Electrical Tech Note — 337

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Neutral-to-Earth Voltage

Customer and utility electrical systems are usually grounded to the earth at multiple locations which gives rise to a small electrical current flowing in the earth. This grounding is required by electrical codes to insure the maximum safety and reliability of the electrical systems. Under normal operating conditions it is not uncommon for a small measurable voltage to be present between the neutral of an electrical system neutral and the earth or from grounded metal equipment and the earth. This voltage is known as neutral-to-earth voltage often abbreviated as NEV. In the case of a properly designed, installed, and maintained electrical system this voltage is so small that it is no concern. However, in very wet conditions this voltage may be at a level that it can have an adverse effect on farm livestock, and in some cases this voltage has been known to cause annoying mild electrical shocks to humans in and around swimming pools and similar installations. On occasion elevated levels of neutral-to-earth voltage can occur, usually due to abnormal conditions that if located can be mitigated eliminating the problem level of NEV. As illustrated in *Figure 337.1* the earth acts as a parallel conductor to the neutral and a very small level of current may flow between the earth and the utility line neutral. Current that flows in the earth generally is returning to the substation that supplies power to the utility distribution line.

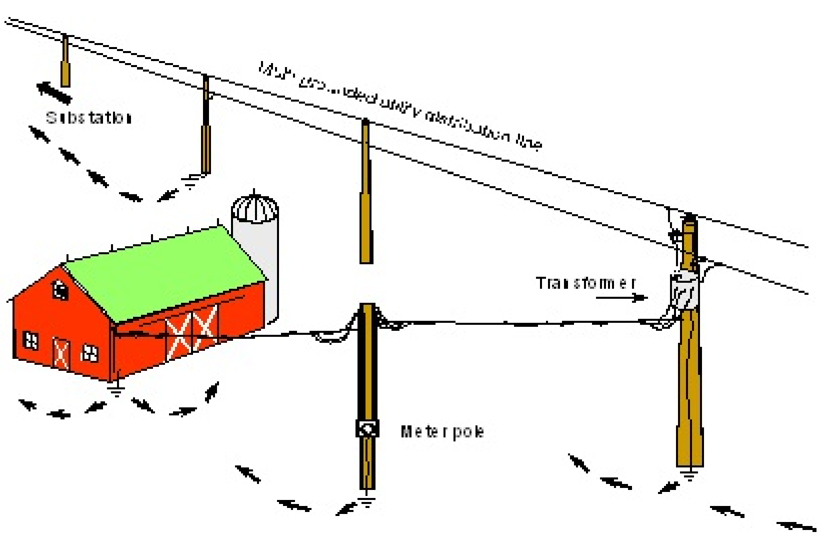

Figure 337.1 *The small amount of power line neutral current that flows in the earth returns to the a grounding system at the substation supplying power to the distribution line.*

There are several common sources of an elevated level NEV and it is not uncommon for more than one source to be present at the same time. The utility system is only one of several common sources of NEV. Identifying the various sources of an elevated neutral-to-earth voltage requires specialized equipment and instrumentation as well as trained personnel. The earth current causing the NEV may be coming from the utility distribution line, but it can also come from the customer's electrical system and in some cases from a neighbor electrical system. To find and correct a condition not located on a customer's property requires involvement by personnel from the utility supplying electrical power to the customer.

Important Electrical Quantities: When a human or an animal feels an electrical sensation such as a tingle or a shock the cause is electrical *current* flowing through the person's or animal's body. Research conducted around the world has quantified levels of current and it's human and animal effects. Three electrical quantities must be understood in order to evaluate conditions that may cause an NEV issue. These electrical quantities are *voltage, current,* and *resistance.* It is *current* that causes an electrical sensation in humans and animals, but it is voltage that pushes the current through the resistance imposed by the person or animal.

