Report To The

Minnesota Department of Agriculture

and

Minnesota Legislature

on.

University of Minnesota Research Related to the

Control of Animl Health and Production Problems

From Stray Voltage"

by

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CONTROL OF ANIMAL HEALTH AND PRODUCTION PROBLEMS FROM STRAY VOLTAGE

Background

The University of Minnesota began in 1977 to address the problem area of stray voltage in dairy facilities when it was identified as a problem in Minnesota by Agricultural Extension personnel working with dairy producers. Lack of information available to our Extension personnel motivated establishment of a research program in the area. A formal research program under the sponsorship of the National Rural Electric Cooperative Association was initiated in July 1980. Since that time, the University of Minnesota has authored over 30 research and Extension publications related to neutral-to-earth voltage and stray voltage in livestock facilities. The University has had an active Extension program in the state to assist farmers, electricians, power suppliers and others in dealing with the stray voltage problems. We have hosted a National workshop for Extenison personnel for training in this area. We have helped organize two national conferences on stray voltage problems in agriculture. Support for research in the area was also received from the Stray Voltage Research Council, Babson Bros. Company and, most recently, the Minnesota Department of Agriculture. Cooperation has been received from numerous electrical power companies and cooperatives, electricians and individual farmers.

The University of Minnesota has had, and is continuing, an interdisciplinary effort involving five departments in four colleges. The principal areas addressed have been:

1) animal sensitivity to electrical currents
2) electrical system characteristics related to creation of stray voltage
3) procedures for source identification, and
4) procedures and devices for stray voltage mitigation.

The following section outlines the areas of principal emphasis of our research program during the last year and highlights some of the findings. Selected articles referenced in the report of projects below are also appended. The included articles are intended to give supporting documentation to the more general summary statements. The work must be viewed in the context of an ongoing program. Results of earlier work form a basis for much of the current program. A bibliography of all publications related to these topics, authored by University of Minnesota personnel, is appended.

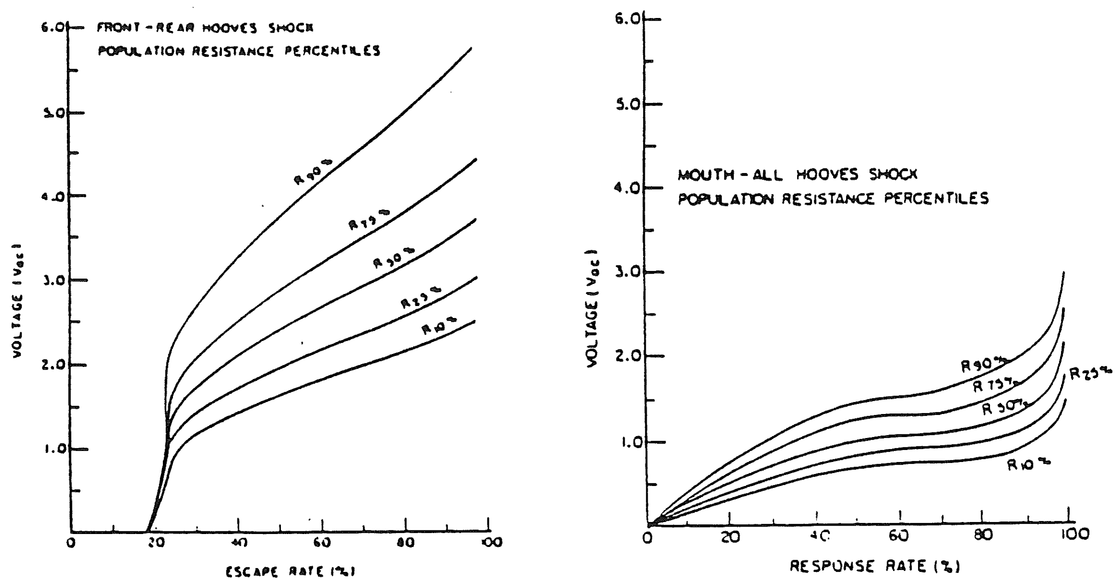
Research Objectives: Results, Current Status and Direction

1) Sensitivity of Dairy Animals to Electrical Currents

In dairy cows, behavioral modification has been determined to be an important aspect relating stray voltage to dairy cow productivity.

Behavioral changes may result in lowered water consumption, poor feed intake, increased nervousness of the animal and the related consequences of these conditions.

Behavioral response experiments with dairy cows at the University for both 60 Hz alternating current (AC) and direct current (DC), are reported in References 3,4,21,28 and 29 of Appendix 1, Bibliography. Reference 21 and 4 are included as Appendix 2 of the report. Figure 1 summarizes response rate for cows for 60 Hz AC voltages, front-to-rear hooves and mouth-to-all hooves, found by experimentation (Ref. 4). The DC current required for the same response rates were found to be 20 to 35 percent higher than the AC (Ref. 21).



