

The Grounding Electrode System by Douglas Hansen

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“Earthing” and “Bonding”

Electrical equipment is subject to damage or danger from outside forces, such as light-nin, line surges, or high-voltage crossovers to low voltage (120/240V) lines. Connecting the electrical system to the earth helps to limit the voltage potential between the equipment and earth. The outside forces could be acting upon the system *even if there was no electrical equipment in use at the time*. In fact, the need for referencing the system to the earth is the same even if the main breaker is turned off. The first part of the subject of grounding therefore has to do with “earthing” the system. The “earthing” system has *nothing* to do with protecting people from electrical shocks from their electrical system.

The next aspect of grounding is the way it provides a system to protect equipment and people from electricity that has gone out of its intended path. This grounding system includes the bonding connections that eliminate voltage potential and possible arcing between electrical components. It includes the conductors and connections that protect equipment that has been accidentally brought in contact with the electrical energy we have created at the utility transformer. It provides an easy path for current to return to the transformer so that fuses, breakers, and other protective devices can do their job and de-energize a circuit. The “bonding” system protects people from potentially damaging affects of electricity.

Grounded Electrical Systems

Residential electrical systems that get their power from a utility company are all “grounded” systems. That does not mean that all the electrical receptacles are grounding types that will accept 3-prong plugs; it means that the system itself has a connection to earth at its source, the utility transformer. The transformer has two secondary windings, one for each 120V-volt system. They are tied together so that when used in series they are a 240-volt system. The point where they are tied together is the place where the neutral, or grounded, conductor originates. That conductor is connected to the earth at the pole. A grounding electrode conductor runs down the side of the power pole and connects to a rod buried below the pole.

The neutral service conductor that is brought to the service panel at the house is therefore a *grounded* conductor. A sec-

ond grounding connection is made to the earth where the neutral connects to the service panel. At the service panel, the enclosure, the incoming neutral conductor, and the grounding electrode conductor are all connected. After the service panel, they are separated according to their function. Neutral conductors complete a circuit and carry current, and therefore they are insulated. Equipment grounding conductors carry no current until a fault occurs, and may be bare conductors. Older systems do not have equipment grounding conductors in the branch circuits and feeders.

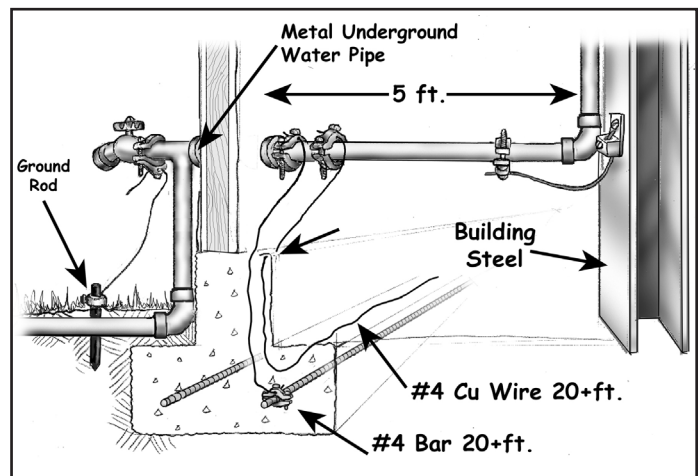


Figure 1 — The Grounding Electrode System

Grounding Electrodes

A grounding electrode provides a connection between the electrical system and earth. The most common grounding electrodes in residential systems are water piping, ground rods, and steel reinforcement inside the foundation. If present, they must all be bonded together to form the grounding electrode system [250-50]. Other grounding electrodes recognized by the NEC® include effectively grounded building steel, ground plates (rare), ground rings, and other buried metal, such as well casings.

Metal Water Piping

Metal water service piping in contact with earth for 10 feet or more must be included as part of the grounding electrode system. However, metal water piping is prone to failure (especially galvanized piping) and is likely to be replaced with plastic. Therefore, the NEC® requires that metal water piping not be the only electrode. It must be supplemented by at least one of the other electrodes in figure 1.

