

Understanding and Dealing with Stray Voltage Problems

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Abstract—Stray voltages are causing serious problems in dairy operations and other confinement livestock systems. The sources are varied and their interactions can create complexities that make diagnosis difficult. This paper reviews the problem and presents diagnostic procedures which will help isolate the contributions from various sources. Corrective measures based on the problem sources are described.

Introduction

Low level voltages existing between electrically conductive equipment and “true earth” are causing serious problems for livestock producers. The national and worldwide nature of the problem has been recognized (Craine, 1980). These voltages are known by various names: (1) tingle voltage; (2) stray voltage; (3) neutral-to-earth (NE) voltage; (4) neutral-to-ground voltage; (5) metal structures-to-earth-voltage; and (6) extraneous voltage. A number of papers reporting case studies or addressing various aspects of the problem are listed in a stray voltage bibliography by Gustafson and Craine (1980). This paper summarizes the material contained in a North Central Regional Agricultural Extension Bulletin by Cloud, Appleman and Gustafson (1980), and papers by Gustafson and Cloud (1981), and Gustafson and Albertson (1981).

Stray voltage problems arise from relatively simple electrical conditions. As an example, Figure 1 shows a dairy cow “bridging the gap” between an electrically grounded stanchion and “true earth.” If the voltmeter in Figure 1 indicates a potential difference between the reference ground (“true earth”) and the electrically grounded stanchion pipe, it may be possible for this voltage to force enough current through the cow’s body to cause serious problems. However, there are so many variables associated with stray voltage that considerable confusion exists as to

effective diagnostic and corrective procedures.

Any electrical condition that creates a potential difference between any two animal contact points has the possibility of creating stray voltage problems. There are numerous sources of these low level voltages. However, they are normally associated with: (1) electrical fault conditions on either the distribution and/or secondary wiring system; (2) induced voltages on ungrounded equipment; (3) inherent neutral-to-earth voltages on non-faulty standard multi-grounded distribution systems; and (4) potential differences on secondary neutrals resulting from 120 volt imbalance.

Stray Voltage Symptoms with Dairy Cows

Animal reactions will vary depending on the severity of the problem. The following symptoms are commonly associated with stray voltage problems in dairy operations:

1. *Uneven milk out.* This is the most common symptom expressed by dairymen. The number of cows affected and the severity of the milk let-down problem appear to be dependent on the level of stray voltage present. The mechanism of how this occurs is not understood. When milk out is uneven, more machine stripping is required and longer milking time becomes apparent.

2. *Cows extremely nervous while in the parlor.* This trait often is characterized by the cows dancing or stepping around almost continuously while in the parlor stall. However, dairymen are reminded that cows may become nervous for other reasons, such as malfunctioning milking equipment or rough handling by the operator.

3. *Cows reluctant to enter 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 had to be driven into the parlor and there was a tendency to “stampede” out of the parlor upon release. But again, this symptom is not specific since cows may be trained to expect the parlor operator to chase them into the milking stalls.

4. *Increased mastitis.* When milk out is incomplete, more mastitis is likely to occur. All that is required is the presence