Voltage vs Response Rate for front-rear hooves shock (4)

Voltage vs Response Rate for mouth-all hooves shock (4)

Figure 1. Animal Sensitivity to AC Currents

Work done at Cornell University and USDA Laboratories in Beltsville, Maryland, indicates current which would result in the production of an immediate endocrine response may be as high as 8 milliamperes (mA) or more. This implies, depending on the pathway and the cow's body resistance, that a voltage difference between two cow contact points must exceed 3 V to begin to initiate immediate endocrine responses from the animal. Therefore, it is likely that the behavioral indicators are a better indicator of immediate response of the animal than are the endocrine responses.

Another aspect being investigated by University of Minnesota researchers is that of a possible change in immune system response. Some producers experiencing stray voltage problems, after having corrected the electrical problem, have experienced continuing animal health problems.

One possible explanation is that animals subjected to long-term exposures to stray voltage lose their immunity or ability to successfully fight off any existing infections. A possible method to test this is by lymphocyte stimulation which is an in vitro technique used to assess blood cellular response to non-specific immune functions. A marked reduction in lymphocyte stimulation would indicate a loss of immune response. Blood samples from thirty-five dairy cattle on four farms were divided into two groups, non-exposed and exposed to stray voltage. However, results were inconclusive, in that variations in test results were much larger than average scores for exposed and non-exposed animals. It was concluded that to obtain meaningful results, controlled experiments where blood samples were obtained prior to, and immediately after, prolonged exposure to stray voltage, would be necessary.

Continued study of sensitivity of dairy animals to electric current when drinking water will be underway at our Rosemount Experiment Station this summer. In the experiments planned, emphasis will be placed on following the response of the exposed animals over a period of four to five months. A microcomputer-based system which includes individual animal identification of up to ten animals and control of the current level by animal has been developed for use in this study. Changes in drinking patterns or quantities, body weight gains, and changes in blood parameters which may be indicators of stress or change in immune response, will be followed through the experimental period.

2) Sensitivity of Swine to Electrical Currents

Field contacts have shown that problems similar to those in dairy facilities are also being experienced to some degree in swine production units. One experiment to test swine sensitivity to electrical currents has been completed. A second, longer-term experiment, is now underway. In the first experiment, eight pigs, 50 - 125 pounds each, were subjected to various current levels with the pathway being from a nipple waterer to all hooves. As reported in Reference 5 included as Appendix 3, water consumption was lowered by 25 percent when pigs were exposed to a 4.0 milliampere (mA) current. A voltage reading of approximately 3.7 V was needed to elicit this response. Although total consumption was not affected, choice experiments showed the pigs could sense currents as low as 0.5 mA.

Sensitivity of nursing sows in farrowing crates to electrical currents is being studied at the swine facility on the St. Paul Campus. Since swine are a somewhat easier and less expensive animal to work with on an experimental basis than dairy cows, a series of experiments with sows in farrowing crates have been planned. Eight farrowing crates have been set up such that the sows receive a controlled level of electrical current each time they come in contact with a water nipple. A monitoring and control system establishes the current level and monitors and records the length of each drink by each animal. Daily total water consumption is monitored.

Results of one preliminary experiment with four sows are summarized in Figure 2 through 4. These are summaries of water consumption, length of drink, and number of drinks over a five-day period.

Exposures were:

Sow 1 - Control (0.09 mA)
Sow 2 - 2.5 mA 50% time
and 0.09mA 50% time (randomly)
Sow 3 - 2.5 mA
Sow 4 - 4.0 mA

Although no statistical tests can be done on this preliminary data, the results tend to indicate a possible change in drinking pattern at the 2.5 mA level.