Electrical potential (voltage)	units are	*Volts*
Current	units are	*Amperes*
Resistance	units are	*Ohms*

These three electrical quantities are related by an equation know as Ohm's law. Divide voltage (NEV) by path resistance to get current flow. An example of an animal receiving an adverse exposure to NEV is shown in *Figure 337.2.* The water device is grounded for safety and the grounding wire is connected to the electrical system neutral at the supply panel. When the animal makes contact with the water in the drinker a small current can flow to earth through the animal.

$$Current = \frac{Voltage}{Resistance}$$

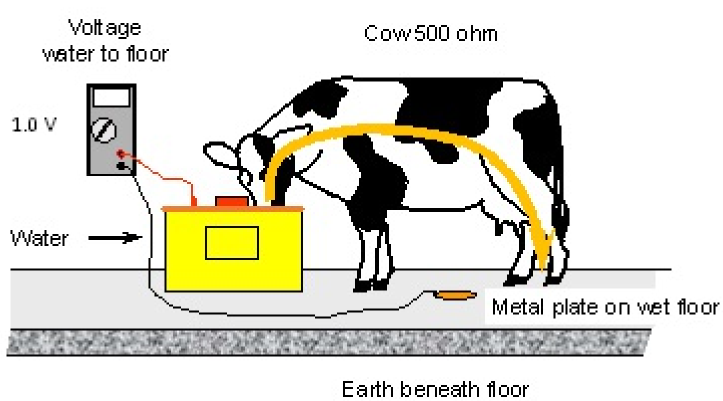

Figure 337.2 *This animal can feel current when it is drinking due to a level of neutral-to-earth voltage that can be measured between the water drinker and the wet concrete where the animal is standing.*

Human Effects of Electrical Current: Farm livestock animal areas are frequently wet resulting in a relatively low resistance through the body and into the earth. Experience has shown that effects due to current flow through the body is similar for humans and livestock. Because livestock are in a wet environment much of the time, they can receive an elevated current at a much lower voltage level than humans. The following are approximate current values that cause the conditions described. These values apply to humans, but university research indicates these values more than likely cause a similar response in farm livestock. The designation mA is milliamperes. One milliampere is one thousandth of an ampere.

Slight tingling sensation	1 mA	
Extreme discomfort	5 mA	(trip level for a ground-fault circuit-interrupter)
Let-go ability may occur as low as	15 mA	
Higher levels can be dangerous		

Human Body Resistance: Current flow through the human body depends upon a number of factors. Most shock conditions are the result of a person's body in contact with an object upon which there is a voltage and another part of the person's body touching a grounded object or the earth. When the human body is very dry the resistance between a source and earth can be in the tens of thousands of ohms. Wearing shoes or boots and the resistance between source and ground may be in the hundreds of thousands of ohms. But with a person's body immersed in water for an extended period of time, human body resistance between the source and ground can be as low as 500 ohms. With body resistance this low touching a metal object with just one volt can cause a body current of two milliamperes (2 mA). This is high enough current level to most likely be annoying and possibly uncomfortable.

Because such small voltages can be a serious issue with humans under wet conditions the electrical codes impose strict electrical bonding preventative procedures for swimming pool installations, fountains, hot tubs, spas, and hydromassage bathtub installations.

How Most Electrical Systems are Connected: Electrical installation codes for utilities and for consumer electrical systems have strict rules for system grounding and equipment grounding. Most customer electrical systems have a neutral wire that is required to be grounded to the earth. Most utility electrical distribution lines that deliver power to customers have a neutral wire that is grounded to the earth. The utility installs transformers at a customer location that adjusts the voltage of the distribution line to the voltage requirements needed by the customer. These transformers are required to be grounded to the earth. If the utility line and the customer electrical system both have a neutral wire, the electrical code the utility must follow requires the utility line neutral to be bonded (connected) to the customer electrical system neutral for safety. *Figure 337.3* shows only the neutral wires of the utility and customer electrical systems neutral. It also shows code required grounding connections to earth which are usually one or more 8 foot long metal rods driven into the earth. At the location on the diagram that represents the customer service disconnect or service panel a grounding point for the customer is established and it is connected to the customer neutral. This grounding wire connection to the customer neutral conductor is required by code.