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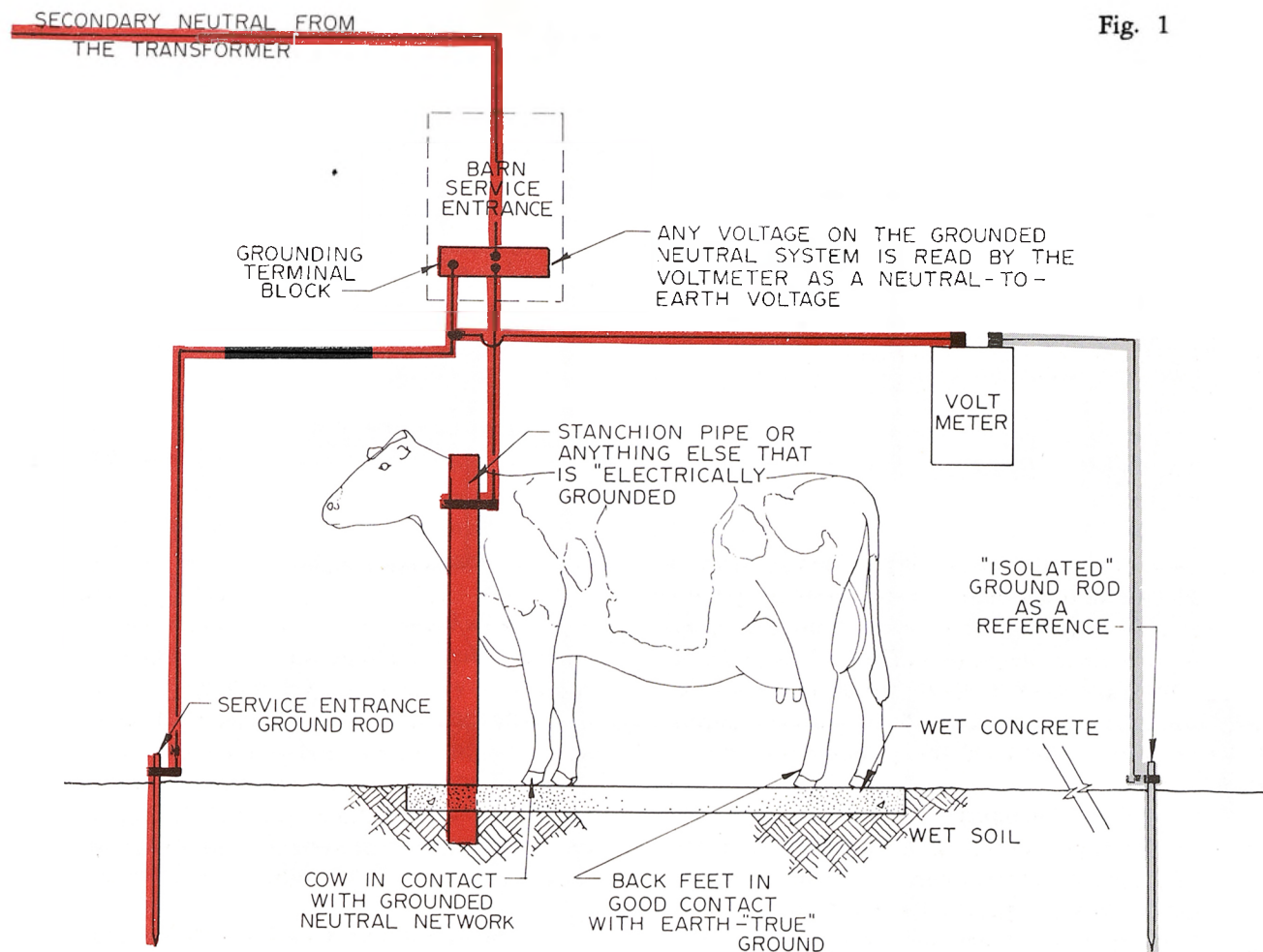


Fig. 1

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of infectious bacteria. This, in turn, will result in an increased somatic cell count.

5. *Reduced feed intake in the parlor.* If cows detect stray voltage while eating from the grain feeders, a reluctance to eat and reduced feed intake is almost certain to occur.

6. *Reluctance to drink water.* Stray voltages may reach the cows in stall barns through the water supply or metal drinking cups. Thus, cows soon become reluctant to drink.

7. *Decreased manure deposition in the parlor.* It is common for operators to report a drastic reduction in manure deposited in the parlor following the solution of a stray voltage problem.

