MEA 2017 NEC
Grounding and Bonding
Part I

2-hour class presented by

Minnesota Electrical Association

This seminar will satisfy the 2-hour electrical code training for electricians required by the State of Minnesota.

Acknowledgements

Some material and illustrations presented are with permission of Cengage Learning from:
Electrical Grounding and Bonding
by Phil Simmons

The National Electrical Code (NEC)® is Document 70 -- from the National Fire Protection Association (NFPA)

Objectives

- Using accepted definitions of terms applicable to grounding & bonding
- Provide a low-impedance path of proper capacity to ensure the operation of overcurrent protective devices
- Various components of the grounding & bonding system
- Electric shock hazards & effect of electricity on the human body
- Grounding practices

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Grounding and bonding concepts

- The subject of grounding and bonding of electrical systems is often misunderstood.
- Are grounded systems safer than ungrounded?
- Many systems are required to be grounded
- Several circuits are not permitted to be grounded
- The NEC has created rules to comply.

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Speaking the Same Language

- Inconsistent use of terms related to grounding and bonding is common and can result in misunderstandings.
- Do terms "grounded" and "bonded" mean the same thing?
- Are they interchangeable?

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Speaking the Same Language

- Is a receptacle on the 17th floor of a building still "grounded?"
- Definition of "Grounded" is:

  "Connected (connecting) to ground or to a conductive body that extends the ground connection."
- Understanding definitions is essential to proper application of the rules related to grounding and bonding.

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Definitions

- Understanding of definitions is essential to understanding grounding and bonding
- Some definitions may have changed from the previous edition of the NEC
- Many rules in the NEC have become more prescriptive to rely less on defined terms

Art. 100: Ground

NEC Def. of Ground: "The earth."

- The earth consists of many types of soil
- Soil resistance is determined largely by its content of electrolytes which consist of moisture, minerals and dissolved salts

Ground- Earth- characteristics

- Soil resistance varies from an average of approximately **2,000** ohm-centimeters (equiv: ohms/ distance) for ashes, cinders, brine or waste to **94,000** ohm-centimeters for gravel, sand, and stones with little clay or loam - highly resistive, little moisture content
- The earth's ability to carry current varies widely depending on temp and moisture content
- In the NEC, connections to earth are not permitted for the purpose of carrying normal current

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Terms Related to the Definition of "Ground"

- What is the electrical system? Source---
  - Typically from the electric utility.
  - Often from the source of a separately derived system
- The purposes of grounding electrical systems is covered at **250.4(A)(2) –** E.g., to limit the voltage to ground on non-current carrying conductive material
- The purposes of grounding equipment for ungrounded systems is covered at **250.4(B)(1):** Similar to A2 but for accidental contact or lightning

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NEC Art 250 one-line

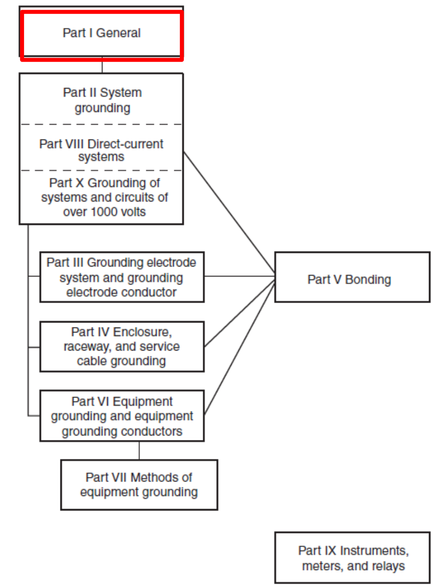

FIGURE 250.1 Grounding and Bonding.

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Art. 100, Grounded (Grounding)

- Def. Grounded (Grounding) "Connected (connecting) to ground or to a conducting body that extends the ground connection"
- Connection to ground is accomplished by means of a recognized grounding electrode (system). See Parts II and III of Article 250
- It is vital to provide an effective ground-fault current path defined and described in Article 250.4(A)(5)
- Grounded objects such as metal conduit, cables with metallic sheaths and structural metal may "extend the earth connection."

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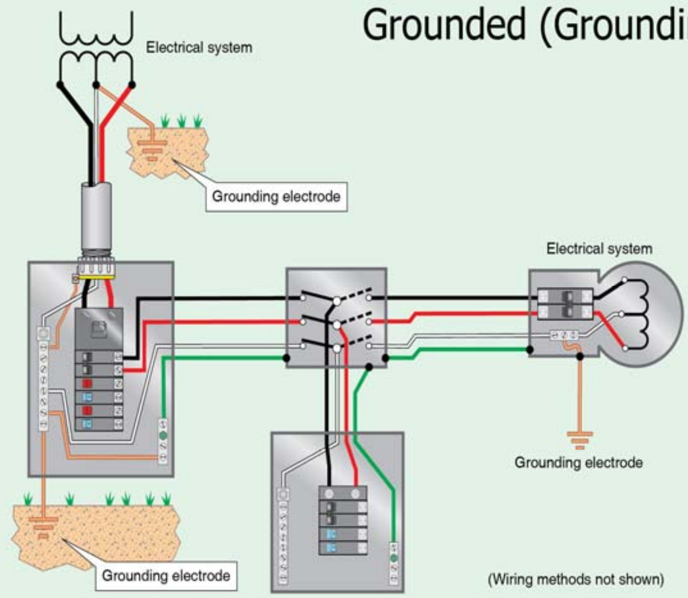
Grounded (Grounding)



Bonding Jumpers ID

- Main bonding jumpers
- System bonding jumpers
- Supply-side bonding jumpers on supply side of the service or a separately derived system
- Equipment bonding jumpers on the load side of the service
- Bonding jumpers to metal piping systems and to structural metal frames of buildings

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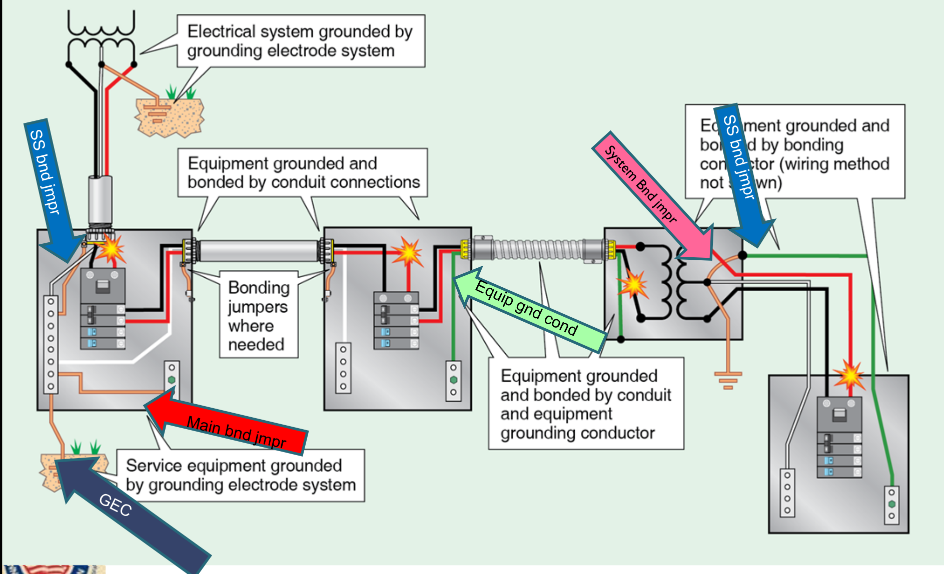
General Requirements for Grounding and Bonding



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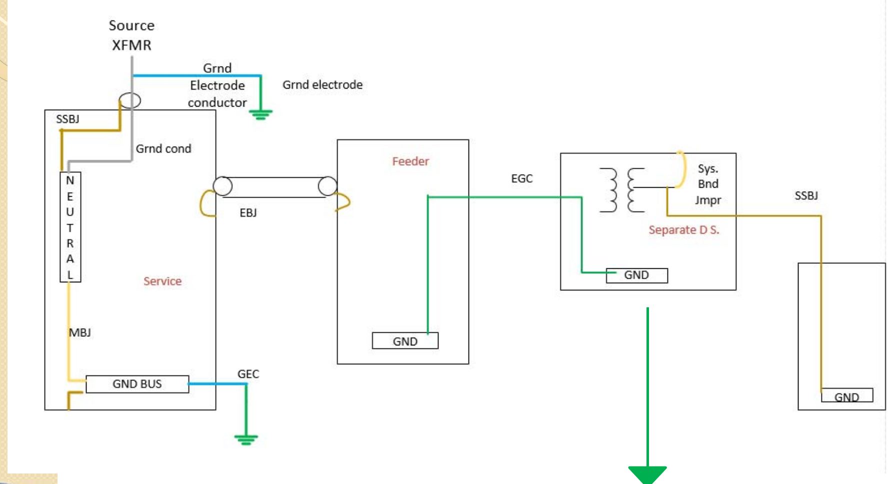
One line grounding



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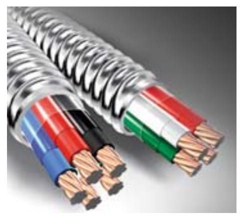
Grounded (Grounding)

- The phrase "a conductive body that extends the earth connection" is not defined in the NEC
- A conductive element such as conduit, cable or wire that extends from the point where an earth connection is made at one or more grounding electrodes to another point on the electrical system where a switchboard, panelboard, junction or pull box or a grounding receptacle is properly connected "extends the earth connection"



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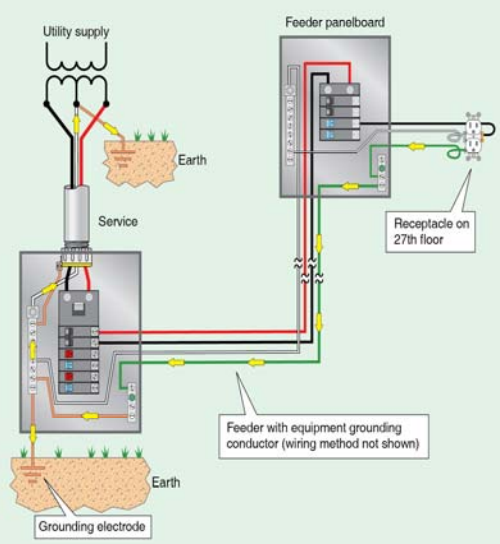
Grounded by Conductive Body that Extends the Earth Connection



Grounded (Grounding)

- Some grounding electrodes also "extend the earth connection" more precisely grounding conductors
  - Structural metal often extends many stories above the point where it makes an earth connection or is connected to a grounding electrode system
  - See 250.52 (A) (2)

  New electrode information

  - Metal water pipes are recognized in certain occupancies for connection purposes throughout a building or structure
- See 250.30 for the rules on grounding separately derived systems

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Grounded, Improperly

- Equipment can be "grounded" but not be in compliance with NEC rules
- "Grounded (Grounding)" means connected (connecting) to earth or to some conducting body that extends the ground connection (low impedance)
- Equipment grounding must be in compliance with the "Effective ground fault path rules" in 250.4(A)(5) and 250.4(B)(4)

