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Number 696

Effects of Electrical Voltage/Current on Farm Animals

How To Detect and Remedy Problems

Not a complete reproduction of USDA Handbook 696.
Only portions listed below.

4. Mitigation

Pages 4-1 through 4-22
Pages 7-11 through 7-13

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This handbook examines 1) the history of stray voltage/current problems on farms, 2) the physical and electrical sources of stray voltage/current phenomena, 3) the physiological and behavioral bases for losses in milk production, 4) methods for identifying and detecting stray voltage/current problems, 5) methods for mitigating such problems, and 6) areas where further research may be warranted. While the primary emphasis is on cattle and dairy farms, the theories and procedures discussed are completely relevant to all types of livestock and livestock housing facilities. Recommendations are made for action levels and concerning mitigation techniques. The fundamental conclusion of this handbook is that stray voltages/currents can be reduced to acceptable levels.

KEYWORDS: Stray voltage/current, neutral-to-earth voltage, electrical shock, history, sources, physiological effects, behavioral modifications, mitigation, dairy farms, cows.

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There were two primary reasons for publishing this handbook. First, we, as scientists, were distressed that our research results were being misinterpreted and misconstrued in media and in courtrooms. Second, we were disheartened by the animosity that sometimes arose among livestock farmers, dairy equipment manufacturers, and public utilities companies because of a lack of understanding of the causes and effects of stray voltages on farms. For these reasons, we met at Cornell University in May of 1988 to review our opinions and concerns, and to discuss the possibility of publishing a "white paper" on stray voltage. At this meeting, we concluded that there was an excellent possibility that a consensus could be reached, and a second meeting was scheduled for October in Minneapolis.

At the first meeting, the question of funding for future meetings and, if relevant, publication of the "white paper" was raised. Several foundations and agencies funded principally by utilities or dairy cooperatives had offered financial support. However, to eliminate any and all potential for even the appearance of bias, we decided to accept *no* industry funding whatsoever. All travel and meeting expenses were borne by individuals, generally by utilizing university or Government funds.

At the second meeting, a firm consensus was reached that a "white paper" should be published and that it be published as a U.S. Department of Agriculture (USDA) Handbook. The Department was chosen as publisher because it represents an unbiased source of funds to pay for publication, because it has a mechanism for making available publications to the public through the Government Printing Office, and because federal publications are 1) understood by the general population to be unbiased and 2) normally viewed as expert testimony in legal proceedings.

To guarantee that the oral consensus reached at the second meeting was faithfully transferred to paper, we decided on a rather complex procedure for actually writing the manuscript. Chapters were written under the guidance of chapter editors, who then distributed copies of the chapters to all participants for comment. Next, these chapter editors revised their chapters and sent copies to the editor in chief, who assembled and integrated the chapters into a manuscript. The manuscript was distributed to all participants to ensure that all comments had been dealt with satisfactorily by the chapter editors. In addition, as part of the original agreement among contributors, Lloyd B. Craine served as the in-depth reviewer. Remaining problems were addressed to the editor in chief for reconciliation. Subsequently, the USDA's Agricultural Research Service Information Staff and Office of Public Affairs reviewed the manuscript. Ultimately, the edited manuscript was distributed for final approval, and each contributor signed a notice acknowledging that the manuscript was factually correct and a faithful represention.

Alan M. Lefcourt
Editor in chief

Warning

Identification and, particularly, diagnosis of stray voltage problems can require considerable electrical expertise. That is not to say that the input of farmers is not necessary and valuable. Often, the input and observations of people in daily association with a stray voltage/current problem are critically important to its solution. *However, electrical systems can be dangerous. Persons without special training should never attempt investigation of the electrical distribution or farm electrical systems.* For example, persons without special training should never open electrical service panels nor should they even contemplate altering any wiring.

Using a voltage measuring device with well insulated probes to measure voltages between possible points of animal or human contact should not result in a safety hazard with one important exception. Voltages that cause stray voltage/current problems are normally so low that they cannot be detected without special instruments. If an electrical shock can actually be felt or if animals are knocked down, a possible hazard to life exists. The device or electric circuit responsible for the shock should be disconnected by unplugging the device or by deenergizing the circuit at the service panel. The situation should be examined by an electrical professional as soon as possible.

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Summary

This chapter presents the various solutions to stray or neutral-to-earth voltage problems in livestock facilities. The advantages and disadvantages of each are covered. The mitigation of existing problems and prevention of future problems demand careful consideration of electrical sources, animal sensitivity, and characteristics of the corrective procedures or devices. Effects of any mitigation, by modifications of the electrical system on either the farmstead or distribution systems under normal and fault conditions, must be considered.

Approaches for controlling stray or neutral-to-earth voltages fall into four categories:

- Voltage reduction by mitigation of the causative or exacerbating conditions (e.g., by removing bad neutral connections and faulty loads; improving or correcting wiring and grounds; balancing loads; or controlling leakage currents by cleaning, reinsulating, or grounding).

- Active suppression of the voltage by a nulling device.

- Gradient control by use of equipotential planes and transition zones to maintain the animals' step and touch potentials at an acceptable level.

- Isolation of a portion of the grounding or grounded neutral system from the animals.

The most suitable approaches in any given situation must be based on the available information and constraints of the specific situation. All of the corrective devices and procedures discussed are theoretically sound. All have their advantages and disadvantages. Specific concepts and devices will continue to evolve; however, the principles underlying the control of problem voltages have been clearly identified.

Understanding the characteristics of various voltage problems, their interactions, and the effect of corrective procedures can be enhanced through the use of circuit models. Gustafson and Hansen (1985) developed two personal computer programs useful in the analyses of single-phase, multigrounded distribution and farmstead systems. The programs use resistive models to simulate systems with a single-phase multigrounded primary serving 120/240-V single-phase farmsteads. Examples 1 and 2 of the appendix of this chapter are used to demonstrate electrical characteristics discussed within this chapter.

Other models have been developed with slightly different circuit parameters. However, the principles demonstrated and results obtained are similar to those of examples 1 and 2.

Voltage Reduction

If investigations show a troublesome level of neutral-to-earth voltage due to such conditions as the presence of 1) high resistance connections either on or off the farm, 2) neutral imbalance currents on or off the farm, 3) undersized neutrals, or 4) fault currents to earth or to equipment grounding conductors, corrections can be made and the remaining voltage assessed. Likely consequences of these conditions are presented in cases 5P, 6P, 8P, 9P, and 10P of example 1, and cases 3F, 5F, and 7F of example 2. The interaction of such conditions and the results of correction procedures, as discussed later, must be evaluated.

Reduction of grounding resistance on the distribution neutral will reduce the neutral-to-earth voltage due to system loading. This is demonstrated by cases 14P and 15P of example 1. Since the proportion of the system grounding supplied by the farmsteads is often large compared with that supplied by the distribution neutral grounds, the effectiveness of this approach may be limited. *It is important to recognize that much of the system grounding on the farmstead is supplied by items which 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 an outbuilding is allowed by the National Electrical Code (NEC) of 1990. Use of a four-wire system as shown in figure 4-1 will reduce the contribution of the secondary neutral voltage between the main service and outbuilding panel to the grounding system at the outbuilding. Only the neutral-to-earth voltage on the grounding system at the main service will be carried to the outbuilding ground system by the fourth wire (the grounding conductor). Neutral-to-earth voltages will remain from all other sources. For the four-wire system, all neutral and grounding conductors in the outbuilding service and all feeders from that service must be completely separated. The originating end of the four-wire system must meet all NEC requirements as a service, i.e., disconnect with over-

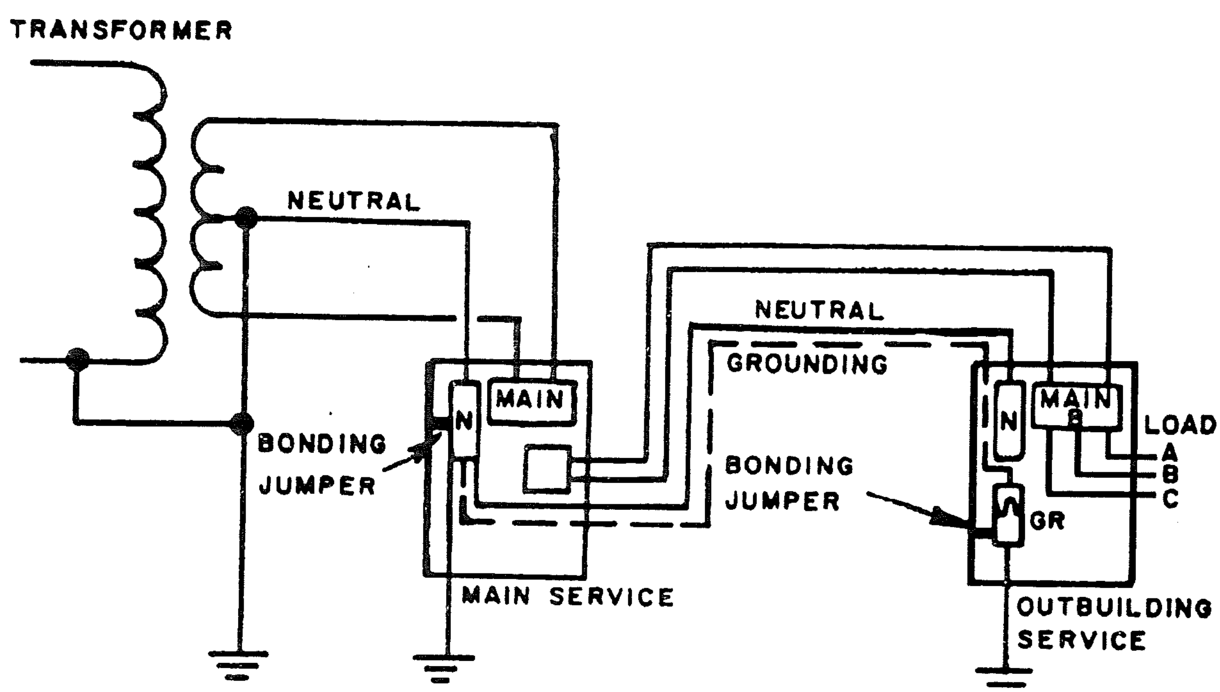


Figure 4-1. A four-wire feeder from farm main to outbuilding. Note that the neutral in the outbuilding is not bonded to the grounding bus (GR) but is bonded at the main service.

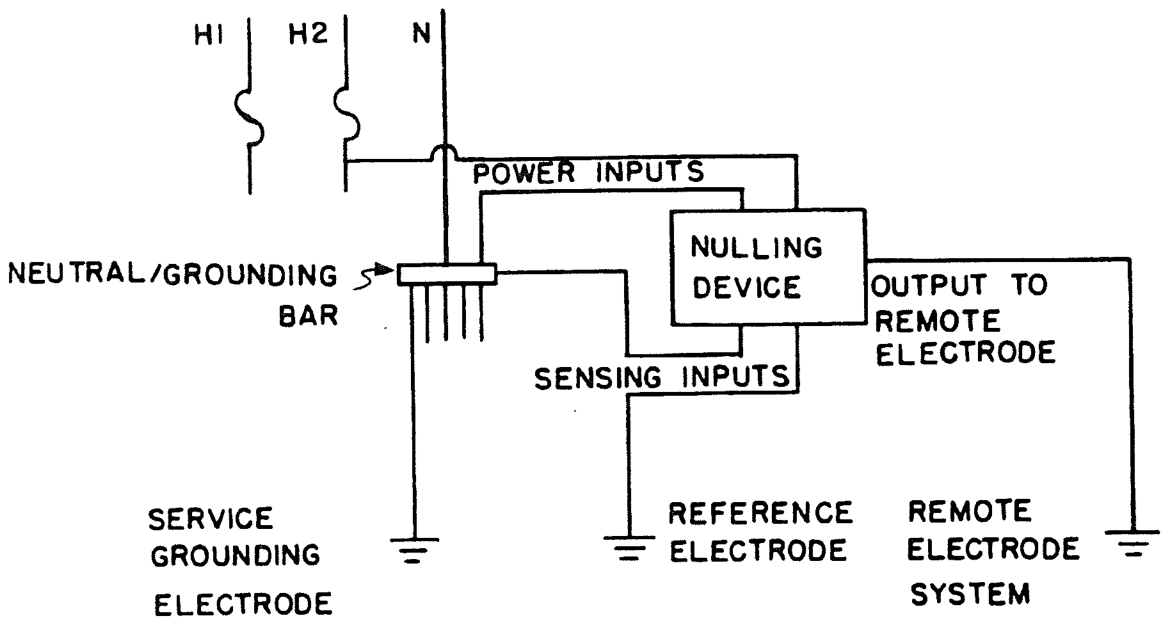


Figure 4-2. Voltage suppression by controlled current to earth.

current protection, system grounding, appropriate enclosure, and neutral-to-ground bonding connection. The equipment grounding conductors must have the same ampacity as the ungrounded conductors.

As discussed in the sources chapter, voltages may appear between metallic objects which are not bonded to the electrical system or equipment grounding. These voltages are commonly caused by what are termed "leakage currents." Leakage due to moisture and dirt or capacitive coupling can also occur. In rare instances leakage currents may arise that are strong enough to cause problems for animals. As described in the measurement chapter, careful testing procedures should be followed to assess current-producing capability. Mitigation involves grounding or bonding of metallic structures and may also require cleaning, repositioning, and adding of drainage holes to deal with moisture and dirt.

