



SCC DIAGNOSTICS TOOL BOX



R-EF-11: Stray Voltage Problems with Dairy Cows

H.A Cloud, R.D Appleman, and R.J Gustafson
Minnesota Extension Service, University of Minnesota, St. Paul
AG-BU-1359, Revised 1987

CONTENTS	<i>Page</i>
Introduction.....	1
Symptoms	1
Behavior Modification	1
Milking Characteristics	2
Production Performance	2
Potential Stray Voltage Sources	2
Primary Neutral Current External to the Farm	4
Primary Neutral Current From On-Farm Loads	4
Secondary Neutral Current in the Farmstead Wiring System	4
Fault Currents on Equipment Grounding Conductors	6
Improper Use of Neutral Conductor	6
Grounded Fault Currents	7
Induced Voltages	7
When can Stray Voltage Be a Problem?	8
Standardized Measurements	9
Screening Procedure	10
Diagnostic Procedures	12
Basic Data	12
Voltage Testing Set-up	12
Detailed Diagnostic Procedures	14
Solutions to the Problem	17
Voltage Reduction	17
Elimination or Reduction of Sources	17
Active Voltage Suppression	18
Gradient Control	19
Equipotential Planes	19
Transition Ramps	19
Isolation	20
Whole Farm Isolation	20
Available Devices at Transformer	20
Isolating Transformers	21
Single Building Service Isolation	22
APPENDIXES	23
I. Testing Equipment	
II. Electrical Grounding	
III. References for Further Study	

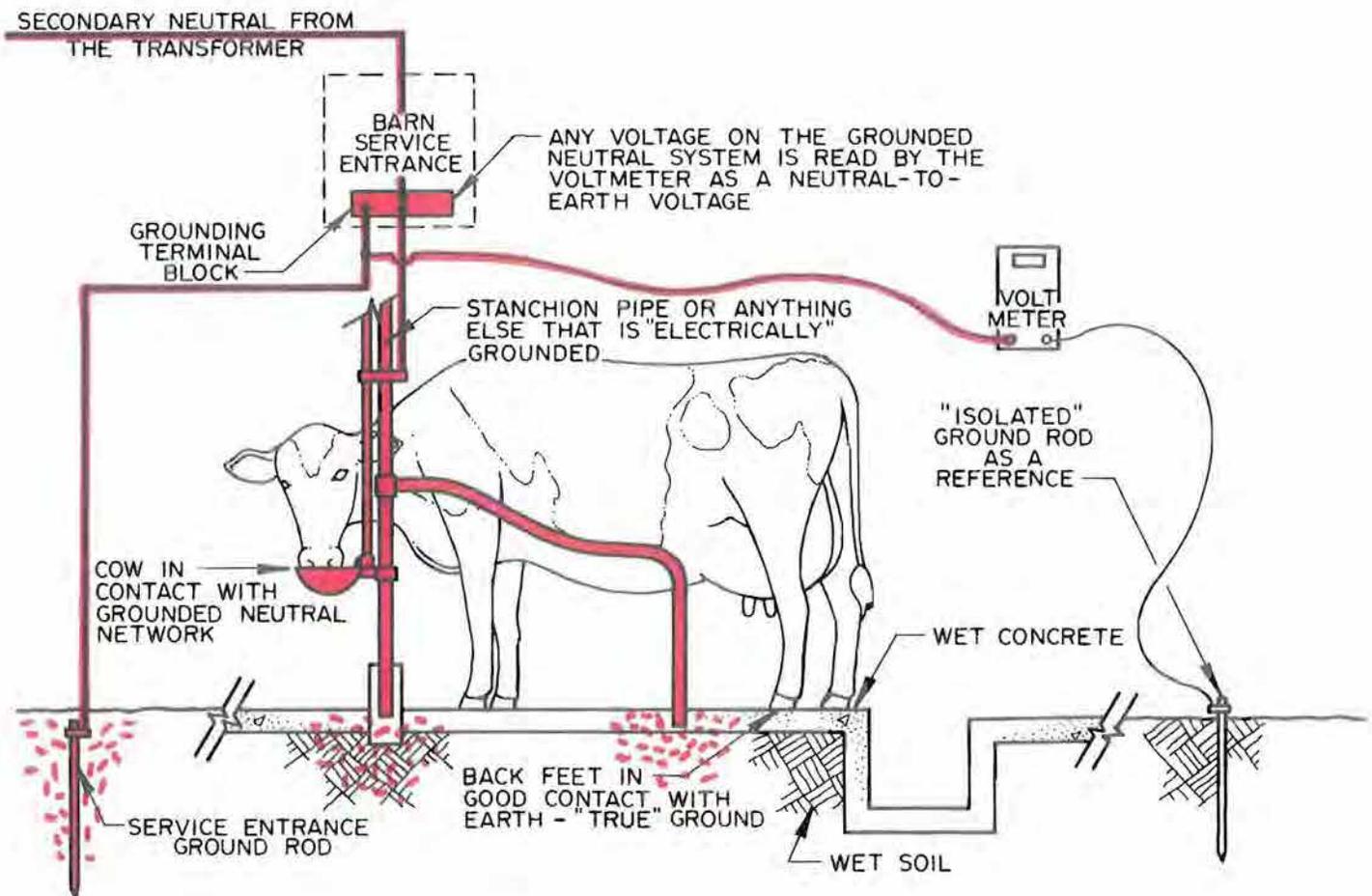


This document was revised December 2011 for use in University of Minnesota Quality Count\$ programs This material is intended for educational use only and may not be altered in any way but may be reproduced with permission of University of Minnesota Extension Dairy Team.

STRAY VOLTAGE PROBLEMS WITH DAIRY COWS

H. A. Cloud, R. D. Appleman, and R. J. Gustafson

Figure 1. A dairy cow subjected to a neutral-to-earth (N-E) voltage



STRAY VOLTAGE PROBLEMS WITH DAIRY COWS



INTRODUCTION

Stray voltages are causing serious problems in certain dairy operations and other confinement livestock systems. Dairymen are losing milk production and are experiencing cow behavior and cow health problems due to small electrical currents passing through the cows' bodies. The voltages are known by several names, including tingle voltage, neutral-to-earth (N-E) voltage, neutral-to-ground voltage, and extraneous voltage. The problem stems from excessive voltage between two animal contact points.

The concept of stray voltage is relatively simple electrically, though the sources can be varied and complex. These voltages may be caused by poor or faulty wiring, faulty equipment, improper grounding, or they may result from the small voltages required to move current through the grounded neutral system. 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, we believe that with a good understanding of: 1) stray voltage sources and their interactions and 2) the sensitivity of animals to electrical currents, stray voltage problems can be analyzed and corrected in existing facilities and prevented in new constructions. This publication is intended to explain the stray voltage problem, describe how to determine if potential for a problem exists in your dairy operation, describe how to determine sources of the problem, and give recommendations on how to correct the problem.

SYMPTOMS

Reactions of animals subjected to stray voltages vary, depending on the pathway through animals and the magnitude of voltage. There are three general classifications of symptoms, related to: 1) behavior modification, 2) milking characteristics, and 3) production performance. It must be remembered, however, that many factors other than stray voltages may cause herd behavior or 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.**

Behavior Modification

Both controlled research and observation on problem farms clearly shows that animals subjected to stray voltages are likely to exhibit a change in behavior. The following are the most common symptoms.

1. Cows Excessively or Unusually Nervous in the Milking Parlor or Stall Barn at Milking Time

This trait often is characterized by cows dancing or stepping around while in the stall. If this behavior is caused by stray voltage, it is usually due to a voltage between the stall pipes (which the cow touches) and the concrete floor (on which the cow is standing). However, dairy farmers are reminded that cows may become nervous for other reasons, such as malfunctioning milking equipment (too high vacuum or inappropriate pulsation ratios) or operator abuse. Even a change in milking routine may result in cows temporarily appearing nervous.

2. Cows must be Chased into the Parlor and/or Rapid Flight from the Parlor

When cows are subjected to stray voltages in the parlor stalls, they soon become reluctant to enter the parlor. In extreme cases, nearly all cows have to be driven into the parlor and they may have a tendency to "stampede" out upon release. But again, this symptom is not specific to stray voltage problems because cows may be trained to expect the parlor operator to chase them into the milking stalls.

3. Increased Number of Defecations and/or Urinations in the Milking Parlor

It is well documented that nervous cattle will excrete body wastes more frequently. These phenomena may be caused by a stray voltage problem, or other causes, including operator abuse, presence of strangers, change to green feed from dry roughages, etc.

4. Reluctance of Animals to Consume Water or Feed

Reduced intake of water and/or feed due to stray voltage problems may occur with any class of livestock. Documented cases include dairy and beef cattle, swine, and poultry. The problem may be general throughout the farmstead, or only at a specific waterer or feeding location. Generally speaking, higher voltages are required to limit water or feed consumption than to alter the other behavioral characteristics discussed previously. A rather specific symptom indicative of a probable stray voltage problem is the uncharacteristic "lapping of water" during animals' attempts to meet their demand for water. Farmers must recognize, too, there are other causes for these symptoms, especially a sudden change in water quality, the feeding of spoiled or unpalatable feeds, sickness, etc.

Milking Characteristics

Poor milk letdown, incomplete milkout (leaving abnormal amounts of residual milk in one or more quarters), and increased milking time are common

symptoms expressed by dairy farmers having stray voltage problems. The mechanism of how this occurs isn't fully understood. Researchers haven't been successful in identifying any significant hormonal changes. However, researchers have demonstrated that the milking machine hose, even under high flow rates, is not a likely pathway for electrical currents to the cow.

5. Poor Milk Letdown and Incomplete or Uneven Milkout

The number of cows affected and the severity of the milk letdown problem appears to be dependent on the level of stray voltage present. When affected cows are moving or stepping about during the milking process, it is difficult to keep the milking unit properly aligned and adjusted to provide an even weight distribution necessary to promote fast, effective milkout. On the other hand, a damaged teat canal may result in one quarter being consistently slow to milk out.

6. Increased Milking Time

If the stray voltage problem is severe enough to affect cows' behavior, milkout may be influenced. This problem can result in additional time needed for milking.

Production Performance

Although stray voltage has not been shown to have a direct physiological effect on cows, severe behavioral responses will complicate management practices. As a result, labor efficiency and profitability may be lowered.

7. Increased Somatic Cell Count and More Clinical Mastitis

Mastitis, whether clinical or sub-clinical (indicated by high somatic cell counts), is the result of a bacterial infection of the mammary gland. Such infections aren't directly caused by stray voltages. However, if cows' behavior is modified, and if the milking routine is altered because of the change in cows' behavior, what may result is a less satisfactory milking performance, increased somatic cell counts, and more clinical mastitis.

8. Lowered Milk Production

If cows drink less water, consume less food, or become more mastitic, they are likely to produce less milk. Whether or not milk production will be adversely affected by stray voltage depends on the extent to which the cows' behavior is altered and how management compensates. When stray voltage problems were corrected, milk production per cow on some farms increased as much as 3,500 pounds per cow per year. On the other hand, improvement in milk production is not always apparent after a stray voltage problem is corrected.

