Gustafson, Robert J., and Mark T. Morgan. 2004. Stray Voltage Problems in Agriculture. Chapter 18 in Fundamentals of Electricity for Agriculture, 4rd edition, 431-451. St. Joseph, Michigan: ASAE.

CHAPTER 18

STRAY VOLTAGE PROBLEMS IN AGRICULTURE

18.1 INTRODUCTION

Stray voltage, defined as the voltage between any two animal contacts, can cause serious problems for livestock, in particular dairy. Dairymen are losing milk production and are experiencing cow behavior and health problems due to small electrical currents passing through the cows' bodies. The voltages are known by several names, including neutral-to-earth (N-E) voltage, neutral-to-ground voltage, tingle voltage, and extraneous voltage. The problem stems from a voltage at an undesirable level between two animal contact points.

The concept of stray voltage is relatively simple electrically, although the sources can be varied and complex. These voltages may be caused by poor or faulty wiring, faulty equipment, or improper grounding, or they may result from the small voltages required to move current through the grounded neutral system **– neutral-to-earth voltage**. As farm operations increase in size and sophistication, as electrical wiring systems become obsolete or deteriorate, and as electrical loads on rural distribution systems increase, it is likely that stray voltage problems will continue to exist. However, with a good understanding of (a) the sources and their interactions, and (b) the sensitivity of animals to electrical currents, stray voltage problems can be analyzed and corrected in existing facilities as well as prevented in new construction. This chapter is intended to explain the problem, describe potential problem sources, and give recommendations on what to do to prevent or correct the problem.

18.2 SYMPTOMS

Reactions of animals subjected to stray voltages vary, depending on the pathway through animals and the severity of the problem. There are three general classifications of symptoms; namely those related to (a) behavior modification, (b) milking characteristics, and (c) production performance. It must be remembered, however, that many factors other than stray voltages may cause herd behavior, health, and production problems. These factors include management and cow handling methods, nutritional disorders, mastitis control methods, sanitation, and disease. A careful analysis of all possible causes is necessary if proper corrective procedures are to be found.

Animals subjected to stray voltages are likely to exhibit a change in behavior. The most common symptoms include:

- Cows excessively or unusually nervous in the milking parlor or stall barn at milking time.
- Cows must be chased into parlor and/or flee rapidly when exiting parlor.
- Increased number of defecations and/or urinations in the milking parlor.
- Reluctance of animals to consume water or feed.

Documented cases include dairy cows, beef, swine and poultry. The problem may be general throughout the farmstead, or only at specific water or feeding location. Generally speaking, higher voltages are required to limit water or feed consumption than to alter the other behavior.

Changes in milking performance that can be related to stray voltage include:

- Poor milk letdown and incomplete or uneven milkout.
- Increased milking time.

However, researchers have demonstrated that the milking machine is an unlikely pathway for electrical currents to access the cow.

Although stray voltage has not been shown to have a direct physiological effect on cows, severe behavioral responses will result in complicated management. As a result, production performance may see changes such as:

- Increased somatic cell count and more clinical mastitis.
- Lowered milk production.

In summary, stray voltage problems alter animal behavior, thereby influencing the milking characteristics and adversely affecting production performance. If unacceptable levels of stray voltage exist, corrective action should be taken. On the other hand, it must be remembered that there are many other, non-electrical, causes of the same symptoms. With careful analysis of all possible causes, proper corrective procedures can be found.

18.3 POTENTIAL STRAY VOLTAGE SOURCES

Stray voltage problems arise from relatively simple electrical conditions. As an example, Fig. 18.1 shows a dairy cow “bridging the gap” between an electrically grounded water cup and “true earth.” If the meter indicates a large enough voltage between the reference ground (representing "true earth") and the electrically grounded watering system, it may force enough current through the cow's body to cause serious problems. However, there are many variables that will cause considerable variation from farm to farm and within a particular building. These variables require both an understanding of the voltage sources and electrical pathways to the animal to assure correct problem diagnosis.

Any electrical condition that sustains a large enough voltage between any two animal contact points may create a stray voltage problem. There are numerous sources of these low level voltages. However, they are normally associated with:

(a) Electrical fault conditions on either the farmstead wiring or the distribution system,
(b) Inherent neutral-to-earth voltages on multi-grounded distribution systems resulting from system loading,
(c) Voltage drops on secondary neutrals resulting from 120 V load imbalance, or
(d) Induced voltage on ungrounded equipment.

Fig. 18.2 is a simplified diagram of a multi-grounded, single-phase distribution system serving a farmstead. In a multi-grounded system, the primary or utility system neutral conductor is grounded at least four times per mile along the line and at each transformer. The on-farm or secondary neutral is grounded at the farm service and at each building service entrance. At the transformer the primary neutral is electrically bonded to the secondary neutral. These grounded and bonded primary and secondary neutrals (as shown by the solid lines in Fig. 18.2) make up a complex network termed the "grounded neutral system."