Active Voltage Suppression

Since voltage is produced by current flow through a system impedance, a second source of current may be used to null or cancel the original source at a point in the system. One procedure used to mitigate neutral-to-earth voltage, as demonstrated by cases 11P, 12P, and 13P of example 1, is to deliver a controlled current to earth (fig. 4-2). Voltage between a point in the neutral/grounding system and an isolated reference ground or grounds is used as the input to a differential amplifier. Current delivered to a remote-grounding-electrode system is then adjusted to null out the measured voltage. A description of this method is given by Winter and Dick (1983). Comparison of the suppressed cases to the base case in example 1 demonstrates that the voltage is also reduced along the line for farms near the location of the device. Power required for the compensating circuit depends on the required current and resistance of the remote-grounding-electrode system. In the example, for the device near the middle of a 10-farm line, the power required would be approximately 250 W for a 10-ohm remote-electrode system.

Two advantages of this approach are that 1) installation of a nulling unit requires no modification of the basic existing electrical system, so if this system has been properly wired the full safety benefits of the interconnected grounded neutral system would be retained and 2) nulling of the neutral-to-earth voltage at a point lowers the level of neutral-to-earth voltage on the distribution system.

Disadvantages include 1) possible maintenance problems inherent to active (amplifier system) type devices, 2) high initial cost, and 3) the potential for offsetting problem sources which should be corrected by other means. Existing units limit the offset capabilities to a level that should not significantly affect the operation of overcurrent protection devices under fault conditions.

Gradient Control

Gradient control by equipotential planes will negate the effects of all neutral-to-earth 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 (foot-to-foot) and touch (hand-to-foot) potentials under fault conditions at substations and around electrical equipment. In addition to protecting people, animals, and equipment under fault or lightning conditions, proper equipotential systems in livestock facilities can solve stray voltage/current problems. They also provide an additional system-grounding electrode. *Equipotential planes add to the electrical safety of humans and animals.*

Equipotential Plane

The definition of the equipotential plane is derived from two words. Equipotential means having the same electrical potential throughout; plane means a flat or level surface, together they form a level surface having the same electrical potential throughout.

Any animal standing on the floor containing a properly installed equipotential plane will have all possible contact points at or very near the same potential. Figure 4-3 shows animals on equipotential planes. *Equipotential planes can alleviate stray voltage/current problems only in areas where they have been properly installed.*

Some areas where an equipotential plane might be installed are stanchion barns, tie-stall barns, free-stall barns, milking parlors (including operator pit and holding areas), and around electrically heated waterers and mechanical feed bunks.

A properly installed equipotential plane must include all of the following: 1) Equipment grounding, 2) metalwork bonding, and 3) a conductive network in the floor bonded to the electrical system grounding.

If an equipotential plane is properly installed, the only possible concern is that the animals will receive an electrical shock when they move on or off the plane as shown in figure 4-4. If the neutral-to-earth voltage is high enough to force an unacceptable current through the animals' bodies from the front to rear hooves they may refuse or be reluctant to move on or off the equipotential plane. This voltage problem can be reduced substantially (but not totally eliminated) by a voltage gradient ramp. A properly constructed voltage ramp subjects the animals to an acceptable

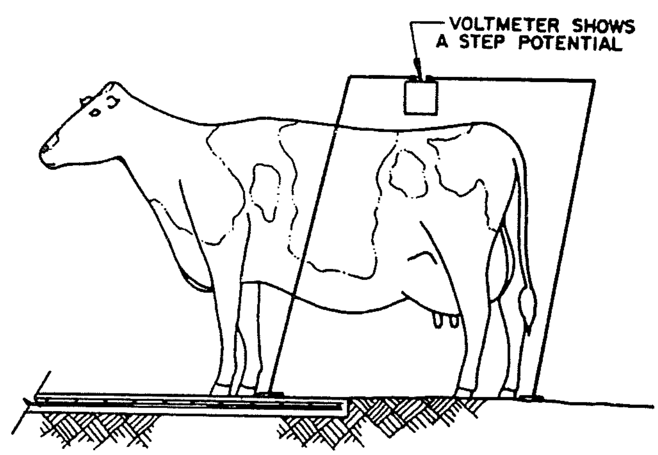


Figure 4-4. Animal approaching an equipotential plane.

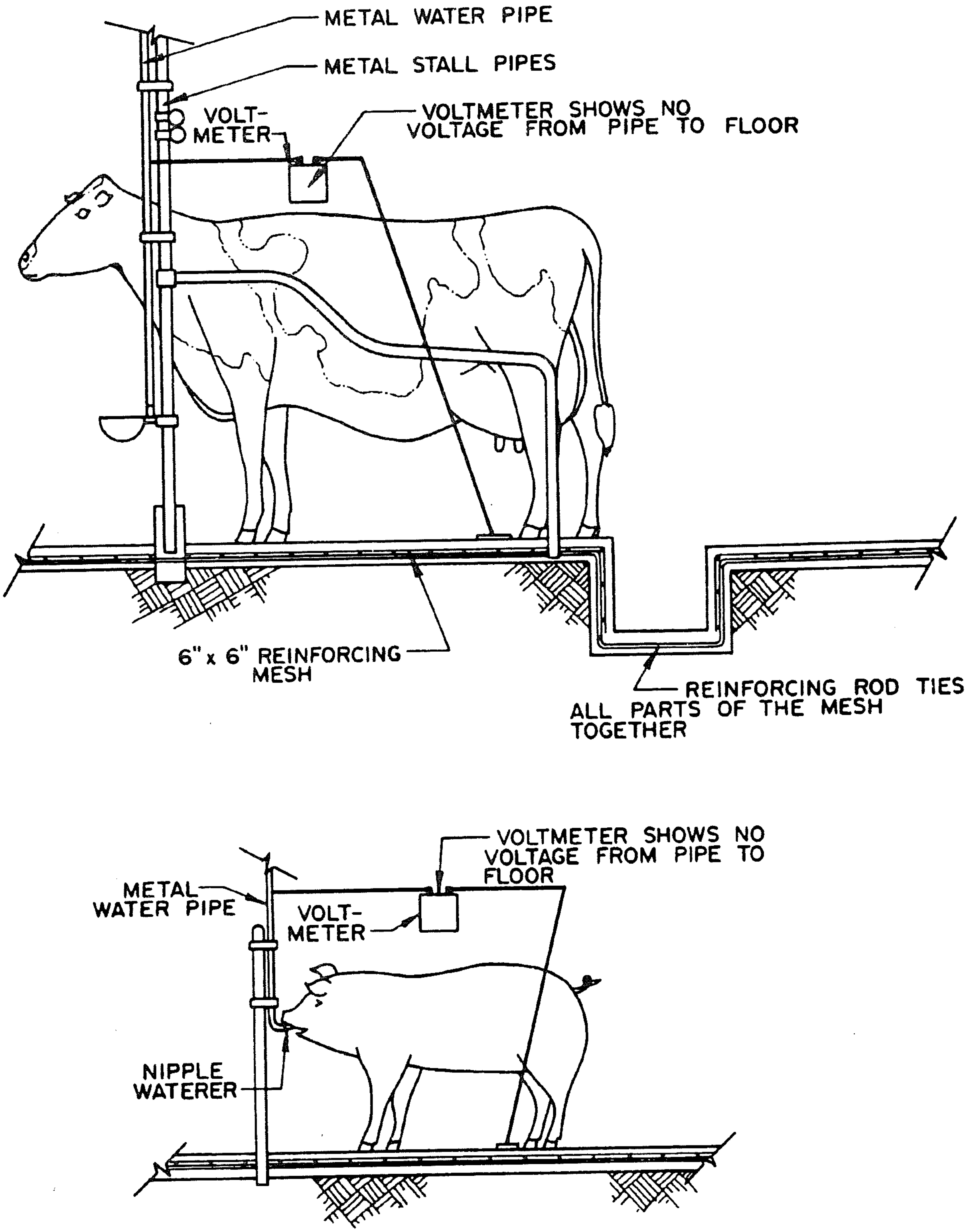


Figure 4-3. Animals on equipotential planes. All body contacts are at the same potential.

change in step voltage as the animals move on or off the plane.

Equipment Grounding and Metalwork Bonding

Electrical equipment must be properly grounded according to all electrical codes. Using a conduit alone as a grounding conductor in livestock facilities is not adequate because corrosion eventually will cause poor electrical connections. The NEC now requires an equipment grounding conductor in any cable or conduit.

All metal structures and equipment in areas used by the animals should be electrically connected (bonded) and also be connected to the grounding bus of the service entrance. This metalwork includes floor gridwork, waterers, feeders, stanchions, pipes, stall dividers, pipe lines, and floor grates. Metal equipment embedded in the concrete should be bonded to the floor grid. With stanchions or tie stalls, #3 steel reinforcing rods may be laid in the front curb to bond posts to the grid, or the back of the dividers may be bonded to the grid in the stall platform.

Welding (resistance or exothermic) or brazing is the best way to make a permanent connection. Clamp-type connecters designed for electrical use can be used with proper surface preparation. Conductors and connections which are not concrete encased should be located where they are clearly visible for inspection and maintenance, and cannot be easily damaged or disturbed.

Many stainless steel milklines are electrically isolated or "floating." As a result, induced voltages may appear on the milkline. It is recommended that they be bonded to eliminate induced voltages and to ensure safety in the unlikely event of an electrical fault to the pipeline. Copper should not be in immediate contact with the stainless steel pipeline for corrosion and resulting sanitation reasons. For proper bonding, a stainless steel hose clamp, a brass terminal, and a copper grounding conductor can be used as shown in figure 4-5. The brass or bronze terminal can be brazed to the hose clamp to provide an electrical connection for the grounding conductor.

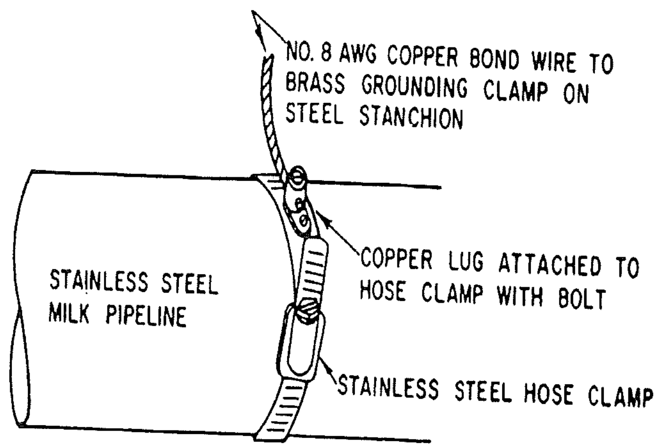


Figure 4-5. Milkline bond.

Research has shown that the electrical resistance of the milk hose connecting the milker claw to the stainless steel milkline is so high, even under very high milk flow rates, that this is not a likely pathway for an objectionable current to enter the cow.

Floor Gridwork

A conductive floor gridwork or mesh bonded to the grounding system will ensure that all points on the floor of a building will be at very nearly the same potential as the other metalwork and grounded electrical equipment.

When a network of conductors is embedded in concrete, the surface voltages may be visualized as a set of peaks and valleys appearing above and between the conductors, respectively. As the conductors are placed farther apart, the voltage difference between the peaks and valleys will increase, as will the voltage variation along the surface.

Any 6- x 6-inch welded wire mesh commonly used for concrete reinforcing will provide a satisfactory conductive gridwork in a concrete floor. Typical sizes available range from #6 to #10 gauge. An interconnected grid of steel reinforcing rods not smaller than #3 gauge (3/8-inch diameter) with a maximum spacing of 12 inches will also be sufficient. The floor grid should be embedded in concrete at least 1-1/2 inches thick above and below to protect the metal from corrosion due to moisture and manure.

The specific arrangement and procedures for properly installing floor gridwork will vary with the type of facility and construction practices. The following guidelines and recommendations are based on the test results and experiences with field installations as well as extensive laboratory testing. A general procedure that has proven very satisfactory is to install an interconnecting grid of steel reinforcing rods that serves as a base for a continuous overcovering of welded wire mesh. The location and spacing of the base reinforcing rods is not critical. In stanchion- or tie-stall facilities, two rods spanning the full length of the floor and three or four placed at intermediate locations across the floor have proved effective.

New Construction

All concrete floors installed in new or remodeled confinement livestock facilities should include an equipotential plane. The installation procedure may vary, depending on the type of facility and construction practices. The wire mesh or reinforcing rods are laid out in the floor area. Before the concrete is poured, the mesh is bonded to all equipment, stalls, and partitions that are to be embedded in the concrete. The bonds in the grid should be checked before the concrete is poured to ensure that they're electrically sound. Any equipment not embedded in concrete should also be bonded to the mesh in an appropriate manner to provide electrical continuity at all surfaces. Provision should be made to allow an exposed means of bonding the equipotential plane to the grounding electrode system. This provision will allow the bond to be visually inspected in the future.

The size of the wire in the mesh or the size of the reinforcing rods is not critical except as related to the possible deterioration through corrosion, etc. Number-10 welded wire mesh (6 by 6 inches) and #3 gauge (3/8 inch) reinforcing rods should be satisfactory.

Figure 4-6 shows a typical layout of the reinforcing-rod base grid and overlying mesh in a stall dairy barn. Figure 4-7 shows an equipotential plane in a milking parlor.

The following recommendations should be considered when designing an equipotential plane for any livestock facility:

- All intersections of the reinforcing rods in the base grid should be solidly welded together (see figs. 4-6 and 4-7).
- All reinforcing rods in the base grid should span the full length or width of the building.
- The cross-reinforcing rods in a stall dairy barn should be bent to go underneath the gutter.
- The milking parlor plane must include the operator's pit.
- The floor gridwork should extend into the holding and exit areas and/or a transition ramp should be installed where the animals move onto and off the floor.
- At intervals (every three or four strands), the welded wire mesh should be tack welded or brazed to the crosswise reinforcing rods where they intersect.
- Where convenient, the reinforcing rods should be welded to the metalwork in the building. For example, the lengthwise reinforcing rods in a stall dairy barn may be welded to the rear pipes of the stall dividers.
- It is preferable to position the equipotential plane so that the mesh is in the center or upper portion of the concrete floor, (1-1/2 to 2 inches from both surfaces).