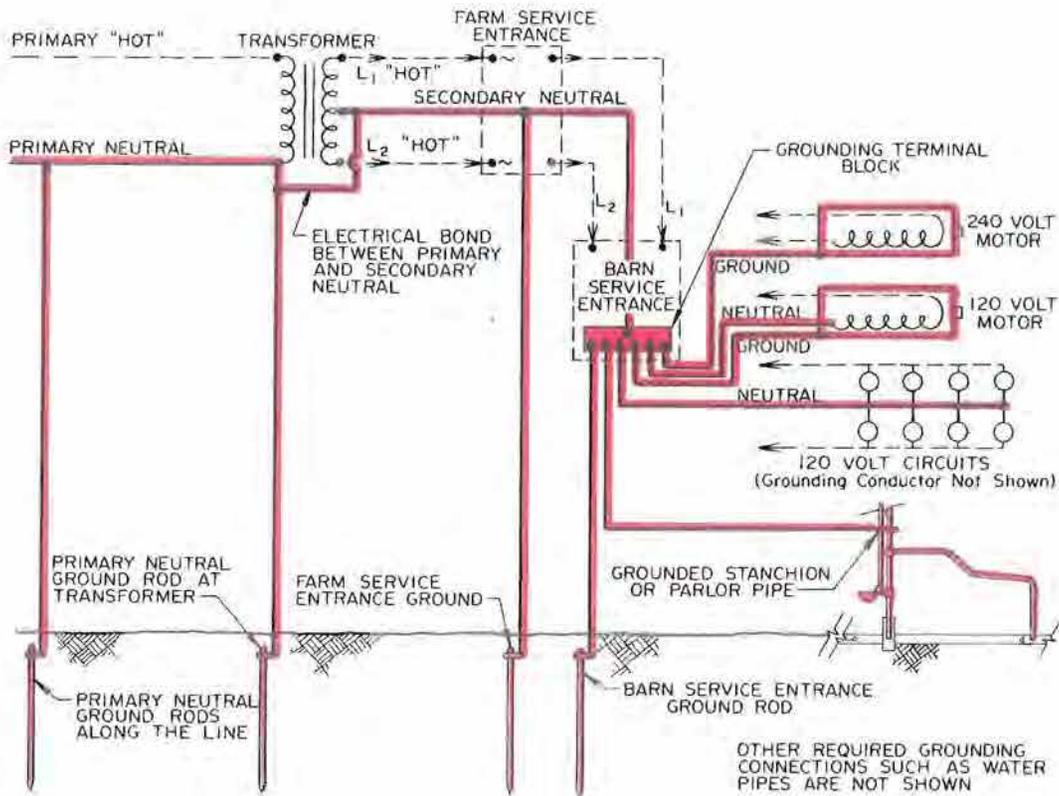
In summary, stray voltage problems alter animal behavior, and may influence milking characteristics or affect production performance. If unacceptable levels of stray voltage exist, take corrective action. Remember that many non-electrical causes can produce the same symptoms. **With careful analysis of all possible causes, proper corrective procedures can be found.**

Attempts have been made to associate the problems of unthrifty and unhealthy animals, poor reproduction, and weak calves with stray voltage. The failure of controlled research to find a direct physiological effect in animals subjected to stray voltages, and the absence of documented case studies demonstrating a marked improvement in these traits upon correction of an existing problem, leads to the conclusion that there is no direct and causal relationship.

POTENTIAL STRAY VOLTAGE SOURCES

Stray voltage problems arise from relatively simple electrical conditions. As an example, figure 1 (front cover) shows a dairy cow "bridging the gap" between an electrically grounded water cup and "true earth." If the meter indicates voltage of sufficient magnitude between the reference ground (representing "true earth") and the electrically grounded watering system, it may force enough current

Figure 2. The grounded neutral network (in red) on a single-phase distribution line



through the cow's body to cause serious problems. However, there are many variables which 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 which creates 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: 1) electrical fault conditions on either the farmstead wiring or the distribution system, 2) inherent neutral-to-earth voltages on multi-grounded distribution systems resulting from system loading, 3) voltage drops on secondary neutrals resulting from 120-volt load imbalance, and 4) induced

voltage on ungrounded equipment.

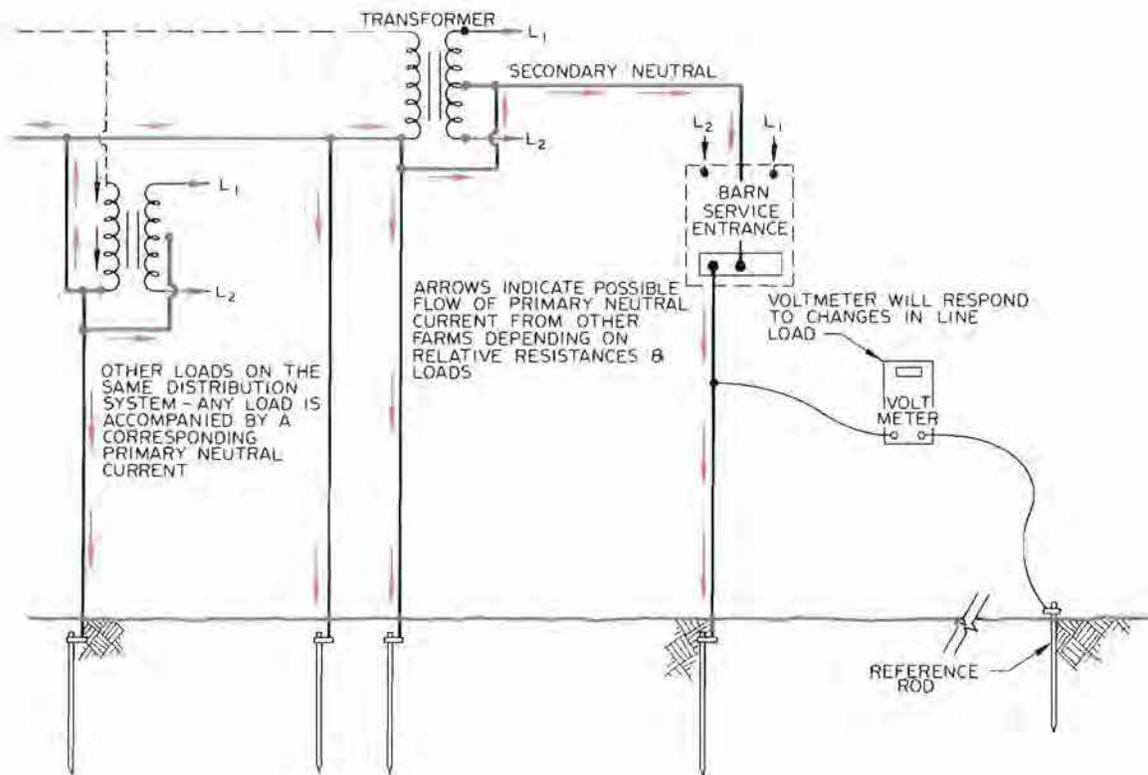
Figure 2 is a simplified diagram of a multi-grounded, single-phase distribution system serving a farmstead. In a multi-grounded system, the primary or utility system neutral conductor is grounded at least four times per mile along the line and at each transformer. The on-farm or secondary neutral is grounded at the farm service and at each building service entrance. (Note: System grounding and equipment grounding are described in more detail in a later section.) 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 figure 2) make up a complex network termed the grounded neutral system.

Every part of the grounded neutral system, including con-

ductors, 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 examples, stray 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

Figure 3. Neutral-to-earth voltage on a farm due to other loads on the same line



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 figure 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 is discussed in the section entitled "Standardized Measurements." In this position the voltmeter reads the maximum voltage to which a cow could be subjected. As described earlier, actual voltage across the animal may vary widely depending on conditions in the barn. The following are potential stray voltage sources.

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. This can be reflected to a greater or lesser degree to the problem farm through the primary-secondary neutral interconnection at the transformer (figure 3). 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).

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 in-

terconnection at the transformer (figure 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 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" 240-volt loads is a primary N-E voltage (or off-farm problem created by an on-farm electrical load).

3. Secondary Neutral Current in the Farmstead Wiring System

A current in any portion of the secondary neutral due to imbalance in 120-volt loads (load connected to L_1 does not equal load connected to L_2) is accompanied by a voltage drop (figure 5).

Since the secondary neutral current may be either in-phase or

Figure 4. Increase in neutral-to-earth voltage due to increasing loads on the same farm

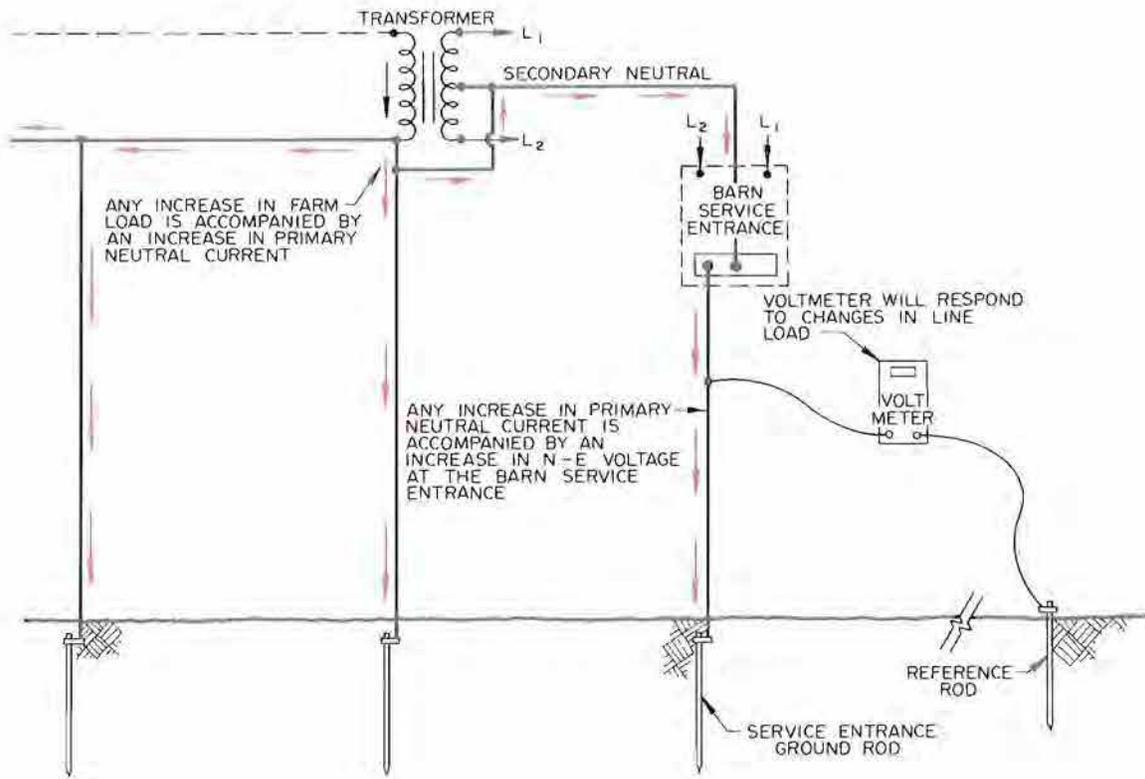


Figure 5. Neutral-to-earth voltage created by the voltage drop in the secondary neutral to the barn

