" is a past tense term meaning the action has already happened. It is generally not permitted to use the grounded conductor (neutral) for grounding or in making grounding connections on the load side of the service or separately derived system [see 250.4(A)(5)]. The goal is to keep current on the path intended for it.

Grounding is a present tense word. Grounding indicates a process that is ongoing. Grounding is an action required at enclosures and equipment in electrical circuits from the source or service to the final outlet(s) on the circuit. It is accomplished by using an equipment grounding conductor of any type specified in 250.118. The equipment grounding conductor of a circuit serves to put all metal enclosures at earth potential along the circuit. It also serves as the low-impedance path (safety circuit) to carry ground-fault current to the source to facilitate the operation of overcurrent devices in ground-fault conditions. Chapter nine covers equipment grounding conductors.

Definitions - Grounding as Compared to Bonding

- **Ground**: The earth.
- **Grounded (Grounding)**: Connected (connecting) to ground or to a conductive body that extends the ground connection.
- **Bonded (Bonding)**: Connected to establish electrical continuity and conductivity.
**Grounding (Connecting to earth)**
- Limit the voltages due to lightning, line surges or unintentional contact with higher voltage lines
- Stabilize voltage to ground during normal operation

**Bonding (Connecting together)**
- Bonding shall be provided where necessary to ensure electrical continuity
- Must have the capacity to conduct safely any fault current likely to be imposed

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**Effective Grounding and Bonding**
- Grounding and bonding must be effective
- These are the safety circuits of the electrical system
- The safety circuit (bonding) path must have the following characteristics for effectiveness anticipated by the NEC
  - Electrically continuous path
  - Have adequate capacity for fault currents imposed
  - Have lowest possible impedance
- See definitions in Article 250
The Earth as a Conductor

Grounded: “Connected (connecting) to ground or to a conductive body that extends the ground connection”

The earth as a conductor is assumed to have an electrical voltage potential of zero

Grounding Fundamentals

During ground-fault conditions current returns to its source

Very little current here

Severe burns

Breathing stops

Heart stops beating

Suffocation possible

Muscle contraction

“Let-go” threshold

GFCI will trip

Mild shock

Threshold of sensation

Severity of Electric Shock

The severity of electric shock is related to four elements

1. Amount of current
2. Length of time current is present
3. Path of current through the body
4. Frequency of the current (Hz)

Effects of Electricity on Humans

1000 milliamperes or 1 ampere

1000
900
800
700
600
500
400
300
200
100
50
20
10
5
1

Will light a 100-watt bulb

Severe burns

Breathing stops

Heart stops beating

Suffocation possible

Muscle contraction

“Let-go” threshold

GFCI will trip

Mild shock

Threshold of sensation

Human Completing Grounding Circuit

Ungrounded

No equipment grounding conductor provided with branch circuit or feeder

Grounded

**Definitions**

- **Ground**: The earth.
- **Grounded (Grounding)**: Connected (connecting) to ground or to a conductive body that extends the ground connection.
- **Grounded Conductor**: A system or circuit conductor that is intentionally grounded.
Electrical Systems (Typical)

- Grounded electrical system
- Ungrounded electrical system

Grounded wye 3-phase, 4-wire
Ungrounded delta 3-phase, 3-wire

250.26 Conductor to be Grounded

For ac premises wiring systems, the grounded conductor shall be as specified in the follows:

- Single-phase, 2-wire: one conductor (either one)
- Single-phase, 3-wire: the neutral conductor
- Multiphase system with one common wire: the neutral conductor
- Multiphase systems that are corner-grounded: one phase conductor
- Multiphase systems with midpoint of one transformer winding used as a neutral conductor

Identification of Grounded Conductors

Sizes 6 AWG or smaller identify as follows:
- By a continuous white outer finish or...
- By a continuous gray outer finish or...
- By three continuous white or gray stripes on other than green insulation along its entire length