It is not necessary to include mesh in the floor of the gutter or to extend the mesh through narrow concrete curbs, such as the curb at the front of the stall dividers in a stall dairy barn, which may be poured before the floor. However, when the mesh is installed in the floor, it should extend up to the edges of any such curbs.

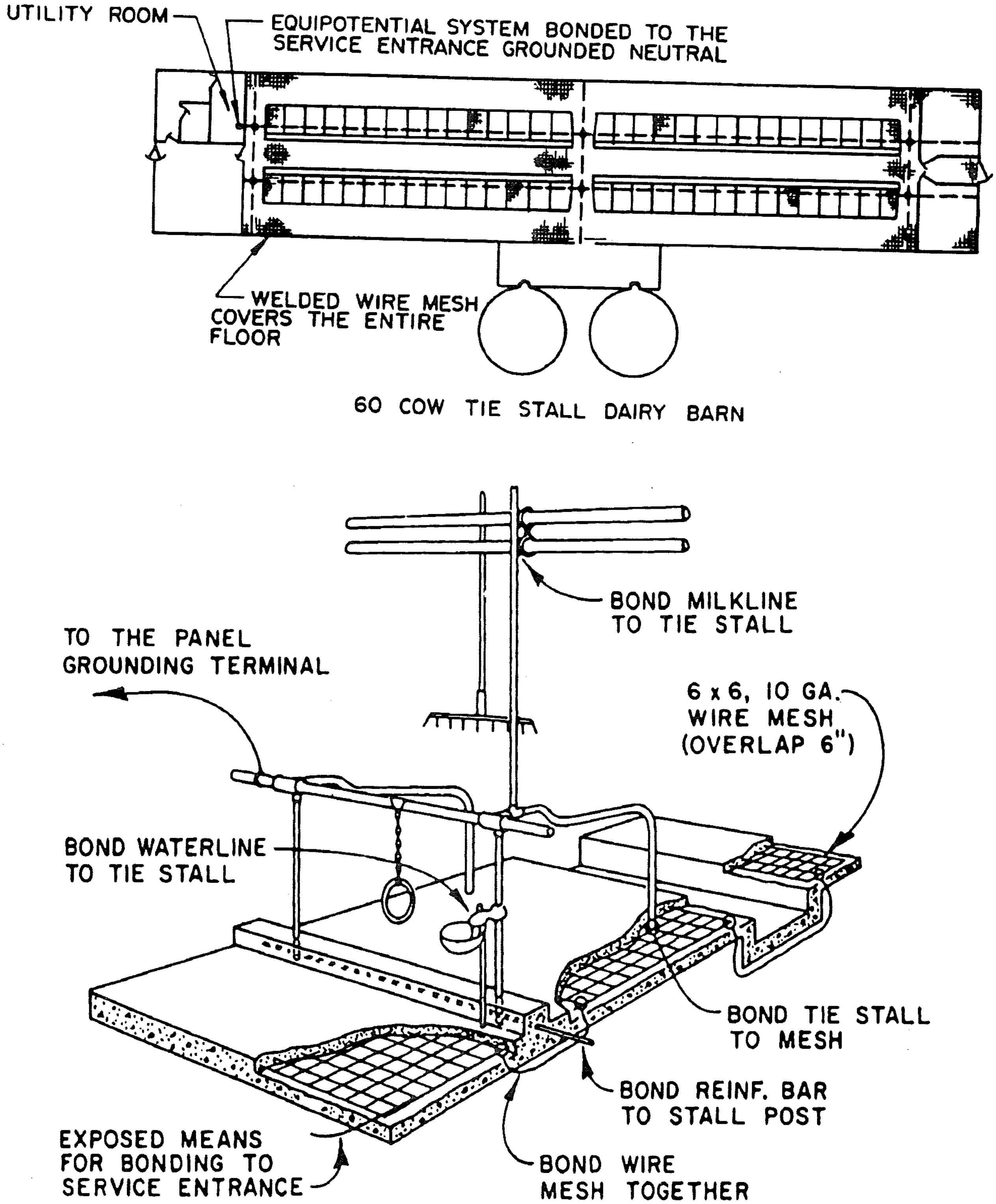


Figure 4-6. Equipotential plane in stall barn: top, typical layout of reinforcing rod grid and overlying mesh in a stall dairy barn; bottom, three-dimensional view.

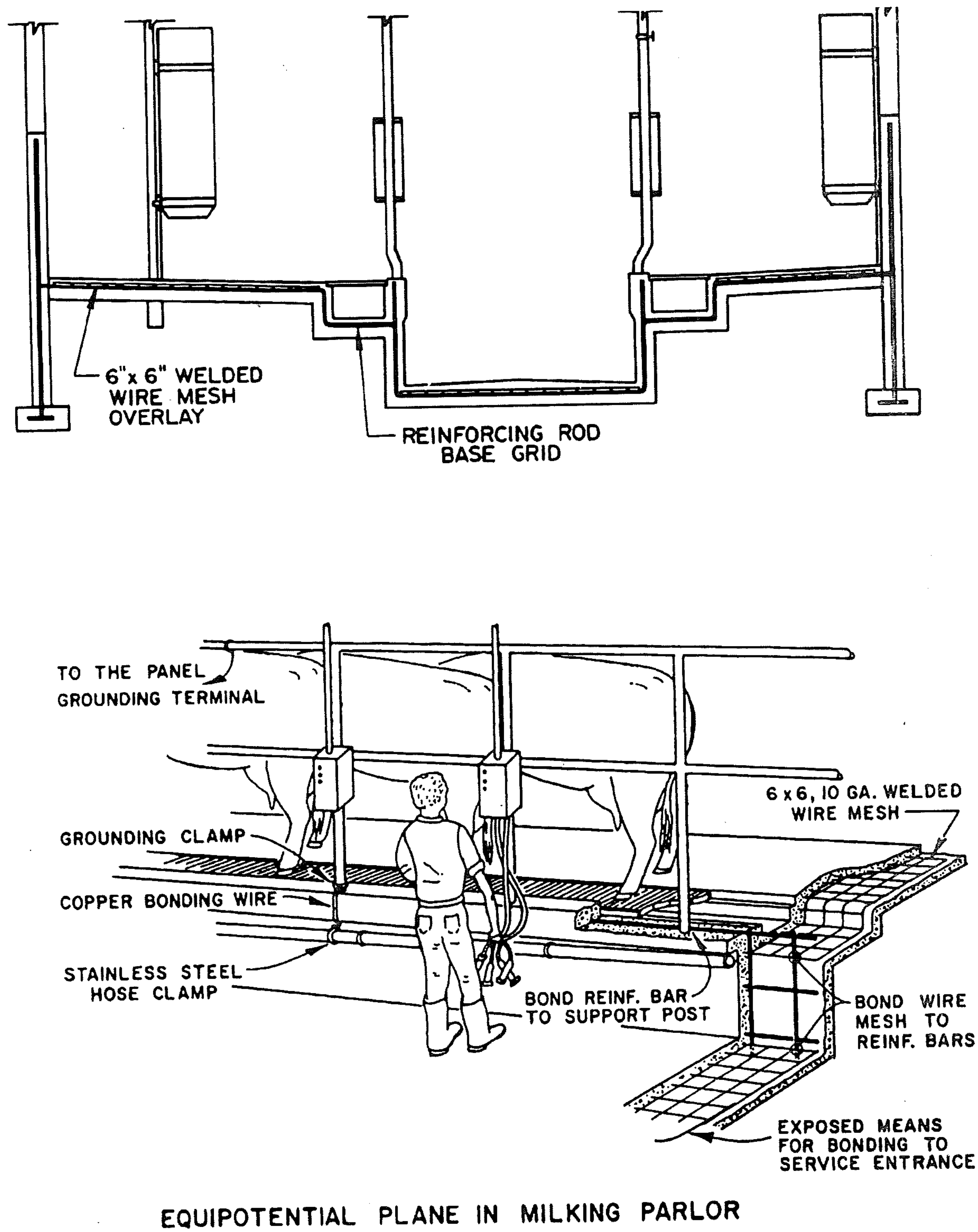


Figure 4-7. Equipotential plane in a milking parlor: top, cross-sectional view; bottom, three-dimensional view. Note that the operator pit is part of the plane.

Proper performance of an equipotential plane depends on positive electrical continuity between the reinforcing rod base, the welded wire mesh, all metalwork in the facility, and the system electrical ground at the service entrance to the building. Multiple connections will help ensure electrical continuity of all components. Where possible, stanchion or stall pipework can be welded or clamped to the reinforcing rod base or welded wire mesh by using short sections of reinforcing rod. It is not necessary to provide connections between every pipe and the equipotential plane, but a few distributed throughout the facility will help ensure electrical continuity. The equipotential plane and its associated metalwork can be bonded to the service-entrance-system ground by extending one of the reinforcing rods into a convenient location in the building, where it is bent upward to project above the concrete. A grounding conductor (AWG #6 or larger copper wire) can then be clamped to the rod and connected to the service-entrance grounding bus.

Voltage Ramp (Gradiant Control)

An animal may be affected when it steps onto or off the floor of the equipotential plane. A properly constructed voltage ramp will reduce the potential effect by providing a more gradual change in voltage at the perimeter of the plane. The voltage difference between an animal's front and rear hooves cannot be totally eliminated as it moves on or off the plane. However, the difference can normally be reduced to an acceptable level.

Based on the results of laboratory tests, an effective voltage ramp can be provided at animal entrance and exit locations by essentially extending the equipotential plane outward and downward at a 45-degree angle as shown in figure 4-8.

The voltage ramp can be made by driving or burying 8- or 10-foot copper-clad ground rods into the soil at an angle to the surface. The rods should be no more than 12 inches apart, and enough should be used to span the width of the access path. The rods should be installed at a 45-degree angle (1:1 slope) to the surface.

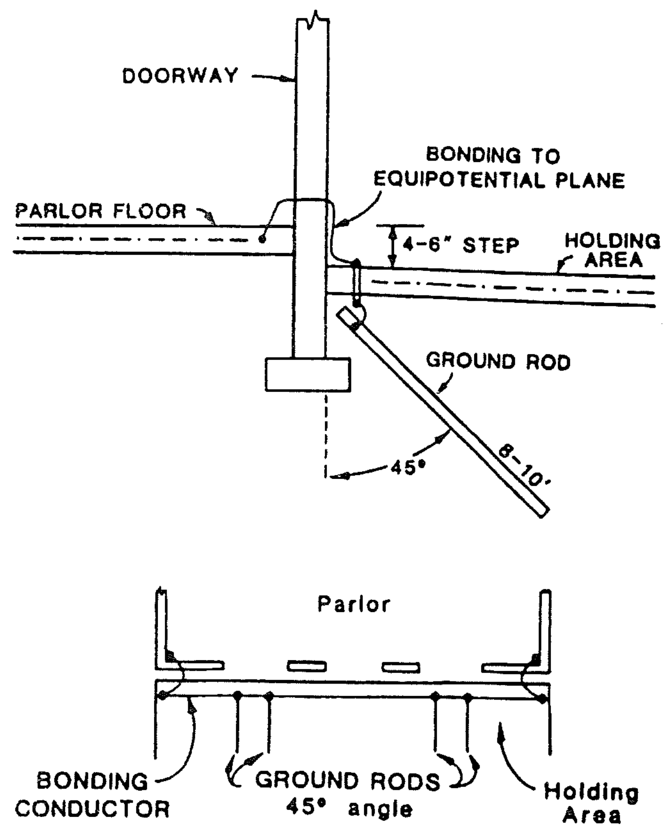


Figure 4-8. Voltage ramp adjacent to an equipotential plane: top, side view; bottom, frontal view.

Electrical connections to the equipotential plane and to the copper-clad ground rods should be encased in concrete. The ground rods for the voltage ramp should be installed at the time the reinforcing-rod base grid and welded wire mesh are laid out for the equipotential plane. A section of reinforcing rod should be attached to the end of the mesh across the access area. The 45-degree rods are then bonded to this reinforcing rod.

Retrofitting Existing Facilities

There are two practical ways to retrofit existing facilities with equipotential systems. If possible, the preferred way is to fabricate the equipotential plane, as explained earlier, over the entire existing floor in the facility and pour a 2-inch overlay of concrete. Retrofitting in this way can be practical in a milking parlor facility but may not be feasible in a stall barn. Sometimes a partial plane is adequate. For example, an equipotentail plane could be installed for the cow platforms and operator's pit in a milking parlor. If the problem in the parlor is solved, no more may need to be done. If the problem remains, additional steps can be taken. For example, if the cows are reluctant to enter the parlor, a voltage ramp may be necessary. In a stall barn, it may be possible to retrofit a section of the cow platform. If doing so solves the problem, the remainder of the cow platform can be retrofitted. If the cows are then reluctant to step across the gutter, it may be necessary to retrofit the center walkway also.