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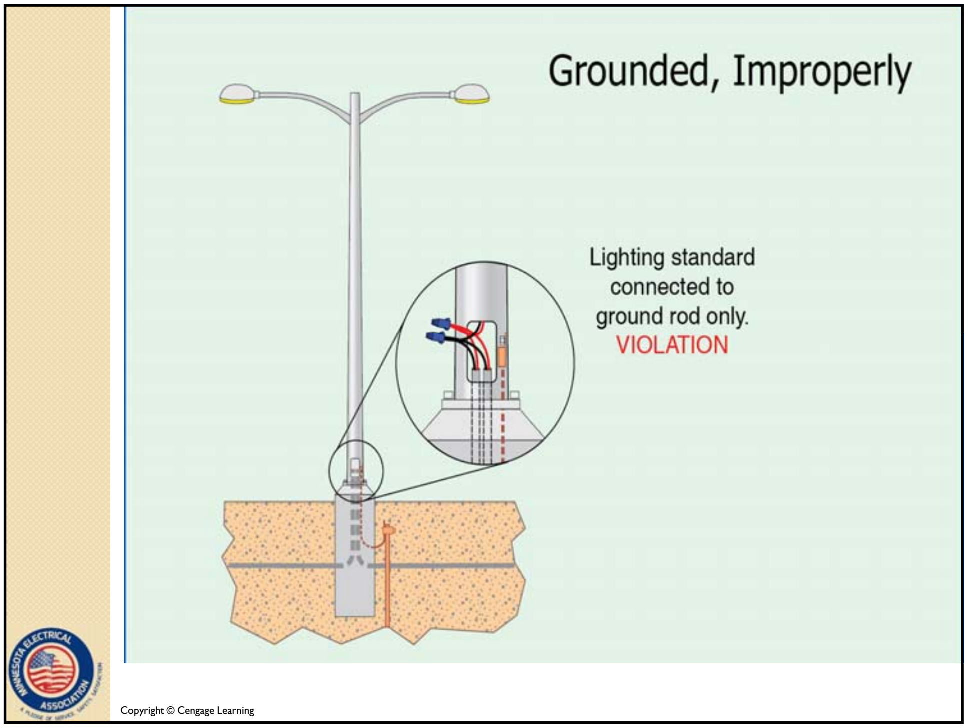

Art. 100, Bonded (Bonding)

- Def. Bonded: "Connected to establish electrical continuity and conductivity"
- In its simplest form, the definition means the conductor and connections to connect equipment together and to provide a complete path for current to flow
- Bonding ensures conductivity around suspect connections

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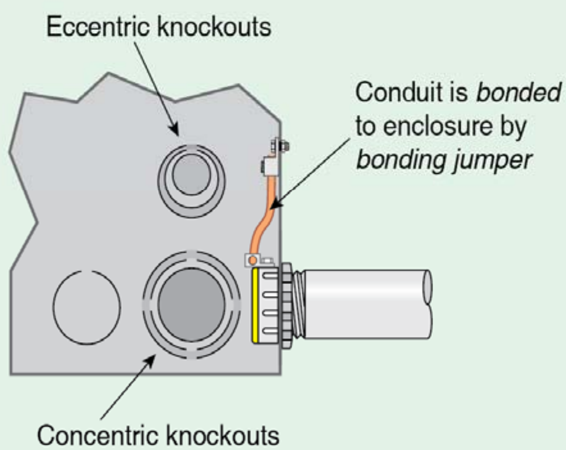
Bonded (Bonding)



Bonded (Bonding)

- Conduit, or equipment grounding conductor in Type MC or other wiring methods, are permitted to be used to bond (connect) enclosures together.
- The function of equipment grounding and bonding become inseparable

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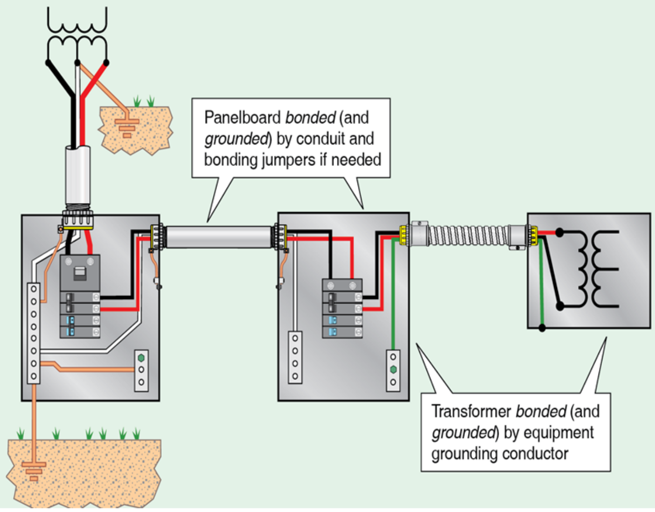
Bonding with Wiring Methods and Equipment Grounding Conductor



Art. 100, Bonding Jumper

- Def. Bonding conductor or jumper: "A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected."
- Usually a wire-type conductor used to connect parts that are required to be electrically continuous
- Specific sizes are given for application

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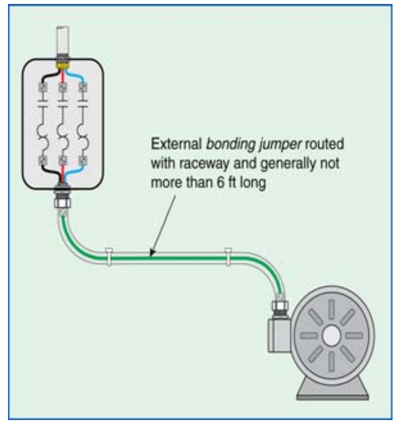
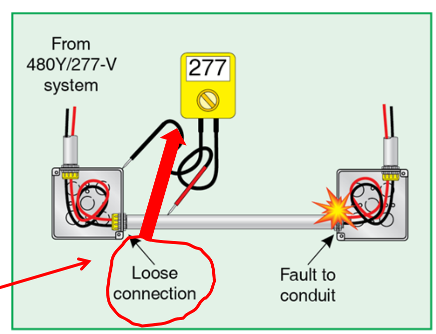
Equipment Bonding/ Grounding Jumpers

- Permitted to be installed outside raceway or cable
- If installed outside conduit, generally limited to not more than 6 ft (1.8 m)
- Longer lengths permitted for poles



Equipment Bonding Jumper

- Def. Equipment bonding jumper: The connections between two or more portions of the equipment grounding conductor.
- Where a metal conduit or tubing serves as bonding means, a single loose connection will impair the fault path.
- This can result in shock hazard.



Main Bonding Jumper (Art 100)

- Def. Bonding jumper, Main : The connection between the grounded circuit conductor and the equipment grounding conductor at the **service.** Size: See 250.24(B) - 250.28 - 250.28(D)1 – 250.102(C)(1)
- Must be large enough so it does not melt while carrying fault current - 250.102(C)(1)
- Permitted to be a wire, a bus, or a screw - 250.8
- Identical in function to "system bonding jumper"
- Provides return path for fault current
- Many rules on the Main Bonding Jumper are in 250.28

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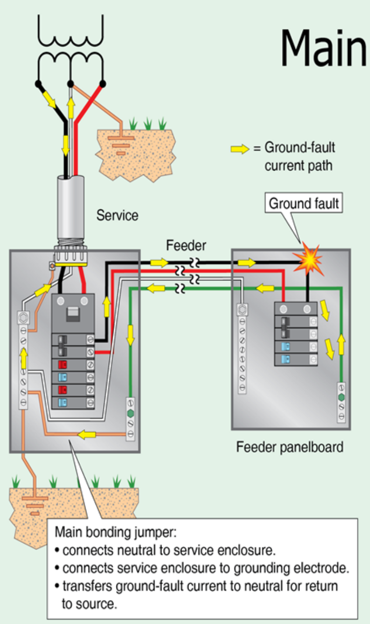
Main Bonding Jumper



Article 100: (Bonding Jumper, Main)
"The connection between the grounded circuit conductor and the equipment grounding conductor at the service."

Supply-Side Bonding Jumper (250.2)

- Def. **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. [250.30(A)(2) for separately derived]
- **Used for bonding raceways, and enclosures containing service conductors**
- Also used to ensure bonding for metal enclosures for separately derived systems
- Bonding jumper sized from Table 250.102(C)(1) on the size of the ungrounded service conductor or the derived ungrounded conductor of separately derived system

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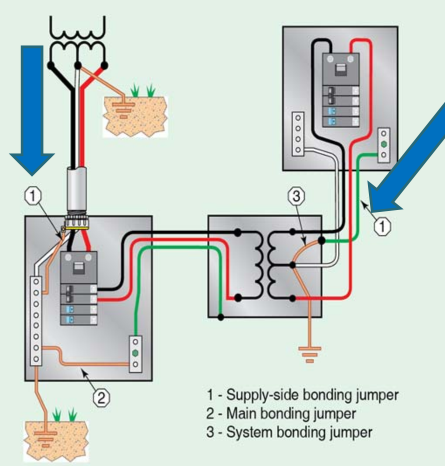
Supply-Side Bonding Jumper



250.2: (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."

System Bonding Jumper (Art 100)

- Def. Bonding Jumper, System. 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.**
- Identical in function to "main bonding jumper" for service
- Must be large enough so it does not melt while carrying fault current
- Permitted to be a wire, a bus, or a screw
- Provides return path for fault current

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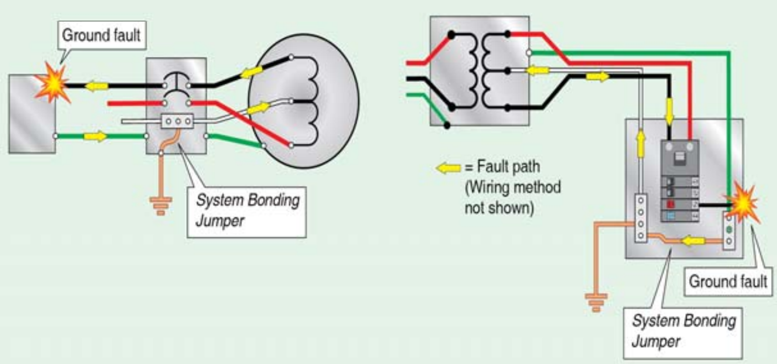
System Bonding Jumper



Art. 100, Grounded, Solidly

- Def. **Grounded, Solidly.** Connected to ground without inserting any resistor or impedance device
- Considered "solidly grounded" if a resistor or impedance device such as an inductor are not inserted in the connection of the system or equipment to the grounding electrode
- High impedance grounded neutral systems are covered in 250.36

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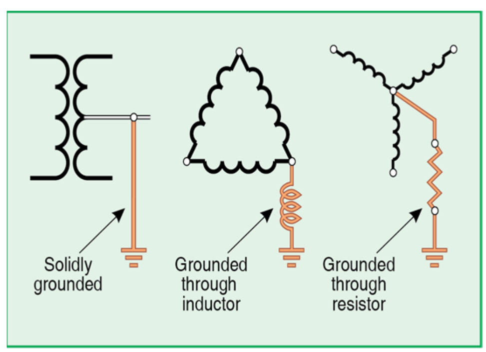
Grounded, Solidly

"Connected to ground without inserting any resistor or impedance device." (Article 100)



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Art. 100, Grounded Conductor

- Def. Grounded conductor: "A system or circuit conductor that is intentionally grounded."
- A broad term that includes both neutral conductors and grounded conductors- that are not a neutral
- All neutral conductors are grounded conductors but not all grounded conductors are neutral conductors (See the definition of "Neutral" and "Neutral Point")

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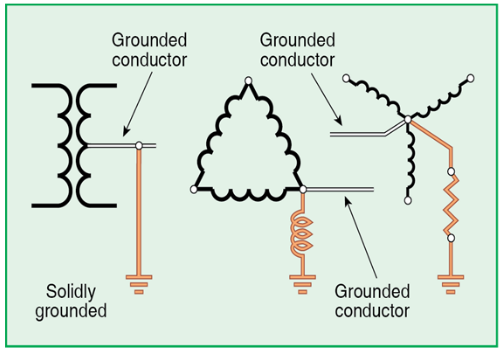
Definitions

- Neutral Conductor: The conductor connected to the neutral point of a system that is intended to carry current under normal conditions
- Neutral Point: The common point on a wye connection in a polyphase system or the midpoint fa single phase, 3-wiresystem, or the midpoint of a single-phase portion of a 3-phase delta system, or the midpoint of a 3-wire, DC current system.
- "Informational Note: At the neutral point of the system, the vectoral sum of the nominal voltages from all other phases within the system that utilize the neutral, with respect to the neutral point, is a zero potential."