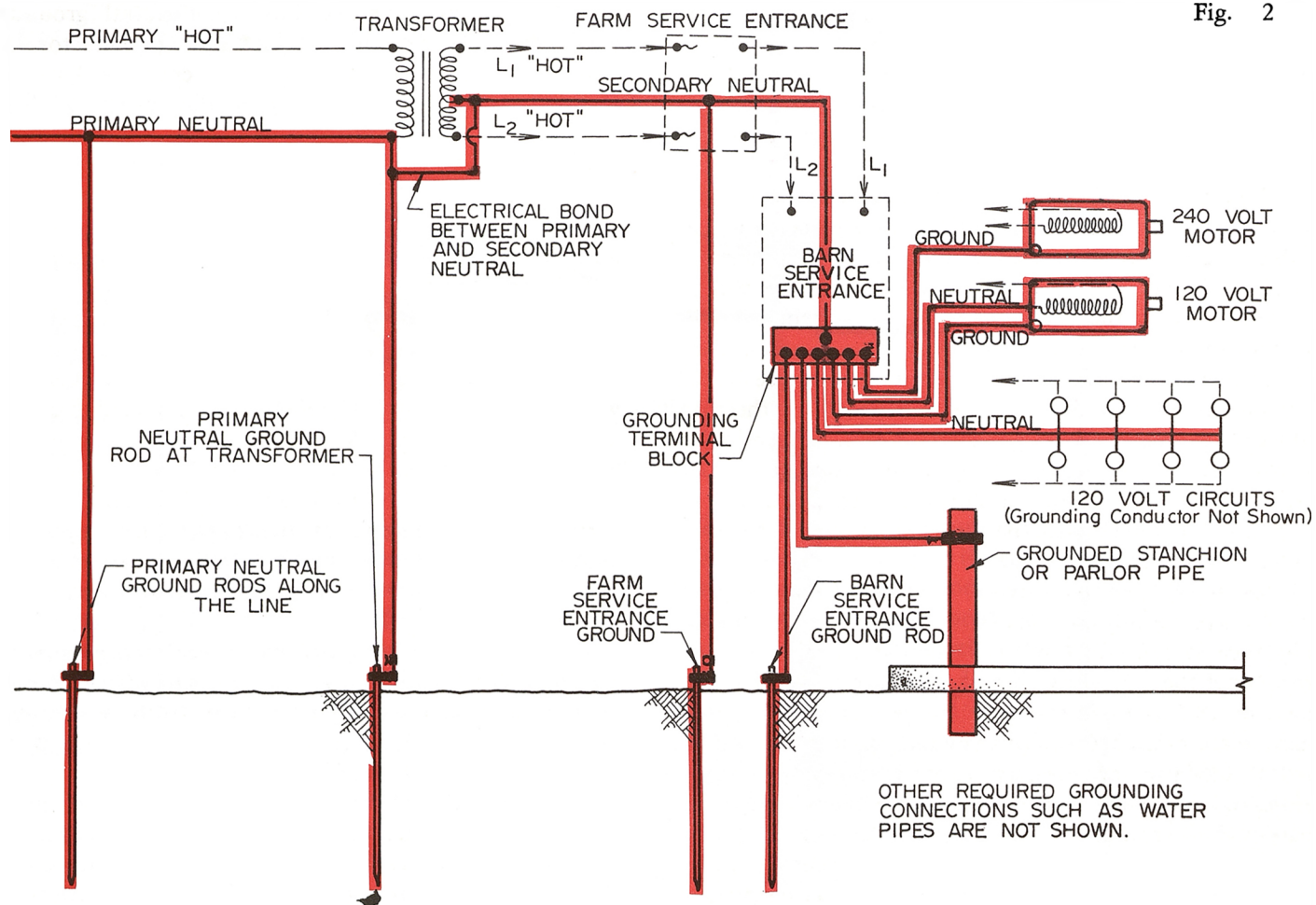
8. *Lowered milk production.* Each of the symptoms described previously is associated with stress, reduced nutrient intake, or disease. In any case, a drop in daily milk production is to be expected. Even when the stray voltage problem has been corrected, milk production may remain abnormally low for awhile because of the associated problems.

It must be remembered that other factors such as mistreatment, milking machine problems, disease, sanitation, and nutritional disorders can create problems which manifest themselves in the above eight symptoms. A

careful analysis of all possible causes is necessary if the proper corrective procedure is to be found.

Potential Stray Voltage Sources

Figure 2 is a simplified diagram of a standard multi-grounded, single-phase distribution system serving a farmstead. In a multi-grounded distribution system, the primary neutral conductor is bonded to at least four grounding electrodes per mile along the line and at each distribution transformer (National Electrical Safety Code, Section 97A). On the farm, the secondary neutral is bonded to a grounding electrode at the farm service entrance and at each individual service entrance. The requirements of the grounding electrode system are spelled out in detail in the National Electrical Code, Section 250-81 through 250-86. At the distribution transformer the primary neutral is electrically bonded to the secondary neutral. As shown in Figure 2, these grounded and bonded primary and secondary neutrals make up a complex system termed the grounded neutral network. The grounded neutral network is electrically connected to "earth" at many locations through the grounding electrodes and through many equipment grounding conductors. An electrical current in any part of it requires a potential difference. Since the system is electrically continuous, this



voltage may be reflected to some degree on all parts of the grounded neutral network.

Current flow on the grounded neutral network originates in several ways. Whenever any distribution transformer on the system is loaded, a current will flow into the grounded neutral network. Current will flow in the primary neutral and will be conducted to earth in varying degrees through the grounding electrodes. Some of this primary neutral current will flow to earth through the grounding electrode system on the farmstead served by the distribution transformer. Unbalanced 120 volt loads will create a current flow in the secondary neutral system on the farmstead. Leakage currents from properly grounded faulty electrical equipment will create a current flow in the secondary neutral. Leakage currents from ungrounded faulty equipment in contact with earth will return to the secondary neutral tap of the distribution transformer through numerous segments of the grounded neutral network. Similarly, leakage currents to earth from hot wires with faulty or broken insulation will return to the center tap of the distribution transformer resulting in a current flow at many locations. These last two sources are complex since some of the leakage current to earth at one farm may return to its distribution transformer through earth and on the primary neutral through the grounding transformer

through earth and on the primary neutral through the grounding electrode system at neighboring farms. In this case, the return circuit for the leakage is the complete grounded neutral (primary and secondary) system. The leakage or ground current will divide and be carried by each component based on the relative electrical impedance of each path.