Another way to retrofit an existing facility with an equipotential plane is to saw grooves in the existing concrete floor and grout in copper conductors that are electrically interconnected to the metalwork in the facility, all of which are then

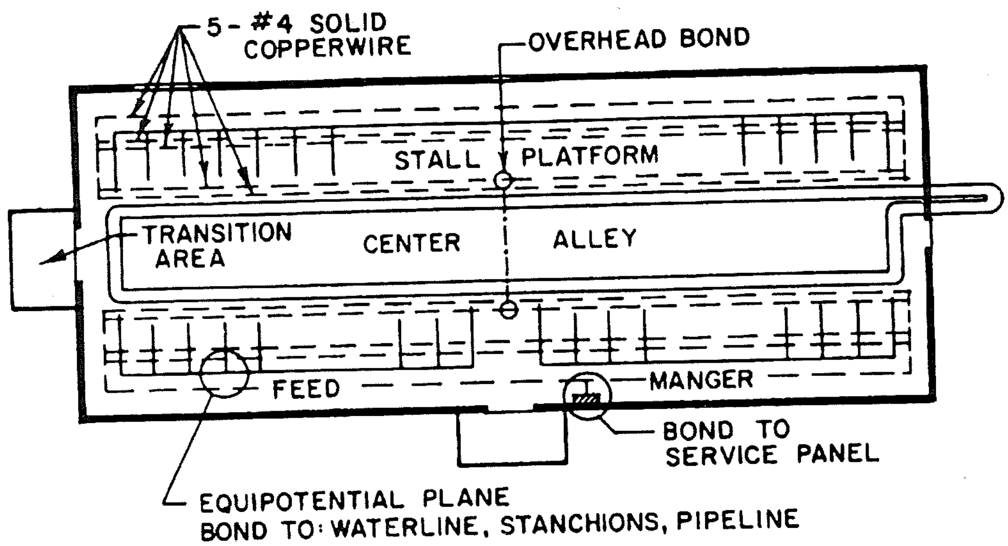


Figure 4-9. Retrofit equipotential plane in stanchion/tie stall barn.

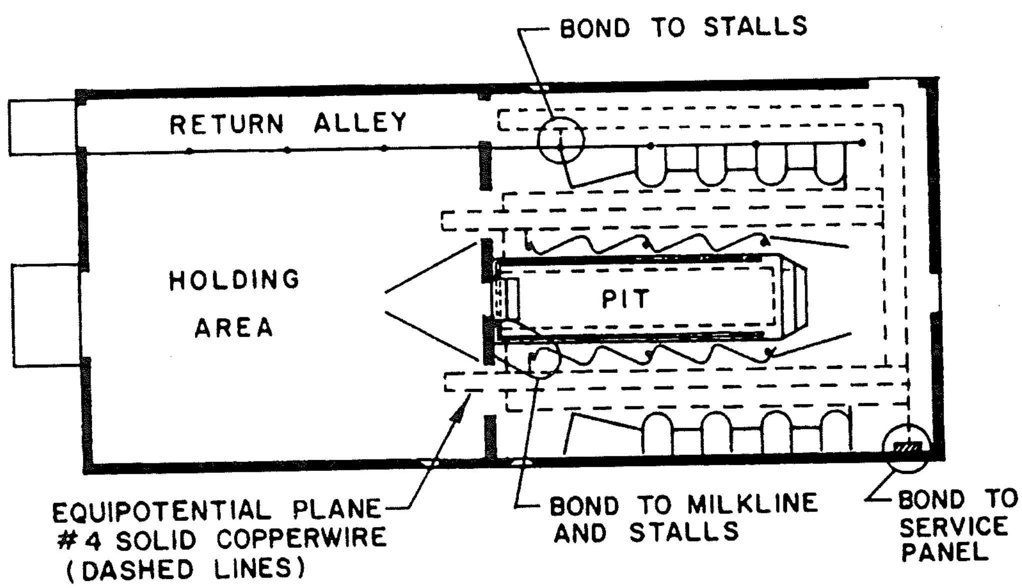


Figure 4-10. Retrofit equipotential plane in milking parlor.

equipment grounded to the service entrance. This method involves grooving the concrete about 1 to 1-1/2 inches deep and 1/4 inch wide, then laying AWG #4 soft copper wire into the grooves and grouting over the grooves. Wires should be placed in the feed manger, front hoof area, and rear hoof area. For example, in a stall barn like that shown in figure 4-9, two conductors spaced 12 inches apart could be located 6 to 10 inches from the edge of and parallel to the gutter. These conductors would provide the system for the back feet. Two conductors spaced 12 inches apart are placed 6 to 10 inches from and parallel to the front curb to take care of the front feet area. One conductor is placed 6 to 10 inches from the front curb in the manger. Welds or pressure-type connections are used to bond these wires together at several points along the length of the barn. At a minimum, the wires should be bonded at each end of the barn and to the stallwork and water line. The exothermic weld, or CADWELD, is particularly good for bonding the copper wires together and to steel posts or other equipment. A quick-setting grout will speed installation. A grout approved by the Department of Health and Human Services' Food and Drug Administration should be used in the manger area, because of its proximity to animal feed. Milking parlors and holding areas can also be retrofitted by this method (fig. 4-10). Wires are spaced 12 to 18 inches apart and are placed in the cow platform area and entrance and exit alleys. Wires should also be placed in the operator pit. To be effective the copper conductors must be interconnected at the end and bonded to the electrically interconnected stallwork. The entire system must then be equipment grounded to the electrical service entrance. This method of retrofitting allows use of the facility during construction, since most of the work can be performed between milkings.

Isolation

The term "isolation" is used to describe electrical separation of all or a portion of the grounded neutral system of a farmstead from the remainder of the power distribution system. Isolation of part of the grounded neutral system can prevent neutral-to-earth voltages on the nonisolated portion of the system from accessing the animals. Isolation can be accomplished at either of two sites of a conventional multigrounded system: 1) ahead of the farm main service (whole farm isolation) and 2) at the livestock building single service (single servive isolation). *Careful consideration must be given to the safety and operational effects if isolation is used.*

Whole Farm Isolation

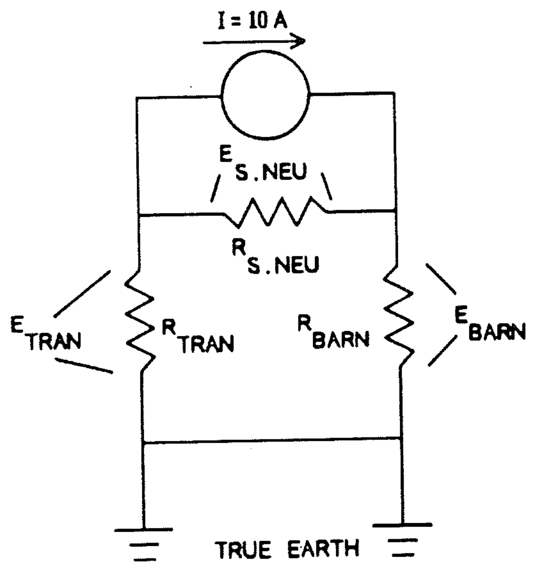
Whole farm isolation can be accomplished 1) at the distribution transformer or 2) with an isolation transformer following the distribution transformer. The important features of these approaches will be discussed. In all cases some system grounding will be removed from the distribution system, at least during nonfault conditions. As will be shown, this can affect both on- and off-farm sources of neutral-to-earth voltage.

Effect of Isolation on the Primary Neutral

Under nonfault conditions, isolation of the farmstead removes its grounding from the grounded neutral system of the distribution primary. This removal increases both the grounding resistance of the distribution neutral system and the neutral-to-earth voltage on the primary. Such neutral-to-earth voltage increases resulting from the isolation of one or more farmsteads under nonfault conditions along a 10-farm, single-phase line are modeled in cases 2P, 3P, and 4P of example 1 (appendix). The effect of isolation of farmsteads along the line diminishes with distance from isolation. However, isolation raises the concern that neutral-to-earth voltages may be raised to a problem level at farms or residences in close proximity. In these cases further action may be necessary to maintain or reduce the neutral-to-earth voltage.

Effect of Neutral Isolation on the Secondary Neutral

Whole farm 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. Changes in magnitude of neutral-to-earth voltages resulting



	CASE 1	CASE 2
$R_{S.NEU}$	0.21 ohm	0.21 ohm
R_{BARN}	2.5 ohm	2.5 ohm
R_{TRAN}	2.5 ohm	25 ohm
$E_{S.NEU}$	2.02 V	2.08 V
E_{BARN}	1.0 V	0.19 V
E_{TRAN}	1.0 V	1.89 V

Figure 4-11. Secondary-neutral voltage-drop distribution under case-1 and case-2 conditions.

from secondary-neutral voltage drops are illustrated in the simple multigrounded secondary circuit shown in figure 4-11. The first case, with equal system-grounding resistances at each end of the secondary neutral, represents a system before primary-secondary-neutral isolation. The neutral-to-earth voltages at the two ends of the secondary neutral will be equal and sum to the secondary neutral drop. When the grounding resistance is increased at the transformer end by neutral isolation (case 2), the secondary neutral voltage drop remains essentially unchanged and equal to the sum of the neutral-to-earth voltages at the two ends. However, the transformer end, now having a higher grounding resistance, will bear a larger neutral-to-earth voltage due to the voltage divider effect of the different ground resistances. This illustrates that the relative grounding resistances at individual services on a farmstead will determine the secondary neutral's contribution to neutral-to-earth voltage at the individual services after isolation. How isolation can affect the secondary neutral's contributions to neutral-to-earth voltages is further demonstrated by comparison of case 1F and 2F and case 3F and 4F of example 2 (appendix).

Some generalizations can be made about redistribution of neutral-to-earth voltages due to secondary-neutral voltage drops after primary-secondary isolation. A neutral-to-earth voltage that exists at a service entrance and that is due to a voltage drop on the secondary neutral to that service, e.g., service a, will be reduced as a result of isolation. This reduction in neutral-to-earth voltage will occur, since the grounding resistance at service a will remain the same while the grounding resistance at the transformer end will increase. On the other hand, the neutral-to-earth voltage at another service entrance, e.g., service b, may increase. If it does, the increase will mean that the grounding resistance at the transformer end includes the grounding resistance of service b. The magnitude of the changes will be determined by the system-grounding resistances at all service entrances on the farm. Thus it is possible for primary-secondary isolation to solve a severely problematic neutral-to-earth voltage at a specific service entrance if the voltage is the result of a secondary-neutral voltage drop. After isolation, the location of an electrically grounded object, such as a water-well casing, will have a major effect on the redistribution of neutral-to-earth voltages due to secondary-neutral voltage drops and grounding resistances.

Primary-secondary neutral isolation will also affect neutral-to-earth voltages due to on-farm fault currents to earth. Since the resistance of the return path of such a fault current to the transformer is increased, the contribution of neutral-to-earth voltage will be increased proportionally. The fault current can create a neutral-to-earth voltage either in phase or 180 degrees out of phase with other existing neutral-to-earth voltages, resulting in a net increase or decrease. Cases 5F through 8F of example 2 demonstrate these effects.

Available Devices for Neutral Isolation

Devices are now available to provide primary-to-secondary-neutral isolation at the distribution transformer in conformance with section 97D of the National Electrical Safety Code (NESC) of 1990. The NESC applies to transmission and distribution systems. The major safety concern is for the prompt interruption of service to the customer in the event of 1) a winding-to-winding fault in the distribution transformer or 2) a primary conductor short to a service conductor. Sufficient fault current must pass from the customer service to the primary system to ensure operation of the line overcurrent protection or transformer fuse. As a result of this concern, the grounding committee of the NESC modified the 1984 code to require the isolating device to have a 3-kV-or-less, 60-Hz breakdown voltage.

Although the NESC deems a 3-kV-device suitable for providing the necessary consumer safety, some persons involved with isolation for animal confinement have the opinion that the lower the sparkover voltage, the safer. The risk is related to high voltage directly entering a household or customer premise. This risk exists even without isolation. Therefore, any safety benefit of such devices must be quantified through the reduction in fault clearing time (fuse or circuit breaker action).

Since the change in the 1984 NESC to specify isolation devices with a breakdown voltage of 3 kV or less, three methods have been developed for isolating the primary and secondary neutrals at the distribution transformers. They make use of 1) conventional spark gap, 2) a saturable reactor, or 3) 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 the extent that the neutrals are essentially bonded. As discussed in the following section, under normal operation these devices will affect neutral-to-earth voltages on both the primary and secondary systems.

Low Voltage Lightning Arresters: Several types of conventional, low-voltage lightning arresters are being used for primary-secondary-neutral isolation. Since most of these gaps are designed as low-current devices, their use may be restricted to systems with appropriate limitations on fault currents.

Saturable Reactors: Saturable reactors designed to give an impedance-change threshold in the range of 10 to 24 V ac are also in use. Figure 4-12 shows the apparent impedance characteristics of three such devices as a function of the root means square (rms) voltage (Vrms) (60 Hz) across the device. Below saturation voltage, the high impedance provides isolation. Above saturation, the impedance drops to a very low level to provide neutral interconnection. As discussed below, when peak voltages are above the saturation threshold, part-cycle conduction will create a nonsinusoidal neutral-to-earth voltage on the secondary. These devices also include a lightning (surge) arrester to divert fast-rising transient voltages, such as lightning voltages. Such transients would otherwise create high voltages across the reactors.

Solid State Switch: 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. 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 arrester in parallel to assist in passing fast rising transients.

