

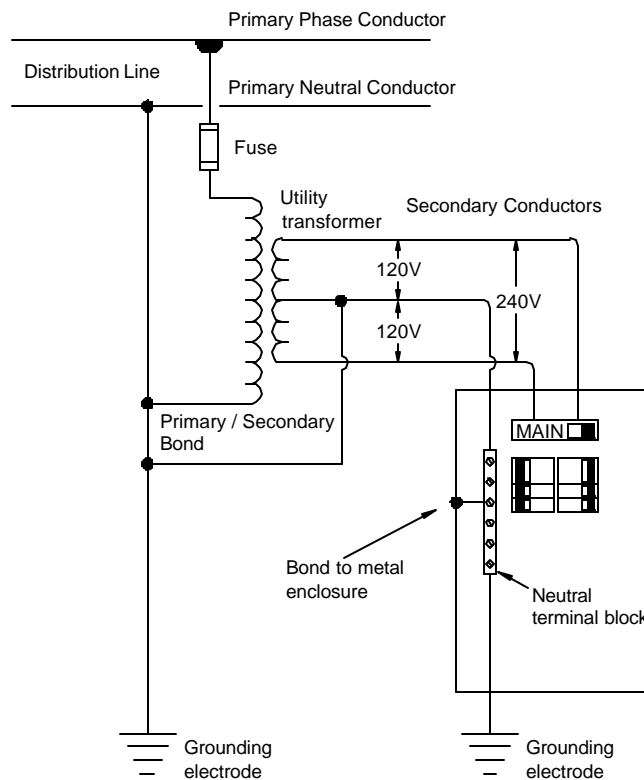
## **On-Farm and Off-Farm Stray Voltage Sources and Pathways**

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The term neutral-to-earth voltage is used to describe a measurable level of voltage which may occur between a metal object and the adjacent floor or earth. When this voltage is present between two points that may be simultaneously contacted by livestock it is called stray voltage. Frequently the animal makes contact with a metal object that has a connection to the neutral conductor of the electrical system. The voltage is usually measured between that metal object and the floor or earth upon which the animal is standing. When the voltage between the metal object and the adjacent floor or earth is very low, the amount of electrical current flowing through the animal's body is so low it cannot be felt. Conditions can occur where the stray voltage rises to a sufficient level to be perceived by livestock and even humans. The concern is to take steps to prevent the stray voltage level from reaching a point that it becomes a factor that makes it difficult to maintain high productivity on a farm. Effective prevention and mitigation requires a good understanding of the conditions that can cause neutral-to-earth voltage.

### **Electrical Systems Serving Farms**

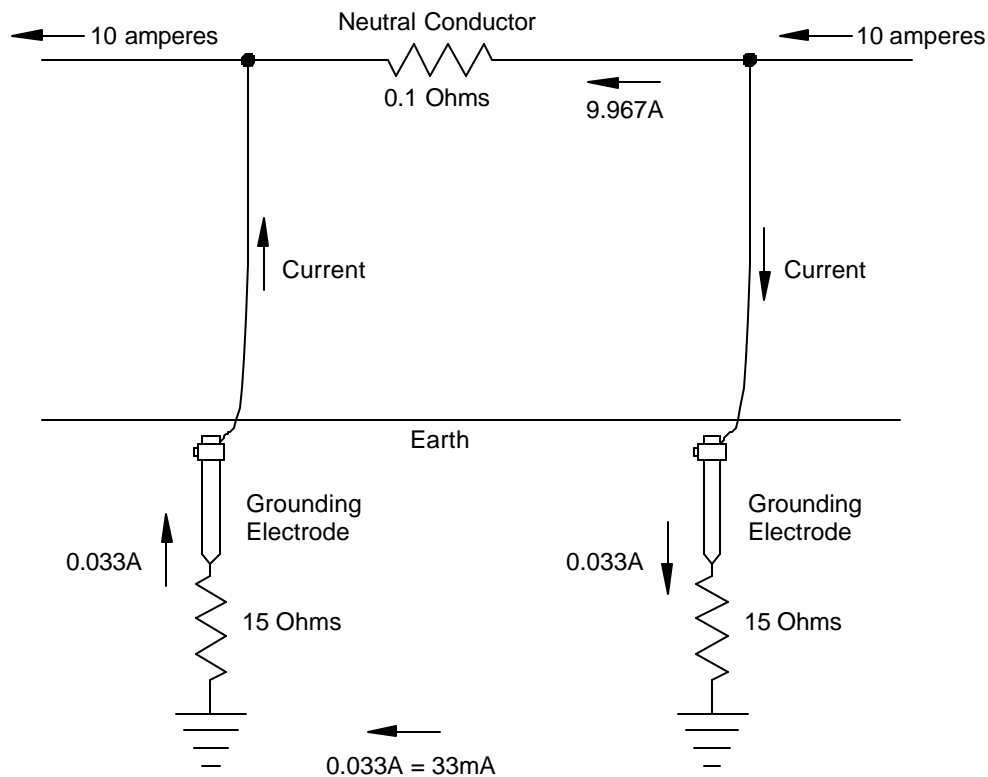
The vast majority of farms in the United States and Canada are supplied electrical power with a 3-wire, single-phase electrical system that provides a nominal 120 volts and 240 volts. The utility transformer and a main service panel is shown in Figure 1. The middle conductor from the transformer is grounded to the earth. The *National Electrical Safety Code* requires the center conductor be grounded to the earth at the transformer, and the *National Electrical Code* requires that same conductor be grounded to the earth at the service panel. If the utility distribution line supplying the transformer has a grounded conductor, then a bond connection is required that connects the utility grounded conductor to the farm grounded conductor. The grounded conductor is generally called the neutral conductor. Farms are also served with 3-phase electrical systems that have a grounded conductor. The principles that apply to create neutral-to-earth voltage with a single-phase electrical system also apply to grounded 3-phase electrical systems.



