



**GROUND
ELECTRICAL POWER
DISTRIBUTION**

Excerpt from Inverter
Charger Series Manual

BY:
VIJAY SHARMA
ENGINEER

GROUNDING ELECTRICAL POWER DISTRIBUTION

1.0 CONDUCTORS FOR ELECTRICAL POWER DISTRIBUTION

For single-phase transmission of AC power or DC power, two conductors are required that will be carrying the current. These are called the “current-carrying” conductors. A third conductor is used for grounding to prevent the build up of voltages that may result in undue hazards to the connected equipment or persons. This is called the “non current-carrying” conductor (will carry current only under ground fault conditions).

2.0 GROUNDING TERMINOLOGY

In electronics, Ground is considered to be a common point, a point of zero potential and an infinite sink of electrons. In reality, most points we consider “grounded” are far from this perfect state.

For purposes of electrical power transmission and distribution, the term “Grounded” indicates that one or more parts of the electrical system are connected to Earth, which is considered to have zero voltage or potential. In some areas, the term “earthing” is used instead of grounding. Connection to Earth may be made using Earth Electrodes like ground rods, buried wires, metallic pipes and other conductors in contact with the Earth.

Earth Ground is described in the context of lightning protection, safety and operational performance and is used for the following functions:

- Dissipate lightning strike energy in a manner that protects the surrounding area. *Please see details under Whitepaper titled “Grounding System and Lightning / Ground Fault Protection”*
- Provide a low impedance connection back to the AC power mains Ground or Neutral to reliably clear fault conditions by blowing a fuse or by tripping a circuit breaker. A “fault condition” occurs when a live, ungrounded current carrying conductor comes in contact with the exposed metal parts of electrical equipment
- Reduce the step potential gradient to safe levels
- Form a natural sink for atmospheric and radiated noise
- Provide an electrical antenna counterpoise.

The following terminology is used in the Grounded Electrical Power Distribution System (please see Fig. 1):

Grounded Conductor (GC): is a “current-carrying” conductor that normally carries current and is also connected to earth. Examples are the “Neutral” conductor in AC wiring and the Negative conductor in many DC systems. A “Grounded System” is a system in which one of the current-carrying conductors is grounded

Equipment Grounding Conductor (EGC): is a conductor that does not normally carry current (except under fault conditions) and is also connected to Earth. It is used to connect the exposed metal surfaces of electrical equipment together and then to Ground. Examples are the bare copper conductor in non-metallic sheathed cable (Romex®) and the green, insulated conductor in power cords in portable equipment. These equipment-grounding conductors help to prevent electric shock and allow over-current devices to operate properly when ground faults occur. The size of this conductor should be coordinated with the size of the over-current devices involved

Grounding Electrode (GE): is the metallic device that is used to make actual contact with the Earth. Other types of grounding electrodes include metal water pipes and metal building frames.

Grounding Electrode Conductor (GEC): is the conductor between a common single grounding point in the system and the grounding electrode

System Bonding Jumper (SBJ): is the bonding (connection) between the bus bar for the Equipment Grounding Conductors (EGC) and the bus bar for the Grounded Conductor (GC) / Neutral.

Bond: refers to the connection between the bus bar for the “Grounded Conductor (GC)”, the bus bar for the “Equipment Grounding Conductors (EGC)” and the “Grounding Electrode Conductor (GEC)”. Bonding is also used to describe connecting all of the exposed metal surfaces together to complete the equipment-grounding conductors.

3.0 GROUNDING ELECTRICAL POWER DISTRIBUTION SYSTEM AS PER NATIONAL ELECTRICAL CODE (NEC)

The National Electrical Code (NEC) requires the use of a “Grounded Electrical Distribution System”.

As per this system, one of the two current-carrying conductors is required to be grounded. This grounded conductor is called the “Neutral / Cold / Return”. As this conductor is bonded to Earth Ground, it will be at near zero voltage or potential. There is no risk of electrical shock if this conductor is touched.

The other current carrying conductor is called the “Line / Live / Hot”. The connection between the “Neutral” and the Grounding Electrode Conductor (GEC) is made only at one point in the system. This is known as the System Ground. This single point connection (bond) is usually made in the Service Entrance Panel or the Load Center. This is also termed as “Single Point Grounding System”. If this connection is inadvertently made in more than one place, then unwanted currents will flow in the equipment grounding conductors. These unwanted currents might cause inverters and charge controllers to be unreliable and may interfere with the operation of ground-fault detectors and over-current devices. Also, Single Point Grounding System provides protection against damage due to lightning.