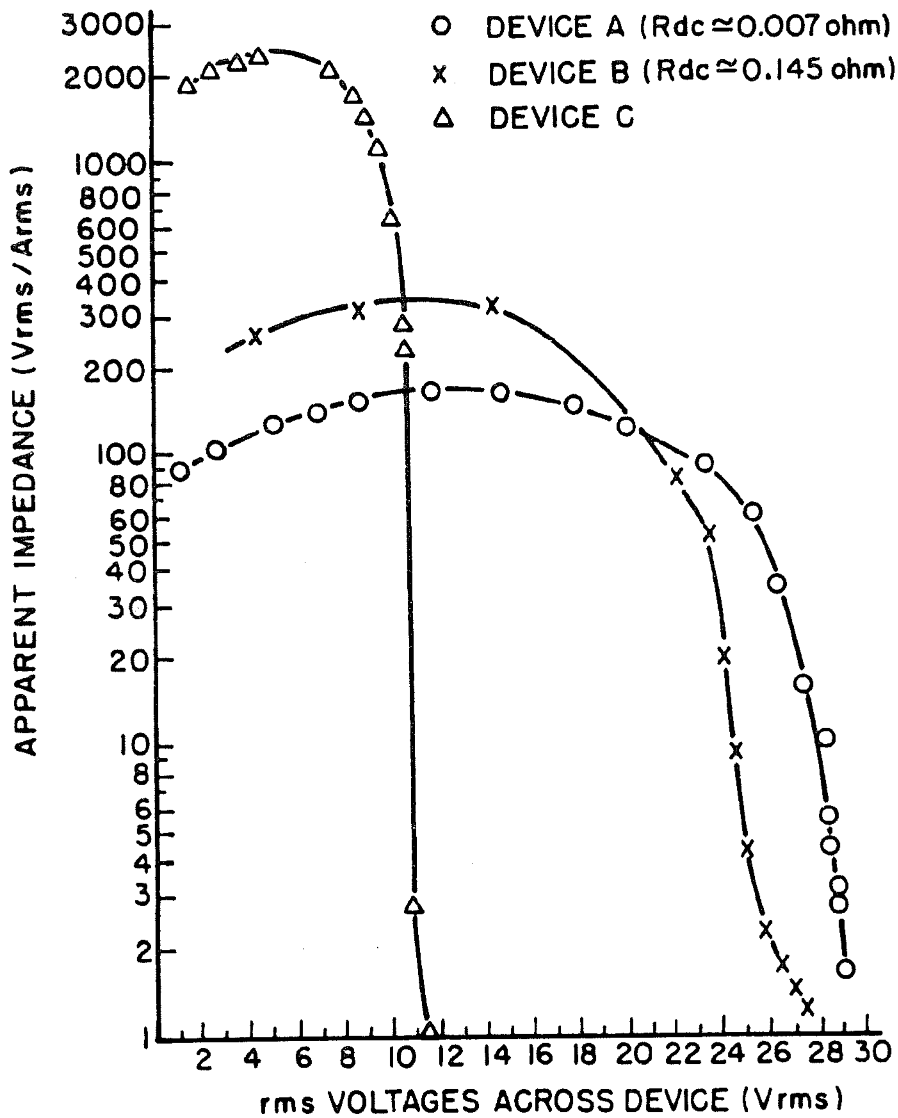


Figure 4-12. Apparent impedance characteristics of three saturable reactors, where Arms=rms amperages.

Characteristics During Part-Cycle Saturation or Triggering: Under certain conditions, the voltage between the grounded-neutral systems of the primary and secondary can saturate or trigger the isolation device during part cycles (Gustafson et al. 1985c). Such a condition can occur, for example, when a short-term large load (as from a large-motor start) is placed on the distribution system. The resulting voltages will cause partial saturation of saturable reactors or will create part-cycle closure of the solid state switch. Either action will lead to the development of a non-sinusoidal neutral-to-earth voltage on the secondary grounded neutral.

To demonstrate the characteristics of devices near saturation or a triggering level, the circuit shown in figure 4-13 was used. In the circuit, R_P repre-

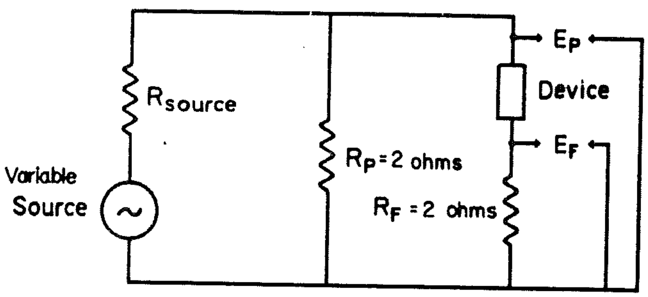


Figure 4-13. Isolation device test circuit. Values for E_P and E_F are shown in figure 4-14. (Subscripts P and F stand for primary and farmstead, respectively.)

sents the lumped resistance of the grounded-neutral system of the primary and R_F the lumped resistance of the grounded-neutral system of the farmstead. An analysis was made of rms and peak voltages and of the waveform under varying conditions at or near the saturation or triggering level. Figure 4-14 shows typical waveforms for the E_P and E_F. Figure 4-15 shows both the peak and rms values of E_F as a function of E_P for three saturable reactors. Human and animal sensitivity in the 60-Hz frequency range for this non-sinusoidal waveform is proportional to the peak current. Since most volt-ohm meters commonly used for monitoring and troubleshooting read average or rms values, they will not provide the necessary data on neutral-to-earth voltages occurring at or near the saturation or triggering level. A voltmeter that can detect peak voltages or an oscilloscope-type instrument will be needed.

Whole Farm Isolation With Isolating Transformer

Isolating transformers such as the transformer shown schematically in figure 4-16 have been used extensively in the past to create a separate grounded neutral system on the farmstead. In this system, a primary-to-secondary fault current in the distribution transformer is carried by the distribution system's neutral and grounding. An isolating transformer represents an investment in the range of $1,000 to $3,000, plus the cost of operating losses of the transformer. Care must be taken to ensure installation according to prevailing codes and recommendations, particularly for overcurrent protection, bonding, and grounding.

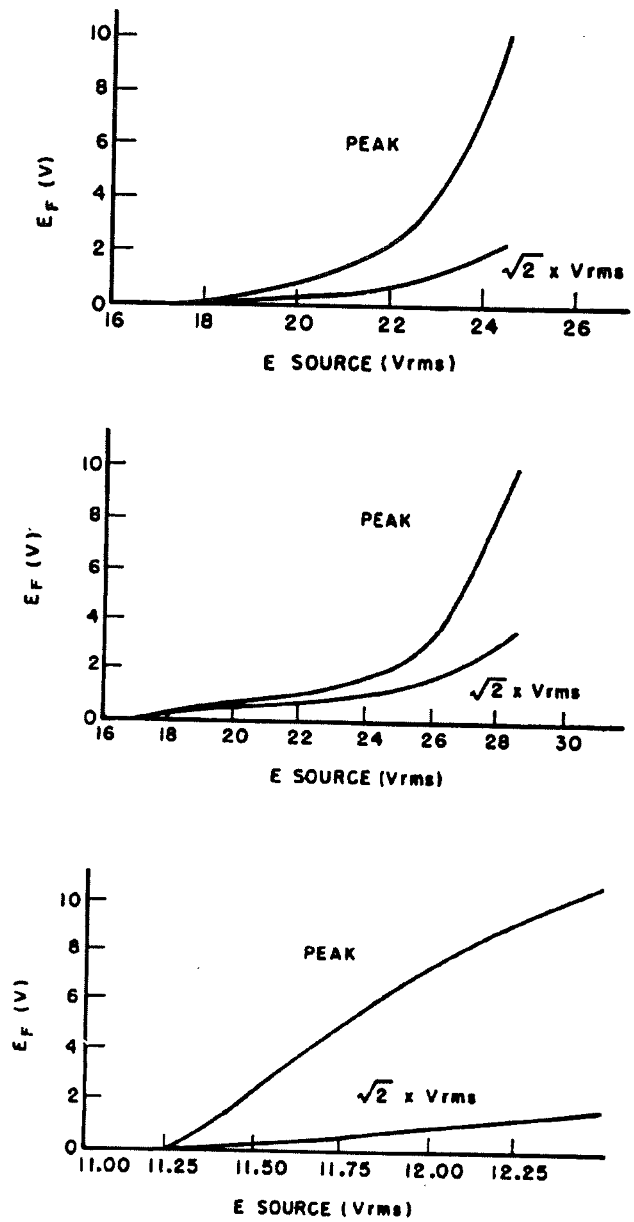
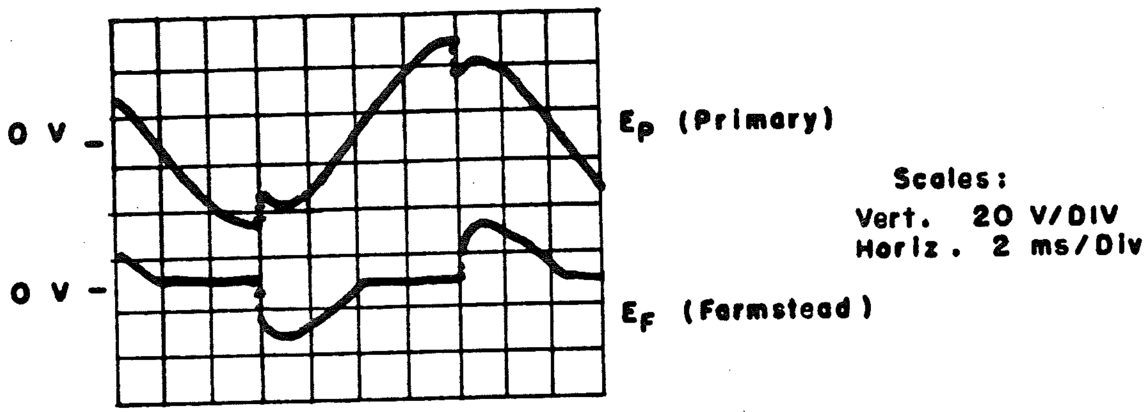
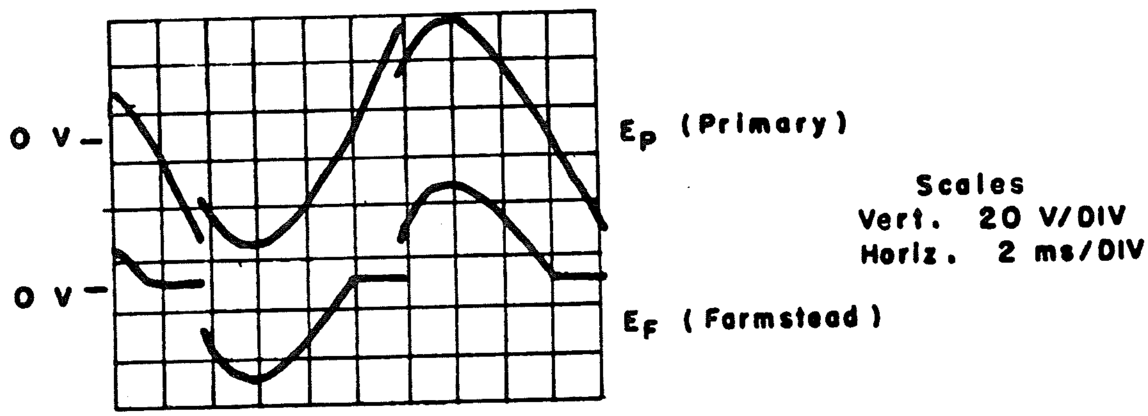


Figure 4-15. Peak and rms voltages vs. source voltage for three saturable reactors.



(a) Saturable Reactor



(b) Solid State Switch

Figure 4-14. Part-cycle saturation and triggering waveforms.

Single-Building-Service Isolation

If a satisfactory solution can be obtained by isolation of a single building service, an isolating transformer can be used for a single service as shown in figure 4-17. Depending on farmstead load, the transformer for the single service can be smaller and less expensive than a transformer for the entire farmstead. In this location, the transformer also eliminates secondary-neutral voltage drops from affecting the isolated system and minimizes the loss of system grounding to the remainder of the system. However, in many dairy facilities the principal system grounding may be associated with the services needing isolation. When an isolating transformer is installed, testing is necessary to verify that no conductive interconnections are bypassing the transformer. Common interconnections are telephone grounds, metallic gas or water pipes, metal feeders, fences, and connected metal buildings. Any conductive bypass will negate the isolation effect of the transformer.

A second approach to single service isolation has been developed by Ontario Hydro in cooperation with Hammond Electrical Industries of Guelph, Ontario, and is now approved for use in Canada. This approach (fig. 4-18) makes use of a saturating reactor for separating the grounded neutral conductors from the equipment grounding conductors, including the grounding electrode, at the building service entrance. Under normal conditions, the reactor acts as the large impedance of a voltage divider consisting of it in series with the building grounding system. Since potential fault currents on the secondary side are larger than those on the primary side (Gustafson et al. 1984a), the specifications for this application may be more stringent than for application of the same principle at the distribution transformer.

This approach has the advantage of low cost for the device. However, since its function is dependent on the complete separation of grounding and neutrals within the service and separation of grounding systems between services, installation may be difficult in some existing facilities.

Devices for this approach have not received listing by Underwriter's Laboratory for use in single service isolation. Their use for such a purpose has not been determined to be acceptable under the National Electrical Code; therefore their use in the United States cannot be recommended at this time unless approved by local electrical inspection authorities and only perhaps on a limited experimental basis.

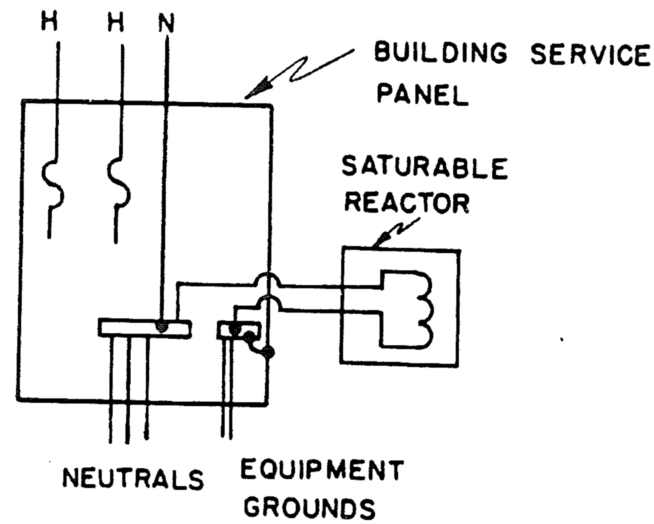


Figure 4-18. Saturating reactor application at a building service entrance.