**Figure 1** A typical single-phase electrical system serving a farm has three wires one of which is grounded to the earth.

### Earth as a Conductor

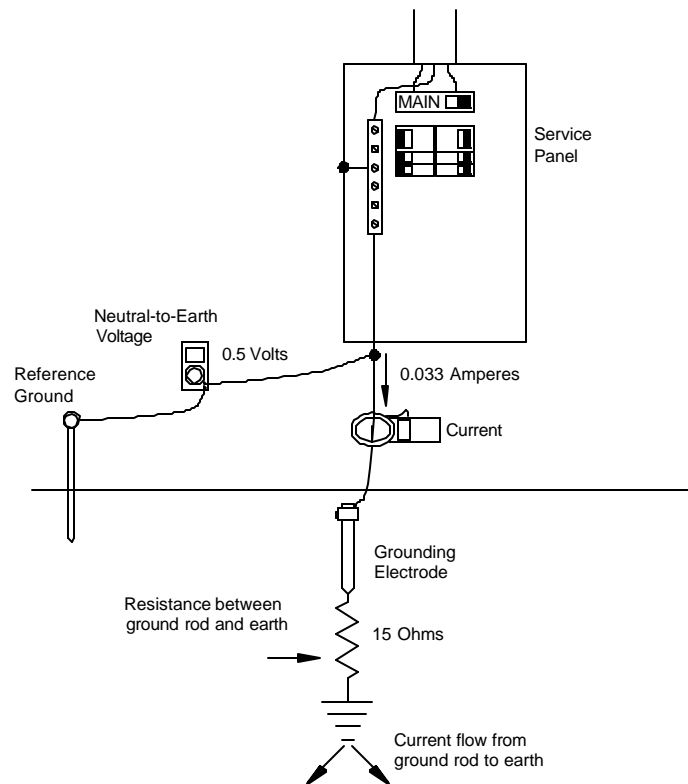
Understanding neutral-to-earth voltage and its causes requires a familiarity with the factors that influence the resistance of a conductor. The factors are resistivity of the material, length of the conductor and cross-sectional area of the conductor. Metals such as copper and aluminum are good conductors, but materials such as water and earth are often not very good conductors because these materials have a high electrical resistivity. Even though earth has a high electrical resistivity it can be a good conductor because it has a very large cross-sectional area. The difficulty is making an electrical connection to the earth. A ground rod has a rather small surface area in contact with the earth which results in a significant resistance between the ground rod and the earth. This resistance can be reduced by installing several ground rods and then connecting them together to form a single grounding electrode. By installing more ground rods, the surface area contact with the earth is increased and the resistance between the ground rods and the earth is reduced. As a general rule the resistance of a path through the earth is assumed to be the resistance between each grounding electrode and the earth. There are a number of techniques and instruments available to measure the resistance between a grounding electrode and the earth. Figure 2 illustrates an electrical path through the earth where the resistance within the earth is generally assumed to be small compared to the resistance between the grounding electrode and the earth.