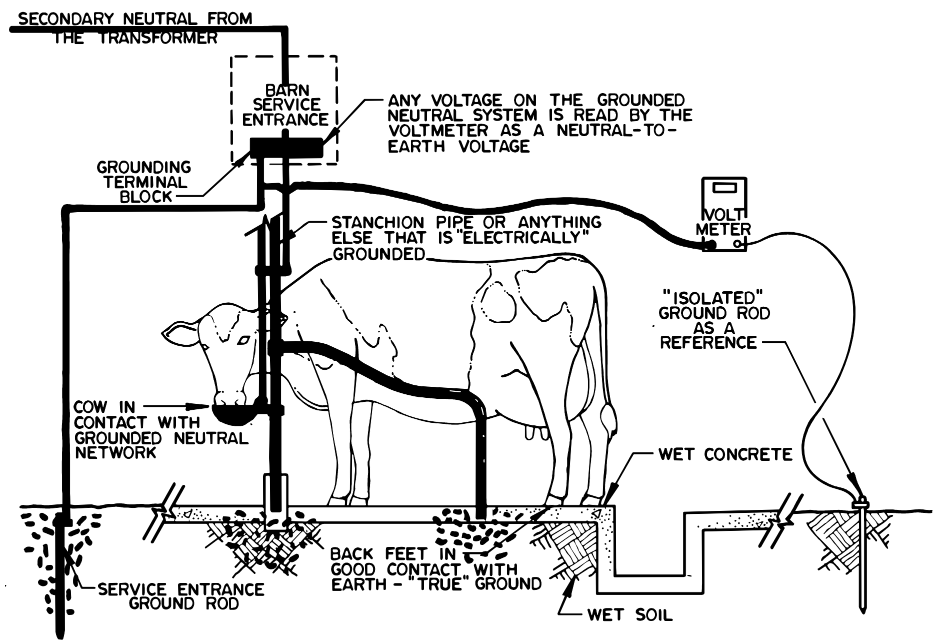


FIG. 18.1 A DAIRY COW SUBJECTED TO A STRAY VOLTAGE

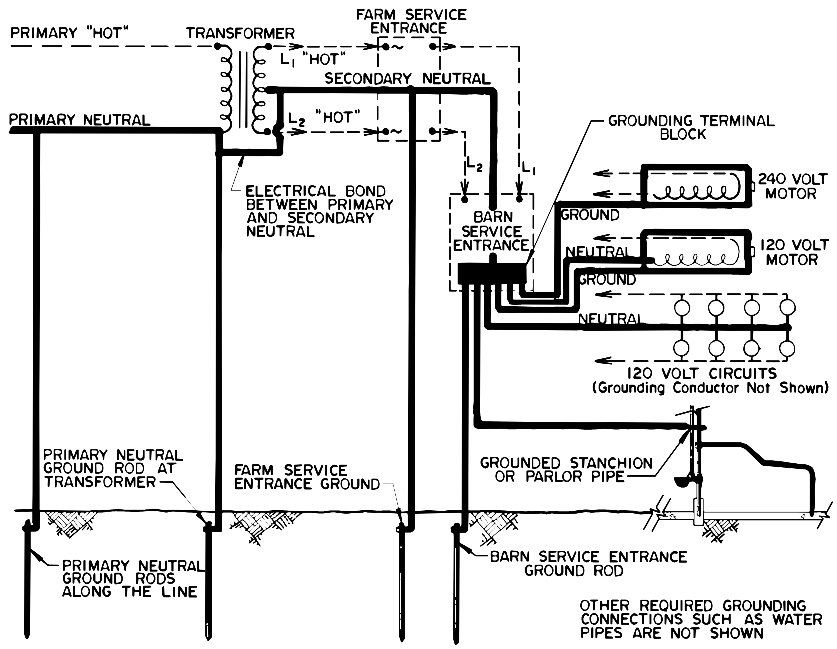


FIG. 18.2 THE GROUNDED NEUTRAL NETWORK ON A SINGLE-PHASE DISTRIBUTION LINE

Every part of the grounded neutral system, including conductors, the connections, the earth, and the contact between the ground rods and earth, has some resistance to the flow of electric current. Due to these resistances, whenever there is a current in the neutral system a voltage exists between it and earth. These voltages are reflected, at varying levels, to all parts of the interconnected system. They exist as **neutral-to-earth (N-E) voltages** and if large enough will cause a perceptible current flow through an animal bridging the gap between the neutral system and the earth.

In the following sections, N-E voltages associated with the distribution system and the farmstead wiring system are separated into several distinct categories. Unfortunately, in the field the contribution from all sources will be superimposed and their interactions can make an accurate diagnosis difficult. If the contribution from each source can be clearly identified and measured, the diagnosis is easy and the appropriate corrective measures can be readily determined. However, a good understanding of the sources and their interactions is necessary. An “isolated” ground rod is used as a reference when measuring N-E voltages. If one lead of a voltmeter is attached to the service entrance ground at the barn, as shown in Fig. 18.3, and the other lead is attached to the “isolated” reference rod, it will read the N-E voltage existing on the network at this location. The location and use of this “isolated” reference rod and voltmeter are discussed in Section 18.5. In this position the voltmeter reads the maximum voltage to which a cow could be subjected. As described earlier, actual voltage across the animal (the stray voltage) may vary widely depending on conditions in the barn.

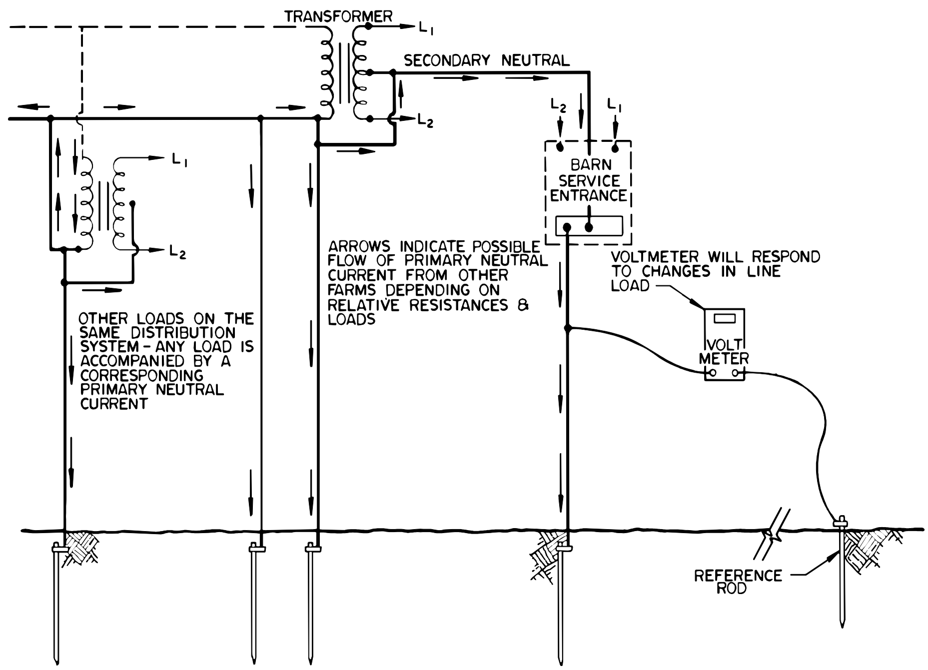


FIG. 18.3 NEUTRAL-TO-EARTH VOLTAGE ON A FARM DUE TO OTHER LOADS ON THE SAME LINE

18.3.1 PRIMARY NEUTRAL CURRENT EXTERNAL TO THE FARM

As the current in the distribution neutral increases due to increased load on other parts of the single-phase tap, or the imbalance current in three-phase feeder increases, the primary N-E voltage will increase (Fig. 18.3). This can be reflected to a greater or lesser degree to the problem farm through the primary-secondary neutral interconnection at the transformer. This contribution can be determined at any specific time by measuring N-E voltages on the problem farm with the main farm disconnect open (neutral intact).

18.3.2 PRIMARY NEUTRAL CURRENTS FROM ON-FARM LOADS

As the electrical load on the distribution transformer of the problem farm increases, the increase in primary neutral current will generally result in increased primary N-E voltages, which will be reflected to the farmstead grounding system through the interconnection at the transformer (Fig. 18.4). In the case of a farm near a three-phase feeder, it is possible for an increase in on-farm load to improve the balance on the feeder and thereby reduce the primary N-E voltage. A common misconception is to

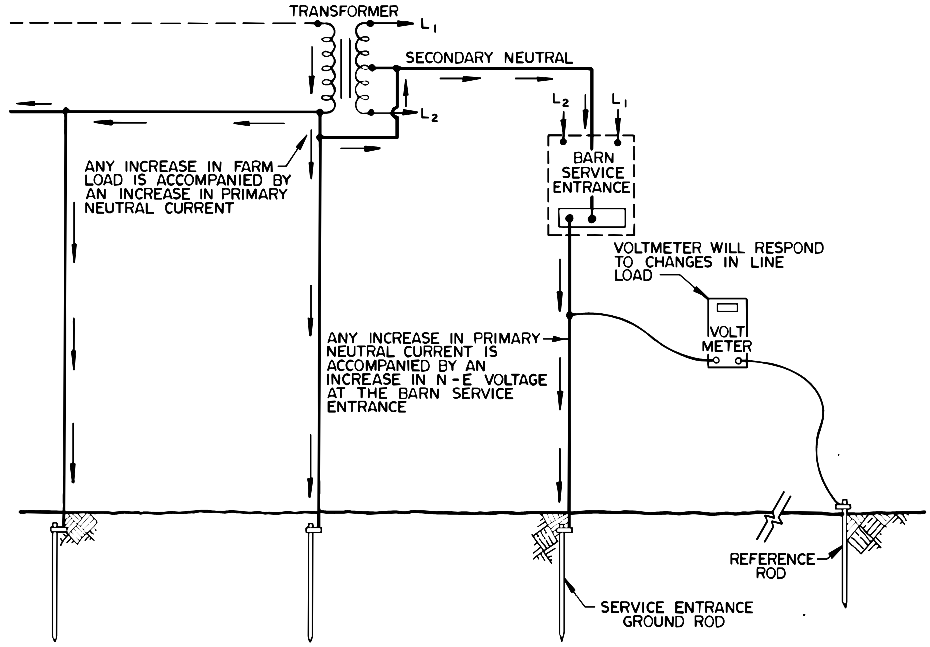


FIG. 18.4 INCREASE IN NEUTRAL-TO-EARTH VOLTAGE DUE TO INCREASING LOAD ON THE SAME FARM

relate an increase in N-E voltage associated with the operation of equipment on the farm to an on-farm problem. An increase in N-E voltage with the operation of “clean” or non-faulty 240 V loads is a primary N-E voltage (or off-farm N-E voltage created by an on-farm electrical load).