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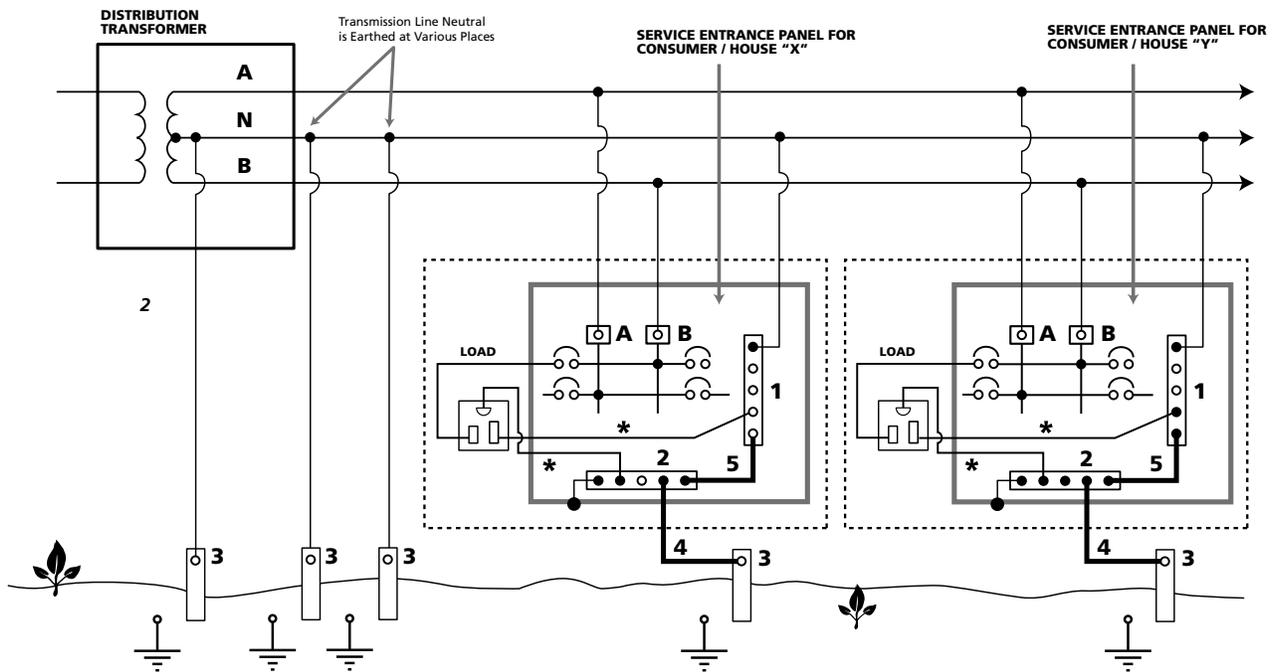


WARNING!

A current-carrying conductor that is not bonded to the earth ground cannot be called a "Neutral". This conductor will be at an elevated voltage with respect to the earth ground and may produce electrical shock when touched.

120 / 240 VAC Split Single Phase Grounded Electrical System

Fig. 5.1 below is an example of a 120 / 240 VAC Split Single Phase Grounded Electrical Distribution System for a group of consumers. The system consists of two Sections: Distribution Transformer / Distribution Lines and Distribution within the Consumer's Premises.



1. Bus bar for Grounded Current Carrying Conductor (GC) or Neutral
 2. Bus bar for Equipment Grounding Conductor (EGC)
 3. Grounding Electrode (GE)
 4. Grounding Electrode Conductor (GEC)
 5. System Bonding Jumper (SBJ)
 - A. Current Carrying Conductor - Hot / Line, Phase A
 - B. Current Carrying Conductor - Hot / Line, Phase B (180° apart from Phase A)
 - N. Grounded Conductor or Neutral
-  Circuit Breaker
- * Note:** Neutral and the Equipment Grounding Conductor (EGC) are separate for all the loads within the consumer's premises.