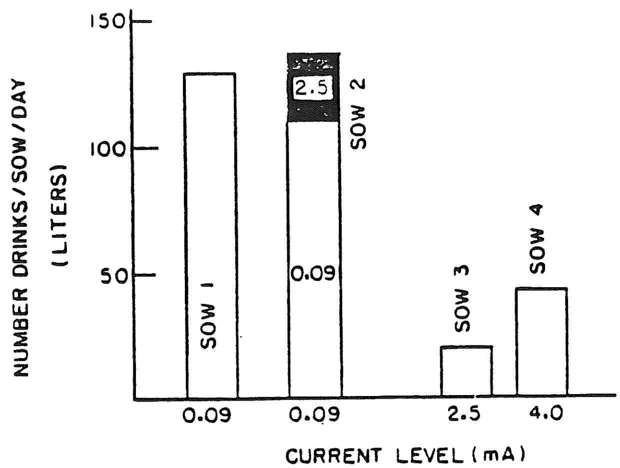


Fig. 2. Water Consumption/Sow/Day vs. Current Level

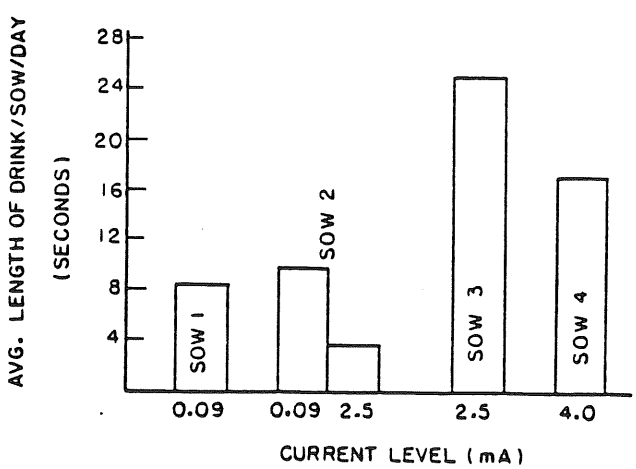


Fig. 3. Length of Drink/Sow/Day vs. Current Level

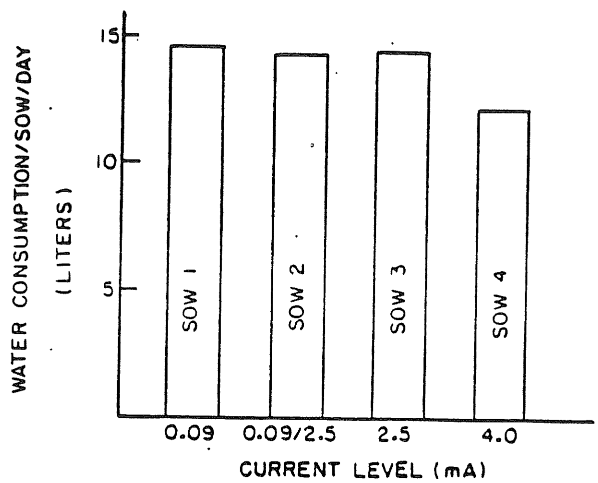


Fig. 4. Number of Drinks/Sow/Day vs. Current Level

In future farrowings, we will look at water consumption, milk production of the sows, and changes in blood composition, which indicate cellular immune response to non-specific immune functions.

3) Electrical Systems Characteristics

Successful detection of, and dealing with, stray voltage problems, requires an understanding of -

1) the electrical system
2) the types of sources of stray voltage which can occur and the effects of interaction of sources, and
3) the available solution procedures and their ramifications.

This knowledge, along with carefully developed testing procedures, is needed. References 1,6,7,8,11,12,13,14,15,18,22,23,24, and 26 are publications of the University which are directed at these topics. Included in Appendix 4 is a copy of a regional Extension publication produced by the University of Minnesota in 1980. This document has been used nationwide as a basic training tool and source of at least an initial screening procedure.

Basic circuit analysis and computer modeling is assisting in improving our understanding of sources of stray voltage and effects of various mitigation procedures on farmstead and distribution systems. Also included in Appendix 4 is a paper to be presented in April to the Rural Electric Power Conference of the Institute of Electrical and Electronics Engineers. The paper presents the three currently available procedures for dealing with stray voltage problems; 1) voltage reduction, 2) gradient control and 3) isolation. The proper application and likely effects of each approach is discussed and demonstrated via results of computer modeling.

Current projects in this segment of our research program include:

a) Survey of Electrical Grounding on Distribution Systems

A grounding resistance survey and neutral-to-earth voltage survey is planned in cooperation with the North Central Area, Rural Electric Administration Representative and the Rural Electric Cooperatives of Minnesota. The survey will compile data at 25 locations per cooperative. Data will be collected on the soil resistivity in the area, grounding resistance of the neutral system as a whole and of single electrodes, neutral and phase current, and neutral-to-earth voltages.

Expansion of this project to include analysis of the contribution of farmstead grounding systems to the grounded neutral system is desired. This would also bring in useful information for system designers and planners. If funding can be obtained, high priority will be given to this component of the project.

b) Use of Groundfault Interrupter Technology in Agricultural Wiring

In recent years, groundfault interrupters have been required by the National Electric Code for additional protection in potentially wet locations of residences and garages. These devices, which detect a leakage current at a 5 mA level, are designed for protection of a person from electrical shock. In Europe, these devices are used in agricultural settings in a manner which would eliminate neutral-to-earth voltages at watering devices. This is done by elimination of the grounding conductor and any other conductive paths to the watering device frame. Therefore, these devices have potential for improving electrical safety when used in the conventional manner and perhaps playing a role in addressing neutral-to-earth problems at selected locations as well.