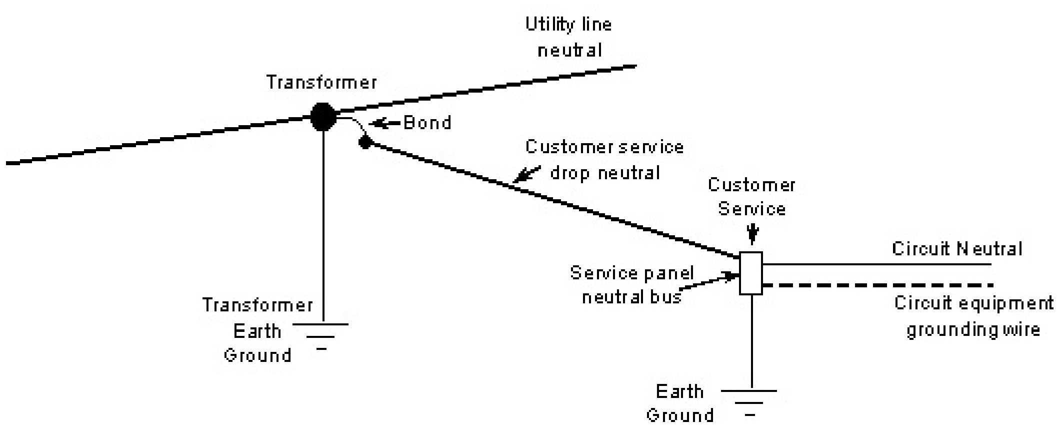

Figure 337.3 *In most cases the utility neutral wire is solidly connected to the customer neutral. This illustration only shows system neutrals and grounds.*

Notice in *Figure 337.1* the required grounding and bonding connects the utility and customer electrical system neutrals together. Everyone in the neighborhood is electrically connected together by means of the utility neutral conductor. This grounding and bonding is essential for customer and utility personnel safety, but it also creates a situation where electrical issues on the customer's property as well as off the customer's property in the neighborhood can result in small voltages that can cause problems for farmer's livestock as well as annoying shocks at someone's swimming pool.

Neutral to earth voltage (NEV) caused by the utility system or other customer issues can be prevented from accessing a customer electrical system by removing the bond connection between the utility neutral and the customer neutral shown in *Figure 337.4.* Utilities prefer <u>not</u> to remove a transformer primary/secondary neutral bond only as a last resort. Removing the bond between the utility line neutral and the customer neutral does not eliminate any of the NEV sources originating on the customer's property.

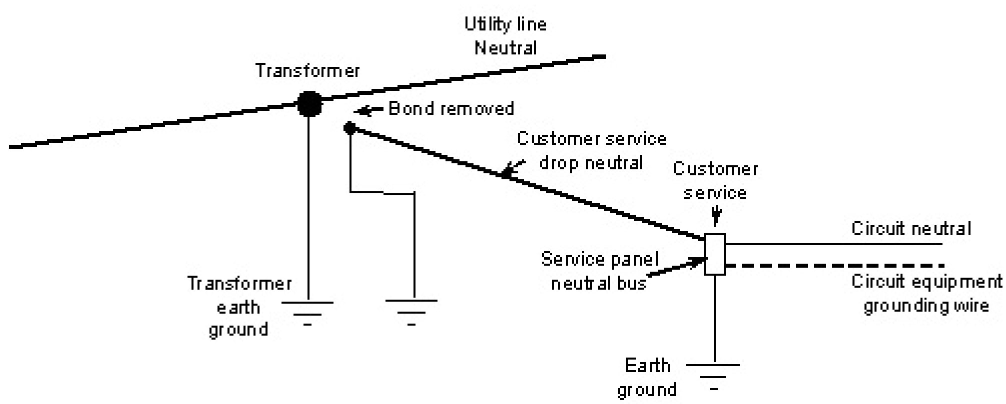

Figure 337.4 *Off property NEV sources can be prevented from accessing a customer electrical system by removing the primary/secondary bond at the transformer. In the rare case when the primary/secondary neutral bond is removed at a transformer, a second ground must be added to the customer side neutral at the transformer.*

Common Causes of NEV: Here is a summary of the most common sources of NEV that could be affecting farm livestock or causing tingle or mild shocks at a swimming pool.