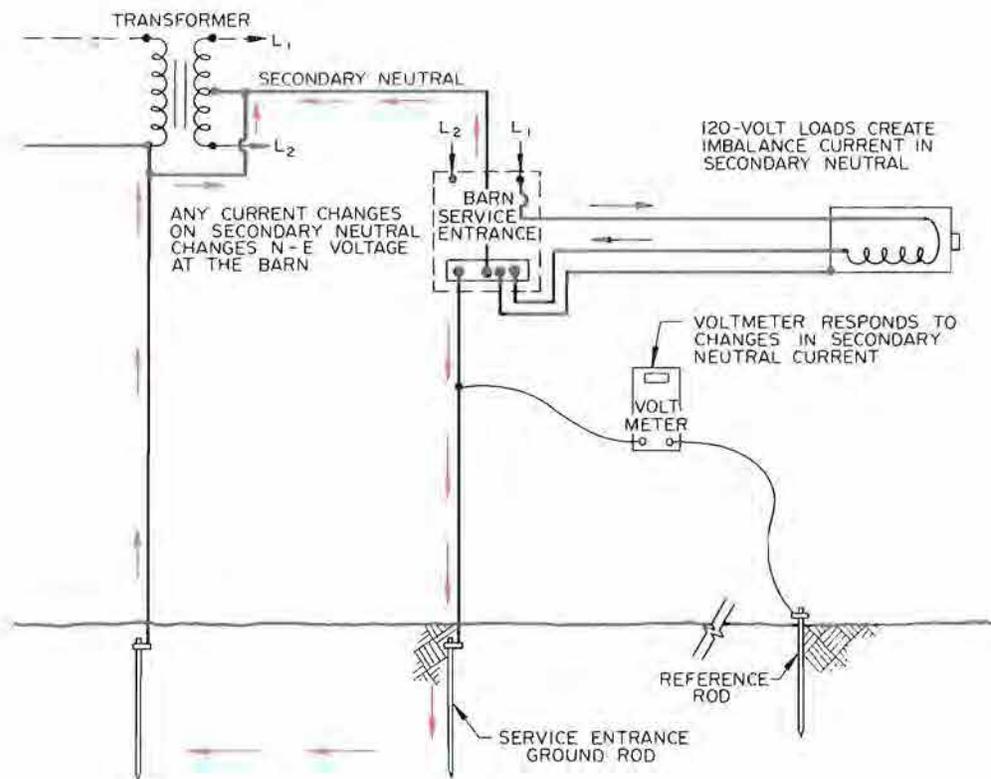
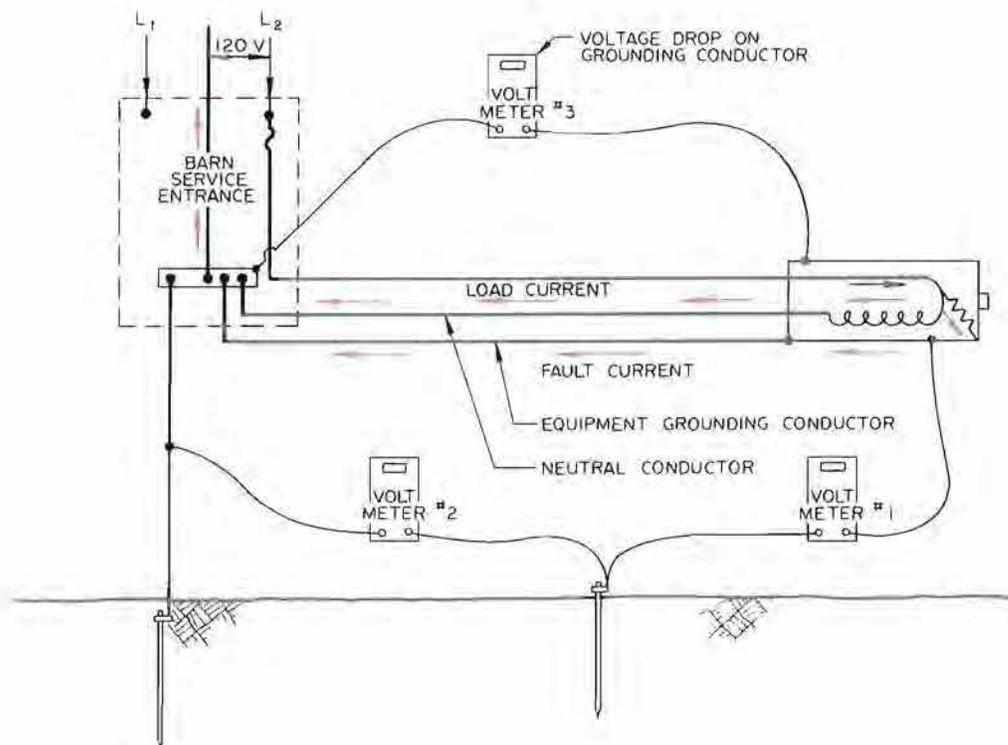


Figure 6. Added neutral-to-earth voltage created by a fault to grounded equipment



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.

4. Fault Currents on Equipment Grounding Conductors

Any fault current flowing in equipment grounding conductors will create a voltage drop on the grounding conductor (figure 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 figure 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 the two voltmeters will read the same. If there is a voltage drop on the secondary neutral, it can either add to or subtract from the N-E voltage at the service entrance. Any difference between the two readings is indicative of either improper equipment grounding or a current in the grounding conductor.

If the fault current is not enough to open the branch circuit protection it may go undetected for some time. Short term intermittent faults can be particularly troublesome. For example, a 20-ampere fault current in 50 feet of #12 copper conductor results in a voltage drop of 1.8 volts. Without proper equipment grounding this would create a hazardous condition. This emphasizes the importance of maintaining low resistance equipment grounding. Corrosive environments in livestock facilities can deteriorate

electrical connections and increase stray voltage problems as a result of fault currents.

5. Improper Use of the Neutral Conductor on 120-volt Equipment as a Grounding Conductor or Interconnection of the Neutral and Grounding Conductor at the Equipment Location

In agricultural wiring systems, the neutral (grounded conductor) and the equipment grounding conductors are bonded together at the building service entrance (figure 7). However, all feeders and branch circuits beyond the building main service must maintain the neutral and equipment grounding separately.

Reportedly, the practice of neutral and equipment grounding conductor interconnection beyond the service entrance is a relatively common practice where the electrical code requirements are not enforced. This is a violation of the code and may create a stray voltage problem in addition to an increased potential

for a hazardous condition. 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-volt motor starting surges since currents may be large.

6. Ground Fault Currents to Earth Through Faulty Insulation on Energized Conductors or Improperly Grounded Equipment

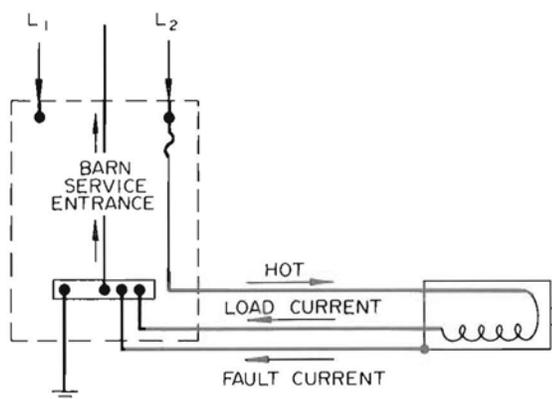
Leakage currents to earth from an energized secondary conductor (fault currents) must return to the center tap of the distribution transformer, thereby creating a neutral-to-earth voltage. Significant fault currents to earth are due to insulation breakdown on a conductor or in ungrounded equipment in contact with earth (figure 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. **Dangerous step and touch potentials can be present in the area of the fault. These could be at a potential which 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.

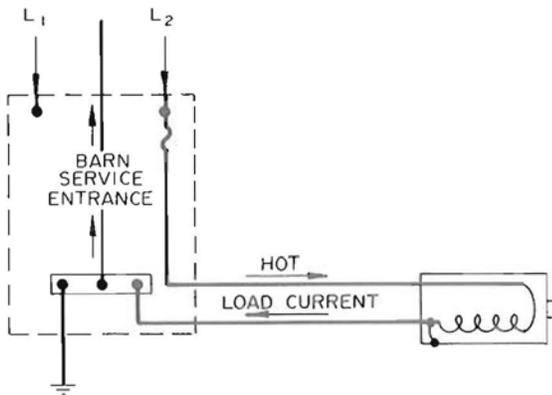
7. Induced Voltages on Electrically Isolated Conductive Equipment

It is possible for induced voltages to exist on isolated conductive equipment. In dairy facilities, electrically isolated water lines, milk pipelines, and vacuum lines

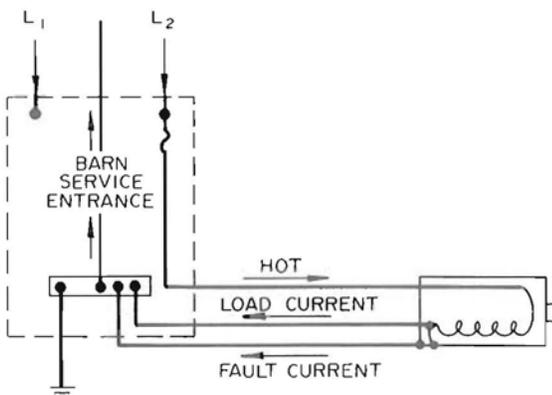
Figure 7. Neutral and equipment grounding of 120-volt equipment



CORRECTLY CONNECTED 120-VOLT BRANCH CIRCUIT

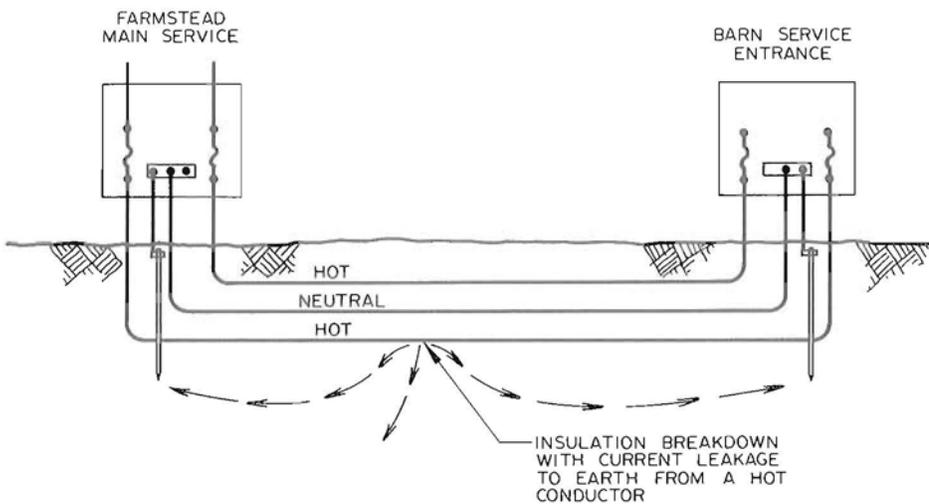


IMPROPER USE OF THE NEUTRAL AS A GROUNDING CONDUCTOR



IMPROPERLY INTERCONNECTED NEUTRAL AND GROUND

Figure 8. Leakage current to earth from an energized secondary conductor



may exhibit a voltage relative to other points when measured with a very high impedance voltmeter. A common source in stanchion barns are high voltage cow trainers running parallel to the lines. Any other isolated conductive equipment in 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.

WHEN CAN STRAY VOLTAGE BE A PROBLEM?

On any electrical distribution system it is necessary to have some voltage existing between all electrically grounded equipment and the earth. These N-E voltages exist on all grounded motor casings, water pipes, sinks, bulk tanks, stall and stanchion pipes, feeders, milking equipment, etc. As described earlier, these voltages will

force an electric current through any conductor, including a cow's body, providing a pathway to earth.

Since all metal pipes and feeders should be connected to the neutral system for safety reasons, there are a number of possible contact points between which these N-E voltages may cause a current flow through the cow's body. Some of those contact points are the feeder, waterer, metal stanchion or stall, metal grate, concrete floor on which the cow stands, and concrete parlor floor on which the operator stands.

Cows may react differently depending on which parts of their bodies are in contact with the grounded neutral network and which parts are communicating with earth or "true" ground. Research has established the "mouth-all hooves" pathway to be the lowest resistance pathway; hence, a sensitive one at relatively low voltages. Furthermore, 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 piping).

Significant stray voltage problems may occur when voltages accessing dairy cows through the "mouth-all hooves" pathway exceed 1.0 volt. Below 0.7 volt, the problems are usually minimal. The authors recommend continued monitoring when measured voltages reach the 0.5-volt level. A reasonable and attainable goal on farms needing correction would be to maintain neutral voltages on the farm grounding system below 0.35 volt.

Dairy cattle are sometimes subjected to low voltage shocks as they enter the milking parlor or holding pen. Because the resistance of the "front-rear hooves" pathway is approximately twice that of the "mouth-all hooves" pathway, it requires a 2.0-volt step potential shock to produce the same response as a 1.0-volt "mouth-all hooves" shock.

Animals vary in their sensitivity to stray voltages. Cows with a poor hoof structure walking on injured soft tissue are likely to be more sensitive. On the other hand, 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 volts on the milk line for cows to obtain perceptible currents through this pathway.

Cows appear to be more responsive to the initial exposure to current than "static (steady) currents associated with low voltages." Several short duration shocks may be more bothersome to animals than a longer shock of the same intensity. Finally, an irregular and intermittent shocking pattern is more likely to be disruptive. Cows appear to be bothered as much, or more, by the anticipation of the shock as the shock itself.