Fig 1: 120 / 240 VAC Grounded Electrical Distribution System

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4.0 120 / 240 VAC SPLIT SINGLE PHASE GROUNDING ELECTRICAL SYSTEM

Fig. 1 below is an example of a 120 / 240 VAC Split Single Phase Grounding Electrical Distribution System for a group of consumers. The system consists of two Sections: Distribution Transformer / Distribution Lines and Distribution within the Consumer's Premises

5.0 DISTRIBUTION

5.1 Distribution Transformer & Distribution Lines

120 / 240 VAC Single Split Phase Utility Power to the building / structure / house is fed from a Distribution Transformer that is either mounted on a utility pole (feeds through overhead lines) or on the ground on a concrete pad (Pad mounted, feeding through underground lines).

The primary side of the Distribution Transformer is connected between Neutral and one of the 2400 V, 7.2 kV, 12.47 kV, 13.2 kV or 13.8 kV phases of the utility company's 3-Phase Distribution Network. The secondary of the Distribution Transformer has a grounded center tap and is wound in a manner that supplies two 120 VAC phases which are 180° out of phase with each other (Split Phases). In urban areas, one Distribution Transformer typically supplies 1-6 residences. *Please read Whitepaper titled "Grid / Utility Power Generation and Distribution System" for more details on transmission of power till the Distribution Transformer.*

The Distribution Transformer may be considered as the Sub-station / AC source of power supplied by the utility. Only two consumers / houses "X" and "Y" are shown being fed from this Distribution Transformer for purposes of explanation. Power from the Distribution Transformer enters the consumer's premises through the Service Entrance / Load Center that contains input and output breakers and grounding arrangement.

As this is a 120 / 240 V, Single, Split Phase System Distribution System, the Distribution Transformer has 3 current carrying conductors "A", "B" and common "N". The voltage between current carrying conductor "A" and the common current carrying conductor "N" is 120 VAC. The Split Phase Voltage between the current carrying conductor "B" and the common current carrying conductor "N" is also 120 VAC but this voltage has a phase difference of 180 degrees with respect to the phase of voltage between the current carrying conductor "A" and the common current carrying conductor "N".

The common current carrying conductor "N" at the Distribution Transformer is grounded to the Earth Ground at the location of the Distribution Transformer through a Grounding Electrode (GE). This common current carrying conductor that is grounded to the Earth Ground at the Distribution Transformer is called the Grounded Conductor (GC) or Neutral.

Please note that in this system, there is no separate conductor for the Earth Ground from the Distribution Transformer till the consumer's premises. The Neutral and Earth Ground are bonded at the Distribution Transformer and are used as a common Grounded Conductor (GC) or Neutral till the consumer's Service Entrance. This Grounded Conductor (GC) or Neutral is bonded to the Earth Ground at various points along its path from the Distribution Transformer to the consumers to provide a more reliable conductive path through the Earth Ground. Up to the consumer's premises, it is a 3 Pole 3 Wire Grounding System (Phase A, Phase B and Grounded Neutral with 3 wires for the 3 poles).

However, the Neutral and the Earth Ground are run separately inside the consumer's premises and are bonded together at the Service Entrance only. Therefore, inside the consumer's premises, it becomes a 3- Pole, 4 Wire Grounding System (Phase A, Phase B, Neutral are the 3 Poles with 3 wires for the 3 Poles and a 4th wire for the Grounding Conductor).

5.2 Distribution Within The Consumer's Premises

120 / 240 VAC Split Phase Electrical power from the utility (called Service) is fed through an electrical power meter to a load center / breaker panel for further distribution. This panel is called the Service Entrance Panel. This panel normally has the following components:

- Main Incoming Circuit Breaker – e.g. 200 A capacity
- Circuit Breakers on the Hot sides of Phases A and B feeding various branch circuits – e.g. 15 A, 20 A, 30 A, 50 A capacities
- Bus bar for Grounded Conductor (GC) / Neutral
- Bus bar for Equipment Grounding Conductors (EGC)
- Bus bar for connection to Grounding Electrode (GE)
- System Bonding Jumper (SBJ)