1. Voltage drop on a utility multi-grounded distribution line neutral. (See *Figure 337.5*)

2. Voltage drop on customer overhead or underground neutral wires between buildings.

3. Ground faults at farm or home electrical equipment that is not properly grounded.

4. Ground faults at a neighbor's property that is putting current into the earth.

5. Improperly grounded electric fence systems. Minimum of three fence charger ground rods that are not connected to electrical system grounds or to any metal equipment.

Most *utility distribution lines* have a neutral wire that is required by code to be grounded at every transformer location and sometimes at other locations along the line. The minimum number of grounds for a utility distribution line is four grounds every mile. These grounds are essential for maximum safety and reliability. But because of all these neutral wire grounds the *earth becomes a parallel conductor for current returning to the substation.* As a result the earth also becomes a return path back to the substation for some of the neutral current. It is common for a vary small voltage to be present between the neutral wire and the earth at each grounding location. *This is what is known as neutral-to-earth voltage.* This phenomenon is explained by Ohm's law which explains that when this very small current flows across the ground rod resistance to earth a very small voltage occurs. This ground rod current is usually only a fraction of an ampere. Assume the ground rod current is 10mA (0.01 ampere) and the ground rod resistance to earth is 30 ohms. The neutral-to-earth voltage at that ground rod location is the product of the current in amperes and the resistance of the ground rod. For this example the NEV is 0.3 volts. Such small voltages have no effect on humans or animals. On occasion a condition can arise that results in an elevated level of NEV. *Figure 337.5* illustrates a typical grounded neutral utility distribution line with a small current flowing in the earth back to the substation.

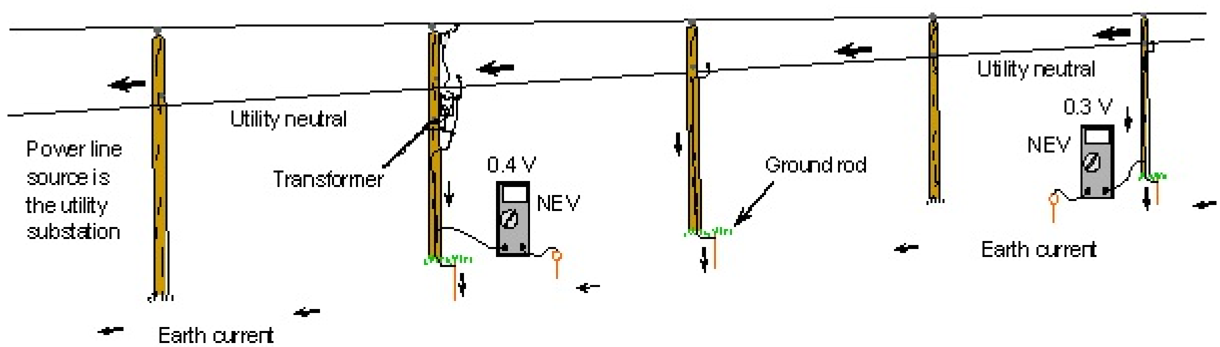

Figure 337.5 *Most utility electrical distribution lines are multi-grounded to the earth and some of the neutral current flows in the earth.*

Electrical service to agricultural operations will have electrical power supplied to a central location. From that central location feeder lines will deliver power to various buildings and points of use. *Figure 337.6* is a simplified example with power delivered to a main service point and power is extended to another building. The wires supplying to remote location are the responsibility of the customer. This is a single-phase example with two "hot" (120 volt) wires and a neutral. It is not uncommon for this neutral wire to be connected to the earth at the supplied building as well as at the main service. This grounding has some advantages but it also makes the earth a parallel neutral path. Usually the neutral current is quite small and the amount of current flowing through the earth is too small to be of any concern. On occasion the resistance of this neutral path and the level of neutral current can result in excessive voltage drop between the second building and the main service. The three volt meters in *Figure 337.6* show that the NEV at the second building is quite elevated (2.25 volts). The cause is excessive voltage drop on the neutral wire (3.0 volts) between the main service and the second building.