Isolation of Grounded Equipment Within a Single Service

A new exception to general practice added to the 1990 National Electrical Code article on agricultural buildings (article 547) permits bonding of material, water piping, and other metal or piping systems to which electrical equipment requiring bonding is not attached or in contact with, by means of a listed impedance device. This approach may be most workable in stall- or stanchion-type facilities where no permanently installed electrical equipment is in the cow area. Effectiveness of the approach will require full separation of the isolated systems from other grounded equipment. The relative impedances of the device and the grounded equipment to earth will also control the effectiveness of this approach. The use of an impedance device is intended to place an additional impedance in series with the animal, thereby limit-

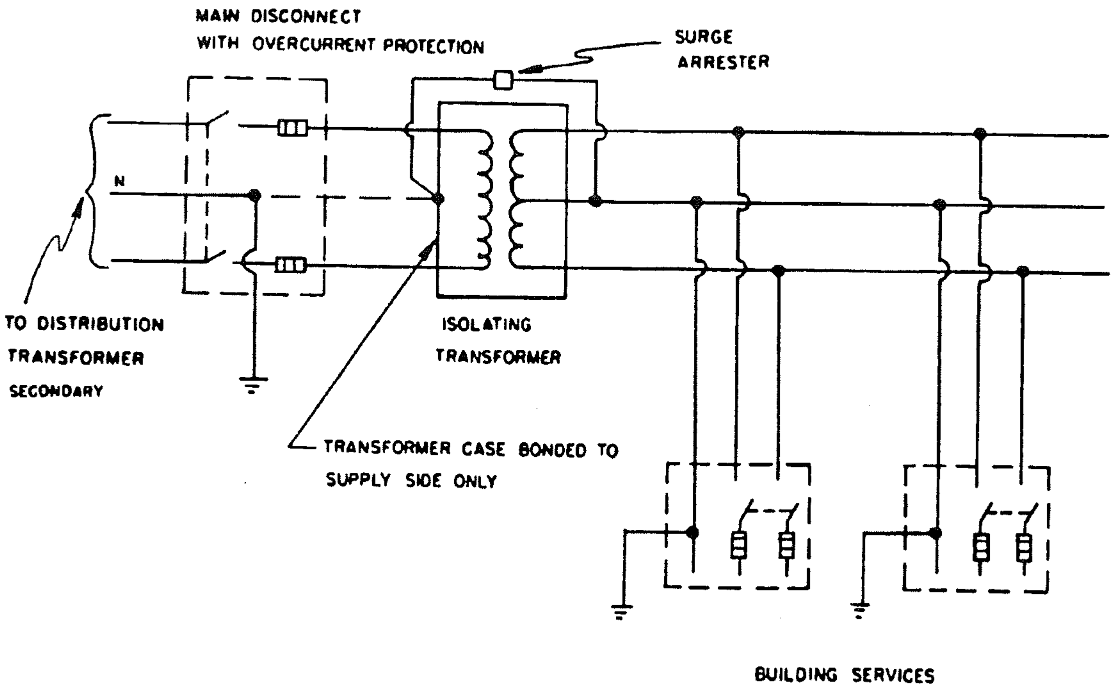


Figure 4-16. Isolating transformer installation, whole farmstead.

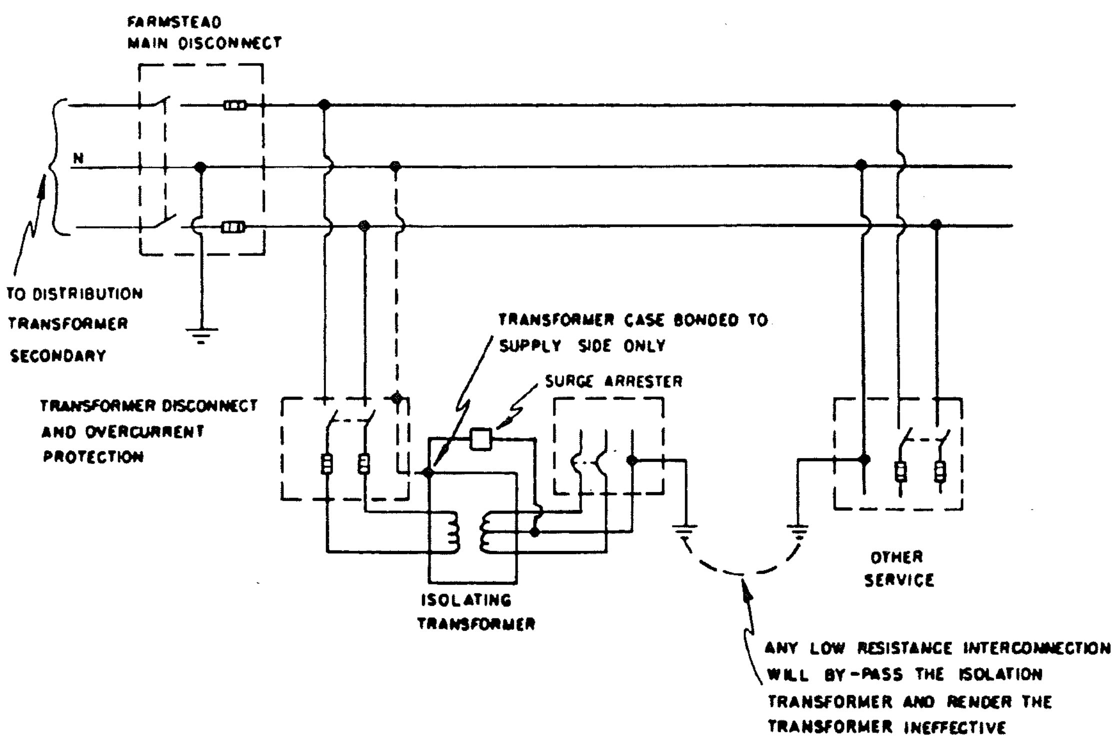


Figure 4-17. Isolation transformer installation, single service.

ing the current that any neutral-to-earth voltage on the system can force through the animal.

Conclusion

Four methods (voltage reduction, active suppression, gradient control, and isolation) are available for dealing with stray voltage/current problems. Since most on-farm sources of stray voltage/current can be adequately dealt with by improvement of wiring, grounding, load balancing, reduction of leakage, and elimination of faults (voltage reduction), the principal development work has been concentrated on methods for dealing with off-farm sources.

The most common off-farm source is the inherent impedance of the grounded-neutral system of the primary. Since it will not always be practical to lower the neutral impedance or primary grounding resistance to the extent of precluding the development of problem voltages for livestock, other measures for protecting livestock from stray voltage/currents are being explored. The on-farm techniques of voltage reduction, active voltage suppression, gradient control, and isolation are options which can be considered. Further work is needed to help the electrical industry develop and select appropriate approaches that meet the needs of specific situations.

There are also situations in which electrical problems on adjacent farms or residences can affect the distribution primary's neutral-to-earth voltage at a farm. These situations are due to the common interconnection of secondary neutrals to the primary neutral at each of the farms or residencies. Identification and mitigation of these problems at other locations may solve a neutral-to-earth problem at a specific farm.

Appendix: Examples

Understanding the characteristics of various voltage problems, their interactions, and the effect of corrective procedures can be enhanced through the use of circuit models. Gustafson and Hansen (1985) developed two personal computer programs useful in the analyses of single-phase, multigrounded distribution and farmstead systems. The programs use resistive models to simulate systems with a single-phase multigrounded primary serving 120/240-V single-phase farmsteads. Examples 1 and 2, below, are used to demonstrate electrical characteristics discussed within this chapter.

Other models have been developed with slightly different circuit parameters. However, the principles demonstrated and results obtained are similar to those of examples 1 and 2.

Example 1. Single-Phase Distribution Line

Neutral-to-earth voltages (voltages across R_{Gi}) for a series of cases based on a model with a single-phase distribution line and certain assumed parameters are shown in figure 4-A1.

Case 1P — Base-Case
In case 1P, the base-case neutral-to-earth voltages are due strictly to the loading of the distribution system (fig. 4-A2).

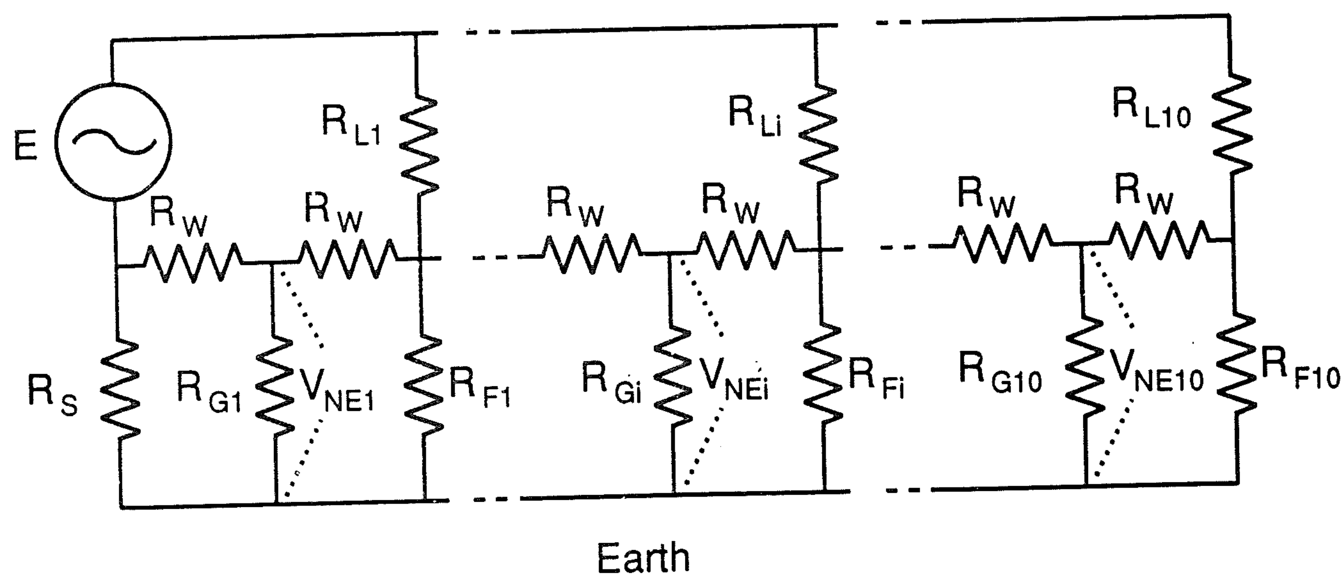


Figure 4-A1. Ten-farm, single-phase-line model, where

- E = Substation voltage source: 7,200 V
- R_{Li} = Load on farm i: Farms 1, 3, 5, 7, 9 at 30 A at 240 V; Farms 2, 4, 6, 8, 10 at 60 A at 240 V
- R_{Fi} = System grounding on farm i: 1.5 ohms/farm
- R_{Gi} = Primary system grounding: Equivalent to four 25-ohm grounds/mile
- R_W = Neutral conductor resistance: Equivalent to #6 copper wire and 1,300 ft between farms
- R_S = Substation grounding resistance: 0.25 ohm
- V_{NEi} = Neutral-to-earth voltage on farm i.

Case 2P — Isolation of Farm 6

Case 2P demonstrates the effect of isolation of a single farm near the middle of the line, farm 6, with a 250-ohm isolating device. The value (neutral-to-earth voltage) shown at farm 6 would be on the primary side of the transformer. Due to isolation, the voltage on farm 6 would be independent of this value (fig. 4-A2).

Case 3P — Isolation of Farms 5, 6, and 7

Case 3P demonstrates the effect of also isolating the two farms on either side of farm 6 (fig. 4-A2).

Case 4P — Isolation of Farms 6, 7, and 8

Case 4P demonstrates the effect of isolation of three farms at slightly different locations along the line (fig. 4-A2).

Case 5P — 5-A Fault to Earth on Farm 6, 180 Degrees Out of Phase With Primary

Case 5P introduces a 5-A fault to earth on farm 6, without isolation, from the secondary phase leg 180 degrees out of phase with the primary. In this case the voltage at farm 6 is increased by 2 V. Increases in voltage diminish in magnitude on both sides of farm 6 (fig. 4-A3).

Case 6P — 5-A Fault to Earth on Farm 6, In Phase With Primary

Case 6P introduces a 5-A fault to earth on farm 6, without isolation, from the secondary phase leg in phase with the primary. In this case the voltage at farm 6 is reduced to near zero. Voltage increases with distance in both directions from the farm. This cancellation effect is the same as would be accomplished by current from the voltage suppression device discussed earlier (fig. 4-A3).

Case 7P — Isolation of Farm 6 With an On-Farm Fault

Case 7P demonstrates that when a fault occurs on an isolated farm, its effect on the distribution system is to add another 120-V load on the transformer. A comparison of cases 7P and 2P shows that the results are not distinguishably different for the distribution line. However, as shown in example 2, isolation will have a significant effect on the on-farm contribution to the neutral-to-earth voltage of fault currents (fig. 4-A3).

Cases 8P, 9P, and 10P — Bad Connectors in Primary Neutral

Cases 8P, 9P, and 10P show the effect of placing one 5-ohm bad connector at one of three different locations along the distribution line (fig. 4-A4).

Cases 11P, 12P, and 13P — Voltage Suppression by Current Device

Cases 11P, 12P, and 13P show the effect of active current suppression at one of three locations along the distribution line (fig. 4-A5).

Cases 14P and 15P — Primary-Grounding-System Changes

Cases 14P and 15P show the effect of additional grounding of the primary system. For case 14P, grounding was increased from four grounds per mile at 25 ohms each, to eight grounds per mile at 12.5 ohms each. At farm 6, for example, this increase in grounds reduced the voltage by 0.3 V, or 13 percent. In contrast, raising the farmstead ground resistance from 1.5 ohms to 3.0 ohms raised the voltage at farm 6 by 1.6 V, or 77 percent (fig. 4-A6).

Example 2. Single-Phase Farmstead

Neutral-to-earth-voltage solutions for a series of cases based on the farmstead shown schematically in figure 4-A7 are given in table 4-A1. These solutions were obtained by using the program described by Gustafson and Hansen (1985).

Case 1F — Base Case

In case 1F, the base case, neutral-to-earth voltages are due to the combination of primary system loading and secondary-neutral voltage drops.