**Figure 2** The resistance of a path through the earth is generally assumed to be the resistance of the grounding electrode to earth, and because of the large cross-section of the earth as a conductor, the resistance within the earth is usually neglected.

### What is Neutral-to-Earth Voltage?

Electrical current will take all paths available, except more current will flow on the paths with the lowest resistance. Figure 2 shows how multiple grounding of a neutral conductor can use the earth as a parallel conductor. In Figure 2 the neutral conductor has a resistance of only 0.1 ohms while the path through the earth is 30 ohms (15 ohms for each ground rod). Assuming 10 amperes must flow through the neutral circuit, a small amount of current will flow through the earth. Assume the electrical panel of Figure 3 is substituted for the ground connection of Figure 2. With the ground rod resistance-to-earth at 15 ohms and the current flow on the grounding electrode wire at 0.033 amperes, the voltmeter will read approximately 0.5 volts. A basic electrical principle called Ohm's law states that current, in amperes, times resistance, in ohms, gives voltage ( $0.033 \text{ amps} \times 15 \text{ ohms} = 0.5 \text{ volts}$ ). This is neutral-to-earth voltage. Current flowing between a grounded conductor and the earth across the resistance of the earth grounding connection results in neutral-to-earth voltage.



**Figure 3** Current flowing between a grounded conductor and the earth across a resistance-to-earth results in neutral-to-earth voltage.

### Typical Strong Sources of Ground Current

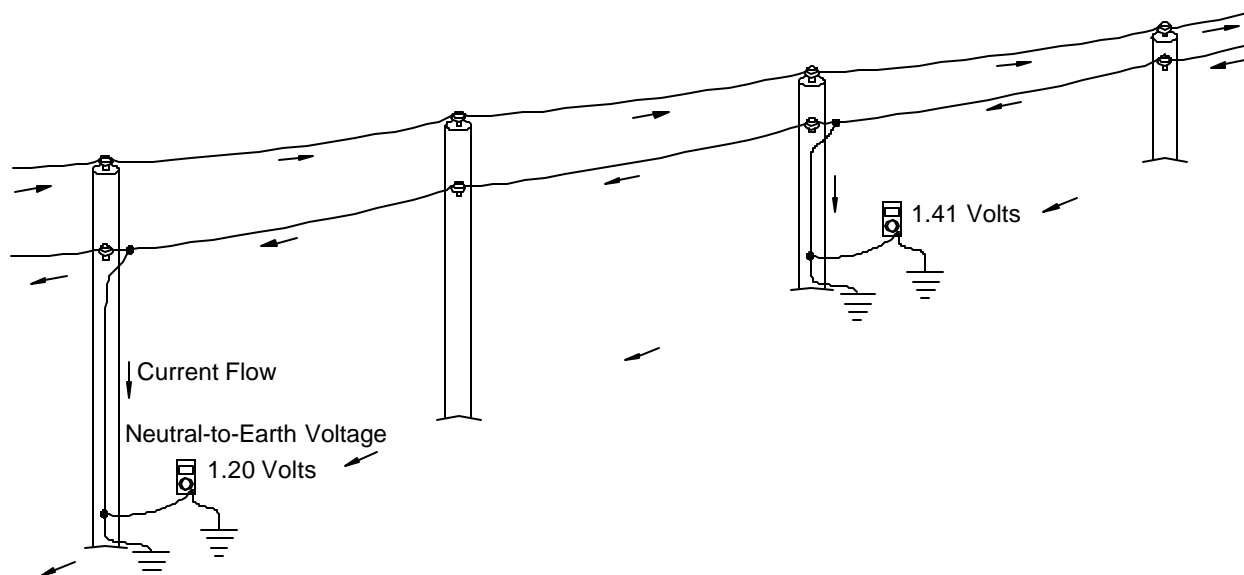
Conditions that produce current flow in the earth can lead to neutral-to-earth voltage. The two most common causes of earth currents is voltage drop along multi-grounded neutral conductors and ground faults at equipment that is not properly grounded and is making low resistance contact with the earth. Other sources are improperly installed electric fence chargers, improperly installed electrical panels, and improperly grounded equipment and electrical panels. Current can be induced into grounding conductors, but usually these currents are of such a low level they cannot be perceived by livestock. In one barn in Michigan the high frequency voltage detected between the metal cow stalls and the floor was caused by the signal from a local country radio station. A lightning strike near wires can induce a pulse in the grounded conductor that is short in duration resulting in neutral-to-earth voltage that can be felt by livestock making contact with a metal object at the wrong time.