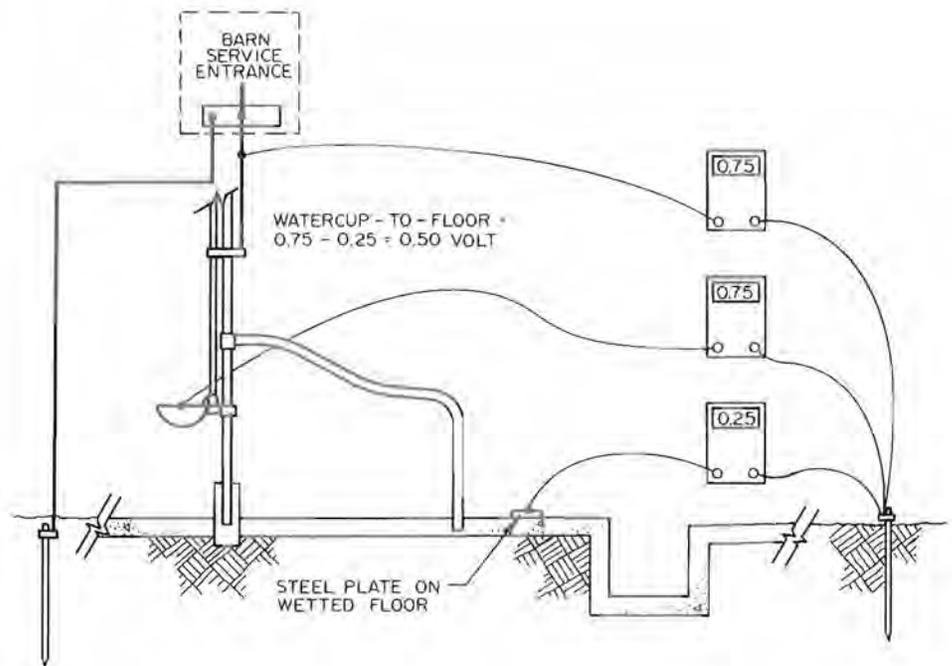
Stray voltage problems aren't limited to the dairy farm. It is known to have affected poultry, swine, and beef operations as well. For example, it has been shown that growing pigs can perceive the presence of voltages on a watering system as low as 0.25 volt. On the other hand, a 2.8-volt shock was required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

STANDARDIZED MEASUREMENTS

Standardized procedures have been developed to assist in 1) testing for the presence of stray voltage (screening procedure), and 2) locating the source or sources of problem-level voltages in livestock facilities (diagnostic procedures). The relative contributions of the various sources of stray voltage are most easily determined when all voltages are measured to an isolated or "true earth" reference ground. As a result, the following procedures are based on these measurements. Since the portion of the voltage the animal experiences depends on equipment grounding being present, as well as contact and path resistances, it would be helpful to estimate what component of the neutral-to-earth voltage is accessed by the animal. A procedure is outlined to meet this need.

To provide the common reference, install a ground rod 25 feet or more from the barn and isolated from any metallic objects, such as waterpipes. Unless grounding conditions are extremely poor, a rod four feet into the soil should be adequate for voltage measurements. Connect an insulated lead from the rod to the voltmeter location. One lead of the voltmeter should in turn be connected to the isolated ground insulated lead. The resistance (size) of the isolated ground lead is not critical for voltage measurements. A wire with sufficient mechanical strength will be

Figure 9. Cow contact to reference ground voltage measurements



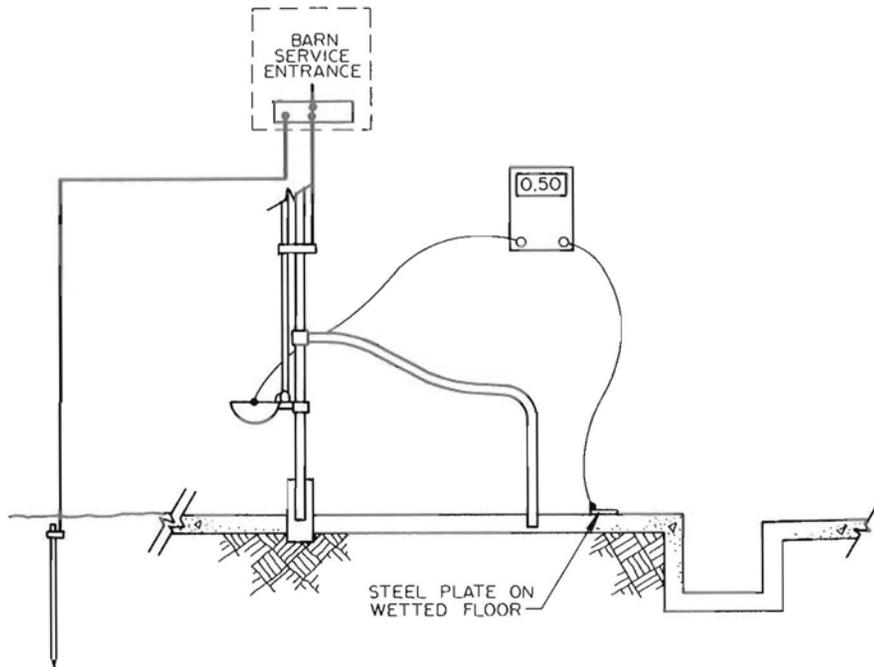
electrically satisfactory. The other lead of the voltmeter is connected to the grounded neutral system at the selected point (e.g., the ground wire leading from the barn service entrance box to the ground rod at the barn). Figure 1 (front cover) demonstrates the voltmeter in this configuration.

Voltmeter and other equipment requirements are outlined in a later section. However, if a voltmeter of questionable quality (internal resistance unknown or less than 5,000 ohm/volt) is to be used, it is advisable to test the effect of the resistance of the reference ground with the following procedure. Place a 350- to 500-ohm resistor across the input terminals of the voltmeter (resistor in parallel with the meter). Normally there will be some reduction in voltage. This is due primarily to the resistance of the isolated ground in comparison to the 350- to 500-ohm resistor. If there is a large reduction in the voltmeter reading (more than 20 percent of the reading) the resistance of the "isolated" ground rod may be too high for the resistance of the meter in use. In this case, relocate the rod or reduce its

resistance by saturating the surrounding soil with water or driving it deeper. After obtaining an adequate rod resistance, remove the added 350- to 500-ohm resistor before continuing the screening or testing procedures. If the point-to-reference ground measurements are made with the 500-ohm resistance across the voltmeter, the resistance to earth of the reference electrode can become a significant factor in the measurement.

When making voltage measurements in the cow contact areas, continue to measure voltage to an isolated reference and determine the voltages across the animal by the differences in values between the points (figure 9). The alternative is to attempt to measure voltages between the two animal contact points directly (figure 10). When using this approach, the resistance of each contact becomes more critical. Use of a 4 inch by 4 inch steel plate on a wetted floor has been shown to reduce the contact resistance at the floor end. If the meter is in parallel with a low value resistor (350- to 500-ohm) the body resistance of the cow can be simulated

Figure 10. Point-to-point voltage measurements at cow contact points



and the voltage drop across a cow in the circuit estimated. However, this will only be valid if the contact resistance for the meter leads are similar to those of the cow. The point-to-point measurement, made with a loading resistor and high contact resistances, may well produce values lower than the cow experiences and varies with concrete and earth moisture.

DIAGNOSTIC PROCEDURES

The following procedures have been developed to assist in locating the source or sources of problem-level voltages in livestock facilities. **It is assumed that the procedures described in this section will be followed by persons who: a) have a good understanding of electricity and farmstead wiring, b) have a basic understanding of stray voltage problems, and c) are sufficiently skilled to safely disconnect and restore distribution panel wiring.** Certain portions of the test will require the cooperation of the power supplier and can be performed only by authorized utility

personnel. These portions are clearly identified. These tests form a comprehensive check for stray voltage. When testing an individual farm, it may become evident that certain tests will not need to be performed as thoroughly as others, or that parts of some tests will be unnecessary or impractical.

Persons using these procedures are encouraged to devise a standardized data sheet for record-keeping. A suggested format is described. A more complete listing of procedures and formats is given in the reference *Stray Voltage: Detection and Diagnostic Procedures, Guide For Rural Electric Systems*, cited in the appended reference list.

Basic Data

A full farmstead analysis should start with collection of basic data about the farmstead and the problem as experienced by the farmer. Questions related to history of the situation and animal reactions can be helpful in determining problem sources. A farmstead map noting the location, ampacity of services and the system voltages (primary and secondary)

should be developed. Suggested questions for the farmer include:

- How long has the problem been evident?
- When does the problem occur (time of day, season, weather and soil conditions?)
- Can the problem be related to a specific location such as part of the barn or parlor?
- What symptoms of the problem have been noticed? (Examples: cows extremely nervous while in parlor, cows reluctant to enter parlor or drink water, increased manure deposition in parlor, reduced feed intake in the parlor, incomplete or uneven milkout, more mastitis, or lowered milk production?)
- Does the problem affect some cows more than others?
- Have sparks been observed or shocks received?
- Who else has been consulted regarding the problem?
- What were the results of any previous tests or measurements?
- What attempts have been made to correct the problem? What effect did they have?
- Is there any other information that may help to understand the problem?

Voltage Testing Set-Up

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 as outlined in the "Standardized Measurements" section. In the following series of tests, two voltages are to be compared. In the initial test the two voltages are 1) between the transformer ground (primary neutral) and the reference ground, and 2) between the barn service neutral and the reference ground. The use of two voltmeters is recommended so that readings may be taken simultaneously. If the two meters change readings abruptly, avoid reading the voltage on one meter before the change and then reading the voltage on the other meter after the change. See figure 11 for an illustration of the meter configuration for the first tests.

Figure 11. Meter configuration for diagnostic procedures one, two, three, five, six, and seven

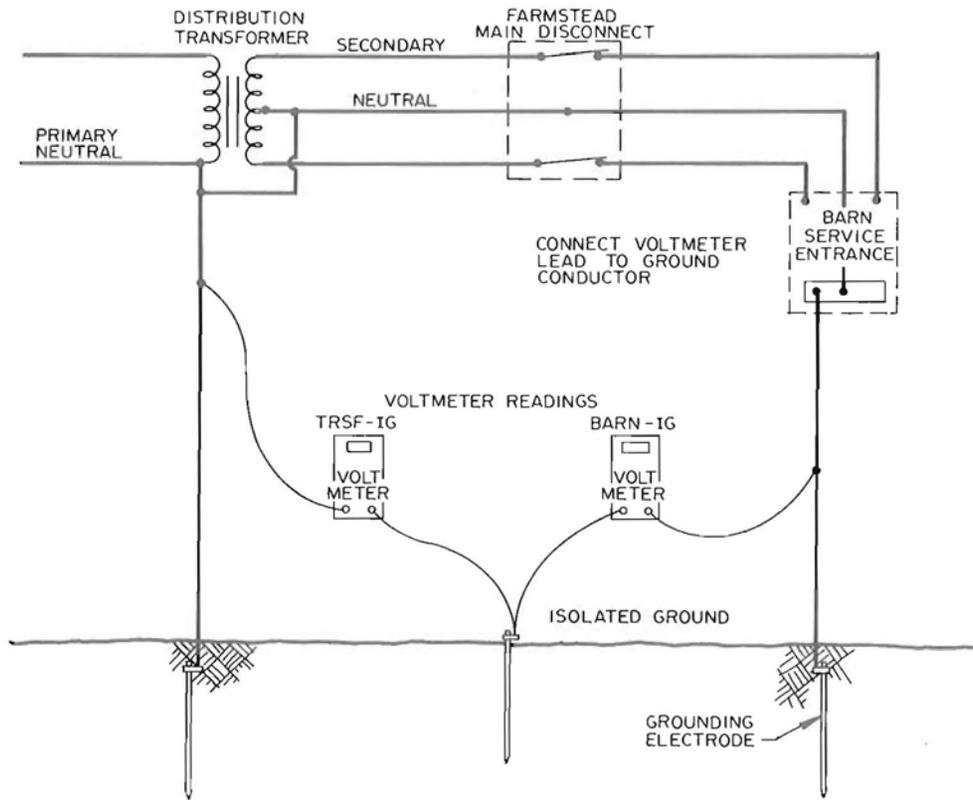
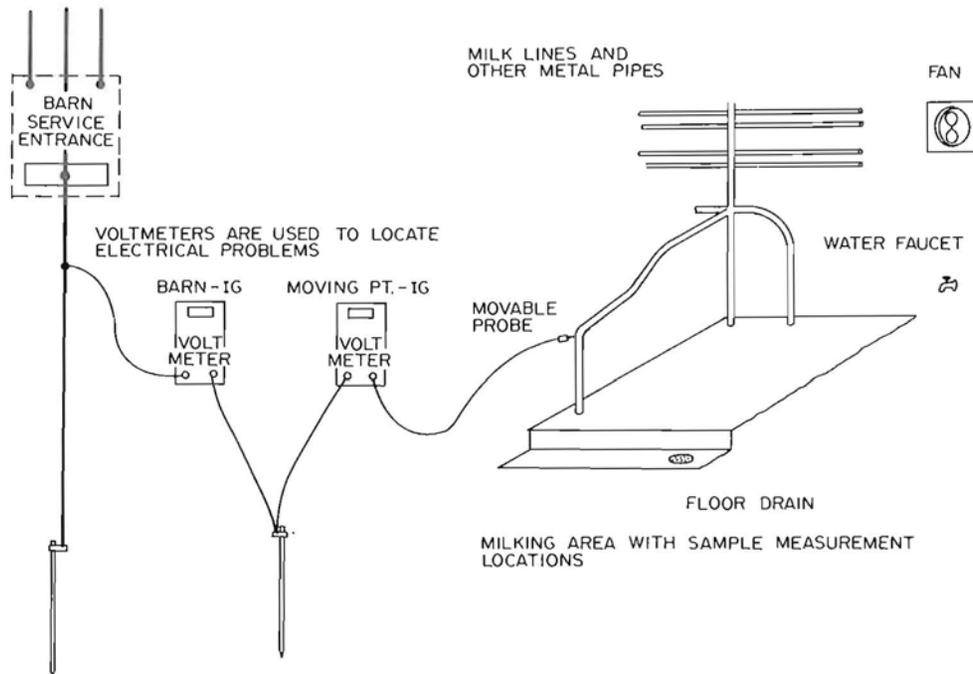


Figure 12. Meter configuration for diagnostic procedure four



DETAILED DIAGNOSTIC PROCEDURES

Test Number One: Initial Voltage Measurements

Objectives: 1) Check the voltages under normal conditions. 2) Check the functioning of the monitoring equipment.