Another problem with metal water piping is the possibility of plastic or dielectric fittings being inserted into the piping system. Therefore the NEC® requires that connections to metal water pipe electrodes be no further than 5 feet from the point where the water pipe enters the building (fig. 1). If the water enters the house on the opposite side as the electrical service, then a wire is supposed to be run over to the place where the water enters the building, rather than just picking up the water piping at a point near the electrical service. This requirement came into the NEC® in the 1993 edition, and many older homes do not comply.

Equipment and fittings connected to metal water piping must be provided with bonding jumpers to assure the continuity of the grounding system even while the equipment is removed for service. A bonding jumper is required around water filters, meters on the house side of the underground piping, regulators, water softeners, or other such equipment. It does not matter if the equipment is electrically conductive; even if it is hooked up with metal unions it is still removable, and requires a bonding jumper.

Driven Rods

Many utility companies and local building jurisdictions require driven rods regardless of what other electrodes might be present. The most common size for a residence is a 1/2 inch rod 8 feet long.

Rods should be driven for their full depth, though little harm will result from leaving one a few inches above the soil [250-52c]. Many electricians use a roto-hammer to drive the rod, as this is usually easier than pounding with a sledge hammer. Installers who have a hard time driving the rod will often cut them, which clearly violates the rule requiring them to be driven their full depth. Copper-clad rods are actually made of steel with a copper coating, and if the rod is cut, inspectors might see rust at the top of the rod. Another clue is the presence of the etched label near the top of the rod. If it is not present in the first few inches, the rod has been cut.



Figure 2 — UL Label Etched into Rod

If bedrock is encountered, rods are allowed to be driven at a 45-degree angle, or to be laid in a trench 2 1/2 feet below the surface. If a rod is fully driven and the top covered by soils, all that an inspector might see is the wire entering the earth.

The resistance of a driven rod is required to be no more than 25 ohms [250-56]. If the resistance is higher than 25 ohms, then a second rod is required, and must be at least 6 feet apart from the first rod. Earth resistance testing is typically done by a fall-of-poten-tial test, and is seldom performed for residential construction. In several parts of the country, jurisdictions will simply require 2 rods instead of performing a test to see if 2 were need for compliance.

Concrete-Encased Electrodes

Reinforcing steel inside a concrete foundation, along with the concrete itself, forms a very effective grounding electrode. The system is sometimes referred to as a "Ufer" ground in honor of the inventor of this system, Herbert Ufer. He originally developed the idea while trying to find a way to ground metal buildings in the desert, and then conducted extensive research and promoted the idea to the NEC®. The concrete itself acts as the electrode; the steel inside the foundation does not directly touch the soils. While concrete at first might not seem to be a conductive material, moisture and salts readily migrate through concrete, and the soils