### Voltage Drop on a Utility Distribution Line Neutral Conductor

A typical method for the utility to distribute electrical power to customers is by means of a multi-grounded distribution line. There are generally three transformer windings at the substation connected in a pattern called a wye. There will be three ungrounded (hot) conductors and a common neutral conductor coming from the substation that deliver power to customers. The common neutral conductor will be grounded to the earth at the substation. A network of bare copper wires and rods beneath the substation act as the grounding electrode for the distribution line neutral. According to the *National Electrical Safety Code*, the distribution line neutral conductor is required to be grounded to the earth at every customer transformer and at many other locations along the distribution line. This is called a multi-grounded distribution line. Figure 1 shows the grounding of a distribution line neutral conductor at a

transformer location. Because of the bond connection between the farm neutral conductor and the utility neutral conductor, the farm grounding electrodes act as part of the utility line grounding electrode. Likewise, the utility line grounding electrodes also act as a part of the farm grounding electrode system.

A multi-grounded utility distribution line is shown in Figure 4 where only one of the ungrounded (hot) conductors is present along with the neutral conductor. The neutral conductor will have some resistance, and when current flows on the neutral conductor there will be some voltage drop on the neutral conductor. This will result in some current flowing in the earth. The principle is the same as illustrated in Figure 2. The earth acts as a parallel path to the neutral conductor. Increasing the current load on the neutral conductor will result in an increase in earth current which means an increase in neutral-to-earth voltage. A high resistance connection in the neutral conductor can also result in an increase in the neutral-to-earth voltage along the line, Surbrook 1988. Generally it is possible to minimize the level of neutral-to-earth voltage produced by load on the distribution line, but it is not possible to eliminate all of the neutral-to-earth voltage.



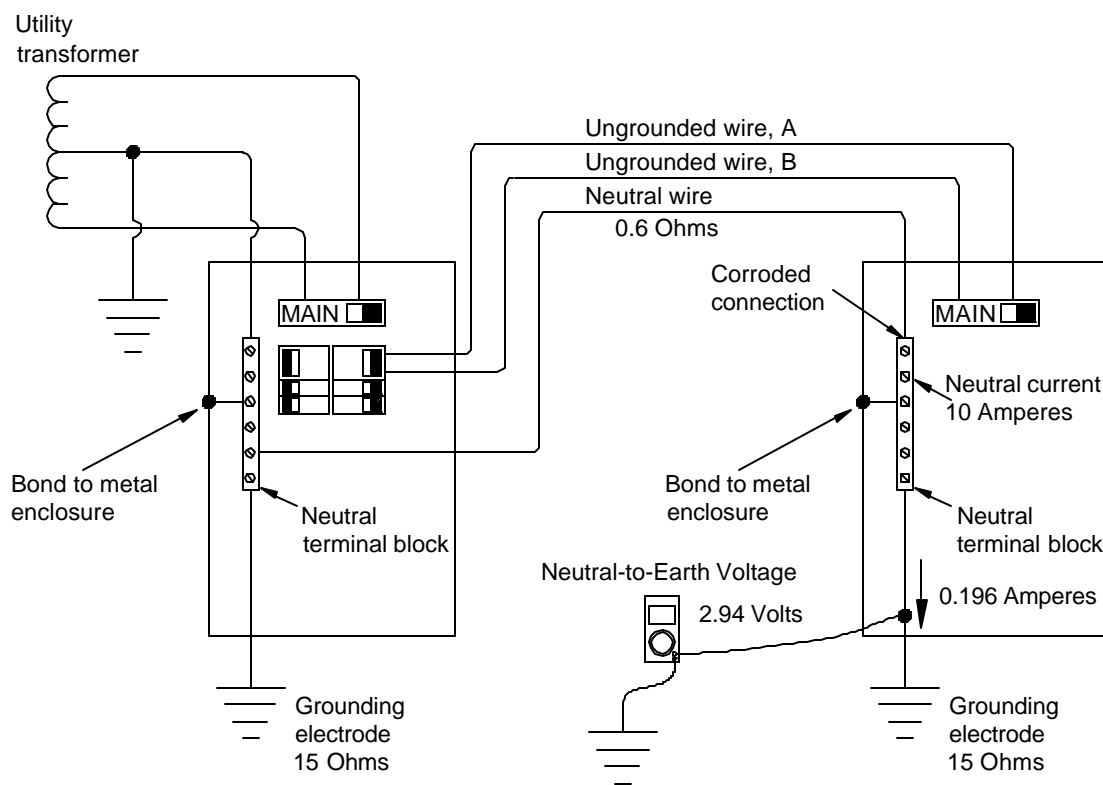
**Figure 4** As current flows along the utility distribution line neutral conductor, some voltage drop will occur which will result in some earth current that can be measured along the line as neutral-to-earth voltage.