Stray voltages associated with the distribution network and the farmstead wiring system can be separated into several categories. Unfortunately, in the field the contribution from all sources will be superimposed and their interactions can make an accurate diagnosis difficult. If the contribution from each source can be clearly identified and measured, the diagnosis is easy and the appropriate corrective measures can be readily determined. However, a good understanding of the sources and their interactions is necessary.

The following potential stray voltage sources are discussed by Gustafson and Cloud (1981) in detail and are summarized here:

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 NE vol-

tage 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. This contribution can be determined at any specific time by measuring NE 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 result in increased primary NE voltages which will be reflected to the farmstead grounding system through the interconnection at the transformer. 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 NE voltage. A common misconception is to relate an increase in NE voltage associated with the operation of equipment on the farm to an on-farm problem. An increase in NE voltage with the operation of "clean" 240 volt loads is a primary NE voltage.

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 is accompanied by a voltage drop. Since the secondary neutral current may be either in-phase or 180° out-of-phase with the primary neutral, the phase relationship between this voltage source and that due to the off-farm or primary neutral source must be considered. A voltage drop created by imbalance current in-phase with the primary will increase the NE voltage at the barn. On the other hand, if the imbalance current is out-of-phase with the primary, the NE voltage at the barn may decrease. If a primary NE voltage exists, an increase in out-of-phase secondary neutral current will decrease the NE voltage at the barn. As this imbalance current continues to increase, the NE voltage at the barn will diminish to zero and then begin to increase in magnitude but 180° out-of-phase with the primary. This means the NE voltage at the barn may be 180° out-of-phase with the primary.

4. *Fault currents on equipment grounding conductors.* Any fault current flowing in equipment grounding conductors will create a voltage drop on the grounding conductor in addition to the effect of this current flowing in the secondary neutral serving the service entrance. If the fault current is not enough to open the branch circuit protection it may go undetected for some time. The major effect of the fault current may be creation of a potential difference between conductive objects in contact or adjacent to the faulty equipment and other objects on different equipment grounding circuits. A 10 ampere fault current in 50 feet of #12 copper conductor results in a potential difference of 0.8 volts. This emphasizes the importance of maintaining low resistance equipment grounding. Corrosive environments in livestock facilities will 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 loca-*

tion. In agricultural wiring systems the neutral (grounded conductor) and the equipment grounding conductors are bonded together at the building service entrance. These are also bonded to an acceptable grounding electrode (NEC paragraph H of Article 250). However, all feeders and branch circuits beyond the building main service must maintain the neutral and equipment grounding separately. This must be done to meet the code requirements of placing no non-fault load current on the grounding conductors (NEC, 250-23 (a)).

Reportedly, the practice of neutral and equipment grounding conductor interconnection beyond the service entrance is a relatively common practice in some locations where the electrical code requirements are not enforced. Not only is this a violation of the code, but it may create an additional serious stray voltage problem even though no lethal hazard exists. In this situation the load current will be carried by the grounding conductor (where it is improperly used as the neutral), or by the grounding conductor in parallel with the neutral (where they are interconnected at the device).

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 must return to the center tap of the distribution transformer. Significant fault currents to earth are either due to insulation breakdown on a conductor or in ungrounded equipment in contact with earth. If such a fault develops, the seriousness of the situation depends on the electrical resistance of the return path from the fault to the grounded neutral system. If this is a high resistance path, dangerous step and touch potentials can be present in the area of the fault. These could be at a potential 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. The NE voltages will be additive if the leakage current is from the out-of-phase leg of the secondary and subtractive if it is 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 located in an electric field. In dairy facilities, electrically isolated water lines, milk pipelines, and vacuum lines may exhibit a potential difference to other animal contact points when measured with a very high impedance voltmeter. A common source of the electric field in stanchion barns are high voltage cow trainers running parallel to the lines. Any other isolated conductive equipment in close proximity to the electrical field source can show a potential difference also.

Due to the high impedance of such a voltage source, the current producing capabilities are very small. However, if the equipment is electrically very well isolated and has sufficient electrical capacitance, it may provide a capacitive discharge of sufficient energy when an animal shorts it to

earth to cause stray voltage problems. Capacitive discharge parameters are discussed in Deno (1979).

Problem Voltage Levels

On multi-grounded electrical distribution systems it is normal to have some potential difference between all electrically grounded equipment and "true earth." As shown earlier, these voltages can force a current through any conductor such as a cow's body which provides a pathway to earth. The effect on dairy cattle is influenced by many factors which combined determine the current flow through the cow's body: (1) the voltage; (2) the resistance of the cow's body; (3) the concrete and soil moisture conditions affecting the resistance to "true earth"; (4) resistance of the cow's contact points; (5) the soil-concrete contact; and (6) resistance of the electrical pathway to the cow's contact points (impedence of the source).