18.3.3 SECONDARY NEUTRAL CURRENT IN THE FARMSTEAD WIRING SYSTEM

A current in any portion of the secondary neutral due to imbalance in 120 V loads (i.e., load connected to L1 does not equal load connected to L2) is accompanied by a voltage drop (Fig. 18.5). Since the secondary neutral current may be either in-phase or 180° out of phase with the primary neutral, the phase relationship between this voltage source and that due to the off-farm or primary neutral source must be considered. A voltage drop created by imbalance current in-phase with the primary will increase the N-E voltage at the barn. On the other hand, if the imbalance current is out of phase with the primary, the N-E voltage at the barn may decrease.

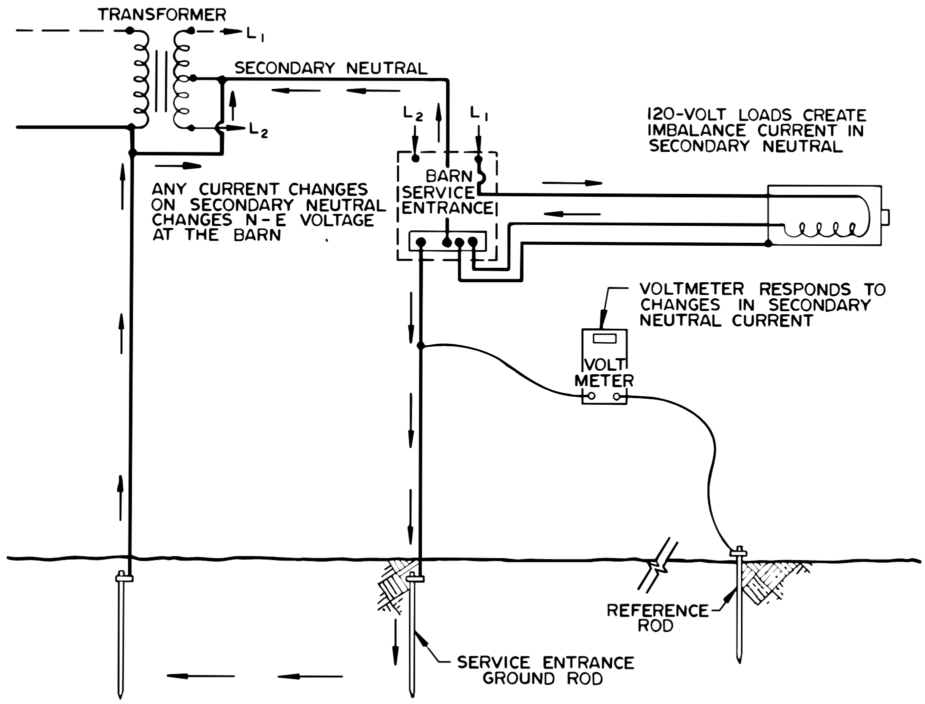


FIG. 18.5 NEUTRAL-TO-EARTH VOLTAGE CREATED BY THE VOLTAGE DROP IN THE SECONDARY NEUTRAL

18.3.4 FAULT CURRENTS ON EQUIPMENT GROUNDING CONDUCTORS

Any fault current flowing in equipment grounding conductors will create a voltage drop on the grounding conductor (Fig. 18.6). It will also affect the current balance in the secondary neutral to that service. Most of the voltage drop will appear as a voltage between the faulty equipment and earth and will access the animals through any conductive equipment in electrical contact with the faulty equipment. The "equipment-to-earth" voltage is indicated by voltmeter #1 in Fig. 18.6. The voltage drop on the equipment grounding conductor is the difference between voltmeter #1 and voltmeter #2 and can be measured as indicated by voltmeter #3. With no faults and proper equipment grounding, voltmeters #1 and #2 will read the same. Any difference between the two is indicative of either improper equipment grounding or a current in the grounding conductor. If there is a voltage drop on the grounding conductor, it can either add to or subtract from the N-E voltage at the service entrance.

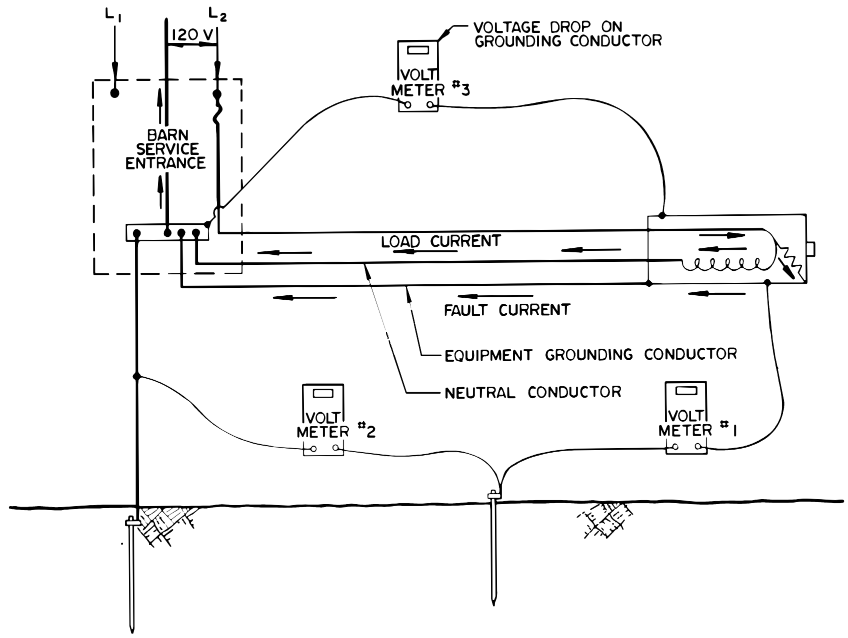
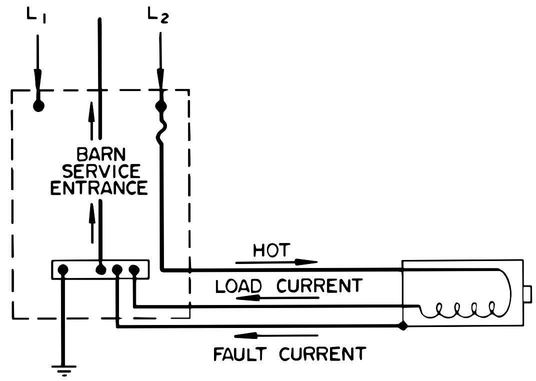


FIG. 18.6 ADDED NEUTRAL-TO-EARTH VOLTAGE FROM A FAULT TO GROUNDED EQUIPMENT

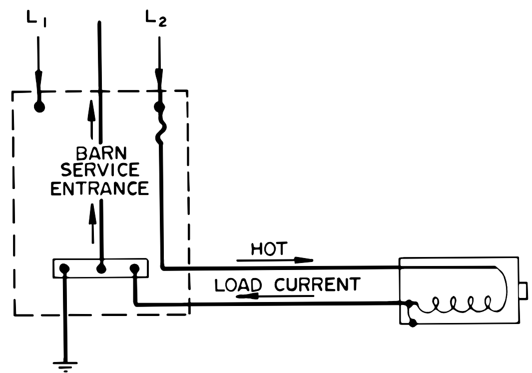
18.3.5 IMPROPER USE OF THE NEUTRAL CONDUCTOR ON 120 V EQUIPMENT

In agricultural wiring systems the neutral (grounded conductor) and the equipment grounding conductors are bonded together at the building service entrance (Fig. 18.7). However, all feeders and branch circuits beyond the building main service must maintain the neutral and equipment grounding separately. Neutral and equipment grounding conductor interconnection beyond the service entrance is a violation of the code and may create an additional serious stray voltage problem, even though no lethal hazard exists. In this situation the load current will be carried by the grounding conductor (where it is improperly used as the neutral), or by the grounding conductor in parallel with the neutral (where they are interconnected at the device).