Case 2F — Farmstead Isolation

Case 2F shows the results of isolation on the primary-system voltage rises. The only neutral-to-earth voltages remaining on the farm are a result of the secondary-neutral voltage drop. Due to the phase of the imbalance current in the secondary neutral, the neutral-to-earth voltage at building 3 is 180 degrees out of phase with the neutral-to-earth voltage at the primary.

Case 3F — Bad Secondary-Neutral Conductor

Case 3F demonstrates the effect, without isolation, of a 0.35 ohm resistance (as might occur due to a bad connector) in the neutral to building 3. The resistance increases the magnitude of the neutral-to-earth voltage at building 3.

Case 4F — Bad Connector With Isolation

If the system with the bad connector is isolated, case 4F, a large component of the secondary-voltage drop is seen at building 3, increasing the magnitude of the neutral-to-earth voltage at building 3.

Case 5F — Ground Fault From the In-Phase Leg

For case 5F, a 3-A fault, which is in phase with the primary, from the hot conductor to the earth is added to the base case loading. The fault current creates a voltage 180 degrees out of phase with the neutral-to-earth voltage created by the nonfault loading. With the fault current effect superimposed on the base case voltages, the resultant voltages are lower in magnitude than the base case voltages.

Case 6F — In-Phase Fault With Isolation

In case 6F, (which is like case 5 but with isolation), all neutral-to-earth voltages increase, and all secondary neutral-to-earth voltages are out of phase with the primary.

Case 7F — Ground Fault From the Out-of-Phase Leg

In case 7F, a 3-A fault from the hot conductor 180 degrees out-of-phase with the primary is added to the base case loading. The fault-created current is in phase with the load currents; therefore, all voltages increase in magnitude.

Case 8F — Out-of-Phase Fault With Isolation

Case 8F shows that the addition of isolation to case 7F has little effect on the magnitude of the voltages. On the secondary, the increase in neutral-to-earth voltage due to the fault current nearly offsets the removed neutral-to-earth voltage from the primary. On the primary side, the increase in neutral-to-earth voltage due to removal of farm grounding nearly offsets the neutral-to-earth voltage resulting from the on-farm fault current.

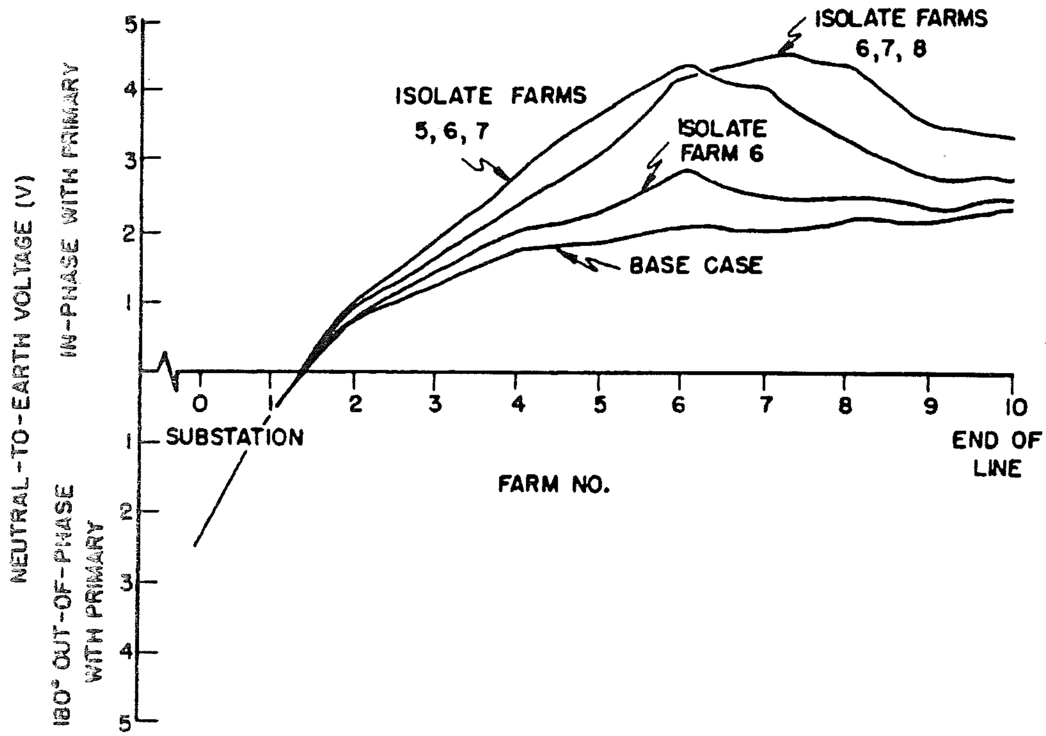


Figure 4-A2. Ten-farm model, nonfault examples.

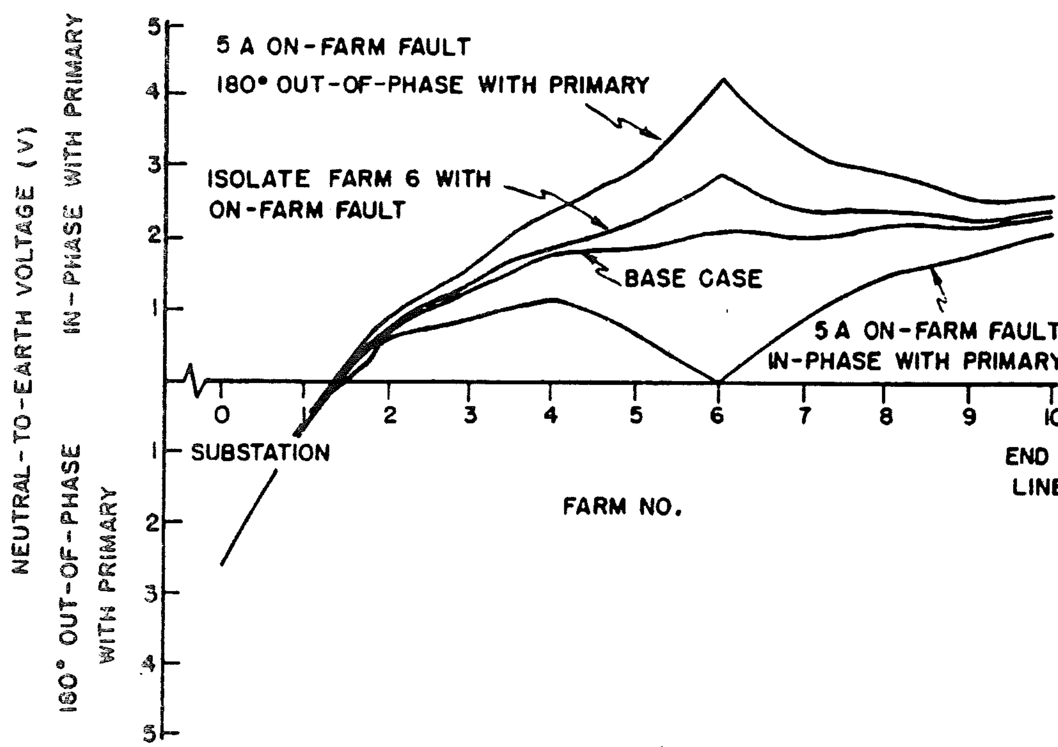


Figure 4-A3. Ten-farm model, fault-to-earth examples.

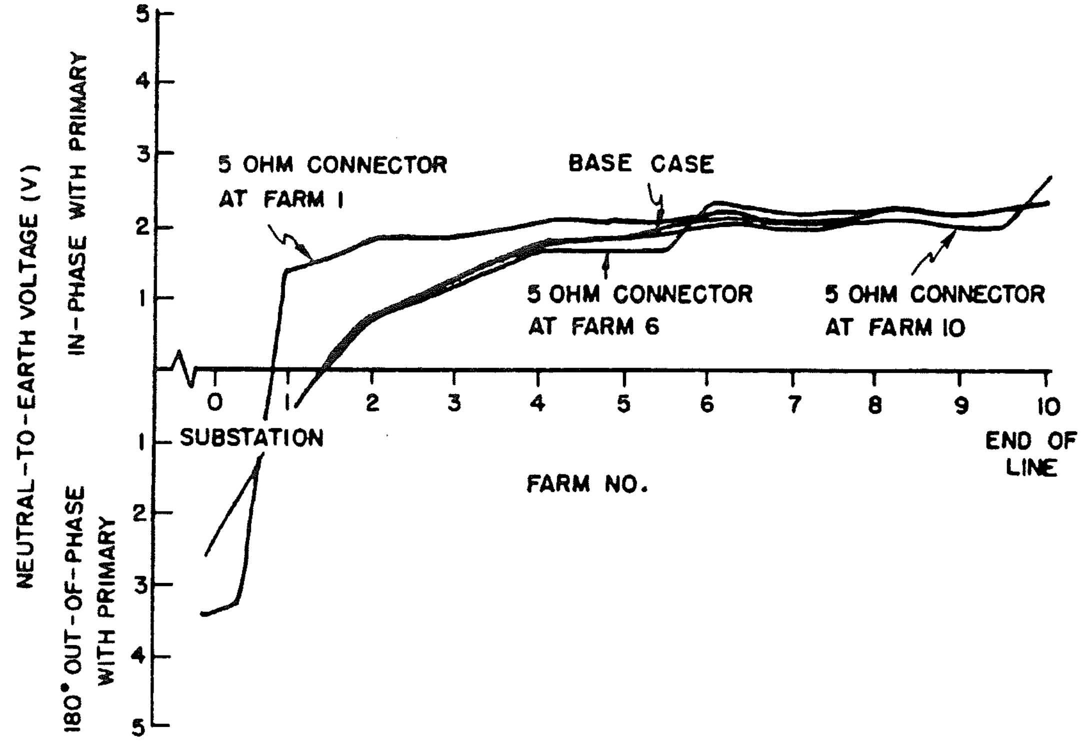


Figure 4-A4. Ten-farm model, bad-connector examples.

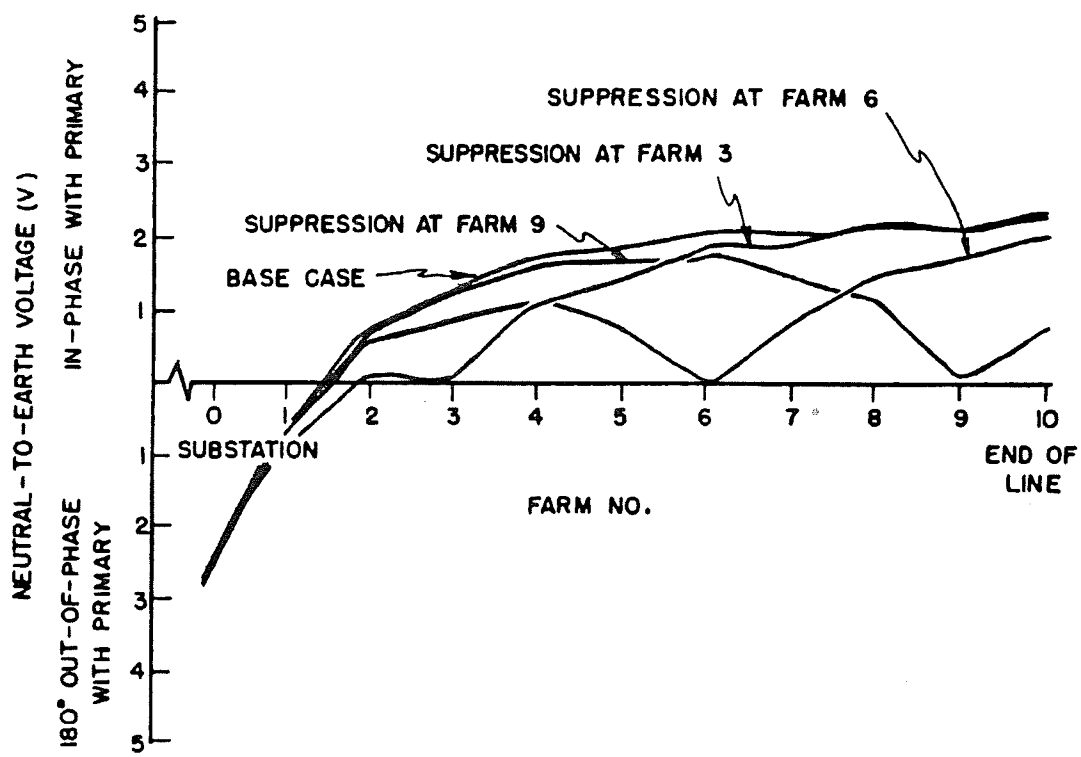


Figure 4-A5. Ten-farm model, voltage suppression at a selected location.