Soil moisture conditions affect both the NE voltage and the resistance of the electrical path through the cow's body to earth. As a result, the problems and symptoms vary greatly with time and weather conditions. The wide variability of all the factors which affect NE voltage, as well as the reaction of the cow to these voltages, partially explains the intermittent "here today, gone tomorrow" nature of the problem.

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. Cows' hoofs are known to be very sensitive, especially after a recent trimming.

Cows' teats may be very sensitive while being machine milked. New Zealand workers reported that "cracked" teats are 5 to 6 times as sensitive as normal teats.

If typical stray voltage symptoms exist and the NE voltage exceeds 1.0 volt during milking, a diagnosis should be made and appropriate corrective action taken. Larger voltages can cause increasingly severe problems. If the voltage is between 0.5 and 1.0 volt during milking, it should be monitored to determine if higher voltages may exist during specific hours, days, seasons of year, or weather conditions. A recording voltmeter for continuous monitoring is helpful. However, indicating meters are satisfactory for periodic monitoring during milking.

Equipment for Monitoring Stray Voltages

Most voltmeters with a full scale AC range of 2 to 5 volts can be used to monitor stray voltages if the operator understands the characteristics of the meter and how they affect the readings. If the meter reads DC voltages when on the AC scale, a 5 to 10 microfarad capacitor should be placed in series with the meter. Many VOM type meters will read DC when on the AC scale. The meter can be easily checked with a conventional 1-1/2 volt flashlight battery.

The input impedance of the meter will be a factor in monitoring stray voltages. If the input impedance of the meter is relatively low compared to the impedance of the source and other circuitry components, it will yield a low reading. On the other hand, meters with a very high input

impedence will commonly yield spurious readings, which may be misunderstood by someone not familiar with the situation. On the other hand, a very high impedance meter may be required to detect induced voltages on well-isolated conductive equipment as discussed in the previous section on potential stray voltage sources.

A 300 to 500 ohm resistor when placed across the voltmeter input will be helpful in estimating the impedance of the source and external circuitry. This resistance is suggested because it is the minimum body resistance to be expected for a dairy cow. When readings are being taken between two locations in the parlor or barn, the resistor can be inserted in parallel with the meter to estimate the voltage drop across a cow's body having the same contact points. When readings are being taken to the floor or other low conductive surface, an "artificial foot" (flat piece of metal) should be placed in wetted contact with the surface.

A clamp-on ammeter will be helpful in relating changes in NE voltages to changes in load current and to changes in imbalance current on the secondary neutral. Equipment for measuring grounding resistances will help determine whether additional grounding may be added to significantly lower the resistance of the grounding electrode system.

In very difficult cases, recording equipment and/or a portable oscilloscope may be helpful in analyzing the problem. Generally this equipment is not necessary unless there is something highly unusual about the situation.

To provide a common reference and to standardize measurements, the authors recommend the use of a copper-clad ground rod located 25 feet or more from any electrically grounded or conductive equipment. The ground rod should be 2 to 4 feet deep and in moist soil. Connect one insulated lead of the voltmeter to the "isolated" ground rod and the other insulated lead to the bare ground wire leading from the barn entrance box to the ground rod at the barn (service entrance grounding conductor). In this position the voltmeter will read the voltage between the grounded neutral system and an isolated or true ground.

When measuring NE voltages, the effect of the resistance of the "isolated" ground rod can be determined by placing a 300- to 500-ohm resistor across the input terminals of the voltmeter (resistor in parallel with meter). Normally there will be a slight reduction in voltage. This is partially caused by the resistance of the "isolated" ground rod. If there is a large reduction in the voltmeter reading (more than 20 percent of the reading) the resistance of the "isolated" ground rod is too high. In this case, relocate the rod or reduce its resistance by saturating the surrounding soil with water.

Field Analysis of Stray Voltage Sources

Once it has been determined, through voltage measurements, history of the situation as discussed with the producer, and a physical examination of the facilities that stray voltage may be a problem, it is necessary to make a diagnosis. Because of the complex and varying nature of stray voltage sources, a systematic, detailed diagnostic procedure

is necessary in arriving at a successful analysis. These procedures are discussed by Craine and Fairbanks (1980), Feistman and White (1975), Lillmars and Surbrook (1980), Stetson et al., (1980) and Cloud et al., (1980). One procedure which has proven valuable is to measure or record two voltages at the same time. Since these voltages change rapidly, two meters or two recording traces are necessary to document differences in voltage patterns at the two locations. If only one meter is available, a single pole-double throw switch can be used to rapidly switch from one location to another with one lead of the voltmeter always to the reference or isolated ground. Voltages to "true earth" through an isolated or reference ground rod as described by Cloud, Appleman, and Gustafson (1980) have proven helpful in the diagnosis. In severe cases where grounding conditions are extremely poor such as in sand, gravel, or shallow bedrock, a "true earth" reference may be difficult or impossible to obtain. In Minnesota, this has not been a problem to date.