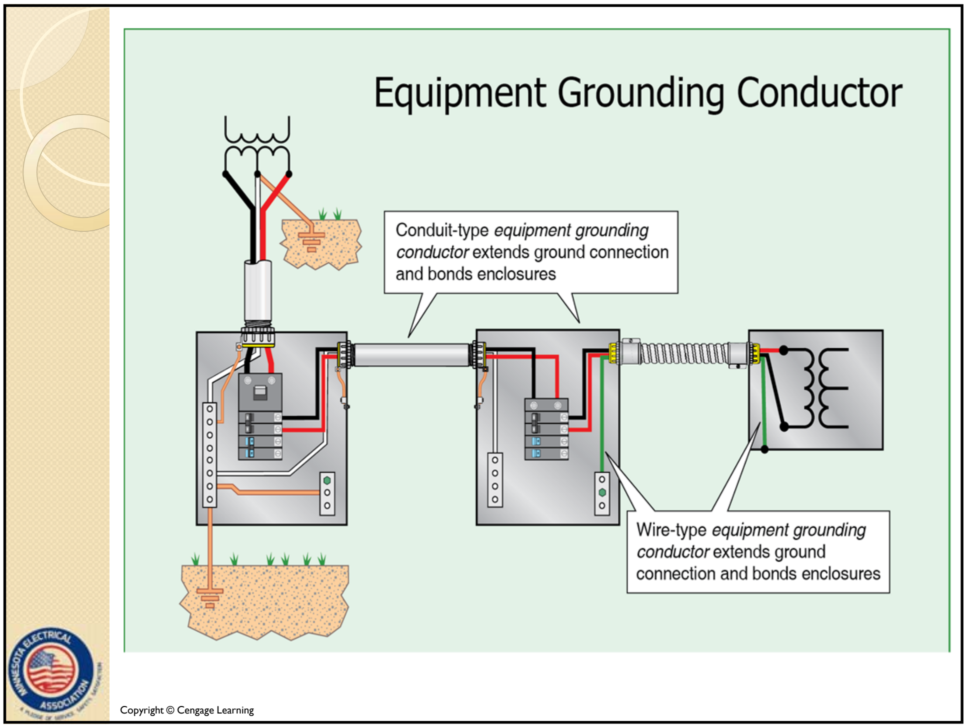
Grounded Conductor

"A system or circuit conductor that is intentionally grounded." (Article 100)



Art. 100, Equipment Grounding Conductor

Def. 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."



Equipment Grounding Conductor

- Conductive path is provided by the equipment grounding conductor
  - Paths recognized include a wire or bus, metallic raceways and metallic cable sheaths
- "Normally non-current-carrying metal parts of equipment …"
  - Equipment grounding conductors do not normally carry current
  - Neutral conductors do carry current under normal conditions

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Equipment Grounding Conductor

- "Together" in definition indicates the equipment grounding conductor performs a bonding function.
- Informational Note No. 1: It is recognized the equipment grounding conductor also performs bonding.
- Informational Note No. 2: See 250.118 for a list of acceptable equipment grounding conductors.

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Grounding Electrode

- Descriptions of grounding electrodes permitted to be used are in 250.52(A)
- 8 items See NEC page 112
- Items NOT permitted to be used as Grounding electrodes 250.52(B)
- 3 items See NEC page 113
- **Grounding electrodes are never used to provide a fault-current path**
- Are used to make an earth connection

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Art. 100, Grounding Electrode

Definition-
Grounding Electrode:
"A conducting object through which a direct connection to earth is established."

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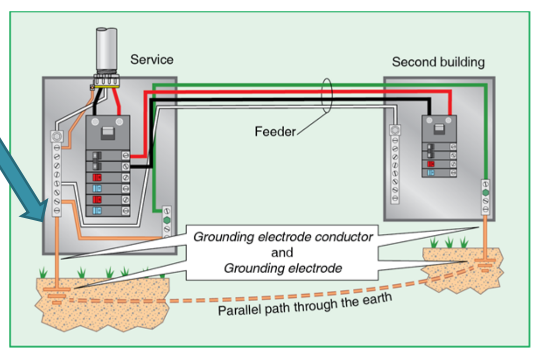
Grounding Electrode Conductor

"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."



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Grounding Electrode Conductor

- Size in compliance with 250.66 (both Table and Section)
- Install under the rules of 250.64(A-E)
- NEC P. 114
- Connect in accordance with 250.8 (Connection methods) and 250.70 (Methods of bonding and grounding conductors to electrodes)

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Art. 100, Intersystem Bonding Termination

- Def: Intersystem Bonding Termination: "A device that provides a means for connecting intersystem **bonding conductors for communications systems** to the grounding electrode system."
- Provides common location for connecting bonding conductors for communications systems.
- Common bonding helps prevent flashover due to elevated voltage events.

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Art. 100, Intersystem Bonding Termination

Intersystem bonding example

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NEC Art. 100, Neutral Conductor

Def. Neutral Conductor: "The conductor connected to the neutral point of a system that is **intended** to **carry current under normal conditions."**

This term is used in conjunction with the definition of "neutral point."

Differs from an equipment grounding conductor in that it is intended to carry current under normal conditions.

Neutrals are also grounded conductors.

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Neutral Point

Typical electrical systems that have a neutral conductor include:

- 120/240, 1-phase, 3-wire
- 120/240-volt, 3-phase, 4-wire (delta-connected)
- 208Y/120-volt, 3-phase, 4-wire (wye-connected)
- 480Y/277-volt, 3-phase, 4-wire (wye-connected)

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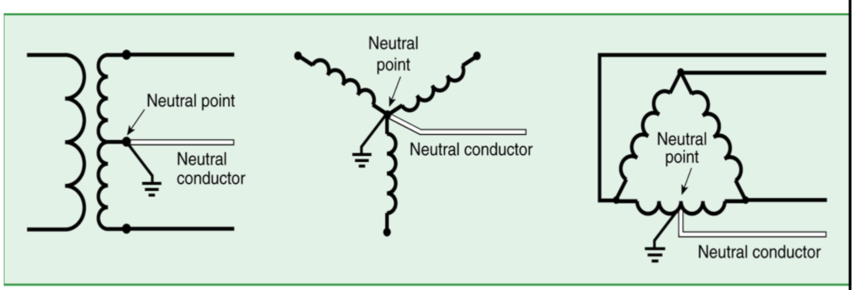
Neutral Point and Neutral Conductor



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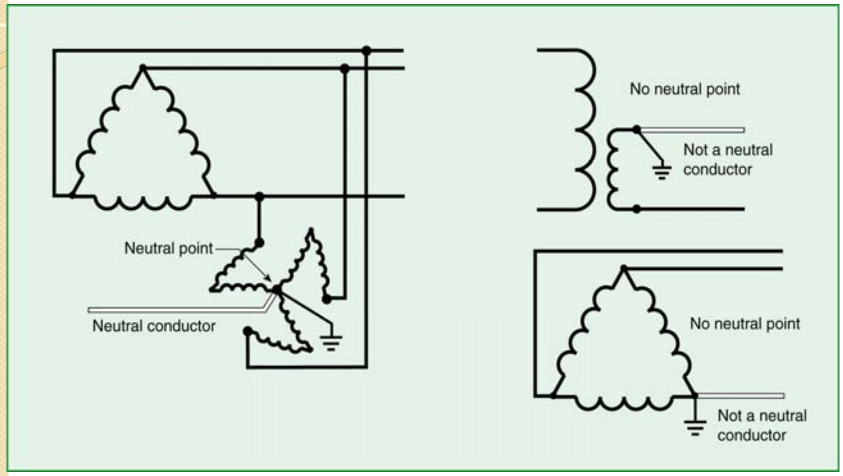
Neutral Point and Neutral Conductor



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NEC Art 100: Separately Derived System

Def. 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 connections."

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Separately Derived System

- Is a premises wiring system
- Is NOT directly supplied by the electric utility
- Transformers are "equipment other than a service." may provide separately derived system
- Path through the earth, metal enclosures, metallic raceways and equipment grounding conductors do not constitute a "direct electrical connection."

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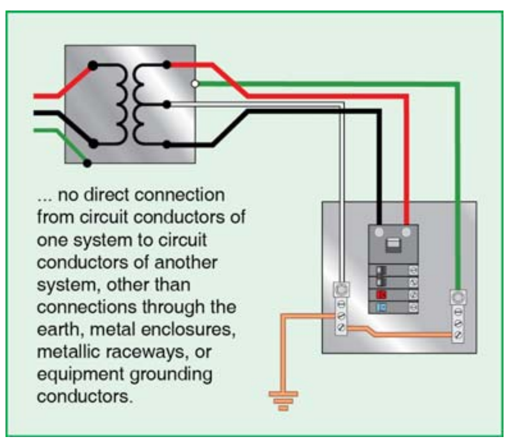
Separately Derived System

A premises wiring system whose power is derived from a source of electric energy or equipment other than the service. Such systems have …



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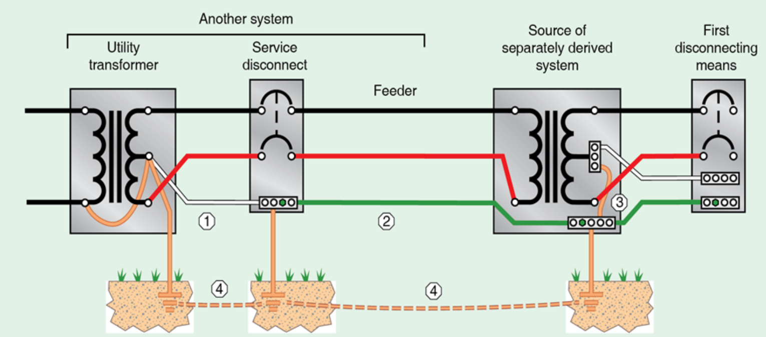
Separately Derived System



1. Neutral connects utility system to service.
2. Equipment grounding conductor connects service to transformer enclosure.
3. System bonding jumper completes connection of derived system to utility system.
4. Path through the earth provides another connection of the two systems.