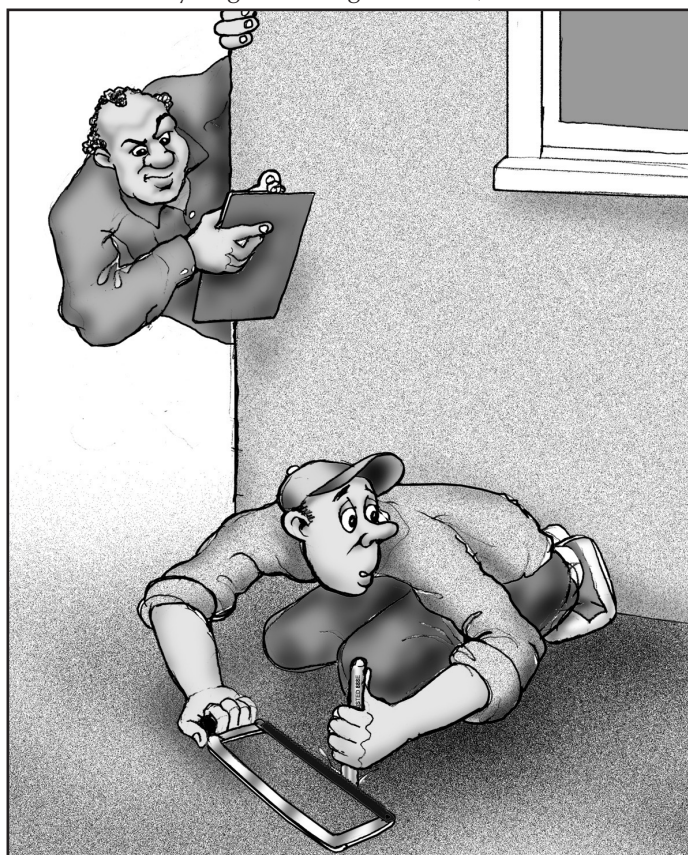


Figure 3 — Caught in the Act

beneath the footing are more likely to be moist than below areas outside the footing. The act of pouring the concrete can also “dope” the soils with chemicals that increase its conductivity. The steel inside the foundation is used as the conductor to reach the concrete.

The NEC® calls for the electrode to include at least 20 feet of reinforcing steel near the bottom of the footing. Of course, after the concrete is poured, the placement of steel can no longer be visually determined. A steel bar can be brought up out of the foundation for the connection to the grounding electrode conductor, or the conductor could actually connect inside the foundation, in which case the inspector would only see a wire emerging from the concrete.



Figure 4 — Ground Clamp inside Foundation

In actual practice, it is very common to see two steel bars emerging from the foundation. The reason for two bars instead of one stems from a common misunderstanding. While the code calls for a connection to a minimum of 20 feet of reinforcing steel, there is no requirement that the conductor clamp directly to those 20 feet of steel. Many jurisdictions fail to appreciate this distinction, and mistakenly assume that the 20 feet of steel is a separate electrode than the reinforcing steel that is already present in the foundation. If a piece of 20-foot rebar is bent to bring a piece up out of the foundation, then less than 20 feet remains encased. To solve this “problem”, inspectors require 2 pieces as in the figure 5.

Many jurisdictions require this steel to be *in addition* to the steel that is already present, despite the fact that the code does not intend for it to be anything other than the original steel. Because of this wide-spread misunderstanding, the NEC® added language to the 1999 edition stating that the ordinary tie wires between pieces of reinforcing steel are considered sufficient for bonding the sections of steel to each other.

Another problem arises from bringing two pieces of steel outside the foundation; suitable clamps are not available for more than one piece of rebar.

Other Grounding Electrodes

The NEC® recognizes several other types of grounding



Figure 5 — Typical Ufer Ground

electrodes. One that is very commonly used in commercial facilities and at substations is the *ground ring*. A ground ring is a piece of #2 or larger copper wire encircling a structure, and buried at least 2¹/₂ feet deep. Ground rings are very effective.

Other buried metal that is available on the premises can be used as a grounding electrode, including buried metal tanks, well casings, or other buried metal piping systems. One system that may NOT be used as a grounding electrode is buried gas piping. There are several reasons not to connect to underground gas pipe. First, it is a poor electrode. The pipe is usually plastic after the first few feet, and even the metallic portion will be wrapped to protect it from direct soil contact. Next, the purpose of the grounding electrode is to safely discharge excess voltage from outside sources, such as lightning, to the earth. Obviously, gas piping is not something that should be in the path of lightning. Finally, the utility company would prefer to see no electrical connections to their gas piping. Their concerns are potential fault currents endangering their workers, as well as electrolysis that can harm the piping.

Grounding Electrode Conductors

The conductors that connect from the service equipment to the grounding electrode are referred to as grounding electrode conductors. This conductor must electrically connect to the incoming neutral service conductor. The connection is usually made inside the service panel, though in some parts of the country the utility companies prefer to see the connection made inside their meter socket.