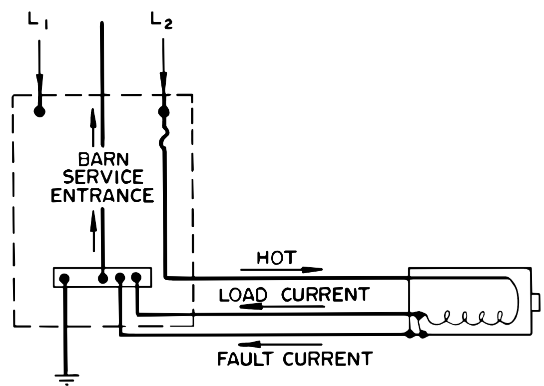
The additional stray voltage component is equal to the voltage drop for the neutral current between the service entrance neutral bar and the equipment. This component can either add to or subtract from the existing N-E voltage at the service entrance. This is particularly important in circuits with 120 V motor starting surges since currents may be large.



CORRECTLY CONNECTED 120-VOLT BRANCH CIRCUIT



IMPROPER USE OF THE NEUTRAL AS A GROUNDING CONDUCTOR



IMPROPERLY INTERCONNECTED NEUTRAL AND GROUND

FIG. 18.7 NEUTRAL AND EQUIPMENT GROUNDING FOR 120 V EQUIPMENT

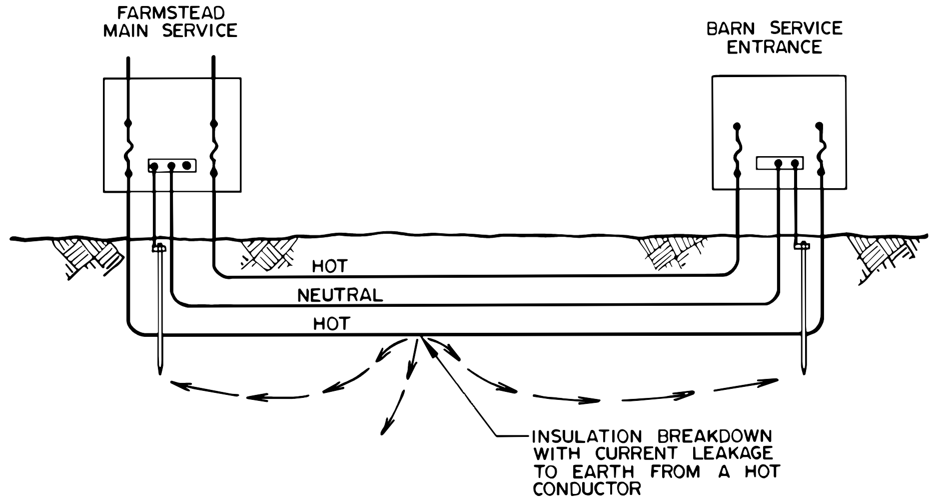


FIG. 18.8 LEAKAGE CURRENT TO EARTH FROM AN ENERGIZED SECONDARY CONDUCTOR

18.3.6 FAULT CURRENTS TO EARTH

Leakage currents to earth from an energized secondary conductor, called fault currents, must return to the center tap of the distribution transformer, thereby creating a N-E voltage. Significant fault currents to earth are due to insulation breakdown on a conductor or to ungrounded equipment in contact with earth (Fig. 18.8). If such a fault develops, the seriousness of the situation depends on the electrical resistance of the return path from the fault to the grounded neutral system. If this is a high resistance path, dangerous step and touch potentials can be present in the area of the fault. These could be at a potential that creates a lethal hazard.

Fault currents to earth returning to the distribution transformer through the grounded neutral network will be superimposed on the primary neutral load current. N-E voltages will be additive if leakage current is from the out-of-phase leg of the secondary; subtractive if from the in-phase leg.

18.3.7 INDUCED VOLTAGES ON ELECTRICALLY ISOLATED CONDUCTIVE EQUIPMENT

It is possible for induced voltages to exist on isolated conductive equipment. In dairy facilities, electrically isolated water lines, milk pipelines, and vacuum lines may exhibit a voltage relative to other points when measured with a very high impedance voltmeter. A common source in stanchion barns is high voltage cow trainers running parallel to the lines. Any other isolated conductive equipment in close proximity to an electrical source can show a potential difference, also.

Due to the high impedance of such a voltage source, the current-producing capabilities are very small and rarely capable of producing problem-level currents. However, if the equipment is electrically well isolated (not grounded) and has sufficient electrical capacitance, it may provide a capacitive discharge of sufficient energy to cause a stray voltage problem when an animal shorts it to earth.

18.4 WHEN CAN STRAY VOLTAGE BE A PROBLEM?

Animals may react differently depending on which parts of their bodies are in contact with the grounded neutral network and which parts are communicating with "true" earth. Research with dairy cows has established the "mouth-all hooves" pathway to be the lowest-resistance pathway. This is a common pathway for current to flow through the cow's body. A cow's hooves may be in contact at one potential (earth or concrete) and her mouth in contact with a metal surface at a significantly different potential (waterer, metal feeder, or stall pipe). Fig. 18.9 summarizes the effects of increasing levels of current (and voltage) on behavioral responses and milk production.

Milking equipment, and the teat end, isn't a likely path of problem currents. Milk isn't a particularly good conductor of electricity, and the resistance of the milk hose from the milk line to the machine claw is inversely proportional to milk flow rate. Thus, in spite of the fact that observed cow behavior modifications are frequently associated with the milking process, it requires more than 25 V on the milk line for cows to obtain perceptible currents through this pathway.

Stray voltage problems are not limited to the dairy farm. It is known to have affected poultry, swine, and beef operations as well. For example, it has been shown that growing pigs can perceive the presence of voltages on a watering system as low as 0.25 V. On the other hand, a 2.8 V shock was required to alter drinking patterns and a 3.6 V shock was necessary before water consumption was lowered.