Because the utility distribution line neutral and the customer neutrals are connected together at the utility transformer it is likely the utility line NEV and this customer wiring produced NEV can add together creating a combined level high enough to adversely affect livestock. The two sources of NEV can also subtract from each other which is a condition that must be understood by a trained NEV evaluator. In a problem situation the elevated level of NEV is likely to only occur at particular times during the day. Sometimes it is necessary to install an NEV recorder and let it operate for a period of time.

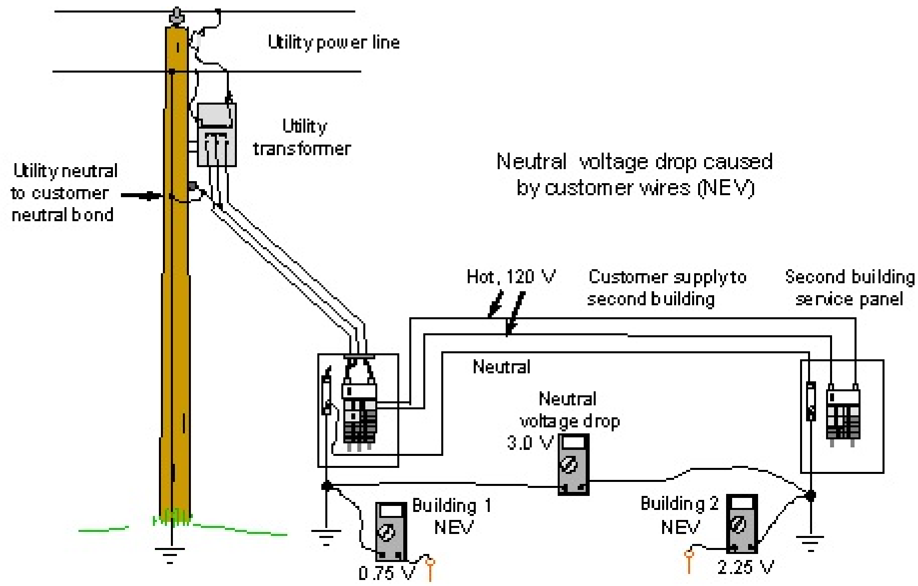

Figure 337.6 Excessive voltage drop on the neutral wire of a feeder line to a remote building can result in neutral-to-earth voltage that is high enough to have an effect on livestock.

Another neutral-to-earth source that can occur at a customer location is a ground-fault at equipment that is not properly grounded and is making contact by some means to the earth. A common example is a basement sump pump. Fault current can enter the earth under wet conditions if the sump pump is not properly grounded. Remember that electricity always returns to it's source. The source at a customer's property is the utility transformer. Current going into the earth at the sump pump will eventually find it's way back to the source. At every ground connection where the current comes out of the ground NEV will be the result. *Figure 337.7* shows how current entering the earth from a faulting sump pump finds it's way back to the utility transformer.

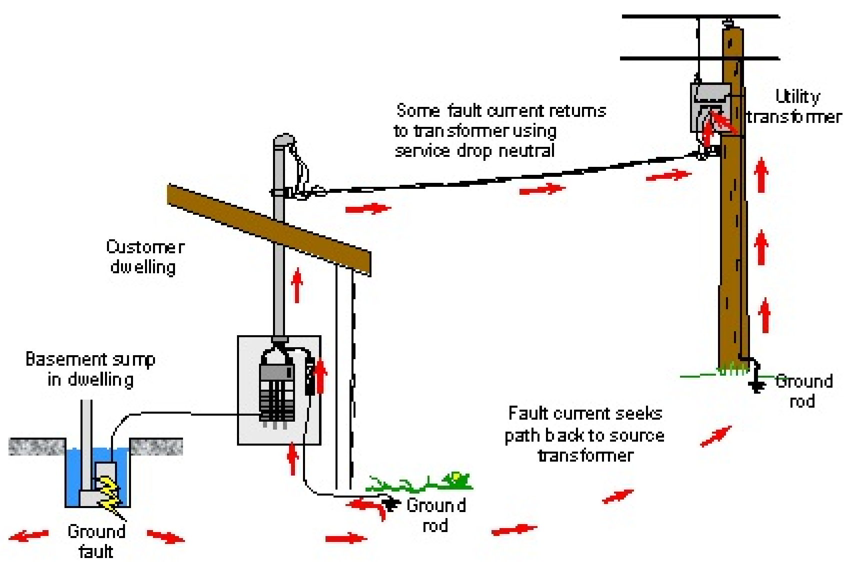

Figure 337.7 *Faulting equipment such as this basement sump pump will create NEV as current returns to the utility transformer.*