### Voltage Drop on a Farm Neutral Conductor

The typical means of distributing electrical power on a farm is with either overhead or underground sets of conductors where there are two ungrounded wires and a neutral wire. The neutral wire is usually grounded to the earth at each building. Figure 5 illustrates one building being supplied from another building with a 3-wire feeder with the neutral conductor grounded at each building. Grounding the neutral conductor at the second building as shown in Figure 5 is permitted by *Section 250.32(B)(2)* of the *National Electrical Code*. Since the neutral is a current carrying conductor for the second building shown in Figure 5, the earth is now acting as a parallel neutral path. Whenever there is neutral current flow there will be some neutral-to-earth voltage produced as shown in Figures 2 and 3. Generally the level of neutral-to-earth voltage

can be minimized by properly sizing the conductors supplying buildings and balancing the 120 volt loads in the buildings to minimize the current on the neutral. The current on the neutral conductor will be the difference between the current on the two ungrounded conductors supplying the building. If the two ungrounded conductors are carrying the same level of current, the current on the neutral will be zero. Zero current on the neutral means no voltage drop and no neutral-to-earth voltage from this source.

With the wet conditions that exist on farms, corrosion in one of the neutral conductor connections can occur. This corrosion increases the resistance in the conductor path. Corrosion in a conductor connection is simulated in Figure 5 by increasing the conductor resistance by an additional 0.5 ohms for a total neutral wire resistance of 0.6 ohms. Assume the same 10 ampere neutral current and the same 15 ohm ground rod resistance as shown in Figure 2. There is a 6 volt drop along the neutral conductor in Figure 5. The current through the earth path is 0.196 amperes which results in 2.94 volts neutral-to-earth at the building. This example illustrates how high levels of neutral-to-earth voltage can be created with a small resistance in a neutral conductor to a building, and 120 volt loads that are not balanced.