Procedure: Connect the voltmeter(s), as shown in figure 11, to measure the voltages from the isolated ground to the barn service grounding conductor and transformer grounding conductor. Measure the two voltages and record the time the readings are made.

Time	Voltage Readings	
	Transformer-Isolated Ground (IG)	Barn-Isolated Ground (IG)
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Interpretation: Differences between the two voltages are due to a voltage drop in the secondary neutral. Either voltage may be larger, depending on the secondary neutral current's phase relationship with the primary.

Test Number Two: Primary Neutral Test

Objectives: Determine whether off-farm problem sources may exist due to on-farm loads.

Procedure: Select three or four 240-volt loads of at least 3 HP or KW. Measure the Transf.-IG and Barn-IG voltages and the barn secondary neutral current as each load is added. When all these loads are connected, record the secondary load current with a clamp-on ammeter on a hot wire at the service. To minimize misleading readings, be sure that 120-volt imbalance is small (less than 5 amperes). This may require leaving some services open and not using 240-volt loads which require operation of 120-volt loads. Remove the loads in reverse sequence, again recording voltages after each removal. If the voltage has changed significantly with the selected loads off, the test should be repeated.

Load Added/Removed	Voltmeter Readings		Secondary Neutral Current
	Transf.-IG	Barn-IG	
None	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
None	_____	_____	_____

Interpretation: Loads are both added and removed during the check to determine whether the base-level voltage changed. A change may be caused by sources either on or off the farm not being tested but activated during the test.

The increase in neutral-to-earth voltage as each load is added is due either to the increase in primary N-E voltage as a result of the increased load or to faulty equipment on that circuit. Increase due to non-faulty load should be directly proportional to the size of the load added.

If any 240-volt load causes a current flow in the secondary neutral to the barn (as indicated by the clamp-on ammeter) it is a result of interconnected 120-volt loads or ground faults in the equipment. Very slight changes in neutral current may be detected as a result of the increased N-E voltage forcing some current through the electrical system grounds at the barn. These will be very small and are not an indication of ground faults in the equipment.

Test Number Three: Secondary Neutral Test

Objectives: Determine what proportion of the stray voltage is due to the secondary neutral voltage drop.

Procedure: With no other loads on the service, measure the voltages and the secondary neutral current when known loads are connected to each of the two 120-volt secondary legs. This can be easily accomplished with existing 120-volt loads or by connection of a portable heater or hair dryer either at the panel or at identified receptacles.

Circuit Number Load	Voltmeter Readings		Secondary Neutral Current
	Transf.-IG	Barn-IG	
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____
_____	_____	_____	_____

Interpretation: Differences in the voltage of the transformer ground and a building grounding electrode are due to a voltage drop somewhere in the secondary neutral.

The primary current and Transf.-IG voltage will increase and decrease with total load. The Barn-IG voltage may increase or decrease as loads are added. It is possible for the N-E voltage at the barn to decrease with an increase in secondary neutral current when the imbalance current is out of phase with the primary current. In addition, the N-E voltage at the transformer is not totally independent of the voltage drop on the secondary neutral. Therefore, a secondary neutral drop can also cause some increase or decrease in voltage at the transformer ground.

If a significant difference (perhaps 0.5 volt or more) exists between the two N-E voltages, the secondary neutral voltage drop may be contributing to the problem. Improved connections, better balancing of 120-volt loads, use of 240-volt rather than 120-volt motors, and/or a larger neutral wire may help alleviate the problem.

**Test Number Four:
Locating Electrical Problems
in Milking Area Equipment**

Objective: Determine the locations of any equipment or wiring faults which may contribute to stray voltage and find equipment which may not be effectively grounded.

Procedure: Maintain the Barn-IG voltmeter connection, but replace the Transf.-IG lead with a lead connected to a sharp movable probe (figure 12). While equipment operates, contact the probe to metal objects in milking area. Record the two voltages as each object is tested.

Object	Voltage Readings	
	Moving Pt.-IG	Barn-IG
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

Interpretation: Differences in the voltage at the barn service entrance, and electrically conductive equipment in the barn or milking areas is due to faulty equipment, improper wiring, induced voltages, or other voltage sources within these areas.

If the voltage on a test object is greater than the Barn-IG voltage, a wiring or electrical fault is likely in that area. If the voltage is substantially below the Barn-IG voltage, it is likely that the object is not effectively equipment grounded.

**Test Number Five:
Further Monitoring**

Objective: Monitor voltages to detect potential short-term problem-level voltages which may not have been detected previously.

Procedure:

Alternative A: Milking time monitoring. Have someone watch the voltmeters throughout milking time and periodically record both the peak and steady-state voltage readings, and the time of these readings.

Alternative B: Continuous monitoring. Connect a voltage recorder to monitor the Barn-IG and Transf.-IG voltage (figure 13). Record times on the chart periodically, as well as starting and stopping of such events as milking and feeding operations.

Time	Alternative A: Voltmeter Readings			
	Transf.-IG		Barn-IG	
	Peak	Static	Peak	Static
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

Interpretation: These voltage fluctuations are often detected as needle deflections on analog meters and as abrupt, momentary jumps in reading on a digital meter. Some meters may not detect these short-term voltages or follow their full magnitude.

If voltages are not at a level immediately indicating a problem, further monitoring, possibly including seasonal monitoring, may be helpful.

Figure 13. Voltage recorder configuration for continuous monitoring

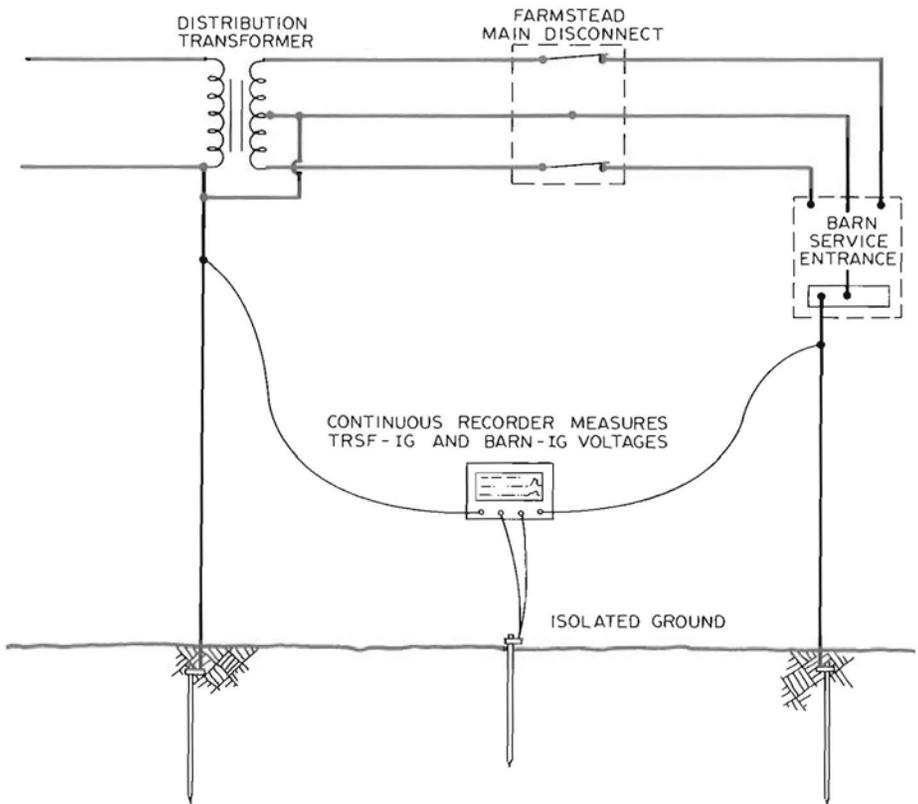
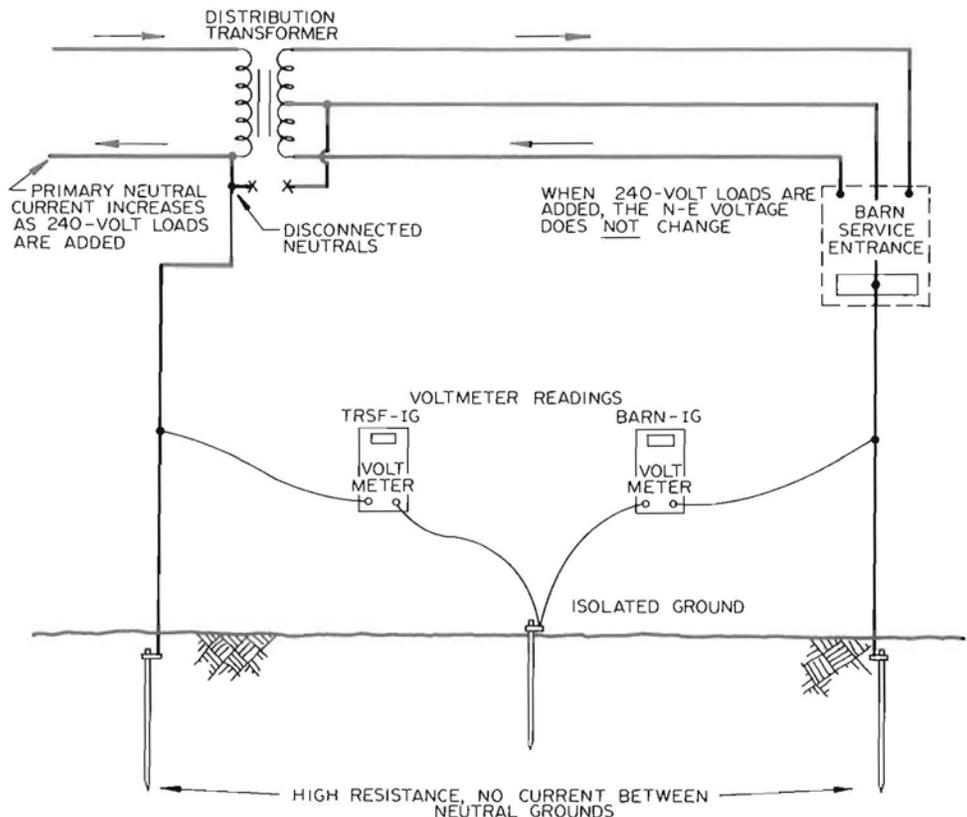


Figure 14. Testing with distribution transformer neutral isolation



SOLUTIONS TO THE PROBLEM

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

- 1) *Voltage reduction* by either a) elimination of the source (e.g., by removing bad neutral connections, faulty loads, or improving or correcting wiring and loading) or b) 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; or
- 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 specific situation. In the authors' opinion, all of the devices and procedures discussed in this paper are theoretically sound. All have their advantages and disadvantages. It will be the responsibility of the industry to select the approach that best meets the needs of the situation. Some of the concepts and devices are still under development and refinement. Changes will occur but the concepts have been clearly identified. (Note: Any mention of a specific manufacturer is not intended to imply endorsement of that manufacturer or their devices.)

Voltage Reduction

Voltage reduction can be divided into two categories: 1) elimination or reduction of sources and 2) active suppression.

Elimination or Reduction of Sources

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.