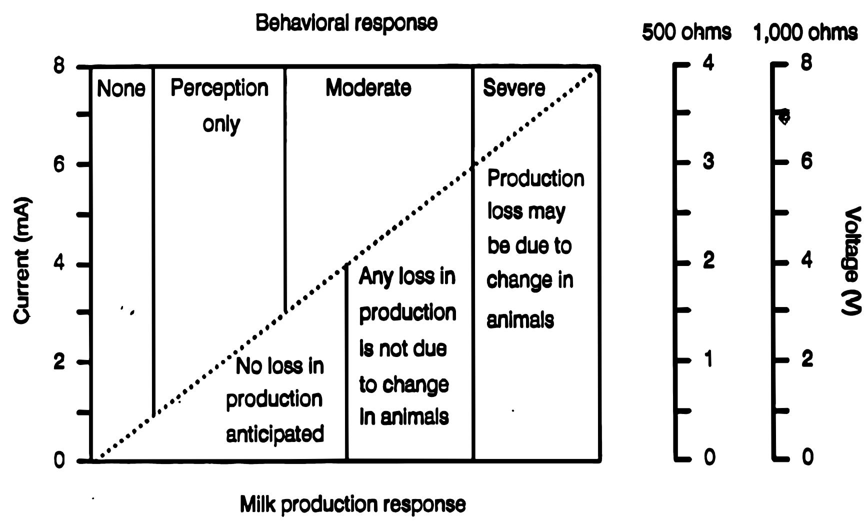


FIG. 18.9 BEHAVIORAL AND MILK PRODUCTION RESPONSES TO INCREASING CURRENT LEVELS. Voltage was estimated using a worst-case circuit impedance (500 ohms) and more realistic impedance (1,000 ohms). (Source: Lefcourt, 1992.)

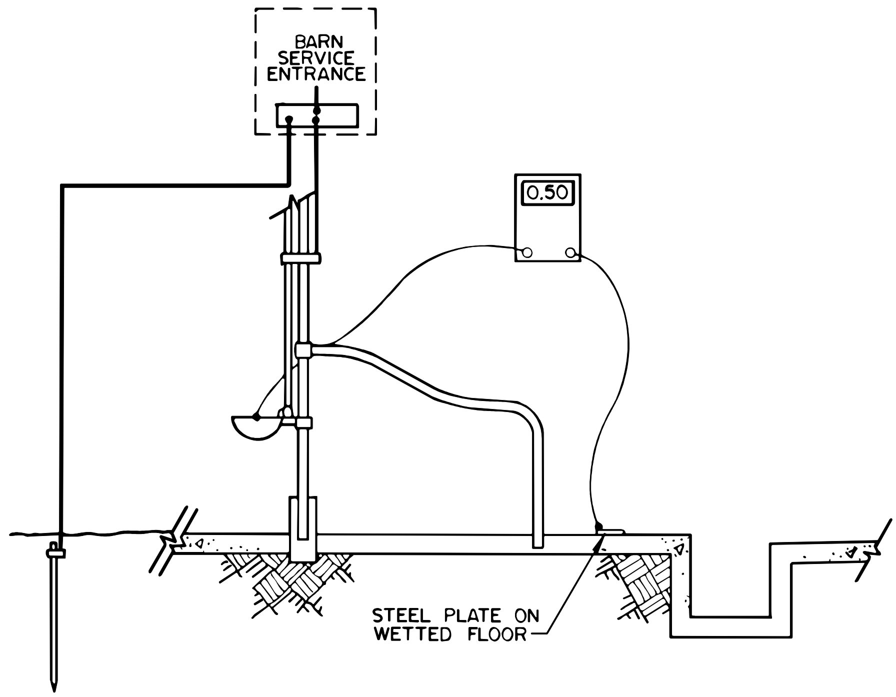


FIG. 18.10 POINT-TO-POINT MEASUREMENT IN COW CONTACT AREAS

18.5 STANDARDIZED MEASUREMENTS

Standardized procedures have been developed to assist in testing for the presence of stray voltage (screening procedure) and locating the source or sources of problem level voltages in livestock facilities (diagnostic procedures) (see Appendix B and references listed at the end of this chapter). Voltage is the easiest electrical quantity to measure and, as shown by experience, the most reliable indicator of a possible stray voltage problem. Two configurations are generally used top make stray voltage measurements:(1) point-to-point or cow contact measurements and (2) point-to-reference ground or neutral-to-earth measurements. Both are useful and will be briefly explained.

18.5.1 POINT-TO-POINT MEASUREMENTS

The point-to-point method simply involves measurement between points that may be contacted simultaneously by an animal or a person (Fig. 18.10). The most common points of contact are a metallic structure, such as a stanchion or stallwork, and the floor or earth. When making this type of measurement, the resistance of each contact is important to getting a meaningful measurement. The use of a 4 in. by 4 in. copper or steel plate on a well-wetted floor has been shown to reduce the contact resistance at the floor end to an acceptable level. If the meter is then paralleled (shunted) with a 500 ohm resistor, the body resistance of a cow can be simulated in the circuit. Measurement of voltage with and without the shunt resistance can be used to determine the path/source resistance in the circuit and an estimated current through the animal (using an assumed path resistance). However, this will only be valid if the contact resistances for the meter leads are similar to those of the cow. The point-to-point measurement made with the shunt resistor and high contact resistances may well produce values lower than the cow experiences.

18.5.2 POINT-TO-REFERENCE GROUND MEASUREMENTS

As with the point-to-reference ground measurements, the relative contributions of the various sources of stray voltage are usually most easily determined when all voltages are measured to an isolated or "true" ground. The first step in using the point-to-reference ground method is to drive a ground rod at a distance of at least 8 m (25 ft) from any electrical system grounding electrode or grounded metal equipment in contact with the earth. Unless grounding conditions are extremely poor, a rod 1.3 m (4 ft) into the soil should be adequate for voltage measurement. An insulated conductor is

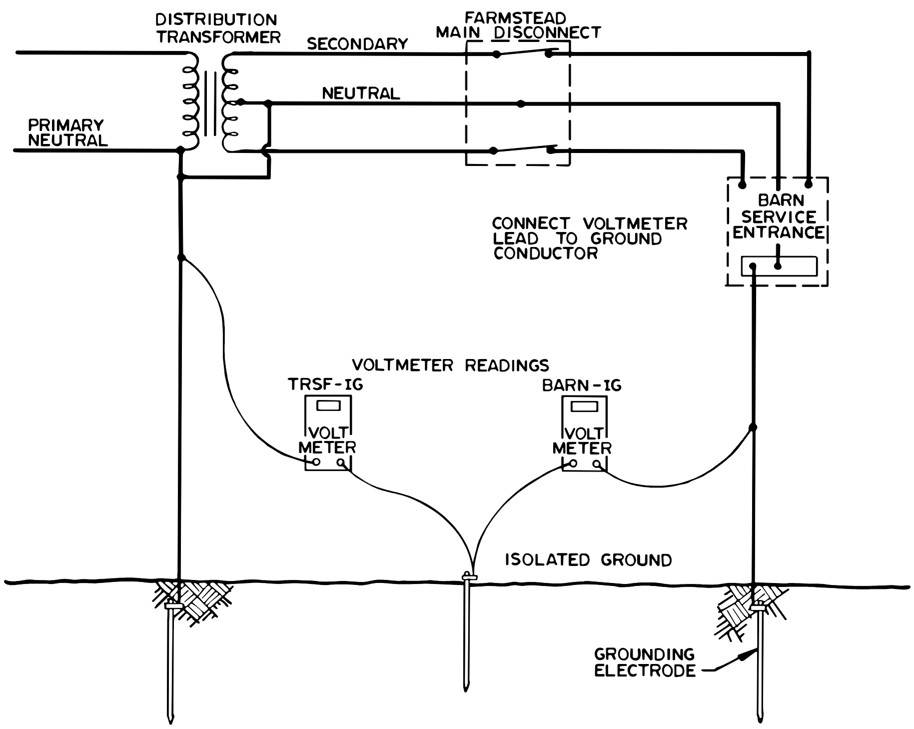


FIG. 18.11 TWO METER DIAGNOSTIC CONFIGURATION

then run from this reference ground to a convenient location for the test equipment and connected to one terminal of the voltmeter. The other meter terminal is connected via a second insulated lead to measure the voltage between the reference ground and various metal equipment or the floor. When connected to grounded equipment this method usually yields higher readings than the animal contact point-to-point method. The cow contact voltage is usually a relatively fixed portion of the voltage to reference ground. Use of two meters simultaneously, as shown in Fig. 18.11, can give additional valuable information for source identification.