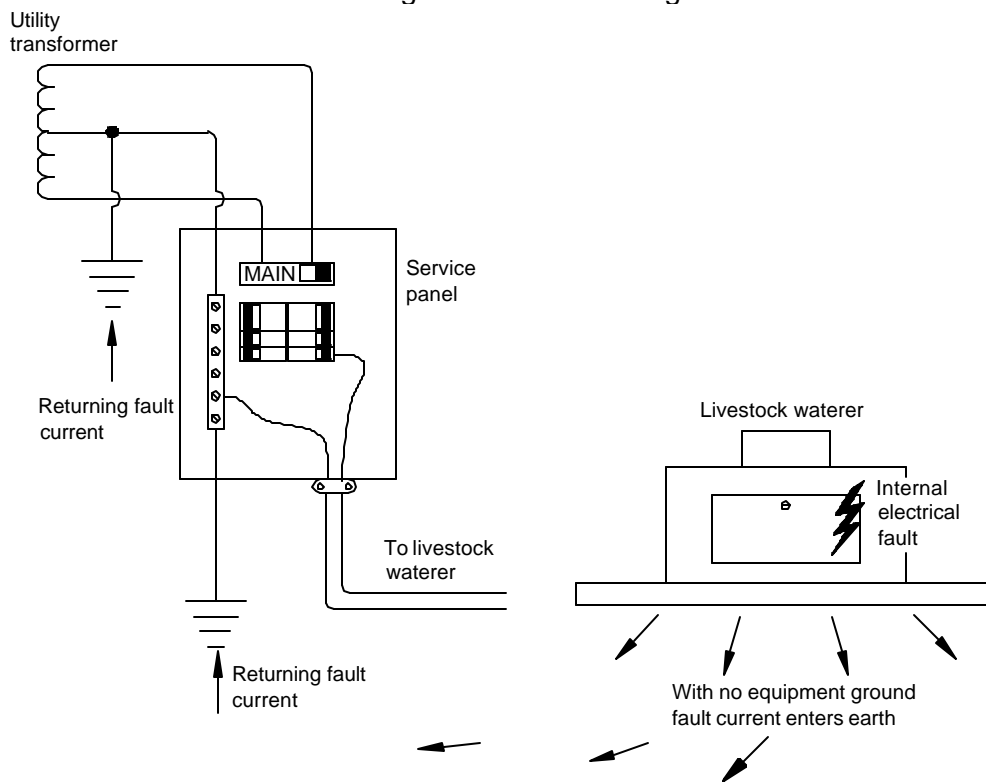


**Figure 5** An abnormal resistance in the neutral conductor supplying a building can result in a significant increase in neutral-to-earth voltage at the building.

### Ground Faults On the Farm Can Increase Earth Current

There are numerous ways electrical current can enter the earth from damaged equipment or wiring. It is important to ground all equipment on the farm with a copper equipment grounding conductor connected in such a way that it will not easily become detached from the equipment. Any equipment that is making contact with the earth, if not properly grounded, can result in earth current if a ground fault occurs. Examples of such equipment are electrically heated livestock waterers, water pumps, sump pumps, and manure pumps. *Section 547.5(F)* of the *National Electrical Code* requires that all metallic electrical equipment likely to become energized in livestock confinement areas be grounded with a copper equipment grounding conductor. Properly connected, the equipment grounding conductor will carry fault current back to the supply transformer and prevent it from entering the earth at a level that will cause neutral-

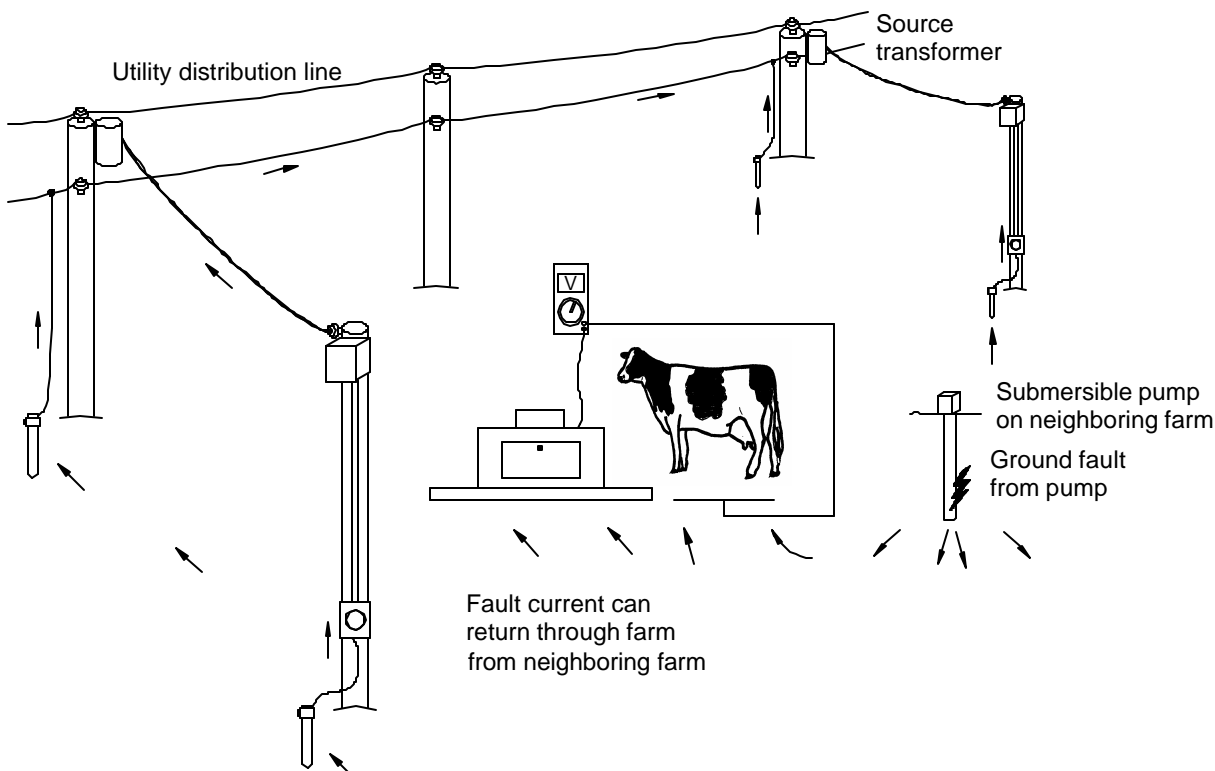
to-earth voltage. Figure 6 illustrates a livestock waterer that has a ground fault, and does not have an attached equipment grounding conductor to carry the fault current. This fault current travels in all directions to find a return path to the farm neutral conductor. A ground fault in one building can cause neutral-to-earth voltage in another building.