Test Number Six: Isolated Neutral Test

Objectives: A very helpful final step in the field analysis is to again measure or record the voltages discussed in previous tests after an authorized person from the power supply company has removed the bond between (isolated) the primary and secondary neutrals at the distribution transformer. This process isolates the effects of the primary neutral currents and off-farm ground fault currents from the farm voltage, indicating that any remaining voltage has an on-farm source. In addition, this will test effectiveness of isolating neutrals as a possible way to eliminate problem-level voltages.

Procedure: This test must be performed with the cooperation of the power utility. Repeat tests one through three after the utility has disconnected the bond between the primary neutral and the secondary neutral and removed any other connection which might affect this isolation (figure 14). A common shunt path is through normal telephone cable shielding. The telephone company can easily determine whether this condition exists, and change it. Isolating the neutrals requires disconnecting the bond only. It is critical that the primary and secondary neutral connection to the transformer remain intact. Only the bond between the two is removed.

Interpretation: When the system is isolated, the N-E voltage at the barn will be a component of the secondary neutral drop. The component seen at the barn will be controlled by the relative resistance of the barn grounding electrode system to the other grounding electrodes which return the earth current to the transformer center tap.

The primary and secondary must be completely isolated. If any conductive paths bypass the isolation, increase in primary neutral current will increase farm N-E voltages, leading to misinterpretation of results.

When the neutrals are isolated, there should be no change in the N-E voltage at the barn when the 240-volt loads are operated. If this voltage increases with these loads, there is either an electrical fault in the equipment or the voltage on the primary neutral is feeding back onto the secondary neutral through the earth or some other electrical connection (poor isolation between primary and secondary neutrals).

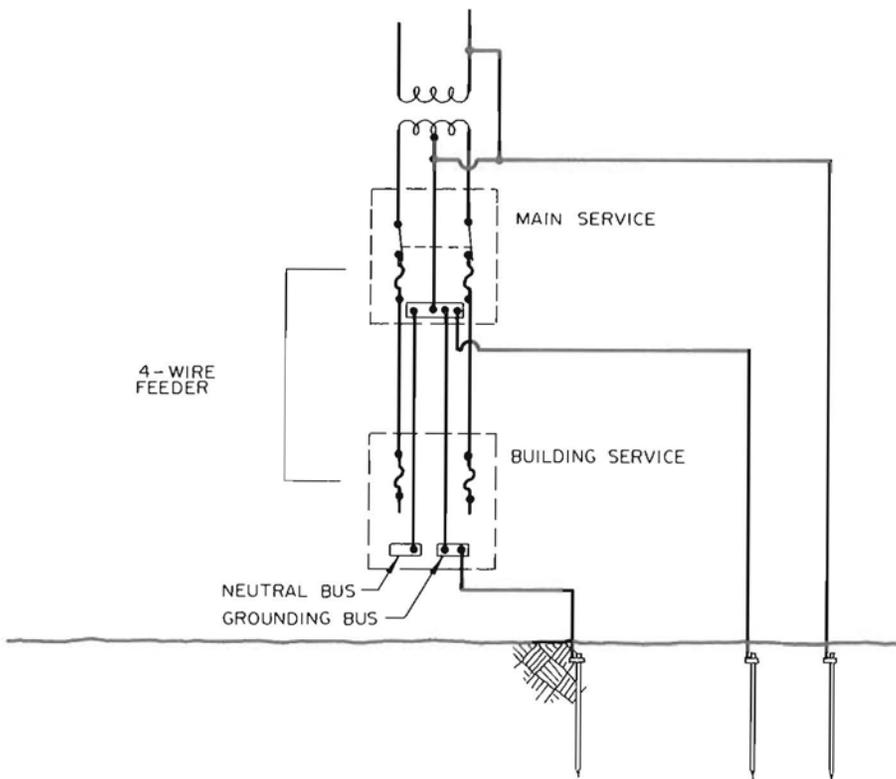
Test Number Seven: Off-Farm Source Confirmation—Standby Power Supply Use

Objectives: If the testing procedures imply that one of the principal sources of stray voltage is off-farm due to on-farm load (that is, a voltage created on the primary neutral due to load added on the farm) the following procedure may assist in confirmation. If a standby power unit is available, operate during critical periods such as at milking time, using the standby unit.

Procedure: Voltages should be monitored prior to starting the standby unit, during its operation, and after shut down.

Interpretation: This procedure reduces the load on the distribution line, and thereby the off-farm source, but does not modify on-farm sources. If voltages measured during this test are at an acceptable level, this would imply isolation of the secondary grounded neutral system from the primary, in an acceptable manner, would likely be effective.

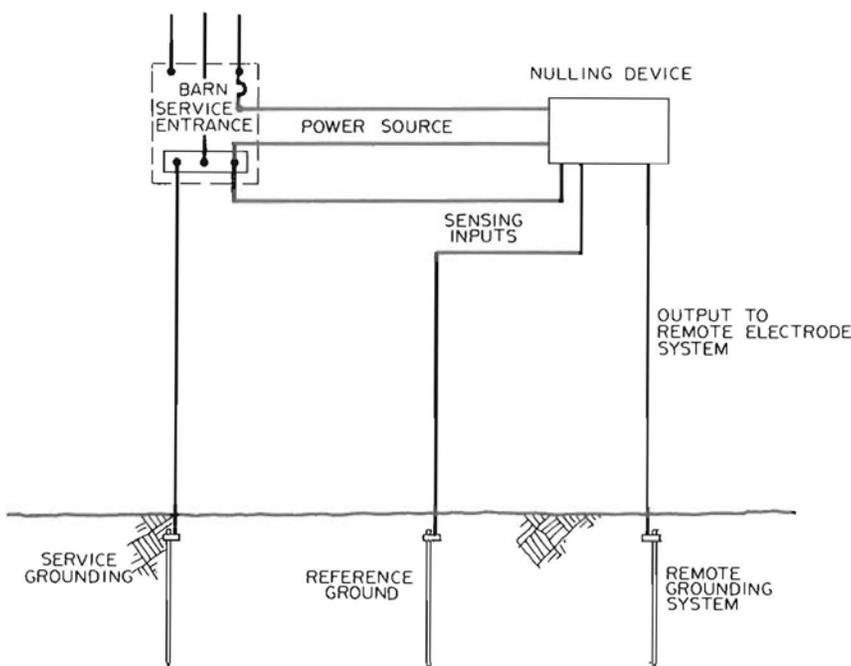
Figure 15. A four-wire feeder from farm main to outbuilding



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 which are equipment grounded and in contact with the earth.

If the farmstead system contains unusually long secondary neutrals, an option of using a four-wire service to the building is allowed by the National Electric Code (NEC). Figure 15 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. For this system, all neutral and grounding conductors in the building service and all feeders from that service must be completely separated. Also, the originating end must meet all NEC Article 230 requirements as a service, (i.e., disconnect with overcurrent protection, system grounding, appropriate enclosure, and neutral-to-ground bonding connection). N-E voltages will remain from all other sources.

Figure 16. Voltage suppression by controlled current to earth

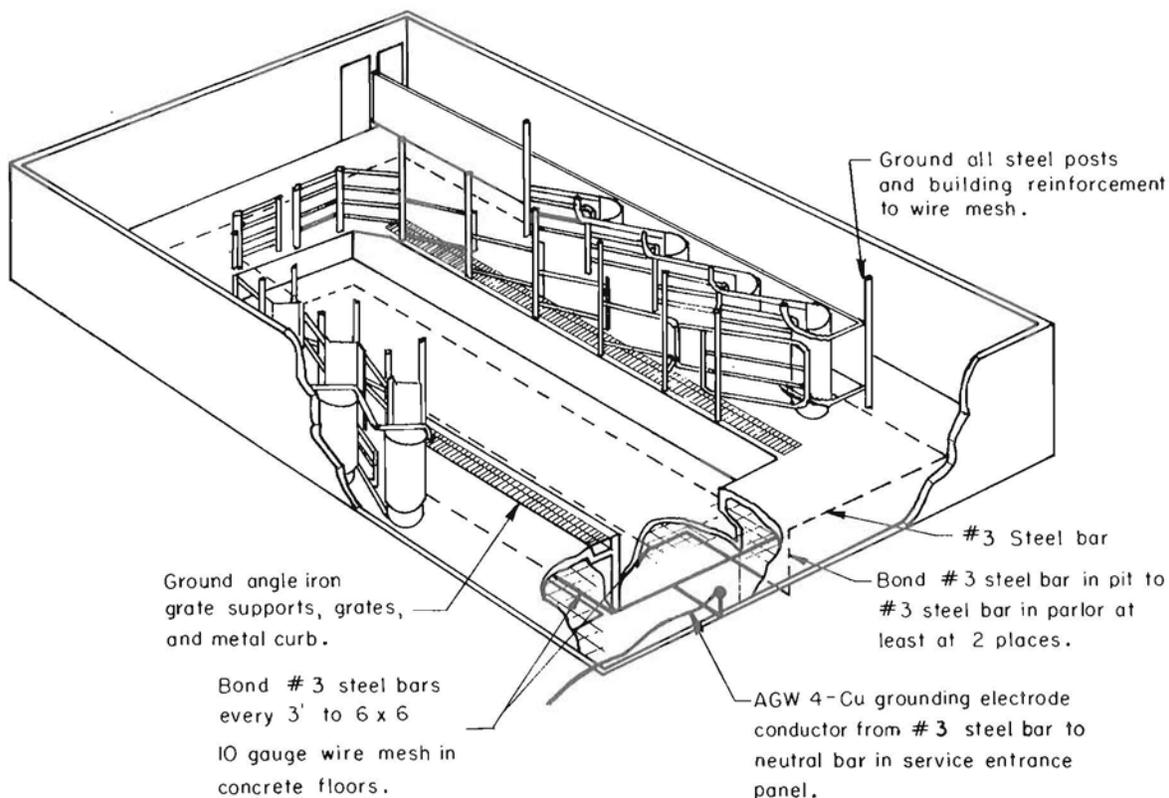


Active Voltage Suppression

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 (figure 16). 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 remote grounding electrode system is then adjusted to null out the N-E voltage. This method has been developed by Blackburn Co. of St. Louis, MO. The voltage is also reduced on farms served by the same primary line and located

Figure 17. Equipotential plane construction



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: 1) installation without modification of the existing electrical system, thereby retaining the full safety benefits of the interconnected grounded neutral system, and 2) nulling of the N-E voltage at a point lowers the level of N-E voltage on the distribution system. Existing units limit the offset capabilities to a level such that it should not significantly affect the operation of overcurrent protection devices under fault conditions.

Disadvantages include: 1) possible maintenance problems inherent with an active (amplifier system) type device, 2)

initial cost, and 3) the potential for offsetting problem sources which should be corrected by other means.

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.

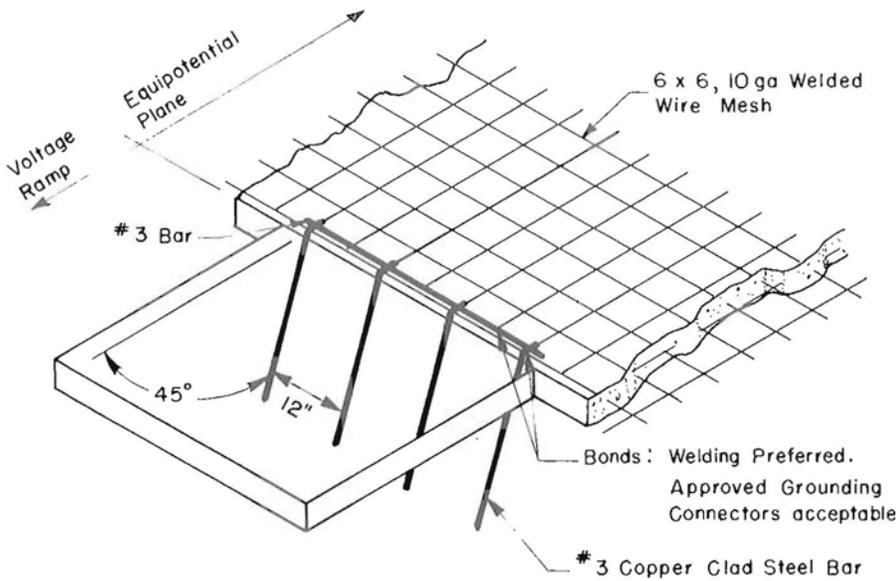
Equipotential Planes

The basic procedure for installing an equipotential plane requires bonding of reinforcement steel in the concrete floor to all metal equipment in the area and to the grounding/neutral bar in the service entrance panel (figure 17). 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.