the voltages at the distribution transformer grounding electrode and the barn grounding electrode system both with reference to the isolated ground. If a third meter or recorder trace is available, a voltage record between conductive equipment in the barn and/or milking parlor and the isolated ground may be helpful. If only two simultaneous measurements or records are available, the voltages at the barn grounding electrode and the conductive equipment in the barn or milking parlor can be made in a separate step. These voltage comparisons, when made under known electrical load conditions on the farm, together with secondary phase and neutral currents, will help in the diagnosis. Since ground fault currents to earth, either through improperly grounded equipment or faulty insulation on energized conductors, will have basically the same effect as the primary neutral current (additive or subtractive depending on the phase relationships) a standard large-scale, clamp-on ammeter may not effectively measure these currents.

Attached to this paper is a step-by-step procedure intended to help isolate the source or sources of a stray voltage problem. A form for recording the data as well as notes or interpretations are included. The following guidelines may help further clarify the results of the voltage readings.

- (1) Differences in voltage on the transformer ground and the barn grounding electrode are due to a voltage drop somewhere on the secondary neutral network. This secondary neutral voltage drop will be additive or subtractive, depending on its phase relationship with the primary.
- (1) Any difference in voltages at the barn grounding electrode and electrically conductive equipment in the barn and/or milking parlor is due to faulty equipment, improperly grounded equipment, improper wiring, induced voltages, or other voltage sources within the barn or milking parlor.
- (3) If there are no major differences in the voltages at the three locations (major with respect to the NE voltage at

the barn), the NE voltages are due to either primary neutral load current or secondary ground fault currents originating on the secondary of some distribution transformer and returning on the grounded neutral network.

- (4) The relative values of the primary neutral load current and the magnitude and phase relationships of the ground fault currents will determine the change in NE voltages as the primary neutral load current changes. A fault current to earth from the secondary of a distribution transformer will have the same effect on NE voltages as the primary neutral load current serving the same transformer. The effects will be additive to the primary if the leakage is from the out-of-phase secondary leg and subtractive if the current is from the in-phase secondary leg.

A very helpful final step in the field analysis is to measure or record the voltages discussed above after the *power supplier* has removed the electrical bond between the primary and secondary neutrals at the distribution transformer. *Complete isolation of the primary from the secondary is necessary.* Any increase in NE voltage on the farm with an increase in primary neutral current only (non-fault, 240 volt loads on the farm) is due to conductive interconnections by-passing the isolation. Slight increases may occur because of earth conductance between the primary and secondary grounding electrode system. Major increases are due to conductive paths such as telephone grounding systems or other metallic or low electrical resistance connections between the two grounding systems.

Removal of the interconnection between the primary and secondary grounding electrode systems will isolate the effects of the primary neutral current and ground fault currents at other distribution transformers from the farm NE voltage. A NE voltage on the barn grounding electrode system is due either to fault currents to earth on the farm or to voltage drops on the secondary neutral system. Relatively steady NE voltage which cannot be associated with operating equipment are likely due to fault currents to earth from energized secondary conductors. NE voltages associated with operation of equipment is due either to a voltage drop on the secondary neutral or to a ground fault current to earth from the equipment or on the energized conductors between the operating switch and the equipment.

When operating under the isolated neutral condition the NE voltage at the barn will now 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.

Solutions To Stray Voltage Problems

There are three basic solutions to stray voltage problems: (1) eliminate or minimize the voltage causing the problem; (2) isolate the voltage from any equipment in the vicinity of all potential animal contact points; and (3) install an equipotential plane that will keep all possible animal contact points at the same potential. The solution or solutions

selected depends on: (1) the source or sources of the stray voltage; (2) the magnitude of the stray voltage; (3) the cost of alternative solutions; (4) the physical facilities involved; and (5) the policies of the power supplier.

The solutions can be relatively simple if the problem is clearly diagnosed and the alternatives evaluated and explained to the farmer. A serious situation can occur if corrective procedures are recommended on the basis of an incorrect diagnosis and the problem is not solved. It is to everyone's benefit, the farmer, the electrician, the power supplier, the milking equipment supplier, and anyone else involved, to attack this problem on a cooperative basis.

The following analysis will discuss individually the three basic solutions listed above as they relate to the stray voltage sources discussed in an earlier section, **POTENTIAL STRAY VOLTAGE SOURCES**.