Sizes 4 AWG and larger identify as follows:
- By a continuous white outer finish or...
- By a continuous gray outer finish or...
- By three continuous white or gray stripes on other than green insulation along its entire length or...
- At the time of installation, by a distinctive white or gray marking at the terminations that encircles the conductor

200.6(D) Grounded Conductors of Different Systems

Where grounded conductors of different systems are installed in same raceway, wireway, etc., grounded conductors to be identified by system in a manner that distinguishes the grounded conductors of different systems from one another

Identification means to be permanently posted or documented in a readily available manner

1. Grounded conductor to be identified by 200.6(A) or 200.6(B)
2. Other system grounded conductor to have a different identification conforming to either 200.6(A) or (B)
3. Other means as allowed by 200.6(A) or 200.6(B) that will distinguish each grounded conductor

Methods of System Grounding

1. Solidly grounded
   (No intentional grounding impedance)
2. Grounded through surge arresters
3. Reactance grounded
   (Grounded through an inductor)
Definitions

- **Grounded Conductor**: A system or circuit conductor that is intentionally grounded.
- **Service**: The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the premises served.
Where the service-entrance conductors are run in parallel, the size of the grounded conductor shall be based on the total cm area of the parallel conductors in the same enclosure.

Where the service-entrance conductors are installed in two or more raceways, the size of the grounded conductor shall be based on the size of the ungrounded service-entrance conductor in the raceway but not smaller than 1/0.

See 250.24(C)(2)

Systems in which a grounding impedance (usually a resistor) limits the ground-fault current to a low value.

Permitted for 3-phase ac systems of 480 volts to 1000 volts.
**High-Impedance Grounded Neutral Systems (cont.)**

- Provides uninterrupted electrical power for industrial plants, data centers, and other continuous operations
- Three conditions must be met to qualify:
  1. Qualified persons must be available to service the system
  2. Ground detectors must be installed to indicate an insulation failure
  3. Line to neutral loads are not served
- See 250.36

**Definitions**

- **Bonded (Bonding):** “Connected to establish electrical continuity and conductivity”
- **Bonding Jumper, Main:** “The connection between the grounded circuit conductor and the equipment grounding conductor at the service”
- **Bonding Jumper, Supply Side:** “A conductor installed on the supply side of a service or within a service equipment enclosure(s), or for a separately derived system, that ensures the required electrical conductivity between metal parts required to be electrically connected” [250.2]
**Sizing Supply-Side Bonding Jumpers**

- Line side of service and main bonding jumper
- Size per Table 250.102(C)(1)
- Based on size of ungrounded service-entrance conductor(s)
- Use rules in 250.102(C)
  - Parallel conductors in the same raceway or enclosure [see 250.102(C)(1)]
  - Parallel conductors in separate raceways or enclosures [see 250.102(C)(2)]
• Special rules are provided for bonding enclosures on the line side of the service disconnecting means.

• This equipment does not have overcurrent protection on the line side (like feeders and branch circuits).

• All metallic enclosures that contain service conductors must be bonded together.

**Bonding Service Equipment Enclosures**

- Bonding ensures that none of the equipment enclosures can become electrically isolated and become a shock hazard should a line-to-ground fault occur in that enclosure.

- Bonding also provides a low-impedance path for fault current so the fuse or circuit breaker on the supply side of the electric utility transformer will open or operate.

- See 250.92(A)(1) and (A)(2)

**Bonding Service Equipment Enclosures (cont.)**

- The normally non-current-carrying metal parts of equipment required to be effectively bonded together include:
  
  (1) The service raceways, cable trays, cablebus framework, auxiliary gutters, or service cable armor or sheath that enclose, contain, or support service conductors, except as permitted in 250.80

  (2) All enclosures containing service conductors, including meter fittings, boxes or the like, interposed in the service raceway or armor
250.92(A) Bonding Service Equipment Enclosures

The normally non-current-carrying metal parts of service equipment required to be bonded together include:

- Main bonding jumper
- Bonding jumper

Service raceways and cable armor or sheath. Service equipment enclosures including meter enclosures

Note: Bonding required around impaired connections, such as reducing washers or oversized, concentric, or eccentric knockouts

Bond together in a method specified by 250.92(B) and size bonding jumpers per sizes in Table 250.102(C)(1)

250.92(B) Bonding Fittings

- Bonding Locknut — Used where no concentric or eccentric knockouts remain. (Standard locknut permitted on opposite side)

- Bonding Wedge — Use with bonding jumper around concentric or eccentric knockouts; with or without bonding jumper where no concentric or eccentric knockouts. (Standard locknut permitted on opposite side)

Use of Grounded (Neutral) Conductor for Bonding (Line Side of Service)

Service disconnects

Grounded conductor permitted to be used for grounding on the supply side of the service disconnect(s) in accordance with 250.142(A)(1)

250.92(B) Methods of Bonding Service Equipment

- Threaded couplings or bosses on enclosures made up wrench tight

- Conduit hub furnished in many trade conduit sizes as accessory by equipment manufacturer. (Install according to manufacturer's instructions)

- Threadless couplings and connectors made up tight for rigid metal conduit, intermediate metal conduit, and electrical metallic tubing
Methods of Bonding at Service [250.92(B)]

- Listed lugs, pressure connectors, other listed means (250.8)
- Threaded couplings and connectors or threaded hubs on enclosures where made up wrenchtight
- Threadless couplings and connectors if made up tight for metal raceways or metal-clad cables
- Other listed devices, such as bonding-type locknuts, bushings, or bushings with bonding jumpers
- Standard locknuts are not permitted for the bonding required by this section
- Bonding jumpers are required to be used around impaired concentric or eccentric knockouts
- Connections cannot depend on solder [250.148(E)]
Section 250.52(A) includes the details and descriptions of grounding electrodes that are required to be used for the grounding electrical systems (where present):

(A)(1) Metal underground water pipe
(A)(2) Metal frame of a building or structure
(A)(3) Concrete-encased electrode
(A)(4) Ground ring
(A)(5) Rod and pipe electrode
(A)(6) Other listed electrodes
(A)(7) Plate electrodes
(A)(8) Other local metal underground systems or structures
Metal Underground Water Piping Systems

- Section 250.52(A)(1) requires metal underground water piping systems to be used for the grounding electrical systems (where present)
- Must be in direct contact with the earth for 3.0 m (10 ft) or more and electrically continuous
- Includes any metal well casing bonded to the pipe
- Can be made electrically continuous by bonding around insulating joints or insulating pipe

Metal Frame of a Building or Structure

- Section 250.52(A)(2) requires the metal frame of a building or structure to be used for the grounding electrical systems (where present and qualifies)
- Must be connected to the earth by one or more of the following methods:
  - At least one structural metal member that is in direct contact with the earth for 3.0 m (10 ft) or more (with or without concrete encasement)
  - Hold-down bolts securing the structural steel column that are connected to a concrete-encased electrode that complies with 250.52(A)(3) located in the support footing or foundation

Concrete-Encased Electrode

- Section 250.52(A)(3) requires concrete-encased electrode is to consist of:
  - At least 6.0 m (20 ft) of bare copper conductor not smaller than 4/AWG or one or more bare or electrically conductive coated steel reinforcing bars or rods of not less than 13 mm (½ in.) in diameter
  - Installed in one continuous 6.0 m (20 ft) length, or multiple pieces connected together by the usual steel tie wires, exothermic welding, welding, etc. to create a 6.0 m (20 ft) or greater length
  - Metallic components to be encased by at least 50 mm (2 in.) of concrete
  - Located horizontally within that portion of a concrete foundation or footing in direct contact with the earth or within vertical structural components in direct contact with the earth
Concrete-Encased Electrode

Concrete-encased electrode to consist of:

- At least 6.0 m (20 ft) of bare copper conductor not smaller than 4 AWG or one or more bare or electrically conductive coated steel reinforcing bars or rods, not less than 13 mm (½ in.) in diameter.
- Installed in one continuous 6.0 m (20 ft) length, or multiple pieces connected together by the usual steel tie wires, exothermic welding, etc. to create a 6.0 m (20 ft) or greater length.
- Metallic components to be encased by at least 50 mm (2 in.) of concrete.
- Located horizontally within that portion of a concrete foundation or footing in direct contact with the earth or within vertical structural components in direct contact with the earth.