Sizes and Materials

The grounding electrode conductor helps to reference the service equipment to earth, and therefore its size is based

upon the size of the service entrance conductors entering the building. While several factors contribute to the rating of the service (conductor size, equipment rating, and main breaker) the only factor to consider in sizing the grounding electrode conductor is the service entrance conductor. However, not all electrodes are considered equal, and in practical terms, the only residential electrode that requires a full-size conductor is metal water piping. Conductors that dead-end at a ground rod need never be large than #6 copper, and conductors that dead end at a concrete-encased electrode need never be larger than #4 copper. If the grounding electrode conductor passes through a clamp on the ground rod, and then dead-ends at the water piping, it would have to be full size.

The following table, based on table 250-66 of the NEC®, shows the minimum sizes of grounding electrode conductors. For convenience, a column showing the maximum service capacity of the service entrance conductors is also shown, though there is no direct relationship between service capacity and the size of the grounding electrode conductor.

Most electricians will use copper grounding electrode conductors. If an aluminum grounding electrode conductor is used, it must not be exposed within 18 inches of the soil outdoors [250-64a].

Protection

#8 grounding electrode conductors must always be protected. Typically they are inside a flexible armor, as in figure 6. Special clamps are used that also attach the conduit to the electrode.



Figure 6 — Protective Armour

#6 grounding electrode conductors may be unprotected if they closely follow a wall surface and are not exposed to physical damage. If a #6 conductor were suspended in air to a grounding electrode, it might be damaged. In such cases, the conductor should be inside a protective conduit. Larger conductors (#4 and up) need only be protected if exposed to severe physical damage [250-64b].

The best form of protection is to use schedule 80 PVC electrical conduit to protect the conductor. When metal conduit is used, currents imposed on the conductor will travel on the conduit. They will do so whether the conductor is insu-

lated or not, as the magnetic fields will induce the current to the conduit. The conduit must therefore be bonded at each end to avoid a “choke coil” effect. It must be bonded at the service equipment, and at the electrode. If the conduit is not bonded, the strong magnetic fields induced into it might actually melt the grounding electrode conductor when a fault occurs.

Splices

Splices are not allowed in the conductor from the service equipment to the grounding electrode system [250-64c]. The main reason for such a rule is simply that the connection could be undone at some later date. If a conductor is cut, it can be repaired by an irreversible compression connection or an exothermic weld.

The rule against splicing is often misunderstood. First, the conductor in question is the one going back from the grounding electrode system to the panel. The rule does not apply to the conductors used to bond the separate portions of the grounding electrode system. It would be acceptable to have a separate conductor from the water piping to the ground rod, and a grounding electrode conductor from either one of them back to the panel. While many jurisdictions might require a single conductor passing through a clamp and connecting in one piece to all components, no such requirement exists in the NEC®.

Another possible arrangement is to have a continuous grounding conductor from the service panel to one of the electrodes in the grounding electrode system, and then taps from that conductor to the other electrodes in the system. Such taps are not considered splices; all that is required is to have one of the electrodes connected to the service equipment with an unspliced conductor.

Clamps

Loose clamps, improper installations, and unsuitable materials are a very common defect. Ground clamps must be suitable for the particular application in question. The basic design of ground clamps is to connect to either pipes or rods. Special markings are required for ground clamps that are suitable for copper water tubing, direct burial or encasement, or for rebar. Information on ground clamps is available from Underwriters Laboratories, as described in *The White Book*, or [General Information for Electrical Equipment Directory](#).

For ground rods, the basic clamp used by most electricians is the *acorn* clamp, as shown in figure 7. Acorn clamps are made of copper or brass, and come in standard 1/2 inch, 5/8 inch, and 3/4 inch for the various sizes of ground rods.

Grounding Electrode Conductor Sizes

Size of Copper Service Entrance Conductors	Size of Aluminum Service Entrance Conductors	Likely Rating of Service	Minimum Size of Copper Grounding Electrode Conductor	Minimum Size Aluminum Grounding Electrode Conductor
2 or smaller	1/0 or smaller	up to 125 amp	8	6
1 or 1/0	2/0 or 3/0	150 amps	6	4
2/0 or 3/0	4/0 or 250kcmil	200 amps	4	2
400kcmil	600kcmil	400	1/0	3/0

This table basically only applies to conductors that must connect to the water piping system. Conductors that end at ground rods need only be #6 copper, and conductors that end at the concrete-encased electrodes need only be #4 copper.