**Figure 6** An electrical fault in improperly grounded equipment can result in current flowing into the earth to find a path back to the neutral conductor.

### Ground Fault at a Neighbor's Property

A ground fault in equipment such as a water pump may cause neutral-to-earth voltage at other property in the neighborhood. The current that is injected into the earth at the faulting equipment is seeking as low a resistance path back to the source transformer as possible. If the grounding at the property where the fault occurs is fairly high in resistance, fault current will have difficulty finding a direct path back to the source transformer. The current may flow to a nearby farm where ground resistance is low and find a path back to the utility neutral through the farm neutral and grounding system. Then the current travels back to the source transformer along the utility neutral conductor. One way to help identify this as a source is to have the utility do a test neutral separation at the farm transformer. If the neutral-to-earth voltage is caused by a fault at a neighbors property, the voltage at the farm will decrease significantly when the utility and farm neutral conductors are separated. Figure 7 illustrates how a fault at a neighbors property can use a nearby farm as the return path for fault current.



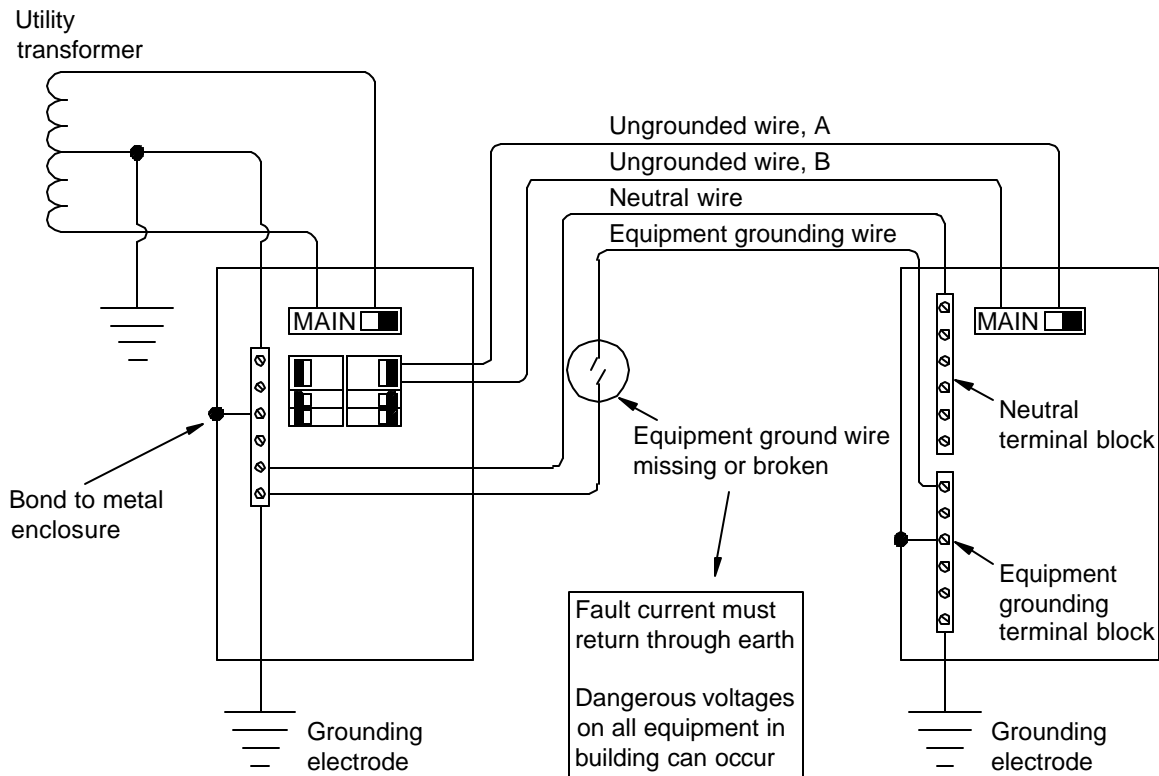
**Figure 7** A ground fault can occur at a neighbor's property which travels out through the earth in the neighborhood to find a return path to the source transformer