Transition Ramps

Installation of transition ramps where animals enter or exit an equipotential plane is necessary (figure 18). The transition gives a reduced step potential for the animals as they move onto the equipotential plane.

Figure 18. Transition ramps for equipotential planes



Procedures for retrofitting existing facilities with equipotential planes are being studied. One possibility is to groove the concrete, insert a copper conductor, and regrout the groove. Necessary spacing, locations, longevity, and effectiveness have not yet been established.

Equipotential systems can successfully minimize stray voltage problems regardless of the source. However, additional work is needed to clarify installation procedures for both new and existing facilities. 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. Additional corrective procedures may be needed when all areas cannot be protected with an equipotential plane.

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. They are:

- 1) whole farm isolation at the farm's main service entrance and
- 2) single service isolation at the livestock building. Whenever isolation is used, careful consideration must be given to the safety and operational effects.

Whole Farm Isolation

Whole farm isolation can be accomplished by: 1) isolation at the distribution transformer with a surge arrester or a switching/reconnect device or 2) with an isolation transformer following the distribution transformer. Either way, some system grounding will be removed from the distribution system, at least during non-fault conditions. This can affect both off-farm and on-farm sources of N-E voltage.

Under non-fault conditions, isolation of the farmstead removes its grounding from the primary grounded neutral system. This increases the resistance of the distribution neutral and results in increased primary N-E voltage. Isolation does raise the concern that the N-E voltage at neighboring farms may be raised to a problem level, particularly for those in proximity. In these cases further action may be necessary

to maintain or reduce the N-E voltage.

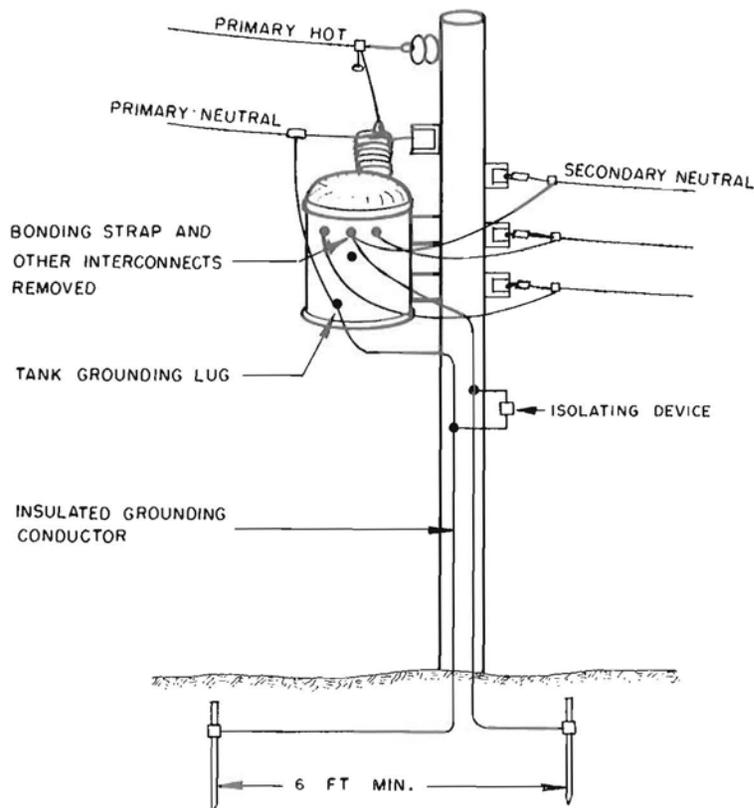
Isolation removes contributions from off-farm sources. However, it will also affect on-farm sources resulting from secondary neutral voltage drops and on-farm faults. Some generalizations can be made about redistribution of N-E voltages due to secondary neutral voltage drops after primary-secondary isolation. N-E voltage at a service entrance due to a voltage drop on the secondary neutral to that service will be reduced as a result of isolation. This occurs since the grounding resistance at the service remains the same while the grounding resistance at the transformer end increases. Conversely the N-E voltage at one service entrance will increase due to a voltage drop on the secondary neutral to another service as a result of isolation. This occurs since the grounding resistance at the other service remains the same, whereas the grounding resistance at the transformer end, including the service, increases. The magnitude of the changes will be determined by the system grounding resistances at all service entrances on the farm. After isolation, the location of an electrically grounded water well casing will have a major effect on the redistribution of N-E voltage due to secondary neutral voltage drops.

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.

Available Devices For Neutral Isolation at Distribution Transformer

Three methods have been developed for isolating the primary and secondary neutrals at the distribution transformers (figure 19). They make use of: 1) conventional spark gap, 2) a saturable reactor (Ronk Blocker, Hammond

Figure 19. Distribution transformer neutral isolation



Tingle Voltage Filter), or 3) a solid state switch (Dairyland Neutral Isolator). 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.

Several types of conventional low voltage lightning arrestors are being used for this application. 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 designed to give an impedance change threshold in the range of 10 to 24 volts AC 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. These devices also include a surge arrester 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 arrester in parallel to assist in passing fast rising transients.

Conditions may occur where voltage between the primary and secondary grounded neutral systems can saturate or trigger the isolation device during part cycles of the AC power waveform. For example, these can exist when the voltages approaching saturation or triggering levels occur due to a short-term large load. If relatively high primary N-E voltages already exist, a large motor start may raise the distribution system load for a short period and result in voltages that will cause partial saturation of saturable reactors or will create part-cycle closure of the solid state switch. This leads to non-sinusoidal N-E voltage on the secondary grounded neutral.

Since most volt-ohm meters (VOM's) commonly used for monitoring and trouble shooting read only rms values, they will not provide the necessary data on N-E voltages occurring due to part cycle saturation or triggering. A peak detecting meter or oscilloscope type instrument will be needed.

Whole Farm Isolation with Isolating Transformer

Isolating transformers, such as shown schematically in figure 20, have been used in the past to create a separate grounded neutral system on the farmstead. In this system, a primary-to-secondary fault in the distribution transformer is carried by the distribution system neutral and grounding. Such systems represent an investment in the range of \$1,000 to \$3,000, plus the cost of operating the transformer. Care must be taken in proper installation to meet prevailing codes and recommendations, particularly for overcurrent protection and bonding. When an isolating transformer is installed, assurance is necessary that no conductive interconnections are bypassing the transformer. Common interconnections are metallic

telephone grounds, gas or water pipes, metal feeders, fences and connected metal buildings. Any conductive bypass will negate the isolation of the transformer.

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 21. 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 principle system grounding is from the barn.

A second approach to single service isolation has been developed in, and is used in, Canada (Hammond Tingle Filter). 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 its 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 between services. **Furthermore, the National Electrical Code has not approved the use of this device in the United States. Thus, it cannot be recommended unless approved by appropriate electrical inspection authorities on an experimental basis.**

Figure 20. Isolation transformer installation—whole farmstead

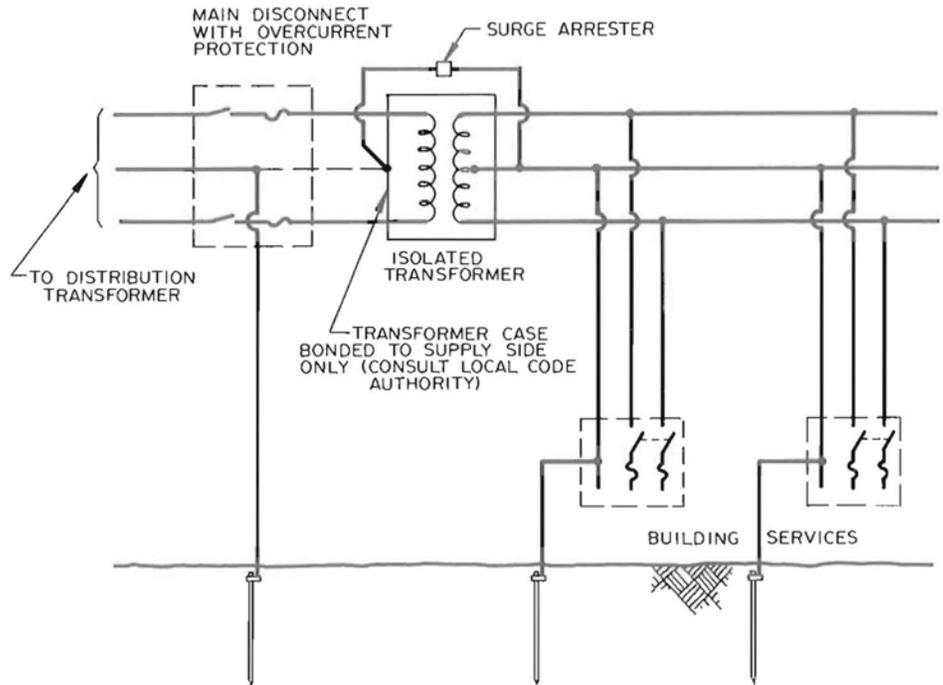
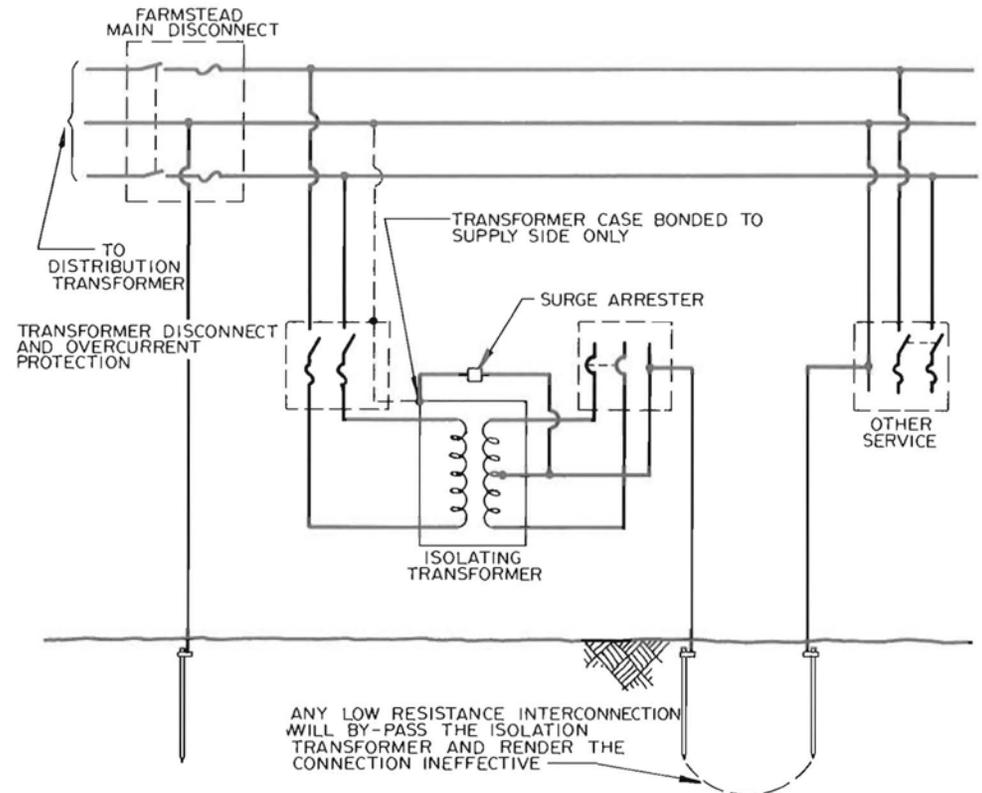


Figure 21. Isolation transformer installation—single service



APPENDIX I—TESTING EQUIPMENT

Voltmeter(s). To avoid improper voltage readings, only instruments meeting the following criteria and tests should be used.

- The meter should have an AC voltage scale with a full scale reading of two to five volts, and capability of reading to 0.1 or 0.01 volt.
- The meter should have a relatively high input impedance (5,000 ohms per volt, AC or higher). Very low-impedance meters may read low because of the voltage drop in the external circuit.
- The meter should not read DC voltage on the AC scale. This can be checked as follows: Connect the voltmeter(s) to be used to a conventional dry cell battery (1.5 - 6 volt). If a meter deflection is obtained on the AC voltage scale, install a five or ten microfarad capacitor in series with one voltmeter lead.