Acorn clamps are often installed incorrectly. The first and most important issue is to use the correct size. If too large a clamp is used, the conductor will not be secured tightly. The next issue is to tighten the clamp, while avoiding over-tightening that could crack the clamp.



Figure 7 — Acorn Clamp

The conductor secured by the acorn clamp should be placed on the opposite side of the clamp from the bolt. The clamp presses the conductor into the electrode as the bolt is tightened. If the conductor is placed on the same side as the bolt, it might be damaged or be loose in the space between the side of the bolt and the clamp.

Any clamp that is used with a buried or encased electrode must be labeled with the words “direct burial” or the letters “DB”. Since the ground rod is intended to be driven below the soil surface, the clamp must be suitable for such conditions. In general, clamps rated for direct burial are brass or copper, with no steel, pot metal, or aluminum components, including the terminal screws.

Weaver clamps are commonly used on pipes. Not all of these clamps are suitable for direct burial, and the cheaper clamps easily crack if over-tightened. Many of these clamps

can be installed one of two ways. The jaws of the clamp can both be wrapped around the pipe or, if the electrode is a rod, one side of the clamp can be turned around. The clamp then looks like spoons in a drawer, with the contours of the two pieces in parallel, as in figure 8.

Clamps that are suitable for copper water pipe (tubing) must be marked for such use. If an ordinary pipe clamp is used on copper tubing, it might damage the tubing without making a proper connection.

The conductor connecting to the clamp must fit in a terminal that is made for the purpose. The conductor



Figure 8 — The clamp is oriented correctly, but the conductor is unprotected.

cannot simply be smashed between the clamp and a pipe. Only one conductor is allowed per clamp, unless the clamp is specifically designed with separate terminals to accommodate more than one conductor.

Strap type clamps are only suitable for telephone equipment. They should not be used for any part of the line-voltage house electrical system.

Clamps that are suitable for rebar must have a tag or marking that states the acceptable size of rebar. Several styles have come on the market in recent years. Unfortunately, many improper clamps are used, especially when attempting to attach to 2 pieces of rebar, as in figure 5. A rebar clamp is shown in figure 9.

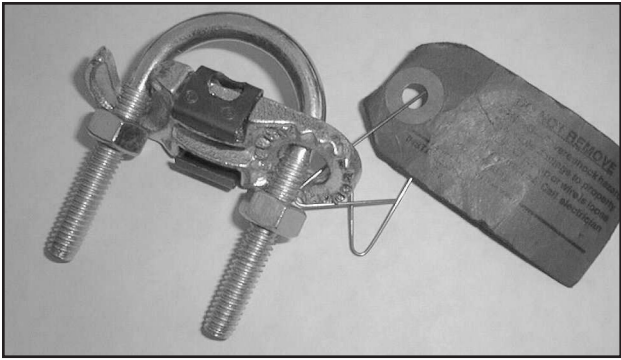


Figure 9 — A rebar clamp.

Accessibility

Clamps that are not buried or encased must be accessible. Sometimes the connection will be inside a wall, and a blank cover plate will cover the place where a connection was made to the concrete-encased electrode. Other times, a “mud ring” will provide access to the clamp.

Inspectors sometimes see a grounding electrode conductor inside the panel, and cannot find any trace of it anywhere else on the property. In new construction, the conductor would be accessible. While inspection standards require reporting the method of connecting to the earth, on many older properties the inspector must report it as “unknown.”

The importance of the grounding electrode depends in large part on the incidence of lightning in a given area. It may be that in some areas we pay an undue amount of attention to the various rules for these electrodes, while in others, even a perfectly complying system will not be sufficient to protect against the assaults of nature. ❖