It is possible for a ground-fault putting current into the earth at a neighbor's property to cause an NEV condition at other neighbor's property. The fault current that enters the earth will find multiple paths back to the source transformer. Remember that the neutral conductor at all of the neighbors are connected by the distribution line neutral conductor because of the customer to primary neutral bond at each transformer. This source of NEV is illustrated in *Figure 337.8.* In the case of the neighbor the source of tingle voltages at the swimming pool are caused by the ground fault at the neighbor's property.

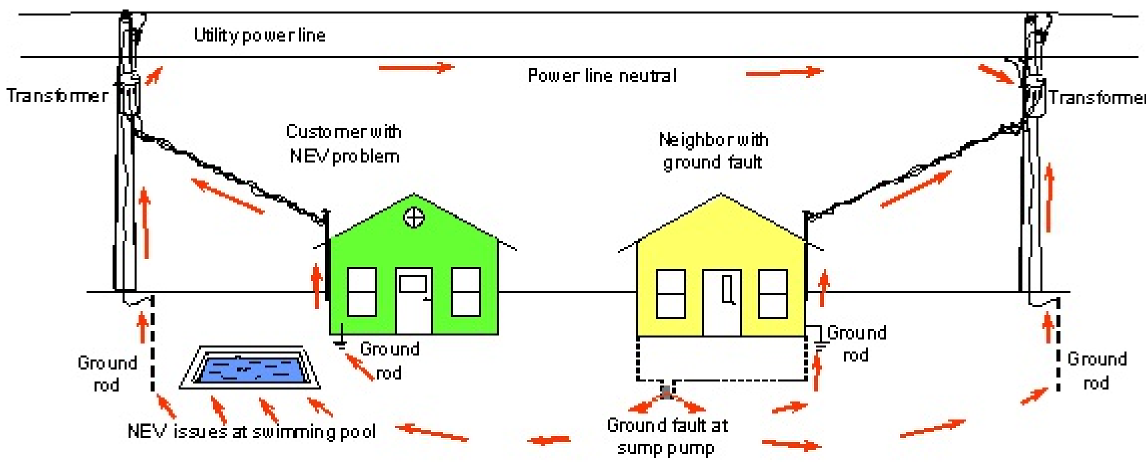

Figure 337.8 The fault current entering the earth at the neighbor's property can travel to all the surrounding neighbor's property to find a path back to the source transformer.

Electric fences are often installed on livestock farms to control mostly dairy cows or horses in grazing areas. The power source for a fence charger can be a battery or plug into a 120 volt receptacle. The charger unit typically releases an extremely short pulse of several thousand volts onto the fence wire. The high voltage pulse is usually less than 50 microseconds in duration. If an animal makes contact with the fence wire it completes a path to the earth. The current pulse than flows through the earth to the charger grounding rods installed near the charger. The ground rods are extremely important. For best results a minimum of three eight foot long ground rods are needed. *Never use the electrical system ground rods to ground a fence charger system.* Fencer current returning to the charger grounding system can cause a pulsing NEV situation. A properly installed fence charger system is shown in *Figure 337.9.*

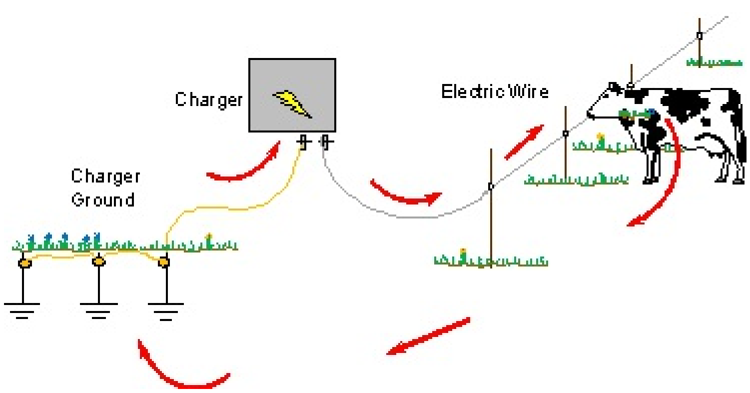

Figure 337.9 A properly installed fence charger system never used electrical system grounds.