AC power enters the consumer's premises through the Service Entrance / Load Center. The incoming Hot / Line / Live Split Phases "A" and "B", that are the current carrying conductors, are connected to the Hot / Line / Live side of the loads through appropriately sized breakers. The incoming Grounded Conductor (GC) or Neutral is connected to a common bus bar (1). A separate bus bar (2) is provided for connecting the Equipment Grounding Conductors (EGC). A Grounding Electrode (GE) (3) is provided for the local Earth Ground at the premises. The Grounding Electrode (GE) (3) is connected to the bus bar for Equipment Grounding Conductors (EGC) (2) with the help of the Grounding Electrode Conductor (GEC) (4). A System Bonding Jumper (SBJ) (5) is used to bond the following to provide a "Single Point Grounding System":

- Bus bar (1) for the Grounded Conductor (GC)
- Bus bar (2) for the Equipment Grounding Conductors (EGC)
- Grounding Electrode (GE) (3)

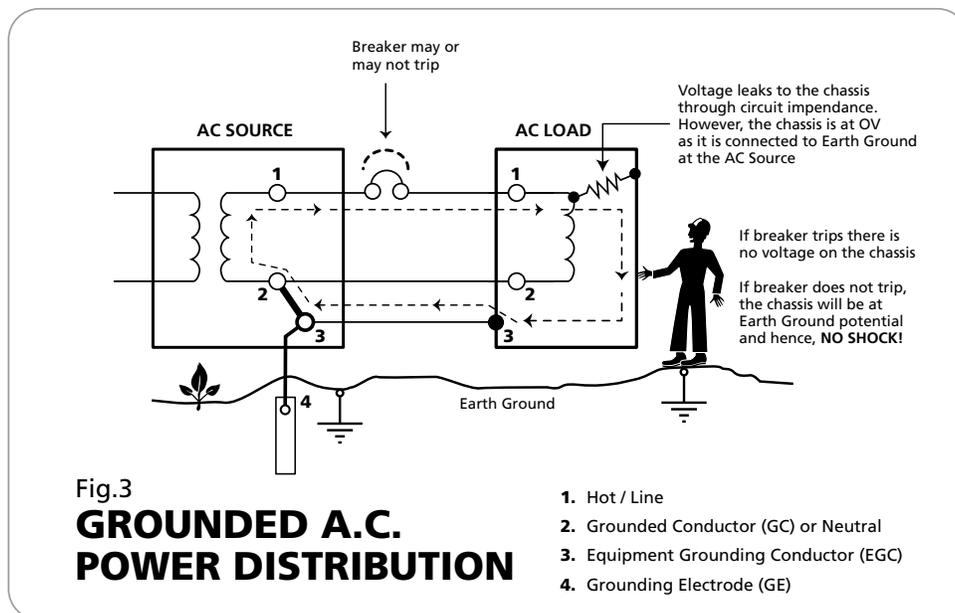
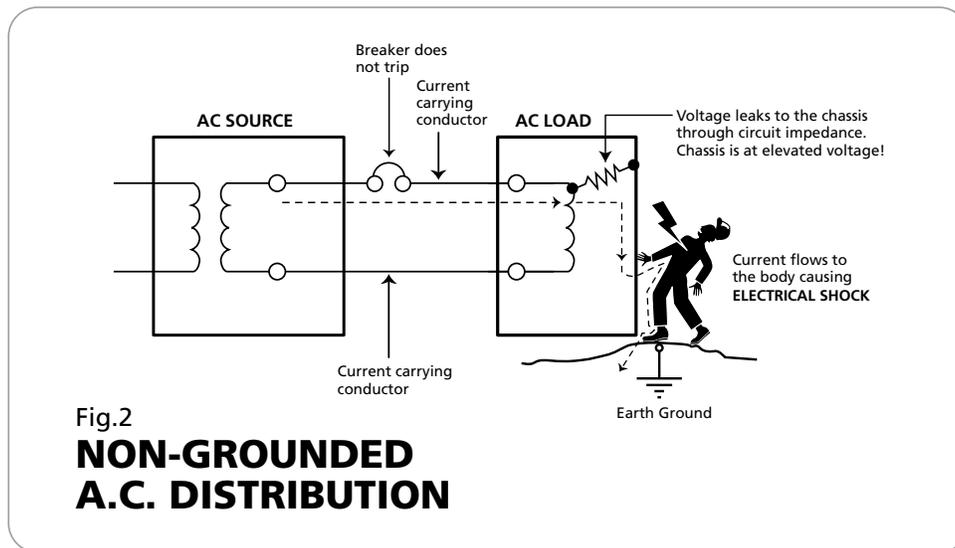
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120 VAC loads are connected to either Phase "A" and the Neutral or to Phase "B" and Neutral. 240 VAC loads are connected between the Split Phases "A" and "B."