1. *Eliminate or Minimize the Voltage Causing the Problem*

If the diagnosis indicates load current on the primary neutral system is a major contributor due to either on-farm or off-farm loads, a careful survey of the distribution neutral by the power supplier is necessary. High resistance connections, breaks in the neutral conductor, inadequate grounding or broken or high resistance grounding electrode connections will increase the resistance of the neutral system and can create excessive primary NE voltages. A procedure for testing distribution neutrals has been presented (Szelich, 1980). The power supplier should also check the imbalance in the three-phase feeder which serves the farm, either directly or through a single-phase distribution tap. Obviously it is not possible to balance a three-phase feeder perfectly, but it may be possible to correct a large imbalance enough to minimize a primary NE voltage problem.

If the diagnosis indicates that voltage drops on the secondary neutral system is a major contributor, several corrective procedures are possible. All neutral connections must be checked. Any loose, corroded or other high resistance connections can cause excessive voltage drops. The length and size of the neutral conductor will be a contributing factor. Reducing the length of the feed or increasing the size of the neutral will reduce the voltage drop. Better balancing of 120 volt loads to reduce the current in the secondary neutral may reduce the voltage drop. If possible, convert all 120 volt motors to 240 volts, particularly the larger-sized motors.

If the diagnosis indicates major contributions from fault currents on equipment grounding conductors, improper use of the neutral as a grounding conductor or improper interconnection of neutral and grounding conductors or ground fault currents to earth, either on-farm or off-farm, they must be corrected. Strict adherence to the requirements of the National Electrical Code on the secondary wiring system will help to minimize on-farm sources of stray voltage.

2. *Isolation of the Voltage from any Equipment in the Vicinity of All Animal Contact Points*

If the diagnosis shows a major contribution from the primary neutral, it is possible to isolate this voltage from

electrically grounded equipment in the proximity of the livestock. One possibility is operation with non-interconnected primary and secondary neutrals. This is accomplished by removal of the electrical bond between the primary and secondary neutrals at the distribution transformer.

It appears Section 97D of the National Electrical Safety Code can be interpreted to allow operation with non-interconnected neutrals if properly done. However, many power suppliers, because of safety considerations, will not operate with non-interconnected neutrals.

Another means of primary neutral isolation is the installation of a general purpose insulating transformer (240 volt to 240/120 volt) between the distribution transformer and the service entrance serving the livestock facility. The "isolation" transformer can be installed at the main farm service entrance or at the service entrance or entrances serving the livestock facility. If the isolation transformer is located at the barn service entrance, it may also be effective in minimizing a secondary neutral contribution due to imbalance currents.

If the diagnosis shows a major contribution from the voltage drop on the secondary neutral to the service entrance at the livestock facility, it is possible to isolate the neutral system from the grounding electrode system at the barn. This is done by separating the neutrals (grounded conductor) from the grounding conductors at the service entrance and running a separate grounding conductor to the main farm service entrance. This will effectively remove the contribution of the secondary neutral voltage drop in the barn service neutral.

When isolation is used to solve stray voltage problems, it is necessary to remove all conductive interconnections which may effectively by-pass the isolation. Some common interconnections are telephone grounding conductors, metal water lines, propane lines, metal buildings, and feeding equipment between buildings. Any conductive interconnection will reduce the effectiveness of isolation. If isolation is contemplated as a solution, tests should be conducted to substantiate the absence of all conductive interconnections.

Some stray voltage cases have reportedly been solved (primarily in stanchion barns) by isolating all conductive equipment (pipes, stanchions, etc.) in the barn from the electrical grounding system at the barn service entrance. **THIS CAN AND OFTEN WILL CREATE A POTENTIAL ELECTRICAL HAZARD.** Any electrical fault to this isolated conductive equipment, since it is not electrically grounded, may create a lethal condition. In the interest of electrical safety, all conductive equipment should be electrically grounded through an equipment grounding conductor to the service entrance, particularly if there is electrical equipment in the area.

3. *Installation of Equi-Potential Planes*

The concept of equi-potential planes or grounding mats as a solution to stray voltage problems is discussed in many of the publications listed in a stray voltage bibliography by Gustafson and Craine (1980).

If all possible animal contact points are maintained at the same potential, there can be no current flow through its body. This may be accomplished by installing a continuous electrically conductive grounding mat in the floor, bonding it to all electrically conductive equipment in the area and electrically grounding the complete system. Properly installed equi-potential planes can be very effective in solving stray voltage problems in milking parlors. Animal access to equi-potential planes should be through some type of voltage ramp installed in the access areas as discussed in the publications listed in the bibliography.