Measuring Ground Rod Resistance: The current flowing to earth at a ground rod is usually only a few milliamperes. Not all current measuring instruments are capable of providing an accurate value when the current is this small. There are some clamp-around ammeters that do make accurate measurements as low as a few milliamperes. *Figure 337.10* shows how ground rod resistance can be calculated. First make an NEV measurement. If the NEV is at lease 0.5 volts and the current is more than 10 milliamperes an accurate measurement is probable possible. As shown in the diagram measure the NEV and the current flowing into the earth. Then using Ohm's law divide the voltage by the current to get the resistance. Remember the current in milliamperes must be converted to amperes. Here is an example where the NEV is 1.4 volts and the current is 40 mA. The current 40 mA is actually 0.04 amperes. Dividing 1.4 volts by 0.04 amperes gives a ground rod resistance of 35 ohms.

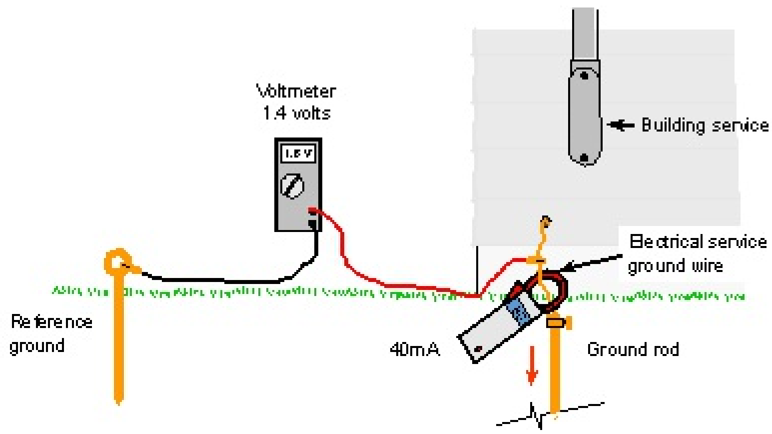

Figure 337.10 *Ground rod resistance can often be calculated by measuring the NEV and the current flowing to earth then divide the voltage by the current in amperes.*

Equipotential Plane: At locations on farms where livestock are likely to be affected by NEV, the *National Electrical Code®* requires a metal grid such as concrete reinforcing metal to be installed in the concrete and bonded to the electrical equipment grounding wire in the local area. A common location where this reinforcing steel should be installed is near livestock watering devices where electric heating is used in winter to prevent water freezing. This creates what is known as an equipotential plane that prevents livestock from becoming part of the NEV path to earth as illustrated in *Figure 337.11.* A similar requirement applies to swimming pools constructed with conductive materials such as concrete. (See *Tech Note 338)*.

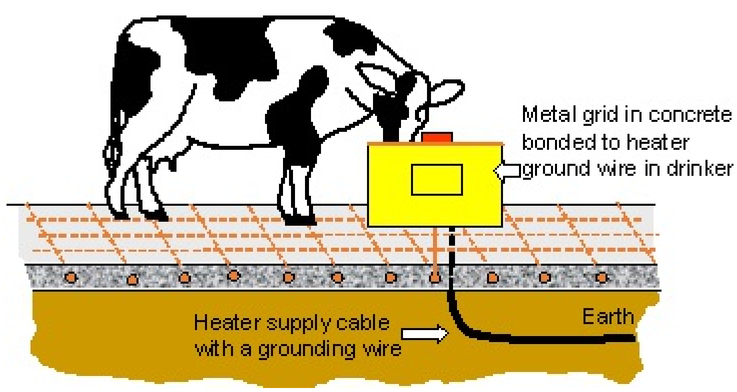

Figure 337.11 *Equipotential planes are required by code in areas where livestock are likely to become a part of an NEV path to earth.*