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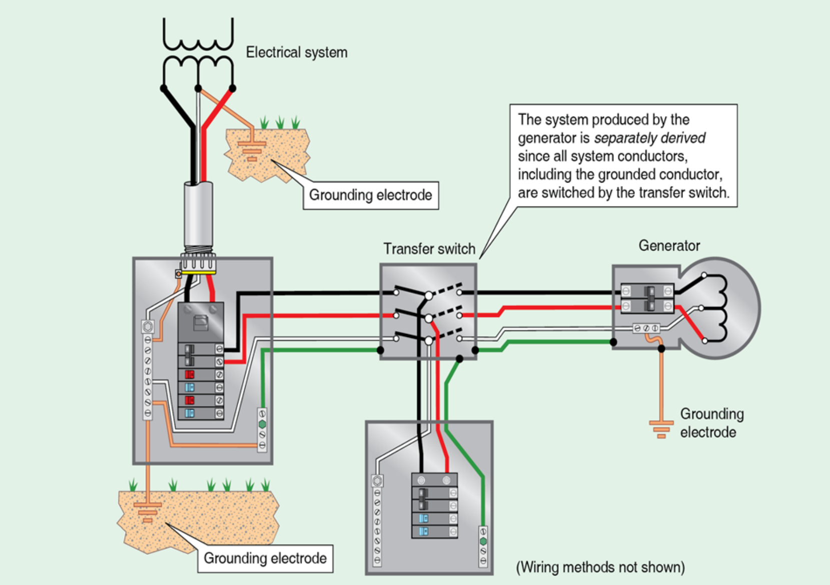
Generator-type Separately Derived System



Fuel Cells and Solar Photovoltaic Systems

- Produce direct current
- Inverter and other conversion equipment create alternating current
- If grounded system conductor connects directly to inverter neutral conductor, it is not a separately derived system

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The current path

- The information in 250.4 (A) (5) provides important concepts regarding an effective ground-fault return path
- Low-impedance path facilitates the operation of overcurrent devices
- Removing the fault quickly reduces the thermal and magnetic stresses on equipment and conductors
- Most overcurrent devices are "inverse time" (the greater the current, the faster the operation of the overcurrent device) so high current are interrupted in less time

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Art 100 Ground-Fault Current Path

- Def. Ground-Fault Current Path. An electrically conductive path from the point of a ground fault on a wiring system through **normally non–current-carrying conductors**, equipment, or the earth, - to the electrical supply source.

- "Facilitates the operation of the overcurrent device or ground fault detectors on a high-impedance grounded systems."

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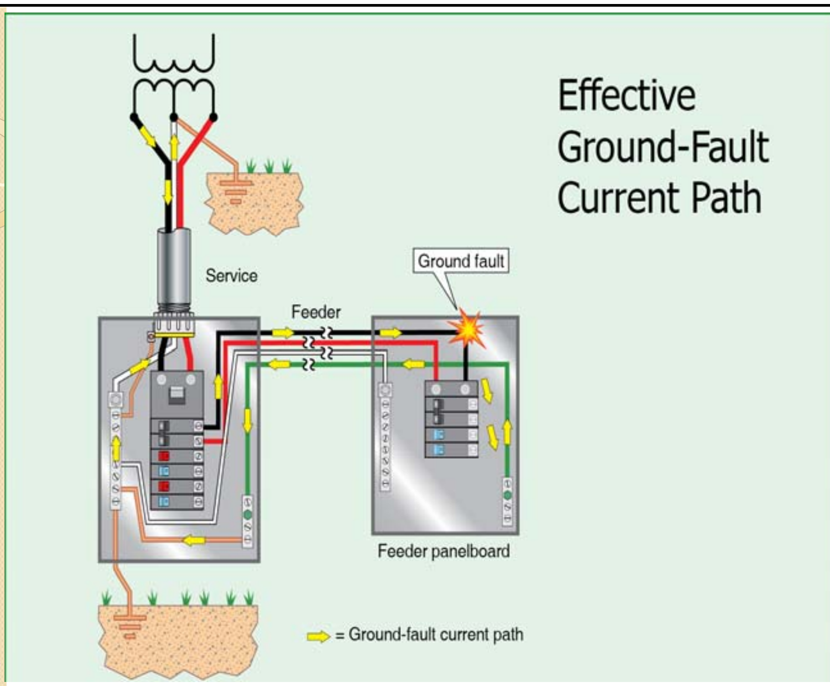

Effective Ground-Fault Current Path

- Intentionally constructed
- Deliberate steps taken to create the path
- Properly connect all components
- Carries fault-current to facilitate operation of overcurrent device or ground-fault detector

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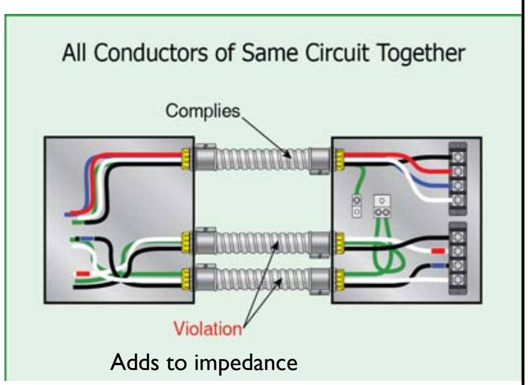
Effective Ground-Fault Current Path

- Low-impedance
- "Impedance" is total opposition to current flow in ac circuits
- All circuit conductors must be installed in close proximity to reduce impedance
- See 300.3(B) – (conductors of the same circuit)



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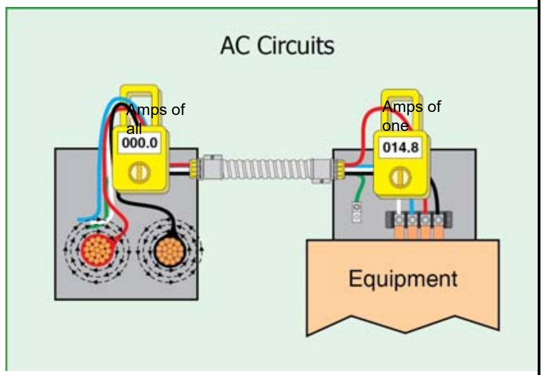
Effective Ground-Fault Current Path

- All circuit conductors must be installed in close proximity so magnetic lines of force can cancel
- This helps ensure a low-impedance fault-current path



All currents measured together- should be zero

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Rating and Operation of Overcurrent Devices

- Tested to carry full load current indefinitely
- NEC requires circuit to be no more than 80 percent of rated current unless overcurrent device is rated for 100 percent operation
- Time-current curves should be consulted to determine the amount of current required to reach the instantaneous trip mode
- Impedance of fault current path must be low enough to facilitate operation of OCP

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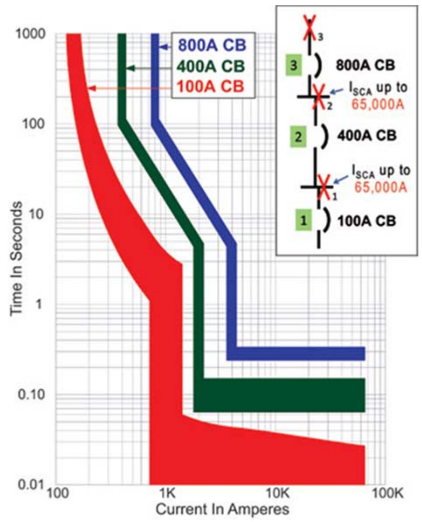
Time current curves



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Effective Ground-Fault Current Path

- **Continuous and reliable**
- Components and connections are intended to last for the life of the installation
- Unless monitored, equipment grounding path can be incomplete without indication (loose fittings)
- **Does not carry current in normal operation**
- Often, a break in the *Path* is discovered by electric shock after faulted equipment becomes energized

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Path Through the Earth

- The path through the earth can be in parallel with ground-fault current return path where more than one connection to earth exists.
- The earth is **not considered an "effective ground-fault current path"**.
- Connections are made to earth for other purposes, but never to carry fault current.
- Path only through the earth will result in electrical equipment presenting a dangerous electric shock hazard.

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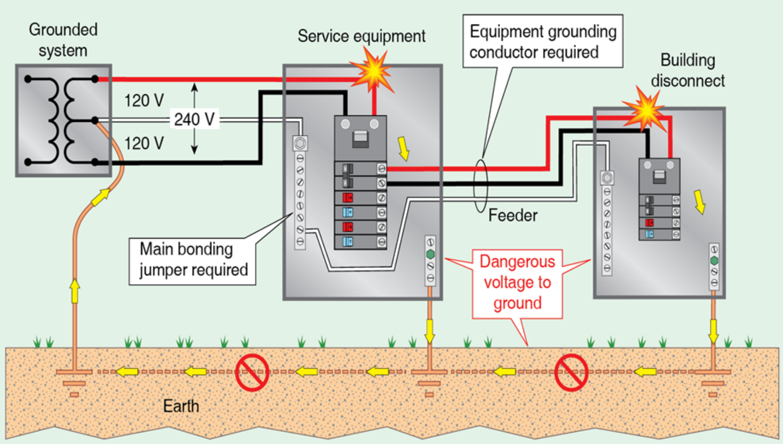
Earth Return Prohibited



Parallel Conductors 310.10 (H)

- Parallel conductor installations to be made under rules in 310.10(H)
- Two or more conductors are connected together at each end to create a conductive path with increased capacity.
- Concept is to have all conductors share current equally
- Equipment grounding conductors are installed in parallel under rules of **250.122(F)** **New parts 1-2**

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250.122 (F) Conductors in parallel

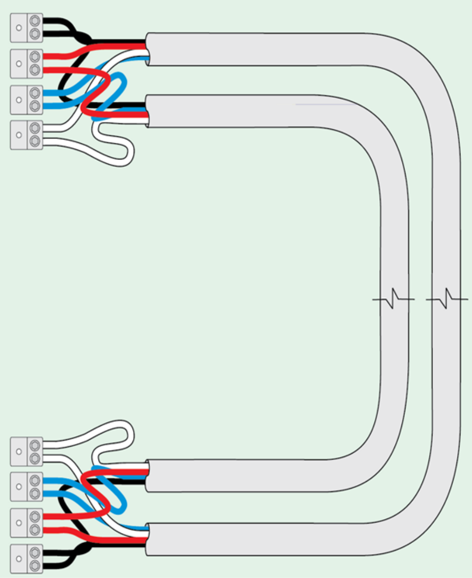
- (F)(1)(a) If conductors are installed in parallel in the same raceway or cable tray, a single wire type conductor shall be permitted as the equipment ground. - based on 250.122 and overcurrent protection
- (b) If wire type conductors are installed in multiple raceways, wire type grounding conductors where used shall be installed in parallel in each raceway based on 250.122 and the overcurrent protection

250.122 (F) Conductors in parallel

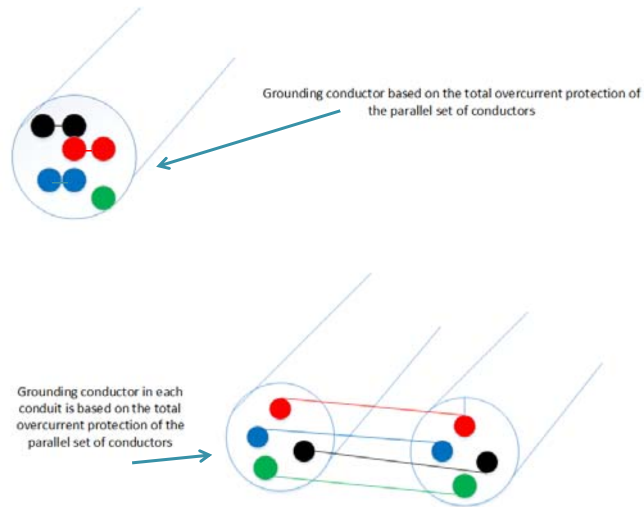
- (F)(2)(a) If multi-conductor cables are installed in parallel the grounding conductors in each cable shall be connected in parallel
- (b) If multi-conductor cables are installed in parallel in the same raceway, a single wire-type grounding conductor with the cable grounding wires shall be permitted to be connected together…

Parallel Conductors

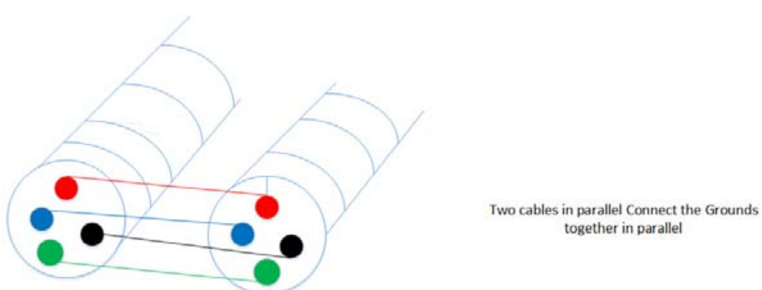
The paralleled conductors must:
(1) Be the same length
(2) Be the same conductor material (AL or CU)
(3) Be the same size in circular mil area
(4) Have the same insulation type
(5) Be terminated in the same manner
If run in separate raceways or cables, the raceways or cables must have the same electrical characteristics.