18.6 SOLUTIONS TO THE PROBLEM

Approaches for controlling N-E voltages fall into the three categories of:

(1) Voltage reduction by either elimination of the source (e.g., by removing bad neutral connections and faulty loads, or improving or correcting wiring and loading), or by active suppression of the voltage by a nulling device.

(2) Gradient control by use of equipotential planes and transition zones to maintain the animal's step and touch potentials at an acceptable level.

(3) Isolation of a portion of the grounding or grounded neutral system from the animals.

The most suitable approach in any given situation must be based on the available information and constraints of the situation.

18.6.1 VOLTAGE REDUCTION

Voltage reduction can be divided into two categories: (1) elimination or reduction of sources, and (2) active suppression. If the analysis shows a troublesome level of N-E voltage due to such items as high resistance connections (either on or off the farm), neutral imbalance currents on or off the farm, undersized neutrals, or fault currents to earth or equipment grounding conductors, corrections can be made and the remaining voltage assessed.

Improvement of grounding on the distribution neutral can reduce the N-E voltage due to system loading. Since that portion of the system grounding supplied by the farmsteads is often large compared to that by the distribution neutral, the effectiveness of this approach may be limited. It is important to recognize much of the system grounding on the farmstead is supplied by items that are equipment grounded and in contact with the earth.

If the farmstead system contains long secondary neutrals, an option of using a four-wire service to the building is allowed by the National Electric Code (NEC). Fig. 18.12 shows a schematic of the four-wire system. This will eliminate the secondary neutral drop on the four-wire system from contributing to the N-E voltage at the building service. N-E voltages will remain from all other sources. For this system, all neutral and grounding conductors in the building service and all feeders from that service must be completely separated.

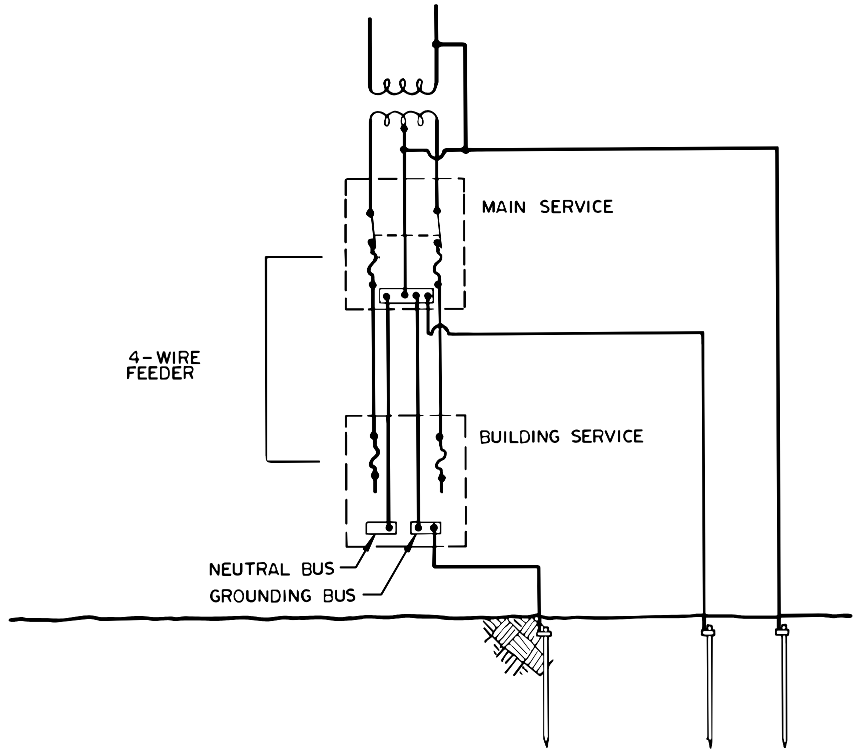


FIG. 18.12 A FOUR-WIRE FEEDER FROM FARM MAIN TO OUTBUILDING

Since N-E voltage is created by current flow through a system impedance, it is possible to create a potential source which nulls or cancels the original source at that point in the system. One procedure is to deliver a controlled current to earth (Fig. 18.13). Voltage between a point in the neutral system and an isolated reference ground or grounds is used as the input to a differential amplifier. Current to the remote grounding electrode system is then adjusted to null out the N-E voltage. The voltage is also reduced on farms served by the same primary line and located near the device. Power required for the compensating circuit depends on the required current and resistance of the remote grounding electrode system.

Advantages of this approach include (a) installation without modification of the existing electrical system, thereby retaining the full safety benefits of the interconnected grounded neutral system; and (b) nulling of the N-E voltage at a point lowers the level of N-E voltage on the distribution system.

Disadvantages include (a) possible maintenance problems inherent to an active (amplifier system) type device; (b) initial cost; and (c) the potential exists for offsetting problem sources that should be corrected by other means.

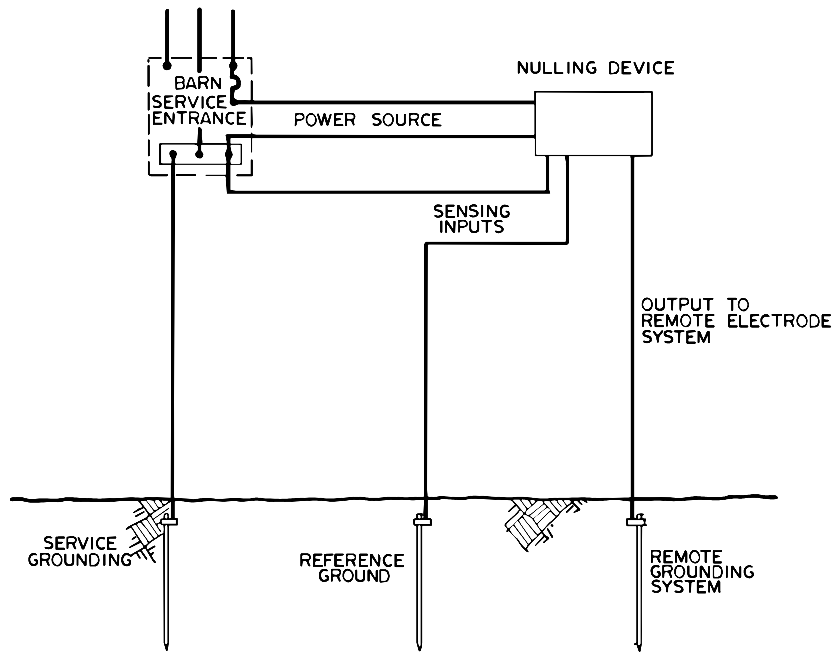


FIG. 18.13 VOLTAGE SUPPRESSION BY CONTROLLED CURRENT TO EARTH

18.6.2 GRADIENT CONTROL

Gradient control by equipotential planes will negate the effects of N-E voltages in livestock facilities if they reduce the potential differences at all possible animal contact points to an acceptable level. Gradient control is used by the electrical industry to minimize the risk of hazardous step and touch potentials under fault conditions at substations and around electrical equipment. Equipotential planes will provide improved protection from lightning strikes and electrical faults to both people and animals. They also will provide an excellent supplement to the grounding electrode for the building. Equipotentail planes are required by the National Electrical Code in new or remodeled livestock facilities where electrical grounded equipment is accessible to the animals (NFPA, 2002).