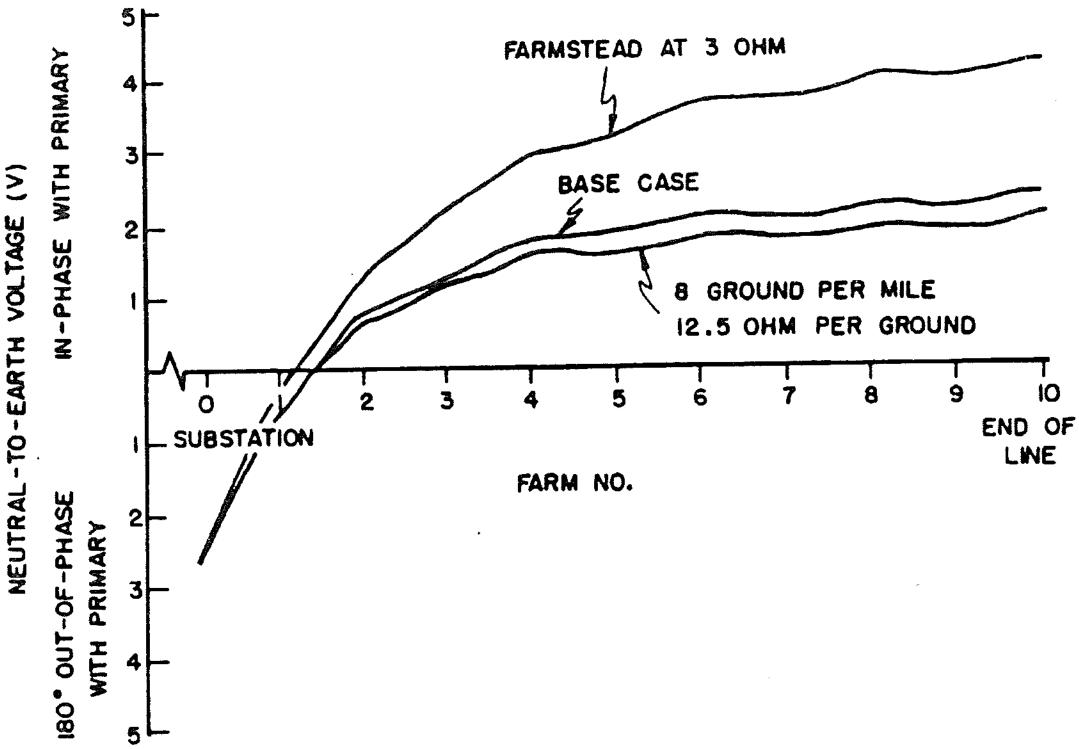


Figure 4-A6. Ten-farm model, modified system resistance.

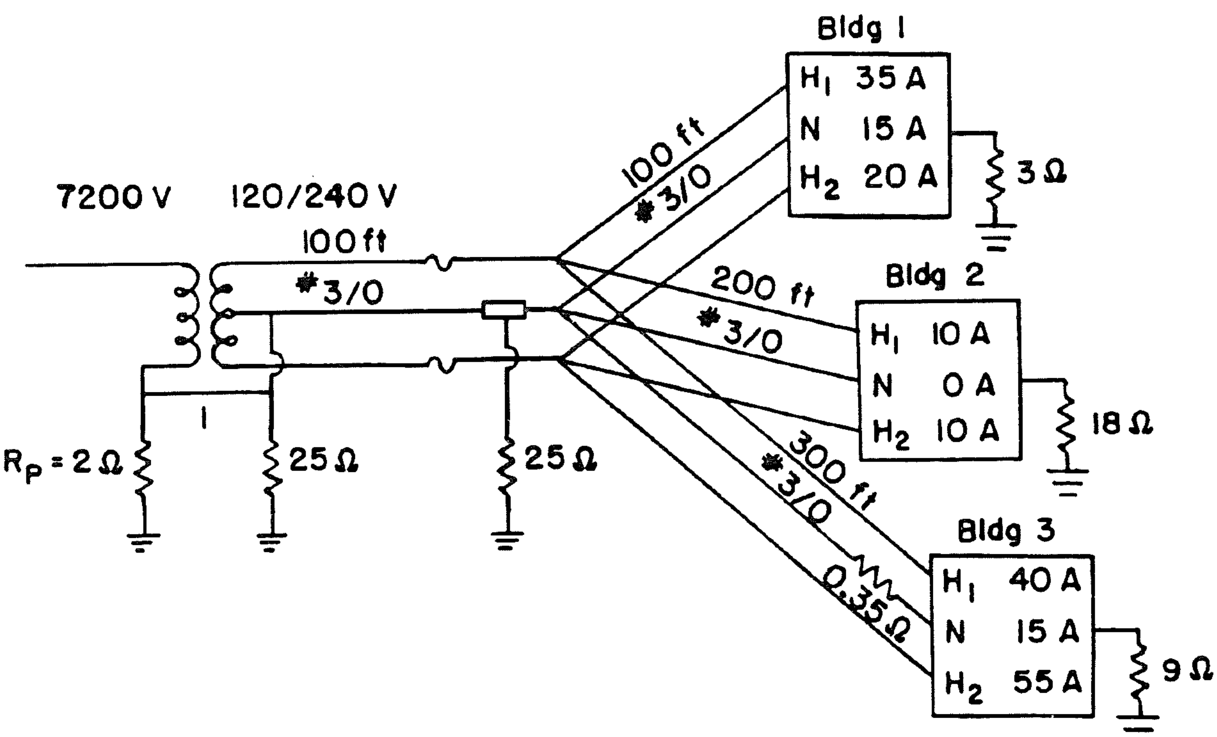


Figure 4-A7. Example farmstead system.

Table 4-A1. Neutral-to-earth voltages for single-phase farmstead cases, based on model shown in figure 4-A7

Case	Neutral-to-earth voltages					
	T-pole P side	T-pole S side	Yard pole	Bldg. 1	Bldg. 2	Bldg. 3
1F Base	2.63	2.63	2.62	2.77	2.61	2.14
2F P-S isolation	5.62	0.04	0.04	0.19	0.04	0.44[1]
3F 0.35-ohm bad connector, bldg. 3, no isolation	3.16	3.16	3.15	3.29	3.14	2.47[1]
4F Bad connect., with isolation	5.63	1.00	1.00	1.16	1.00	4.53[1]
5F 3-A fault, inphase, bldg. 3, no isolation	0.15[1]	0.15[1]	0.14[1]	0.01	0.148	0.71[1]
6F Inphase fault, with isolation	5.58	5.12[1]	5.09	4.92[1]	5.09[1]	5.65[1]
7F 3-A fault, out of phase, bldg. 3, no isolation	5.42	5.42	5.38	5.52	5.38	4.98
8F Out of phase fault, with isolation	5.66	5.20	5.17	5.31	5.16	4.77

[1]180 degrees out of phase with primary hot conductor.

ces. These past recommendations need to be reviewed in light of recent research on the economic impact of electrical currents. Recent research indicates that there are no direct changes in production, reproduction, or animal health for currents below 6 mA. Furthermore, no evidence has been found that such currents adversely affect the levels of hormones naturally released during milking and stress. Currents between 3 and 6 mA do elicit some moderate behavioral changes that might require an additional investment of time from the dairy operator. Using the estimates for worst case and realistic impedances, these currents translate to voltages of 1.5 to 6 V. However, it also appears that the large majority of cows probably do not demonstrate problem behaviors until voltages are above 3.0 to 4.0 V. Direct economic effects, including reductions in milk yield, have been shown for a small percentage of cows (7 percent) at voltages of 4.0 V and above.

In addition, experiments involving long term (full lactation) exposures of cows have shown that cows quickly became acclimated both physiologically and behaviorally to constant and intermittent currents below 6 mA.

Mitigation

Mitigating existing stray voltage/current problems and preventing their future development demand careful consideration of the electrical sources and the characteristics of the corrective and preventetive procedures or devices that might be used, including their costs. Effects of any mitigation technique on the electrical power distribution system under normal and fault conditions must be considered. Approaches for controlling neutral-to-earth voltages are outlined below and discussed in detail in chapter 4 of this handbook.

Voltage Reduction

If analysis shows a troublesome level of neutral-to-earth voltage due to such conditions as 1) high-resistance neutral or grounding connections (either on or off the farm), 2) neutral imbalance currents on or off the farm, 3) undersized neutrals, and 4) fault currents to earth or to equipment grounding conductors, corrections can be made and the remaining voltage assessed.

Four-Wire System

If the farmstead system contains long secondary neutrals, an option of using a four-wire service to a building is allowed by the National Electrical Code. In a four-wire system, the grounding bus is not connected to the neutral bus at a building service; a fourth wire is used to carry the ground back to the primary service where the grounding and neutral buses *are* connected and grounded to earth. The four-wire system will reduce the contribution of the secondary neutral drop to the neutral-to-earth voltage at the building service.

Active Voltage Suppression

Since voltage is produced by current flow through a system impedance, a second source of current can be used to null or cancel the original source at a point in the system. One way to mitigate neutral-to-earth voltage is to deliver a controlled current to earth. Voltage between a point in the neutral/grounding system and an isolated reference ground or grounds is used as the input to a differential amplifier. Current delivered to a remote-grounding-electrode system is then adjusted to null out the measured neutral-to-earth voltage.

Gradient Control

Gradient control by equipotential planes will negate the effects of all neutral-to-earth 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 (foot to foot) and touch (hand to foot) potentials under fault conditions at substations and around electrical equipment. In addition to protecting people, animals, and equipment under fault or lightning conditions, properly installed equipotential systems in livestock facilities can solve stray voltage/current problems.

Equipotential Plane

The definition of the equipotential plane is derived from two words. Equipotential means having the same electrical potential throughout; plane means a flat or level surface. Together they form a level surface having the same electrical potential throughout. Any animal standing on a properly installed equipotential plane will have all possible contact points at or very near the same electrical potential.

A properly installed equipotential plane must include all of the following: 1) Equipment grounding, 2) metalwork bonding, and 3) a conductive network in the floor bonded to the electrical system grounding. It may also require entrance and exit transition ramps.

Voltage Ramp

An animal may receive a shock when it steps onto or off an equipotential plane from or to an area beyond the perimeter. A properly constructed voltage ramp will reduce the magnitude of the current flow through the animal by providing a more gradual change in voltage at the perimeter of the plane. The voltage difference between the animal's front and rear hooves cannot be totally eliminated as it moves on or off the plane; however, the difference can normally be reduced to an acceptable level.

New Construction

All concrete floors installed in new or remodeled confinement livestock facilities should include an equipotential plane.

Retrofitting Existing Facilities

There are two practical ways to retrofit existing facilities with equipotential systems. One way is to fabricate the equipotential plane over the existing floor in the facility and pour a 2-inch overlay of concrete. Where possible, retrofitting with a complete system and overlaying with concrete is recommended.

Alternatively, it is possible to saw grooves in an existing concrete floor and grout in copper conductors, electrically interconnect the conductors and the metalwork in the facility, and then equipment ground the entire system to the service entrance.

Isolation

The term "isolation" is used to mean the electrical separation of all or a portion of the grounded neutral system of a farmstead from the remainder of the system. Isolation of part of the grounded neutral system can prevent neutral-to-earth voltage on the nonisolated portion of the system from accessing the animals. Isolation can be accomplished on a conventional multigrounded system 1) ahead of the farm main service (whole farm isolation), or 2) at the livestock building (single service isolation). Careful consideration must be given to the safety and operational effects if isolation is used.

Whole Farm Isolation

Whole farm isolation can be accomplished 1) by isolation at the distribution transformer or 2) with an isolation transformer following the distribution transformer. In all cases some system grounding will be removed from the distribution system, at least during nonfault conditions; and the removal can affect both on-farm and off-farm sources of neutral-to-earth voltage (chapter 4, "Mitigation").

Available Devices for Neutral Isolation

- Several types of conventional low-voltage lightning arresters are being used for neutral isolation. Since most of these devices have low-current capacities, their use may be restricted to systems with appropriate limitations on fault currents.

- Saturable reactors designed to give an impedance-change threshold in the range of 10 to 24 Vac are also in use. Below saturation voltage, the high impedance provides isolation. Above saturation, the impedance drops to a very low level to provide neutral interconnection.

- 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 50/60-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 arrester in parallel to assist in passing fast rising transients.

- Isolating transformers have been used extensively in the past to create a separate grounded neutral system on the farmstead. In this system, a primary-to-secondary fault current in the distribution transformer is carried by the distribution system's neutral and grounding. An isolating transformer represents an investment in the range of $1,000 to $3,000, plus the cost of operating losses of the transformer. Care must be taken in proper installation to meet prevailing codes and recommendations, particularly for overcurrent protection, bonding, and grounding.

Single Building Service Isolation

If a satisfactory solution can be obtained by isolation of a single building service, an isolating transformer can be used. Depending on farmstead load, the transformer for the single service can be smaller and less expensive than a transformer for the entire farmstead.

Isolation of Grounded Equipment Within a Single Service

A new exception to general practice added to the 1990 National Electrical Code article on agricultural buildings (article 547) permits bonding of material, water piping, other metal or piping systems to which electrical equipment requiring bonding is not attached or in contact with, by means of a listed impedance device. This approach may be most workable in stall- or stanchion-type facilities where no permanently installed electrical equipment is in the cow area. Effectiveness of the approach will require full separation of the isolated systems from other grounded equipment. The relative impedances of the device and the grounded equipment to earth will also influence the effectiveness of this procedure. The use of an impedance device is intended to place an additional impedance in series with the animal, thereby limiting the current that any neutral-to-earth voltage on the system can force through the animal.

Detection and Measurement

Simple cases of stray voltage can be detected by persons with minimal electrical experience if they select the appropriate equipment and adhere strictly to the detection procedures outlined in this handbook. However, identifying the source of a stray voltage can require considerable expertise. Also, detailed knowledge of the farm and local distribution electrical systems is often needed to determine appropriate mitigation techniques.

Because of these constraints, we recommend that voltage and current measurements related to stray voltage investigations be made by persons knowledgeable about farm electrification, instrument characteristics, and proper measurement procedures and capable of properly interpreting the measured values.

Warning

Electrical systems can be dangerous. Identification and, particularly, diagnosis of stray voltage problems can require considerable electrical expertise. That is not to say that the input of farmers is not necessary and valuable. Often, the input and observations of people in daily association with a stray voltage/current problem are critically important to its solution. *However, electrical systems can be dangerous. Persons without special training should never attempt investigation of the electrical distribution or farm electrical systems.* For example, persons without special training should never open electrical service panels nor should they even contemplate altering any wiring.

Using a voltage measuring device with well insulated probes to measure voltages between possible points of animal or human contact should not result in a safety hazard with one important exception. Voltages that cause stray voltage/current problems are normally so low that they cannot be detected without special instruments. If an electrical shock can actually be felt or if animals are knocked down, a possible hazard to life exists. The device or electric circuit responsible for the