Parallel Conductor Grounding 250.122 (F) (1)

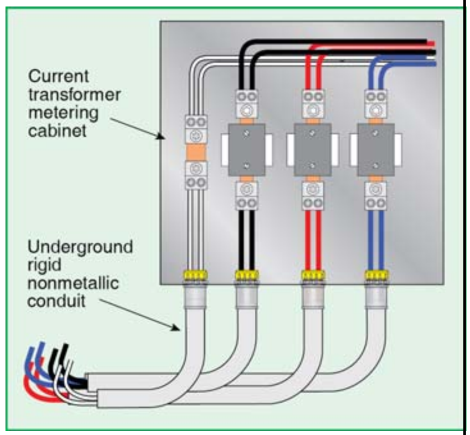


Parallel Cable grounding 250.122(F)(2)



Underground Parallel Sets

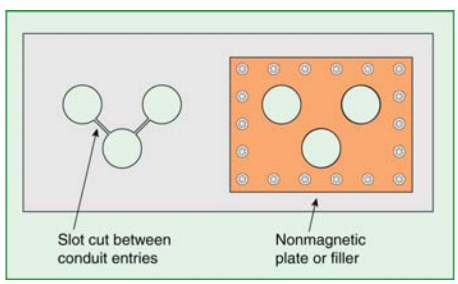
- In nonmetallic raceways run underground, permitted to have isolated phase installations
- Conductors line up with bussing in larger installations
- Caution about wire bending space rules



77

Underground Parallel Sets

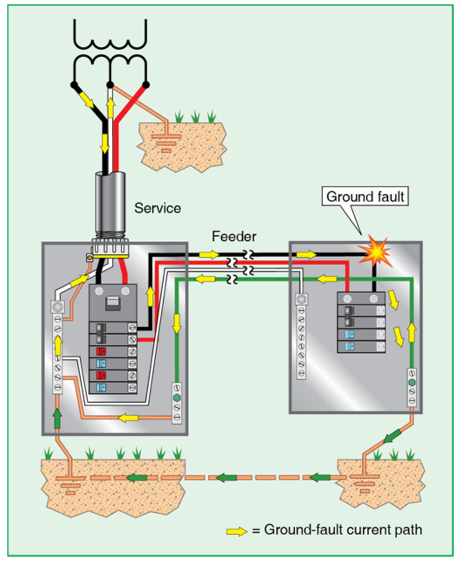
- Avoid heating surrounding metal by induction
- Cut a slot between conduit entries in magnetic enclosures
- Non-ferrous plate can be installed for entries



78

Art 100 Ground Fault

Def. Ground Fault: An unintentional, electrically conductive connection **between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors**, metallic enclosures, metallic raceways, metallic equipment or earth.



79

Ground Fault on Grounded Conductor

- A grounded conductor (may be a neutral) is grounded at the source and at the service
- Some separately derived systems are required to be grounded
- The grounded system conductor is generally required to be isolated (insulated) downstream from the service and source of a separately derived system.
- Improper grounding of grounded conductor can cause malfunction or improper system operation

80

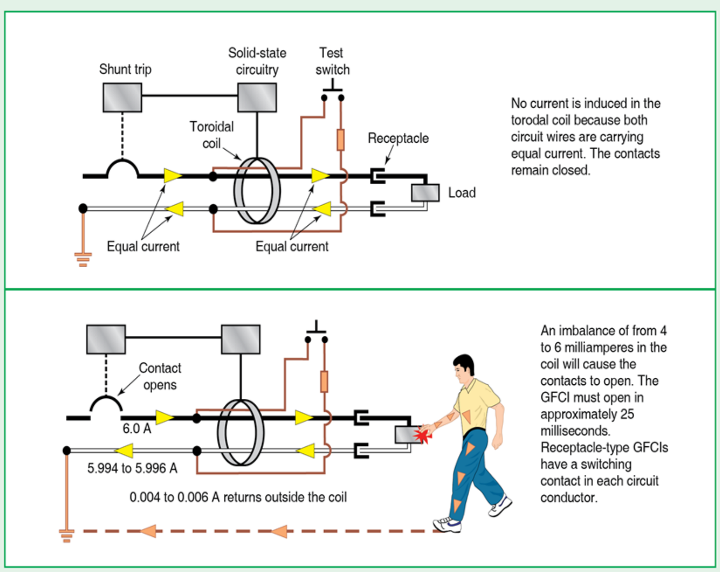
Ground Fault on Conductors

Ground-fault circuit-interrupters:

- GFCI monitors current flowing to and from the load
- Listed Class A device not permitted to trip at less than 4 mA, must trip at 6 mA or greater imbalance of current
- A grounded conductor that is grounded beyond the GFCI device will result in a parallel path for neutral current
- This will usually result in "nuisance trips"

81

GFCI Principles of Operation



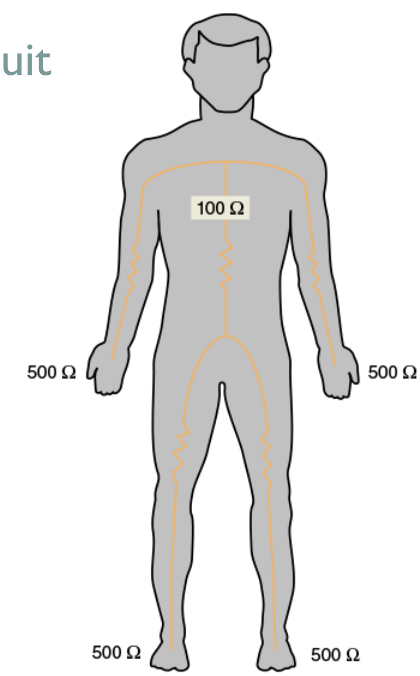
Factors That Determine Severity of Electric Shock

- The amount of current that flows
- The path the current takes through the body
- The length of time the current flows

Human Body Circuit

Note that the resistance of skin can vary significantly from one person to another and from one time to another.

Skin that is wet or moist may have much lower resistance. Skin that is dry may have much higher resistance.



Current through 1100 Ohm Human Circuit

CIRCUIT VOLTAGE	Current (Amperes or mA)	
	1100 Ohms (Dry Skin)	300 Ohms (Wet Skin)
480	0.436	1.60
277	0.252	0.92
240	0.218	0.80
120	0.109	0.40

85

Dangerous Electric Currents

EFFECT(S)	Current mA, 60 Hz	
	MEN	WOMEN
Slight sensation on hand	0.4	0.3
Perception of "let-go" threshold, median	1.1	0.7
Shock, not painful, and no loss of muscular control	1.8	1.2
Painful shock – muscular control lost by half of participants	9	6
Painful shock – "let-go" threshold, median	16	10.5
Painful and severe shock – breathing difficult, muscular control lost	23	15

86

Reducing Shock Hazards

- Proper grounding and bonding can reduce likelihood of electric shock
- Electric shock when current passes through the chest can result in ventricular fibrillation
- Death can occur if condition is not corrected

87

Ground Fault on Conductors

Ground-fault protection of equipment (GFPE) required for a grounded systems where:

- The voltage to ground is more than 150 volts
- The phase-to-phase voltage is 600 volts or less
- For overcurrent devices rated 1000 amperes or more
- 230.95 for services; 215.10 for feeders; 210.13 Branch Circuits: 240.13 for building disconnecting means

88

Arc Fault on Conductors

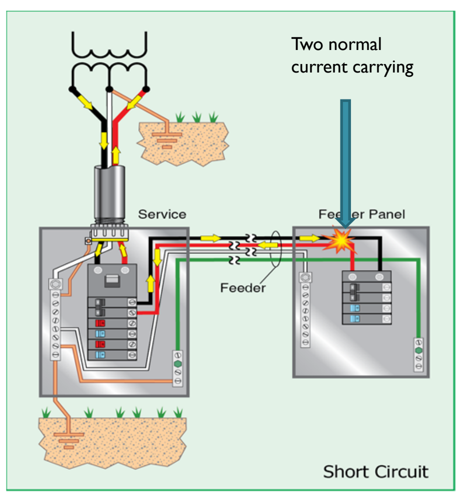
Arc-fault circuit interrupters (AFCI)

- Intended to provide protection from the effects of arcing faults by recognizing characteristics unique to arcing by de-energizing the circuit when an undesirable arc is detected
- Neutral fault to grounded enclosure, raceway or equipment on load side of AFCI device can result in unintended operation

89

Short Circuit

An abnormal connection of relatively low impedance, whether made accidentally or intentionally, between two points of different potential on any circuit.



90

Ground-Fault Current Path

"An electrically conductive path from the point of a ground fault on a wiring system through normally non-current-carrying conductors, equipment, or the earth to the electrical supply source."

91

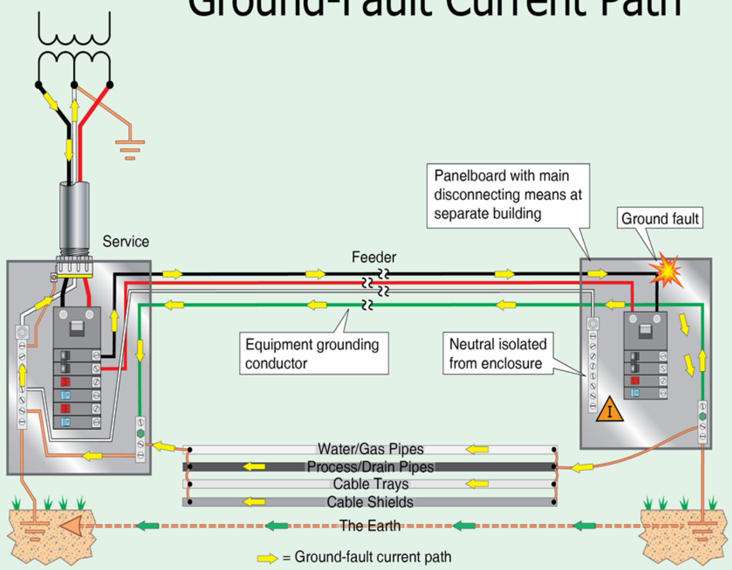
Ground-Fault Current Path

"Informational Note:

Examples of ground-fault current paths could consist of any combination of equipment grounding conductors, metallic raceways, metallic cable sheaths, electrical equipment, and any other electrically conductive material such as metal water and gas piping, steel framing members, stucco mesh, metal ducting, reinforcing steel, shields of communications cables, and the earth itself."