The basic procedure for installing an equipotential plane, as described in the American Society of Agricultural Engineering's Engineering Practice EP473.1 (ASAE Standards, 2002), fundamentally requires bonding of steel in the concrete floor to all metal equipment in the area and to the grounding/neutral bar in the service entrance panel. To be effective, all metal-to-metal bonds must be sound. Welding is recommended for bonding the steel reinforcing bars or mesh to each other and to the equipment. Other approved grounding connections may also be adequate. Fig. 18.14 shows an equipotential plane for a dairy milking parlor.

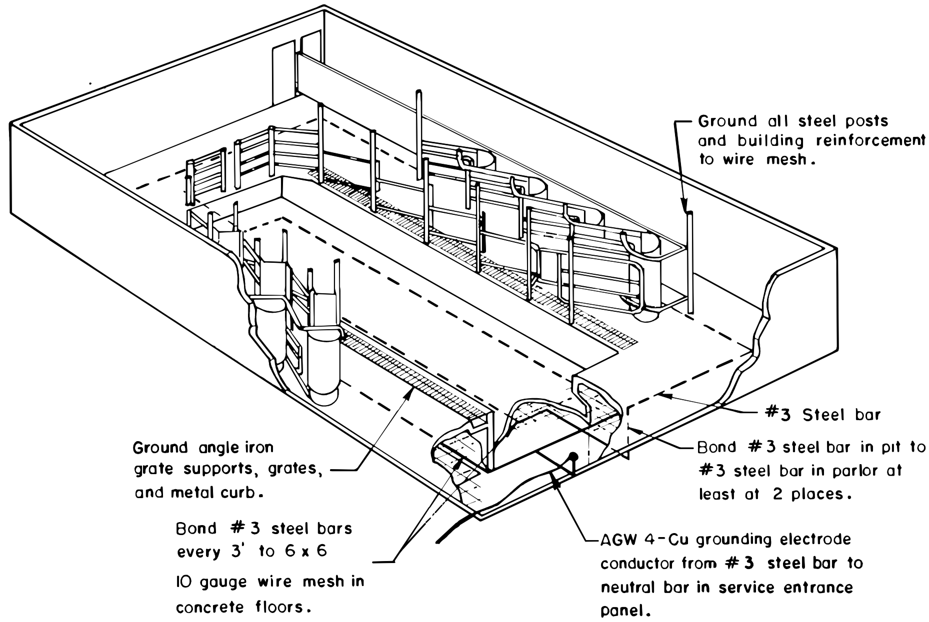


FIG. 18.14 EQUIPOTENTIAL PLANE CONSTRUCTION

Installation of transition ramps where animals enter or exit an equipotential plane should be considered at the time of construction (Fig. 18.15). The transition gives a reduced step potential for the animals as they move onto the equipotential plane.

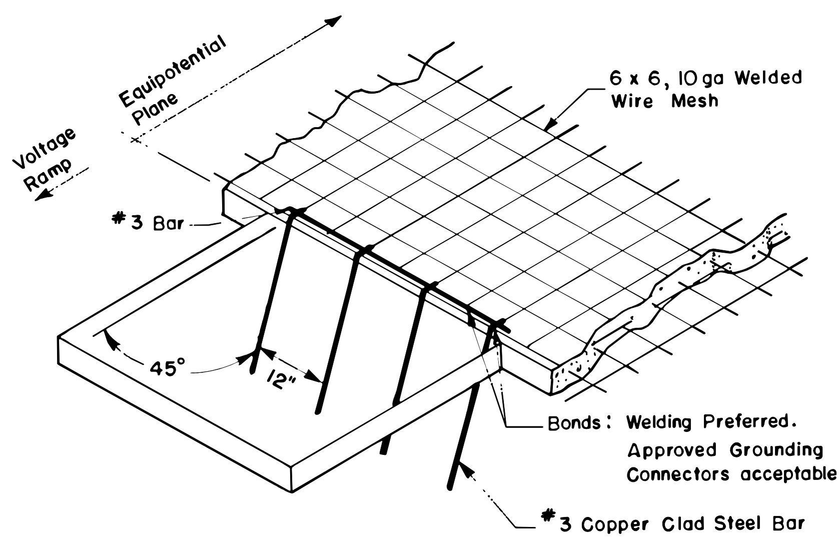


FIG. 18.15 TRANSITION RAMP FOR AN EQUIPOTENTIAL PLANE

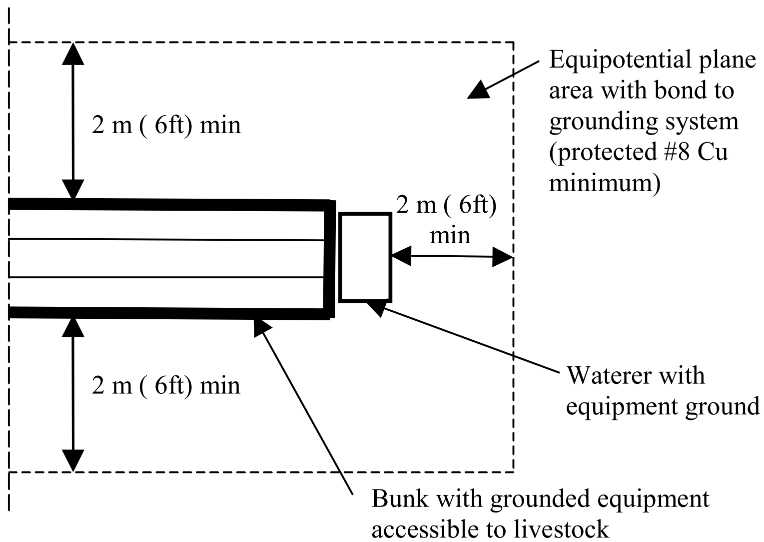


FIG. 18.16 EQUIPOTENTIAL PLANE INSTALLATION FOR OUTSIDE BUNK AND WATERER

Equipotential systems can successfully minimize stray voltage problems regardless of the source. When using this approach, consideration must be given to all areas where electrically grounded equipment is accessed by the livestock or exposed to livestock traffic. Fig. 18.16 demonstrates the application of an equipotential plane in a housing and feeding area.

18.6.3 ISOLATION

Isolation of part of the grounded neutral system can prevent the source from accessing the animals. If isolation is used there are two locations where it can be accomplished on a conventional multi-grounded system: (1) whole farm isolation at the farm's main service; and (2) single service isolation at the livestock building. Whenever isolation is used, careful consideration must be given to the safety and operational effects. In addition, when isolation is used, assure that no conductive interconnections are bypassing the isolation device. Common interconnections are metallic telephone grounds, gas or water pipes, metal feeders, fences, and connected metal buildings. Any conductive bypass will negate the isolation.

Whole farm isolation can be accomplished by isolation at the distribution transformer. Three methods have been developed for isolating the primary and secondary neutrals at the distribution transformers (Fig. 18.17). They make use of (a) a conventional spark gap, (b) a saturable reactor, or (c) a solid-state switch. These methods provide a high-impedance interconnect below a specified threshold voltage and a low impedance interconnect when the voltage exceeds that threshold. The "high" impedance is relative to the grounding impedance of the isolated secondary system. The "low" impedance provides that, under any condition creating a primary to secondary voltage above the threshold level, the device impedance will be reduced to a value such that the neutrals are essentially bonded.