Any voltmeter meeting the above specifications and tests will generally be satisfactory. However, confusion may be created if a high impedance meter, like most digital meters, is used to measure from non-metallic or ungrounded objects. In this case, voltages from truly high impedance sources (very low current-producing capability) can be measured by the meter. Since these voltages are not of general concern, using a loading resistor of 10 kohm across the meter gives a sufficient indicator of whether or not the source is truly a high impedance source.

Other Equipment

Clamp-on Ammeter

Insulated Leads. One lead must be long enough to extend from the isolated ground to the location of the voltmeter, usually at the barn location. Other leads from the transformer ground and to the milking area may be needed. Any wire with sufficient mechanical strength to take repeated winding and unwinding will be satisfactory electrically.

Sharp Test Probe. This probe must be sharp enough to make good elec-

trical contact through dirt and rust on metal objects in the milking area.

Ground Rod. A 4 to 8 foot copper-clad ground rod with connecting clamp.

Optional Equipment

Multiple Channel Continuous Recorder. Continuous recorder with two or three channels and a range of 0 to less than 5 volt AC.

Portable Oscilloscope. A portable oscilloscope can be helpful in following rapidly changing voltages that may occur due to motor starts or faults.

300- to 500-ohm Resistor. This resistor can be used for testing the resistance of the isolated reference rod.

APPENDIX II—ELECTRICAL GROUNDING

The terms “ground,” “grounded,” and “grounding” can be very confusing when used in an electrical sense. Although the terms relate, in one way or another, to connections to earth, they should not be confused with “true earth.” The National Electric Code and National Electric Safety Code require that certain parts of electrical systems be electrically connected to earth through appropriate “grounding electrodes.” One common form of grounding electrode is an 8 or 10 foot long metal rod driven into the earth. The wiring systems are then “grounded” by solidly bonding one of the electrical conductors to the grounding electrode. This is referred to as “system” grounding. That is, the electrical “system” is “grounded” or connected to earth through the “grounding electrodes.” Other required and acceptable “grounding electrodes” are explained in the applicable codes. The conductor that is connected to earth is called the “grounded” conductor, more commonly referred to as the “neutral.”

Another type of electrical “grounding” is referred to as “equipment” grounding. Metal structures and equipment that are properly “grounded” are solidly bonded with a low resistance conductor to the electrical system at the location where it is “system” grounded, (i.e.,

connected to earth through the “grounding electrode”). In contrast to the grounded or neutral conductor, the conductor bonding the metal structures and equipment back to the grounded electrical system is called the “grounding” conductor, or more commonly the “ground” wire.

The extensive network consisting of all parts of the grounded electrical system and all grounded objects is sometimes called the grounded neutral network.

System Grounding

The main reason for “system” grounding is to limit the voltage between any conductor and the earth to a minimum value. Voltage to ground, the voltage between any point in the electrical system and the grounded neutral system, is also minimized. Figure A.1 shows the typical 120/240-volt single-phase system. The neutral wire is “system” grounded. The voltage between any “equipment” grounded object and either hot conductor is 120 volt. The voltage to ground is the lowest possible for a 120/240-volt system, and the voltage from each hot conductor to ground is the same. Both are requirements of the National Electric Code.

Good system grounding is dependent on establishing low resistant paths to earth at each system grounding point. The National Electric Code (Article 250-81) specifies the requirements for grounding electrodes.

Equipment Grounding

Equipment grounding is necessary to prevent electrical shock to persons or animals coming in contact with metallic objects, which due to some fault, have come in contact with a hot conductor. To illustrate the potential problem, consider the situation in figure A.2. If a fault develops in the motor windings such that the hot conductor comes in contact with the ungrounded frame, a 120-volt potential exists between the motor frame and earth. If a person standing on earth comes in contact with the frame, that person will be subjected to a very hazardous, if not fatal shock. This type of hazard can be avoided by equipment grounding

Figure A.1. Voltage to ground for 120/240-volt service

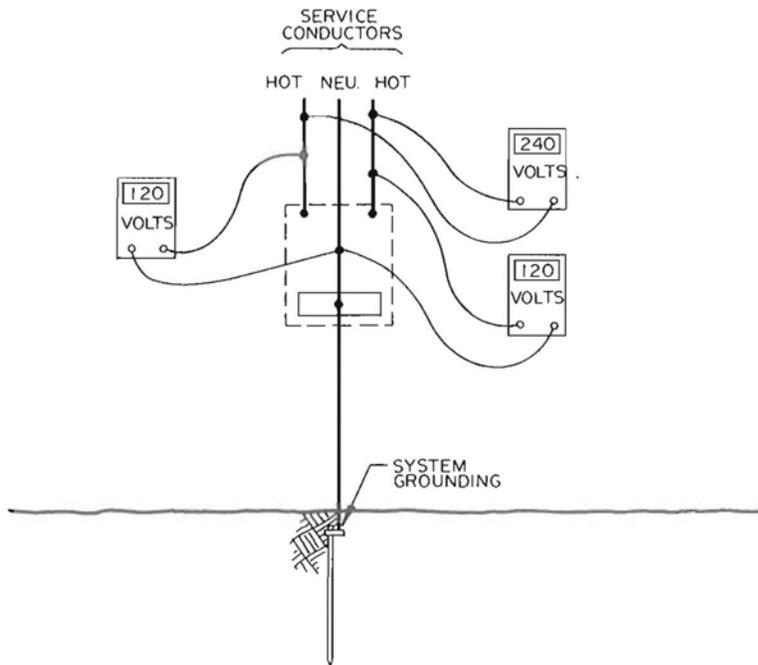
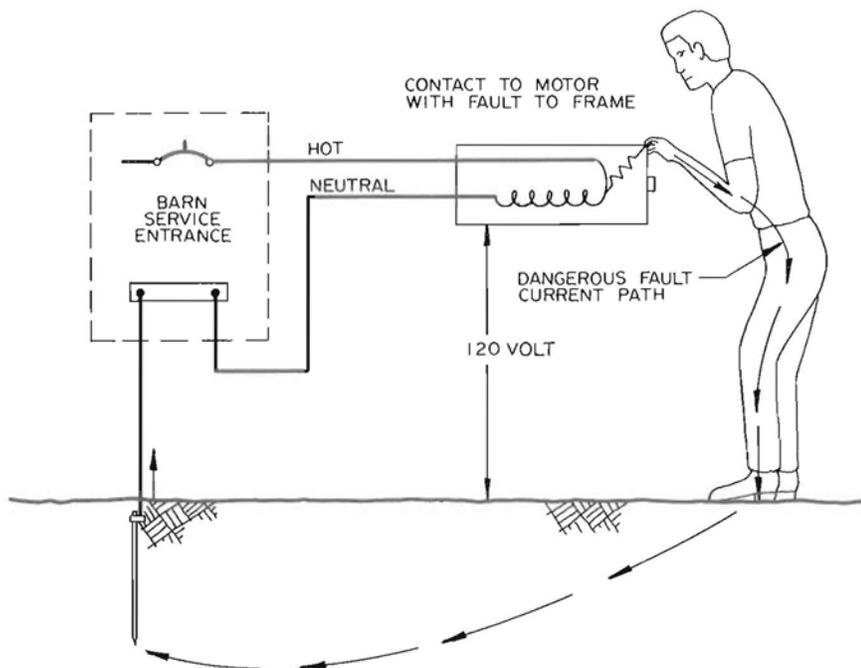


Figure A.2. Ungrounded motor with fault to frame



the frame as shown in figure A.3. If the hot conductor were to come in contact with the frame, a short circuit would exist, and the overcurrent protection for the circuit would then "blow" or open the circuit due to the high current flow. Even during the fault, the voltage rise on the motor frame should be limited to a safe level for a person in contact with it.

Use of grounding electrodes at remote equipment cannot substitute for equipment grounding. As shown in figure A.4, if a fault occurs to a piece of equipment which is not equipment grounded, the fault current will not open the overcurrent protection because of the relatively high resistance of the ground rod.

APPENDIX III— REFERENCES FOR FURTHER STUDY

Animal Sensitivity

Appleman, R.D. and R.J. Gustafson. 1985. *Sources of stray voltage and effect on cow health and performance*. J. Dairy Sci. 68:1554-1567.

Gustafson, R.J., R.D. Appleman and T.M. Brennan. 1986. *Electrical current sensitivity of growing/finishing swine for drinking*. Trans. of American Society of Agricultural Engineering, 29(2):592-596,600.

Understanding Sources of Stray Voltage

Gustafson, R.J., H.A. Cloud, and R.D. Appleman. 1982. *Understanding and dealing with stray voltage problems*. Bovine Practitioner 17 (Nov):4-15.

Gustafson, R.J. and D.J. Hansen. 1985. *Distribution and farmstead neutral-to-earth voltage modeling—A personal computer application*. Research Publication 85-A, Natl. Rural Elec. Coop. Assoc., 1800 Mass. Ave. N.W., Washington, DC 20036.

Methods For Source Determination

Gustafson, R.J. 1983. *Stray voltage: detection and diagnostic procedures, guide for rural electrical system*. Research Publication 80-1, Natl. Rural Elec. Coop. Assoc., 1800 Mass. Ave. N.W., Washington, DC 20036.

Solution Procedures

Gustafson, R.J. and H.A. Cloud. 1986. *Available procedures for stray voltage problem solution*. Research Publication 86-A, Natl. Rural Elec. Coop. Assoc., 1800 Mass. Ave. N.W., Washington, DC 20036.

Gustafson, R.J. and H.A. Cloud. 1986. *Equipotential plane installation*. Research Publication 86-B, Natl. Rural Elec. Coop. Assoc., 1800 Mass. Ave. N.W., Washington DC 20036.

Gustafson, R.J. and V.D. Albertson. 1986. *Distribution transformer primary to secondary isolation devices and system responses*. Paper No. 86 T&D 530-0, Instit. of Elec. and Electronic Eng., New York, NY.

Issued in furtherance of cooperative extension work in agriculture and home economics acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Patrick J. Borich, Director of Minnesota Extension Service, University of Minnesota, St. Paul, MN 55108. The University of Minnesota, including the Minnesota Extension Service is committed to the policy that all persons shall have equal access to its programs, facilities, and employment without regard to race, religion, color, sex, national origin, handicap, age, veteran status, or sexual orientation.

The information given in this publication is for educational purposes only. Reference to commercial products or trade names is made with the understanding that no discrimination is intended and no endorsement by the Minnesota Extension Service is implied.

Figure A.3. Grounded motor with fault to frame

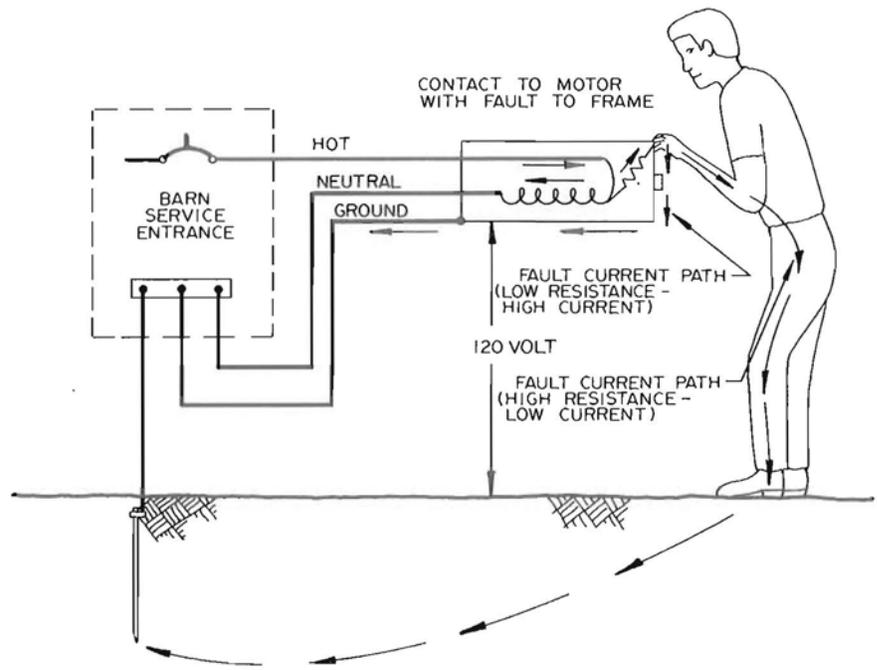


Figure A.4. System grounding at remote equipment