Minimum 6.0 m (20 ft) reinforcing bars (typical)

Clamp suitable for concrete encasement or exothermic weld

4 AWG copper conductor

6.0 m (20 ft) or more installed in one continuous length
250.52(A)(6) Other Listed Electrodes

Other listed grounding electrodes shall be permitted to be used such as a chemical ground electrode system.

Required to be listed as grounding and bonding equipment [UL 467]

Grounding Electrode Required

- Where the grounding electrodes described in 250.52(A) are not present, a grounding electrode must be installed.
- Where none of these grounding electrodes exist, one or more of the grounding electrodes specified in 250.52(A)(4) through (A)(8) shall be installed and used.
- These “made” electrodes can consist of rod, pipe, and plate electrodes, or other listed electrodes, or local metal underground systems or structures.
- See 250.50 and 250.52(A)(4) through (A)(8)

Supplemental Electrode

- An underground metal water pipe electrode is required to be supplemented by an additional grounding electrode.
- Any of the electrodes described in 250.52(A)(2) through (A)(8) are permitted to be used (not limited to just a ground rod).
- If the supplemental electrodes are of the rod, pipe, or plate types, these must be supplemented as well or must meet the 25 ohm rule at 250.53(A)(2). Exception.
- See 250.53(D)(2)
Loose connections, loose fittings, missing screws, stripped screws, bonding bushing screws loose or missing, bonding bushing lugs missing, re-bar covered without inspection, etc.
NEC Art. 110.3 – 14, 300.10-13

Neutral splice lugs not stacked on a common bolt in CT or wireway.
NEC Art. 200.2 (B)

Ungrounded system installed/upgraded with no ground detectors.
NEC Art. 250.21 (B)(C)

Grounding electrode conductor not terminated TO the neutral. NEC Art. 250.24
Generator neutral installed with no grounding electrode conductor (neutral lifted on transfer).
NEC Art. 250.35(A)

Ground rod cut off.
NEC Art. 250.52(A)(5)

Water meter not jumpered.
NEC 250.53(D)(1)

Ground rod not driven flush with or below grade (or otherwise protected).
NEC Art. 250.53(G)

Grounding electrode conductor spliced with split-bolt.
NEC 250.64(C)

Numerous errors on multi-disconnect services. There is a general non-understanding that NEC Art. 250.64(D)(1) – (3) is prescriptive.
Improper use and application of Tables 250.66 and 250.122.

Improper termination(s) of grounding electrode conductors. NEC Art. 250.70

Isolated Service mast not bonded. NEC Art. 250.80

Improper bonding of service equipment, raceways, nipples, cabinets, enclosures and fittings. NEC Art. 250.92

Intersystem Bonding missing or improperly installed. NEC Art. 250.94

Bonding missing at concentric K.O.s for 277V, 480V installations. NEC Art. 250.97
Improperly sized single daisy chain conductors.
For Service – see NEC Art. 250.102(C)(1) (see last sentence of 250.102(C)(2)),
For Feeder – see NEC 250.102(D)

8AWG (and smaller) re-identified conductors used for equipment grounding conductors.
NEC Art. 250.119

Neutral bonded in sub-panel.
NEC Art. 250.142(B)

Grounds not spliced, device not tailed, and other ground continuity issues in device boxes.
NEC Art. 250.148

THANK YOU!!

SW DIVISION IAEI

Grounding Defects Commonly Found During Inspection
(Based on information provided by the IBI crew of 2014)