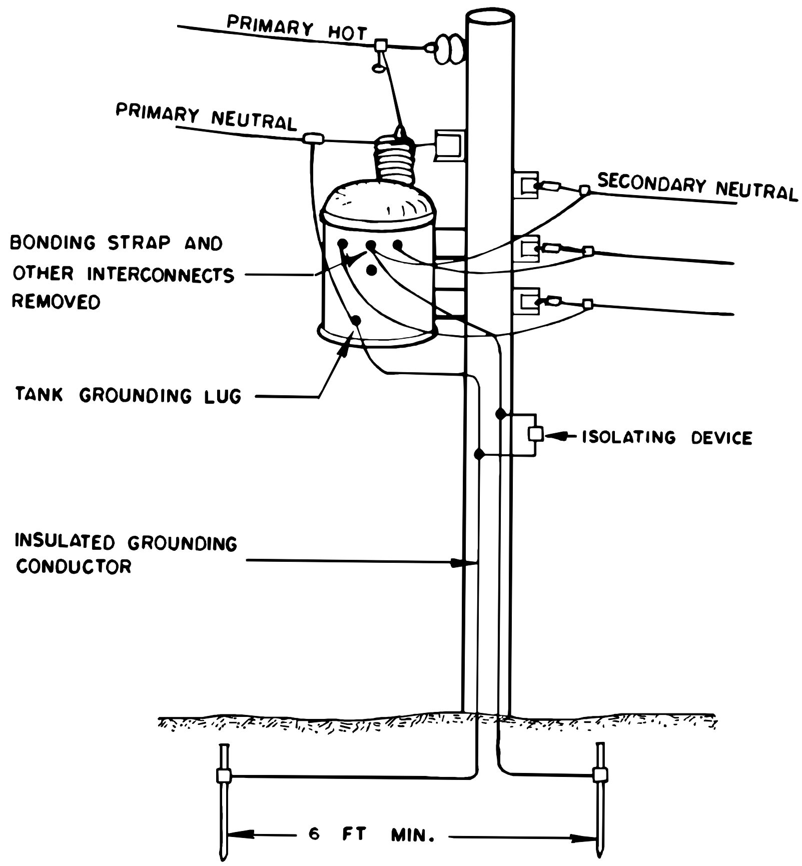


FIG. 18.17 DISTRIBUTION TRANSFORMER NEUTRAL ISOLATION

In all cases some system grounding of the farmstead will be separated from that of the distribution system, at least during non-fault conditions. This can affect both off-farm and on-farm sources of N-E voltage. Isolation removes contributions from off-farm sources. However, it will also affect on-farm sources resulting from secondary neutral voltage drops and on-farm faults. Primary-secondary neutral isolation will also affect N-E voltage due to on-farm fault currents to earth. Since the resistance of the return path of the fault current to the transformer is increased, the N-E voltage contribution will be increased proportionally. Effects of neutral isolation are more fully discussed in USDA Handbook 696 (Lefcourt, 1992).

Saturable reactors, designed to give a rapid impedance change at a design voltage threshold in the range of 10 to 24 V ac, are in use. Below saturation voltage, the high impedance (100 to 2,000 ohm) provides isolation. Above saturation, the impedance drops to a very low level to provide neutral interconnection. These devices also include a surge arrestor to divert fast-rising transient voltages, such as lightning. Such transients would otherwise create high voltages across the reactors.

The solid-state switching device is equipped with two thyristors and a control circuit for each. The control circuit triggers the thyristors when an instantaneous voltage above the specified threshold occurs across the device. The device remains in a low-impedance state until the voltage differential reaches zero. For a 60 Hz waveform whose peak is above the threshold, the device triggers during each half cycle and remains closed for the remainder of the half cycle. This device also has a surge arrestor in parallel to assist in passing fast rising transients.

Isolating transformers have been used in the past to create a separate grounded neutral system on the farmstead (Fig. 18.18). If a satisfactory solution can be obtained by isolation of a single building service, an isolating transformer can be used for a single service. A concern with this system is that a primary-to-secondary fault in the distribution transformer is carried by the distribution system neutral and grounding. Care must be taken in proper installation to meet prevailing codes and recommendations, particularly for overcurrent protection and bonding.

An approach to single service isolation has been developed in, and is used in, Canada. This approach makes use of a saturating reactor for separating the grounded (neutral) conductors from the grounding conductors and electrode, at the building service entrance. The advantage of this approach is low cost. However, installation may be difficult in some existing facilities since its function is dependent on complete separation of grounding and neutrals within the service and separation of grounding systems

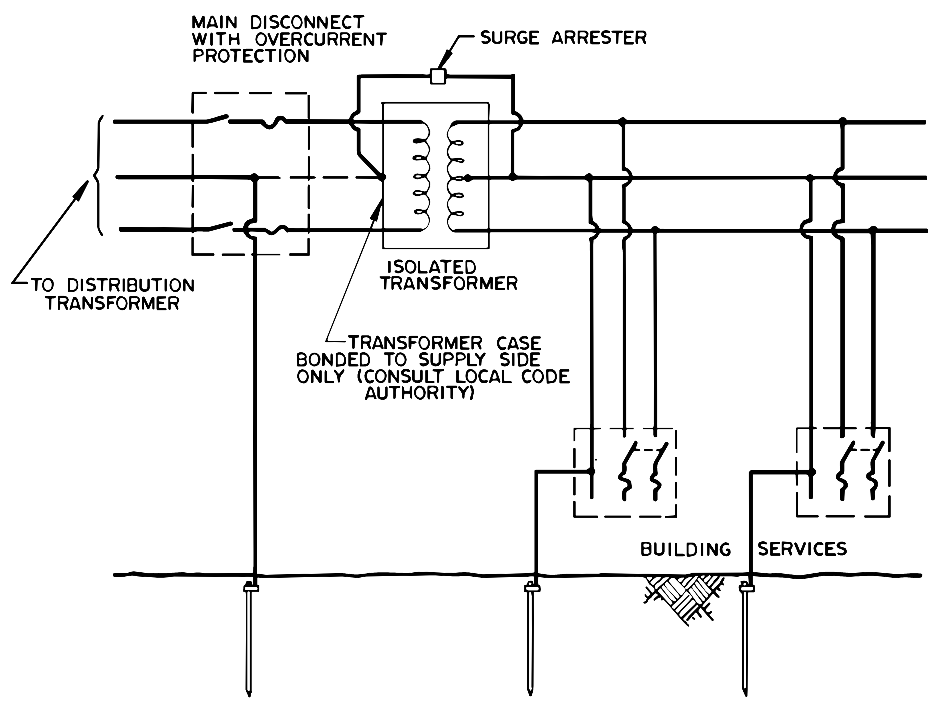


FIG. 18.18 ISOLATION TRANSFORMER INSTALLATION

between services. Furthermore, the National Electrical Code has not approved the use of this approach in the United States, thus, it cannot be recommended unless approved by appropriate electrical inspection authorities on an experimental basis.

18.7 CLOSURE

This chapter has introduced the basic concepts of N-E and stray voltage on farmsteads. A large body of literature has been developed describing animal sensitivity, voltage sources, procedures for source determination, and mitigation procedures. The following references are intended to lead the interested person to more detailed and quantitative information on the various aspects of the problem than could be included in this chapter.

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