92

Ground-Fault Current Path



250.3 Application of Other Articles

- Table 250.3 covers additional grounding requirements that are found in other articles
- The rules in NEC Chapters 5, 6 and 7 can amend or supplement the rules in Chapters 1 through 4
- Examples include: Articles 547 (agricultural buildings), 600 (signs) and 517 (health care facilities)

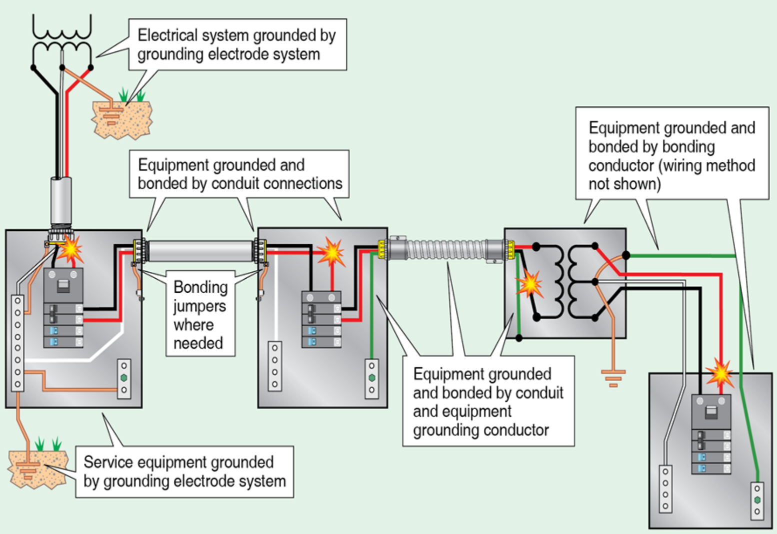
94

250.4 General Requirements for Grounding and Bonding

- Includes "performance requirements" - results
- "Prescriptive requirements" – how to do requirements-- are provided in the remainder of Article 250
- 250.4(A)(1) gives example of performance rule.
- No specific measurable requirements are provided

95

General Requirements for Grounding and Bonding



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250.4(A) Grounded Systems

- 250.4(A) provides "performance" rules for grounded systems
- 250.4(B) provides "performance" rules for ungrounded systems

97

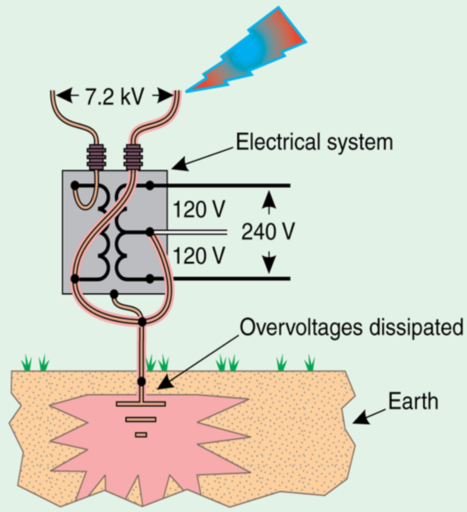
250.4(A)(1) Electrical System Grounding

Electrical systems that are grounded are required to be connected to earth in a way that will limit the voltage imposed by

- lightning,
- line surges, or
- unintentional contact with higher-voltage lines and will
- stabilize the voltage of the system to earth during normal operation.

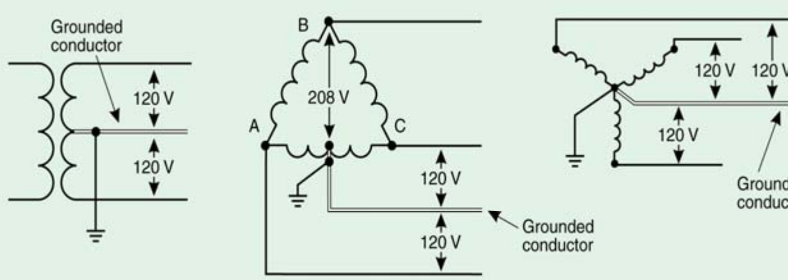
98

Grounding Electrical System



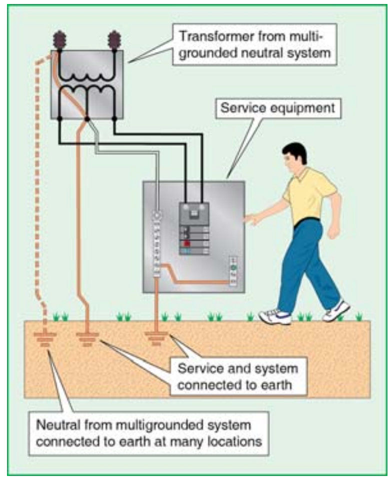
99

Typical Voltages-to-Ground



250.4(A)(2) Grounding of Electrical Equipment

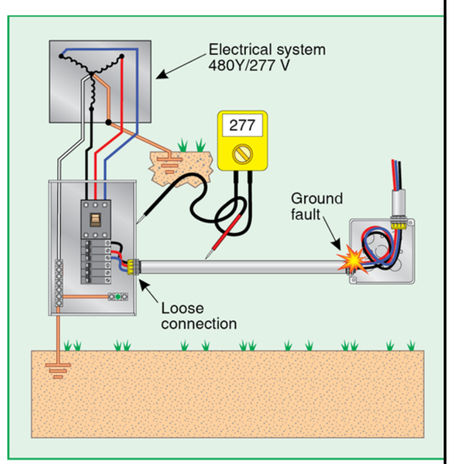
"Normally non–current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are required to be connected to earth to limit the voltage to ground on these materials."



101

250.4(A)(2) Grounding of Electrical Equipment

A shock or electrocution hazard can occur if there is a break in the ground-fault return path



102

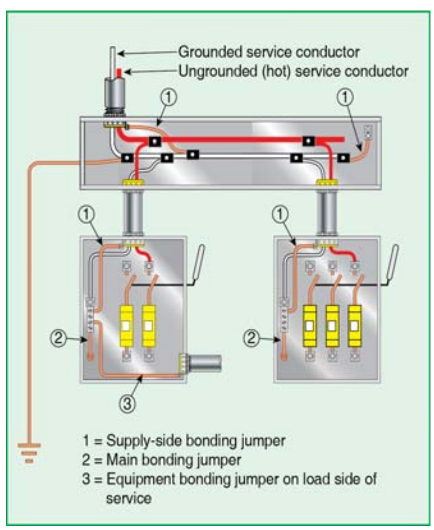
250.4(A)(3) Bonding of Electrical Equipment

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

103

250.4(A)(3) Bonding of Electrical Equipment

- In its simplest form, bonding completes a path through which current can flow
- Bonding also keeps connected parts at the same potential
- Eliminates shock hazard



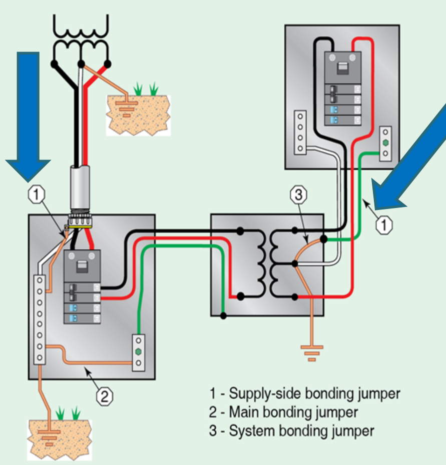
104

Bonding Jumpers

- Main bonding jumpers
- System bonding jumpers
- Supply-side bonding jumpers on supply side of the service or a separately derived system
- Equipment bonding jumpers on the load side of the service
- Bonding jumpers to metal piping systems and to structural metal frames of buildings

105

Supply-Side Bonding Jumper



250.2: (Bonding Jumper, Supply-Side)
"A conductor installed on the supply side of a ser-vice or within a service equipment enclosure(s), or for a separately de-rived system, that en-sures the required electri-cal conductivity between metal parts required to be electrically connected."

Bonding Jumpers Required

- Loose locknut connections
- For conduit or cable connections to painted enclosures
- Service equipment enclosures
- Around concentric and eccentric knockouts
- Around knockout reducing washers (if suspect connection)
- Hazardous (classified) locations
- Over 250 volts-to-ground

107

250.4(A)(4) Bonding of Electrically Conductive Materials

Normally non-current-carrying electrically conductive materials that are likely to become energized are required to be connected together and to the electrical supply source to form effective ground-fault current path

108

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

Electrical equipment and other electrically conductive material likely to become energized to be connected (bonded) in a manner that is:

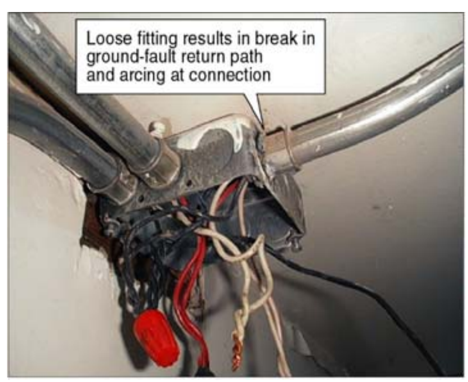
1. Reliable
2. Provides a circuit of low impedance
3. Facilitates the operation of the overcurrent device or ground detection

The conductor must safely carry the maximum fault current likely to be imposed

109

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

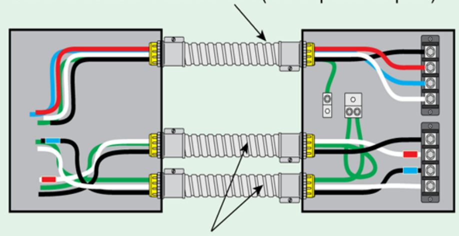
- Metal conduit becomes current-carrying conductor when returning fault current to source
- Single loose locknut or loose or broken fitting can result in break in fault path



110

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

- Ohmic value of low-impedance path not specified in NEC
- Keep all circuit conductors, including ungrounded, grounded and equipment grounding conductors together



Violations include: High-impedance path (all circuit conductors are not in same cable).
Induced currents in metal enclosure, *300.20(A)*

111

Operating Characteristics of Overcurrent Devices

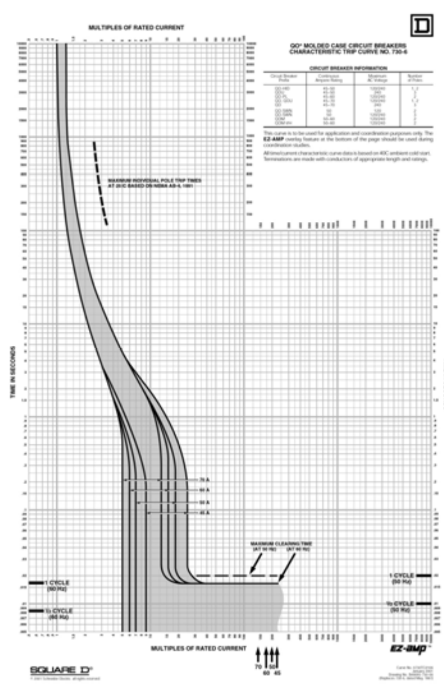
- Most overcurrent devices such as circuit breakers and fuses are "inverse-time"
- Manufacturers furnish time-current curves for the overcurrent devices they manufacture

112

Operating Characteristics of Circuit Breakers

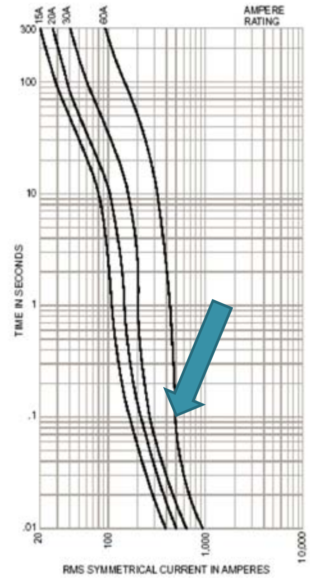
- Vertical line in time-current curve represents trip time in seconds
- Curved portion represents time-delay mode of circuit breaker
- Width of curve represents the permitted range of time-delay and instantaneous trip operation

113



Operating Characteristics of Fuses

- Time in seconds are on the left
- RMS Symmetrical current across the bottom
- 60A fuse will clear in about 0.1 seconds for 400-ampere fault



115

Keep All Circuit Conductors Together

- Required in 250.134 and 300.3(B)(1) through (4)
- Low impedance of fault return path will ensure adequate current will flow to provide for rapid operation of overcurrent device
- See "White Paper" report of R.K. Kaufmann.