The use of equi-potential systems will solve stray voltage problems regardless of the source if they are successful in maintaining the same potential at all possible animal contact points. In addition, they improve the electrical safety characteristics of the installation. Equi-potential planes are an extension of good electrical wiring and grounding practices. They should be included in the design of all milking parlors.

They should also be considered for all areas where electrically grounded equipment is located in areas occupied by livestock or exposed to livestock traffic.

Summary

Stray voltages are causing serious problems in dairy operations and other confinement livestock systems. As farm operations get larger and more sophisticated, as electrical loads on rural distribution systems increase, and as production levels increase, it is likely that stray voltage problems will increase.

The concept of stray voltage is relatively simple electrically, although the sources can be widely varied and complex. A good understanding of the sources and their interactions, the electrical nature of the problem, and the effects of the electrical characteristics of the system are important to proper diagnosis and solution. With the cooperation of everyone involved and a good understanding of the situation, stray voltage problems can be properly analyzed and corrected.

How to Determine Problem Source

The following step-by-step procedure is intended to help isolate the causes of a stray voltage problem. A form for recording the data as well as notes on how to interpret the data are included. The tests may take several hours to conduct. However, the entire procedure needs to be completed to determine the potential for a problem and what the cause or causes might be. The tests suggest the use of a clamp-on ammeter. The ammeter readings are optional for preliminary screening purposes.

Procedure	Record of Results	Interpretation
Step 1. After establishing an isolated ground rod (IG) and connecting voltmeter(s) between the 1) barn neutral and IG and 2) transformer ground and IG as described in FIELD	Time _____ Voltmeter Readings Barn-IG Transformer-IG _____ _____	The voltmeter is now reading the NE voltage at the barn and the distribution transformer. The barn service neutral is measured rather than voltages in the milking area itself, because generally it is the maximum which would be expected between any two points in the milking area, unless a fault exists. Difference between the two voltages are due to a voltage drop somewhere on the secondary neutral network. This secondary neutral voltage drop will be additive or subtractive, depending on the imbalance current's phase relationship with the primary.
Step 2. NE voltages without the barn load: Open the main disconnect at the barn service entrance. If the NE voltages in Step 2 are low (below 0.25 volt) and nearly equal, skip Steps 3 and 4 and go to Step 5.	Voltmeter Readings Barn-IG Transformer-IG _____ _____	No load is operating in the barn at this time. However, the neutral to the barn is not disconnected. Any voltage in the barn at this time is being transmitted to the barn through the neutral or grounding system and originates somewhere else.

Step 8. Milking time monitoring: Have someone watch the voltmeter throughout the miling time and periodically record the readings, both the values and static (steady) values. (You will probably require additional space for recording this data.)

Voltmeter Readings				
Barn-IG		Transf.-IG		Time
Peak	Static	Peak	Static	
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____
_____	_____	_____	_____	_____

Pay particular attention to major changes in fluctuations in the readings. These may occur rapidly and may last only a short time. Close attention is necessary to observe these changes. Starting of motors is the most common cause of short-term peaks.

If voltages above 1.0 volts are present during milking, some corrective action necessary. Refer to the section "WHEN CAN STRAY VOLTAGE BE A PROBLEM?" If voltages in the 0.5 to 1.0 volt range are present, the NE voltage should be continuously monitored and some corrective measures may be necessary. If the symptoms persist and voltages above 0.5 are not present, the NE voltage should be monitored to see if it is periodic due to weather, soil moisture conditions, or other systematic fluctuations.

Step 9. Locating faults—checking equipment grounding in milking area: A two voltage measurement method can be used to locate faults or lack of equipment grounding in the milking area. Replace the lead to the transformer ground with a movable lead within the milking area. With equipment operating, move around the milking area making contact to metal objects. Record the voltage measurements.

Voltmeter Readings		
Object	Moving Point-IG	Barn-IG
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
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If the voltage on an object in the milking area is greater than the Barn-IG voltage, it is likely that a wiring or electrical fault exists in that area. If the voltage is substantially below the Barn-IG voltage, it is likely that the object is not effectively equipment grounded.

Step 10. Isolated system testing: Repeat the procedure outlined in cooperation with the power supplier after its employees, under the direction of their supervisors and engineering consultants, have disconnected the bond between the primary neutral and the secondary neutral at the transformer. The disconnection of this bond is not possible with single bushing transformers in common use today and requires changing transformers. This step requires disconnecting the bond only; it is critical that the primary neutral and secondary neutral connections to the transformer remain intact and are not disconnected. This bond is shown schematically in figure 1. After the bond between the primary and secondary neutrals has been disconnected, there should be no change in the NE 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. (Primary and secondary neutral systems have not been isolated). If the tests outlined show an NE voltage problem, the results should indicate whether the problem originates on the farm, off the farm as a result of an excessive primary NE voltage, or a combination of the two.

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