The exposed metal surfaces of all the loads are not connected to the Earth at different places to avoid multiple grounds but to a single bus bar (2) at the Service Entrance / Load Center.

It will be seen that inside the consumer's premises, the connection between the "Neutral" and the Grounding Electrode Conductor (GEC) is made only at one point in the system i.e. at the service Entrance / Load Center. This is known as the System Ground. **This is also termed as "Single Point Grounding System".**

How Does Grounded Electrical System / Neutral Protect Against Electrical Shock?



Figs 2 and 3: Explanation of how electrical shock is produced and prevented

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The concept of a Neutral is explained with respect to 120 VAC source of power like utility / generator. Fig. 2 shows an ungrounded AC system that has no safety against electric shock. An AC Power Source feeds AC power to a load through two current carrying conductors. A circuit breaker is installed in series with one of the two current carrying conductors to disconnect the load from the AC source in case of overload or short circuit in the load circuit. Let this current carrying conductor with a series connected breaker be called "Hot / Line" conductor. Let us assume that due to internal malfunction or mechanical damage, the 120 VAC from the Hot / Line circuit inside the load got connected to the metal chassis of the load either directly or through circuit impedance. (This unintentional feeding of the "Hot / Line" voltage to the metal chassis of the load is also called "fault condition"). This condition does not produce any current flow / overload / short circuit condition as there is no return path for the current back to the source and hence, the circuit breaker in the distribution panel does not trip. The metal chassis continues to be at a dangerous voltage of 120 VAC. If a person now touches this metal chassis, a current will flow through his body and he will receive a shock.

As the current flow through the human body will be very low due to the human body resistance of 1 K Ohm to 100 K Ohm and the impedance of the leakage circuit in the load, the circuit breaker will not trip during this time and the person will be electrocuted. Please read details under "Section 1: Title Safety Instructions: Electrical Shock – Cause and Effect on the Human Body."

Let us now make the following connections that will constitute a Grounded AC Distribution System and will provide safety against electrical shock. Please refer to the arrangement in Fig. 3:

- At the output of the AC source, let one of the current carrying conductors be called as "Hot / Line(1)".
- Bond (connect) the second current carrying conductor at the AC source to the Earth Ground through a Grounding Electrode (GE) (4) and let this be called as the "Neutral" (2). As per NEC, this grounded conductor or "Neutral" (2) is called the "Grounded Conductor (GC)". As this Neutral conductor is bonded to the Earth Ground, it will be at 0 V potential and can be touched without getting any shock.
- At the load, let the corresponding two AC input terminals be called "Hot / Line" (1) and "Neutral" (2). Both these terminals at the load are isolated from the chassis of the load
- Connect the "Hot / Line" (1) of the AC source and the "Hot / Line" (1) of the load through a Circuit Breaker to disconnect the load in case of short circuit or overload. Connect the "Neutral" (2) of the AC source directly to the "Neutral" (2) of the load
- Connect the metal chassis of the load (3) to the "Neutral" connection (2) of the AC source. Call this conductor as the Equipment Grounding Conductor (EGC) (3). This connection is similar to the Green wire connection in the power cord of the AC loads that connects the metal chassis of the load to the round Grounding pin of the plug of the power cord and through the outlet, gets bonded to the Neutral and the Earth Ground of the Service Entrance Panel through the outlet
- In this condition, the metal chassis of the load (3), the "Neutral" (2) of the load, the "Neutral" (2) of the AC source and the Grounding Electrode (GE) (4) / Earth Ground are all bonded together at a single point at the AC source.
- In a normal situation, when the load is switched on, current from the "Hot / Line" terminal (1) of the AC source will flow through the AC breaker to the load and return to the AC source through the Neutral conductor (2). Although the "Neutral" (2) and the chassis of the load (3) are bonded at the "Neutral" (2) of the AC source, no current flows in the Equipment Grounding Conductor (EGC) (3) under normal operation because the "Neutral" (2) of the load is isolated from the metal chassis of the load
- Now, if by accident, the 120 VAC "Hot / Line" voltage leaked to the chassis of the load, safety against electrical shock will be provided as follows:
 - The return current path will be completed through the Equipment Grounding Conductor (EGC) (3), a fault current will flow back to the AC source and the AC breaker may trip and remove AC power from the load if the impedance of the leakage circuit in the load is low and produces fault current which is more than the breaker capacity
 - If the leakage impedance is higher and the fault current is lower than the breaker capacity, the breaker will not trip. However, the metal chassis (3) of the load will get bonded to the Earth Ground through the Earth Ground bonding of the Equipment Grounding Conductor (EGC) (3) at the AC source as explained above. This will force the metal chassis of the load to be at Earth Ground potential of 0 V. Hence, a person standing on the Earth Ground will be touching another metal object which is also at Earth Ground and hence, he will not receive electrical shock.