116

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

- The conductor must be capable of safely carrying the maximum fault current likely to be imposed on it
- Table 250.102C1 & Notes used on line side of service
- Table 250.122 used on load side of service Overcurrent
- Fault-return path through the earth not permitted as "sole" path

117

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

- Fault current will flow over all paths available (including through the earth)
- The lowest impedance path will carry the most current
- The highest impedance path will carry the lowest current

118

250.4(B) Ungrounded Systems

Even though the "system" is not grounded, the enclosures must be grounded and bonded

119

250.4(B)(1) Grounding Electrical Equipment

- Non-current-carrying conductive materials enclosing electrical conductors or equipment or forming part of such equipment are required to be connected to earth in a manner that:
- Limits the voltage imposed by lightning or unintentional contact with higher-voltage lines and limits the voltage-to-ground on these materials.

120

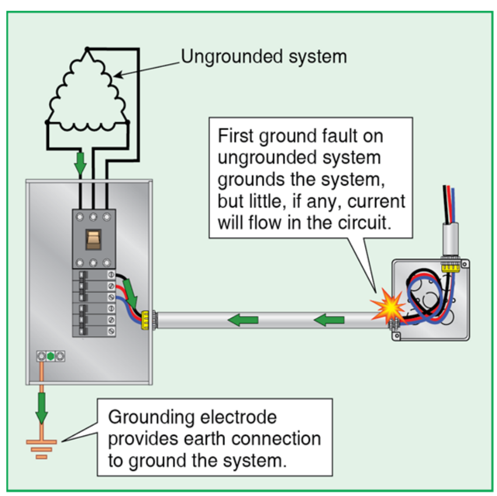
250.4(B)(2) Bonding of Electrical Equipment

Non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, are required to be connected together and to the supply system grounded equipment in a manner that creates a low-impedance path for ground-fault current that is capable of carrying the maximum fault current likely to be imposed on it.

121

250.4(B)(2) Bonding of Electrical Equipment

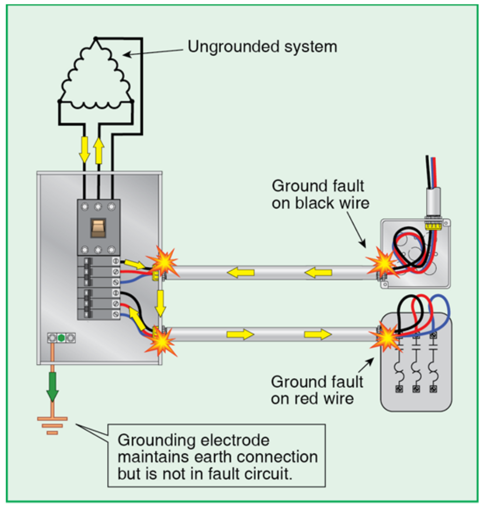
First ground fault on ungrounded system – creates a grounded system



122

250.4(B)(2) Bonding of Electrical Equipment

- Second ground fault at different location on ungrounded system
- Current will flow from the source to the first fault, over metal paths to the second fault and return to the source - in a short circuit



123

250.4(B)(3) Bonding of Electrically Conductive Materials

Electrically conductive materials that are likely to become energized are required to be bonded to create a permanent, low-impedance path for fault current that will carry the maximum fault current likely to be imposed

124

250.4(B)(4) Path for Fault Current

- Low-impedance path required from any point on the wiring system to facilitate the operation of overcurrent device(s) should a second fault occur
- Earth not permitted as sole (only) equipment grounding conductor
- Earth not considered an effective fault-current path

125

250.6 Objectionable Current

- "Over grounding conductors" removed from title of section. It broadens the application.
- Term "objectionable current" not defined - so subject to varying interpretations
- Equipment grounding conductors are not designed to carry current on a regular basis
- These conductors are often sized on their short-time current rating

126

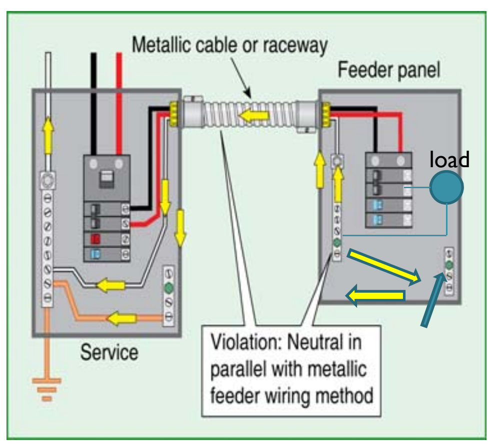
250.6(A) Arrangement to Prevent Objectionable Current

The grounding of electrical systems, circuit conductors, surge arresters, surge protective devices, and conductive normally non-current-carrying metal parts of equipment is required to be installed and arranged in a manner that will prevent "objectionable current".

127

250.6(A) Objectionable Current

- Improper grounding of neutral past the service causes normal neutral current to flow on metallic paths
- This is generally considered "objectionable current"



128

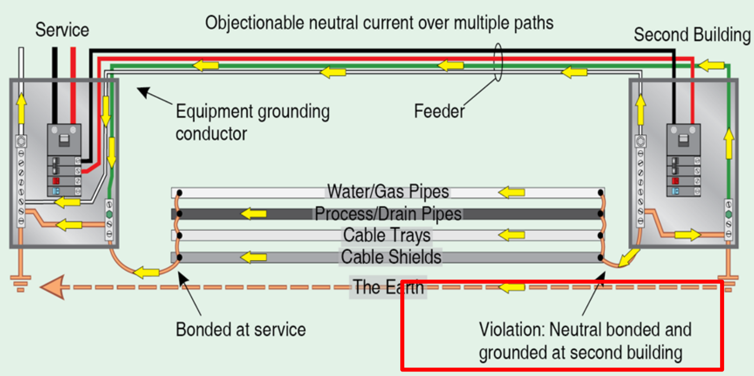
250.6(B) Alterations to Stop Objectionable Current

If the use of multiple grounding connections results in objectionable current, take one or more of the following actions so long as the requirements of 250.4(A)(5) or (B)(4) are met:

1. Discontinue one or more but not all of the grounding connections
2. Change the locations of the grounding connections
3. Interrupt the continuity of the conductor or conductive path interconnecting the grounding connections
4. Other remedial action that are approved

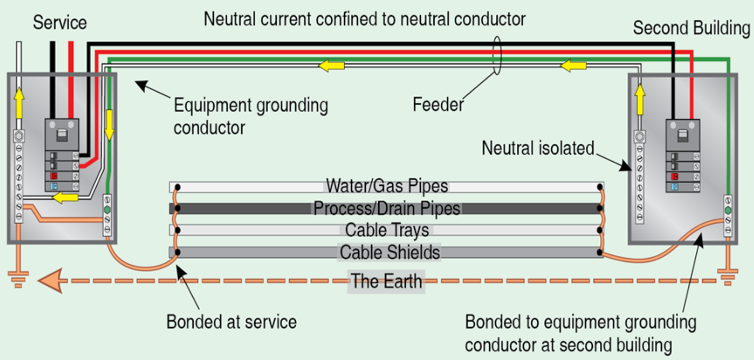
129

Arrangement to Prevent Objectionable Current



13

Arrangement to Prevent Objectionable Current

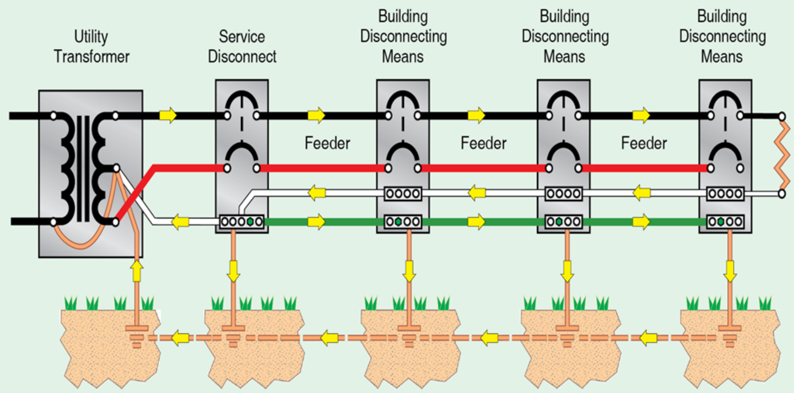


Current Over Grounding Conductors

- Neutral current can flow over equipment grounding conductors that are connected correctly where multiple grounding electrode connections are made
- Neutral current will flow over all paths that are available.
- This includes between grounding electrodes, to the service and to utility grounding electrodes.

132

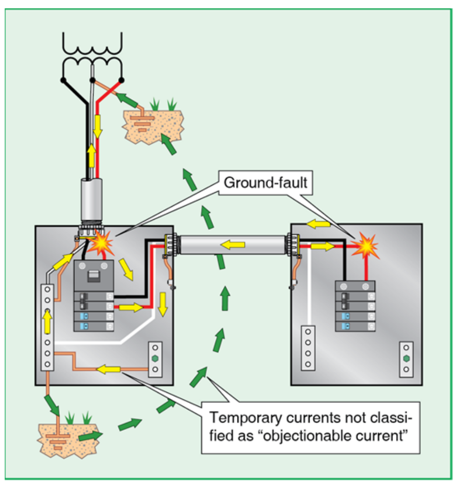
Parallel Path for Neutral Current



13

250.6(C) Temporary Currents

Temporary currents resulting from accidental conditions such as ground-fault currents that occur only while the grounding conductors are performing their intended protective functions are not classified as objectionable current



134

250.6(D) Limitations to Permissible Alterations

- Alterations not permitted to isolate electronic equipment from equipment grounding conductor path
- Currents that introduce data errors not classified as "objectionable"

- Install equipment grounding conductor with branch circuit conductors.
- Local auxiliary grounding electrode permitted to supplement but not replace equipment grounding conductor.