### Improper Neutral Separation at a Building

A technique for preventing voltage drop on farm neutral conductors from creating a neutral-to-earth voltage condition is to separate all of the neutrals from the equipment grounding conductors in a building. A separate equipment grounding bus must be installed in the service panel to the building and the bonding device must be removed from the neutral bus in the service panel. This is illustrated in Figure 8. In order for this technique to be effective, repairs may be necessary to circuits in the building to make sure all equipment grounding conductors and neutral conductors are effectively separated. Note in Figure 8 that the grounding electrode is connected to the equipment grounding bus and not to the neutral bus. Neutral current from the building no longer has the earth as a parallel path to return to the source transformer. This technique prevents neutral-to-earth voltage in the building from being caused by voltage drop on the neutral supplying the building, but it does not prevent other sources of neutral-to-earth voltage from accessing the building.

Separation of the equipment grounding conductors and the neutral conductors in a building is not complete until a separate equipment grounding conductor is installed from the equipment grounding bus in the building panel back to the electrical supply. Omitting this conductor is a violation of *Section 250.4(A)(5)* of the *National Electrical Code*, and it is dangerous. Figure 8 illustrates that without the equipment grounding conductor run back to the source, all current from a ground fault in the building must flow through the earth. As discussed earlier, an earth path is a high resistance path compared to a conductor. A high voltage can develop on all exposed metal equipment in the building if a ground fault occurs at any piece of equipment in the building. Rules for sizing the equipment grounding conductor are found in *Section 250.32(B)(1)* of the *National Electrical Code*.





**Figure 8** A disconnected equipment grounding wire to a building where the neutrals and equipment grounds have been separated can result in a dangerous conditions as well as being a major source for stray voltage.

### Improper Electric Fence System Installation

Electric fence systems and cow trainers can be a source of stray voltage if they are not installed properly, Fick 1999. Livestock that touch an energized fence wire complete a circuit from the wire through their body to the earth and back to the fence system energizer. The current flow through the livestock body is a pulse usually lasting less than a millisecond. Since a grounding electrode is required to complete the path back to the energizer, this pulse of current must flow across the resistance of the fence system grounding electrode. There will be a pulse of neutral-to-earth voltage at the grounding electrode every time the circuit is completed, Fick 1998.

Electric fence chargers in common use are of the low impedance type so they can still deliver a repelling shock to livestock even with vegetation making contact with the fence. If vegetation is making contact with the fence, there will be a pulse of current and thus a neutral-to-earth voltage produced every few seconds for as long as vegetation is making contact with the fence. For this reason it is extremely important that an electric fence system have a separate grounding electrode spaced not closer than 50 feet from other grounding electrodes or metal equipment contacting the earth, Wilson 2003. Electric fence systems usually require a grounding electrode consisting of a minimum of three ground rods driven 8 feet into the earth and spaced a minimum of 10 feet apart. Electric fence systems should never be connected to the electrical system grounding electrode system. Such a connection can place livestock throughout the farm as a part of the electric fence earth return circuit.

## Summary

Neutral-to-earth voltage is created when electrical current flows between metal equipment and neutral conductors and the earth. If the neutral-to-earth voltage is present between two points that may be simultaneously contacted by livestock it is considered to be stray voltage. The most common conditions that create a current flow between the earth and neutral conductors is voltage drop as current flows on neutral conductors that are grounded to the earth at multiple locations. This condition includes both the farm neutral conductors as well as a multi-grounded utility neutral conductor. Another condition that results in current flow into the earth is a ground fault at equipment where an equipment grounding conductor is not properly installed. The purpose of the equipment grounding conductor is to harmlessly conduct fault current back to the supply transformer and prevent it from entering the earth or taking any other path that may create a hazard. Farm wiring systems that are properly sized, installed, and maintained will give good service without producing neutral-to-earth voltage at a level that is harmful to livestock or personnel.

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