6.0 ISOLATING NEUTRAL CONDUCTOR IN RV AC POWER DISTRIBUTION

In an RV / vehicle, the chassis of the vehicle remains isolated from the Earth Ground because the rubber tires of the vehicle act as insulators between the metal chassis and the Earth Ground.

As explained above, one of the AC current carrying conductors is bonded to the Earth Ground for safety purposes. This conductor is called the Grounded Conductor (GC) or the Neutral. If a person standing on the Earth Ground touches this conductor, he will not receive any shock because both he and the Neutral conductor are at the same potential of the Earth Ground. The other current carrying conductor (Hot / Line / Live) is at an elevated voltage (120 VAC / 240 VAC) and if a person standing on Earth Ground touches this conductor, he will be electrocuted!

Shore AC power from the utility is received by the Main AC Panel in the RV through the external AC inlet plug. Shore AC power is fed to this plug through a shore power cord (also called a Cord). It can be a 30 A, 120 VAC Service or a 50 A, 120 / 240 Split Phase Service

The Main AC Panel of the RV has the following Bus Bars for making AC connections:

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- **Hot Bus Bar:** The Hot conductor (Black) from the shore power is connected to this Bus Bar through a Main Incoming Breaker (e.g. 30 A breaker for a 30 A Service). Hot conductors (Black) to Branch Circuits in the RV are fed from this Hot Bus Bar through breakers
- **Neutral Bus Bar:** The Neutral conductor (White) from the shore power is fed to the Neutral Bus Bar. The Neutral conductors of the Branch Circuits are connected to this Bus Bar. THIS BUS BAR IS NOT BONDED TO THE CHASSIS OF THE RV. HENCE, THE NEUTRAL IS FLOATING IN THE RV.
- **Bus Bar for Equipment Grounding Conductors (Green / bare copper):** The Equipment Grounding Conductor from the shore power (Green) is fed to this Bus Bar. Equipment Grounding Conductors from the Branch Circuits are connected to this Bus Bar



INFO

Please note that in the RV, the Neutral Bus Bar is NOT bonded to the Chassis of the RV. In the RV, the Neutral is floating with respect to the chassis of the RV. This is necessary for safety because if the Neutral was bonded to the chassis of the RV and if the Neutral and the Hot got reversed by mistake, the chassis of the RV will be at 120 VAC with respect to the Earth Ground. If a person standing on the Earth Ground touches the chassis of the RV, he will be fed with 120 VAC and he/she will be electrocuted!

7.0 POLARITY AND COLOR CODES FOR POWER CORDS AND PLUGS FOR AC DEVICES AND APPLIANCES

Single phase 120 VAC, 60 Hz AC devices and appliances use 2 pole, 3 wire grounding configuration for connection to the AC power source. For example, the 120 VAC, 15 A, NEMA5-15 plug of the power cord has three pins – two flat pins (also called poles) that are connected to the two current-carrying conductors and a round pin which is connected to a non-current carrying conductor (this will carry current only during ground fault conditions). One flat pin is connected to a black current-carrying conductor that is also called “Line / Live / Hot” pole. The other flat pin is connected to the white current-carrying conductor also called the “Neutral / Return / Cold” pole. The third round pin is connected to the non-current carrying, green colored, “Equipment Grounding Conductor (EGC)”. This green “Equipment Grounding Conductor (EGC)” is bonded to the metal chassis of the device or appliance.

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