135

250.6(D) Limitations to Permissible Alterations

- Not permitted to isolate data processing equipment and connect a "local" grounding electrode
- To do so violates 250.50, 250.110 and 250.134 and can create shock hazard
- A remote grounding electrode will usually not carry enough current to operate a 15-ampere circuit breaker

136

250.8 Connection of Grounding and Bonding Equipment

Equipment grounding conductors, grounding electrode conductors, and bonding jumpers must be connected by any of the following methods:

1. Listed pressure connectors

137

250.8 Connection of Grounding and Bonding Equipment

2. Terminal bars

3. Pressure connectors listed as grounding and bonding equipment

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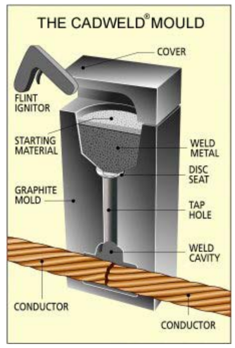
4. Exothermic Welding Process

- Use proper form for conductors and objects
- Follow manufacturer's instructions
- Welding temperature reaches about 4000°F
- Follow safety procedures
- Examine and test finished weld



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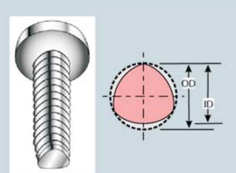
250.8 Connection of Grounding and Bonding Equipment

5. Machine screw-type fasteners that engage not less than two threads in the enclosure or are secured with a nut

6. Thread-forming machine screws that engage not less than two threads in the enclosure



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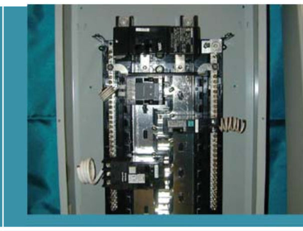
250.8 Connection of Grounding and Bonding Equipment

7. Connections that are a part of a listed assembly



8. Other listed means.

141

Compression Connectors

- Suitability for wire material marked on shipping carton or connector itself
- Some connectors are pre-filled with inhibitor for dissimilar metals
- Connectors are designed and marked for range of conductor sizes
- Select proper compression tool
- Some manufacturers use color-coding dies and connectors

142

Compression Wire Connectors and Compression Tool

143

250.8(B) Methods **Not** Permitted

Connection devices that depend solely (only) on solder are not permitted

- Soldered connections can fail due to heating as they carry fault current
- Also see 250.148(E) for restrictions on the use of solder for connecting equipment grounding conductor

144

250.12 Clean Surfaces

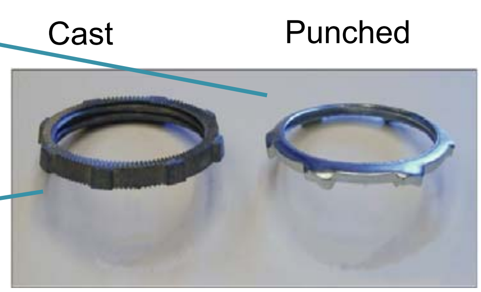
- Nonconductive coatings (i.e. paint, lacquer, and enamel) to be removed from threads and other contact surfaces to provide good electrical continuity
- Connection by means of fittings designed to make such removal unnecessary
- Paint is an insulator
  - Meyers hub ®

No Welding
 - Unique serrations on both nut and hub bite into metal assuring a positive electrical ground. (UL approved for use with service entrance conduit).

Conduit Locknuts

Two general forms:

- Cut (punched) from flat stock, crowned, threaded, tabs (or ears) bent and left sharp
- Cast from iron, aluminum, zinc or other materials (may have relatively flat contact surfaces)



- The End   Part I
- Questions ?????

- Remaining are additional slides for reference

Ohm's Law and Basic Electrical Theory

- Electrical pressure (voltage), current (amperes) and resistance (ohms) of electrical systems can be compared in many ways to water piping systems.
- Higher voltage (pressure) will force more current (volume or gpi) through the same resistance (pipe size) than a lower voltage.

149

Theory Terms and Definitions

- Volt – A unit of electrical pressure. 1 volt will force 1 ampere through 1 ohm
- Ampere – The unit of electrical current. 1 ampere will flow through a resistance of 1 ohm when 1 volt (pressure) is applied
- Ohm – The unit of electrical resistance in the circuit. 1 ohm will permit 1 ampere to flow when a pressure of 1 volt is applied

150

Ohm's Law Formula

- Electrical pressure (volts or E) equals the product of the current (amperes or I) and resistance (ohms or R)

- The 3 common forms of the formula are
  - $E = I \times R$
  - $I = E \div R$
  - $R = E \div I$

151

Ohm's Law

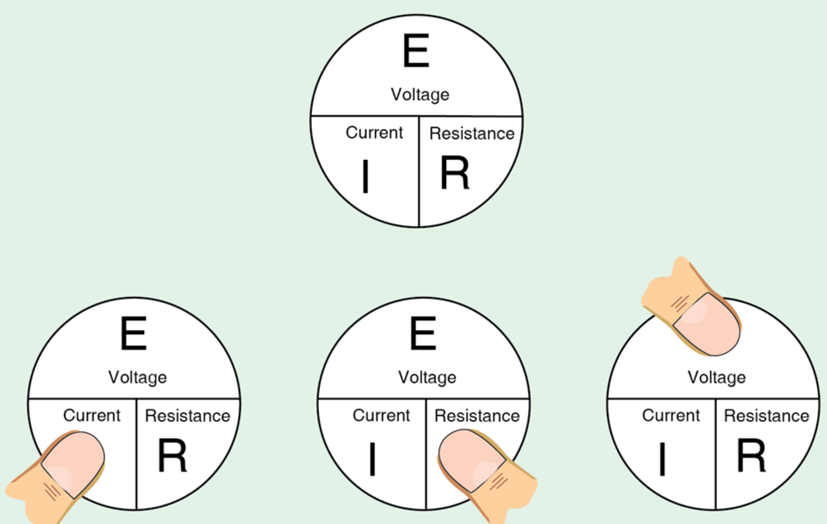


Fig. I-32

152

Watt

- The unit of measurement of the energy in an electrical circuit at any given moment.
- It is also the amount of work being performed in the electrical circuit as a result of conversion of electrical energy to some other form of energy such as heat or mechanical.
- The Watt was named in honor of James Watt, an English scientist.

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Watt (continued)

- The term "watt" or kilowatt" has been used more commonly to express the amount of work done in the electrical circuit rather than the term "joule."
- "Watts" is simply the product of multiplying volts and amperes for DC systems
- AC systems use the power factor of the system to determine watts compared to Volt-Amps
- Common usage is "volt-amperes" for apparent power and "Watts" for true power
- One thousand volt-amperes is referred to as one kilovolt-ampere or one kVA.

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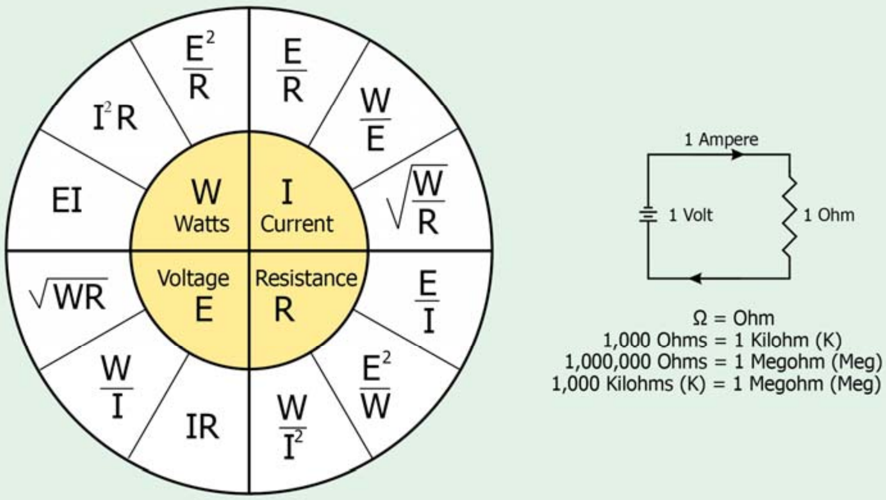
Watts Wheel



Ω = Ohm
1,000 Ohms = 1 Kilohm (K)
1,000,000 Ohms = 1 Megohm (Meg)
1,000 Kilohms (K) = 1 Megohm (Meg)

Fig. I-33

Impedance

- "Impedance" is used to describe the total opposition to current flow in AC systems
- Includes resistance, inductive reactance and capacitive reactance
- Represented by "Z" in formulas
- Providing a "low impedance path" is referred to in Article 250

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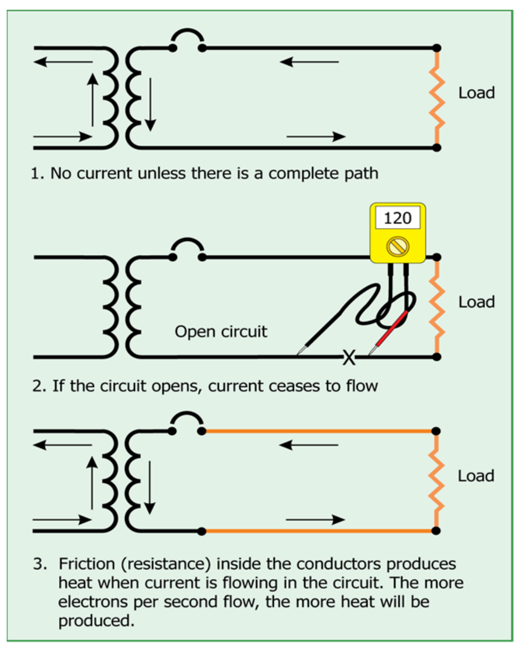
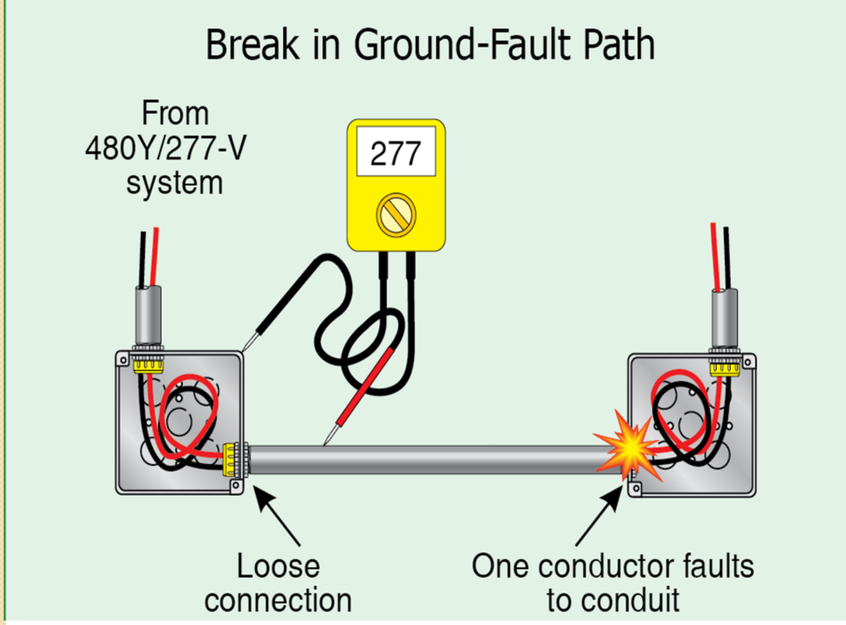
Circuits and Paths

- A complete path (circuit) must exist for current to flow
- A break in the path causes current to cease
- Break in grounding or bonding connection or path can leave equipment at a dangerous voltage above ground

The Basic Circuit





Electrical Shock Hazards

- Expanded use of electricity can result in increased shocks and electrocutions
- 30,000 non-fatal shock accidents per year
- 600-1000 electrocutions per year
- Fourth leading cause of industrial fatalities
- The current drawn by a 7½ watt, 120-volt lamp can be fatal if the current path is across the chest of a human

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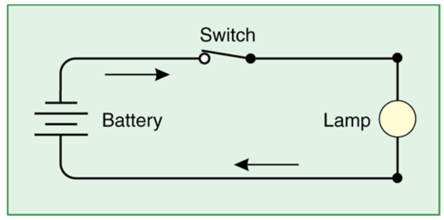
Series Circuit

- A circuit where only one path for current exists
- The lamp performs work as current passes through the circuit



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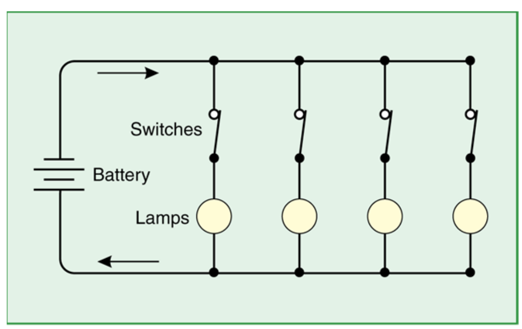
Parallel Circuit

- A circuit where there is more than one path for current to flow
- Ground-fault current will flow on each path that exists
- Neutral current will flow on multiple paths if grounded improperly



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