The objective of one of our current research projects is to collect baseline data as to the normally occurring leakage currents in livestock facilities, particularly dairies. This data is needed as evidence of the feasibility of such technology. Data collection equipment for measurement and characterization of leakage currents in actual facilities is under development. Plans are to work with cooperating farmers in the next year to monitor leakage currents under a range of weather and loading conditions on their farmsteads.

c) Equipotential Plane Design Considerations

One procedure recommended for minimizing stray voltage potentials, particularly in new facilities, is the use of equipotential planes in the building construction. An area which needed further definition is that of creating a voltage transition zone to move animals on and off the equipotential plane. Reference 9 summarizes work in design of such transitions. Theoretical analysis of such transitions showed a mesh embedded into the soil at an angle of 45 degrees for a distance of at least eight feet at each entrance and exit gives the best possible results. Field trial of this procedure is planned in the near future.

d) Personal Computer Models for Neutral-to-Earth Voltages

Agricultural Engineering personnel are developing a series of computer programs which can be used on personal computers to model neutral-to-earth voltages on rural single-phase distribution lines and farmsteads. The first program, for single phase line distribution lines, is currently available. This program allows the user to specify the design and loading of a single phase line with up to ten farms. Appendix 4 contains a more complete description of the program.

Identified Research

The following two topics are areas which have been identified through our current research and Extension programs as being in need of immediate research attention, but which are beyond the scope of our present program. Although the University has interest in pursuing these topics, funding for working in these areas has not been identified at this time.

i) Surge Current Considerations

Short term surges in use of electrical current frequently occur on farmsteads; an example is when a motor is started. These surges load the system in a manner which may produce a neutral-to-earth voltage above the threshold of perception or annoyance to an animal. This can occur when steady state values are below what would be considered a problem level, but surges are present. Even when available transformer isolation devices are being used, these occurrences may be of concern. Two types of devices are currently being used for transformer primary to secondary isolation; inductive devices and solid state switches. Cases have arisen where off-farm, or primary neutral-to-earth voltage may, during times of peak loading, approach a high saturation state of the inductor or breakdown level of the solid state device. In particular, this may happen during surges as during motor starts. This raises the question: are these short term surges, which may occur during motor starts on "isolated" systems, of concern?

A two-stage project is necessary to address this issue. The first stage includes quantifying the form of the surge currents being experienced on grounded neutral systems. This information would be used to allow the design of a system for subjecting animals to similar surges under controlled conditions. The second phase would be animal behavioral experiments to collect data on sensitivity of the animal to such surges.

ii) Electrical Transients in Agricultural Wiring Systems.

Frequently the question of the occurrence and effects of electrical transients on farmstead and rural distribution systems is raised. These vary from the surges described earlier, in that they are not events occurring at the power line frequency of 60 Hz. Two research components are needed to address questions in this area. The first is what type of transient events are occurring in agricultural facilities.

The transients need to be quantified in terms of waveform, peak values, energy, frequency and rate of occurrence. Sources of such transients need to be identified. Items unique to agriculture, such as cow trainers, may need to be studied in detail. The second element is to attempt to define the role of these events in affecting animals. Although human response data will provide some basis for judgement, direct experimentation with animals, as has been done with DC and AC 60 Hz, may be needed with livestock to fully address this issue.

Summary of Accomplishments

The University of Minnesota's research and Extension programs have been in the forefront in the creation and dissemination of information on stray voltage topics nationwide. Methods developed through research and Extension efforts at the University of Minnesota are now accepted as a basic approach to identification of stray voltage sources. In order to create the awareness and knowledge to help dairymen and others who may experience stray voltage problems, it has been necessary to work closely with not only the dairymen, but rural electricians, electric power suppliers and others supplying electrical expertise and support to the producer.

University personnel have worked directly with electrical equipment manufacturers to develop acceptable mitigation devices. We have held numerous training sessions on investigation techniques and addressing problems. We have worked directly with electrical code making bodies to seek help in making necessary changes to allow implementation of newly developed devices and concepts.

Since it is not feasible to eliminate neutral-to-earth voltage on our electrical systems and since animals, like humans, cannot sense a current below a certain threshold level, it is necessary to expand our understanding of what is an acceptable level for animal exposure.

In some cases, our present distribution systems are found to be unacceptable when livestock constraints are considered. Available mitigation procedures create what are non-standard electrical distribution systems. The University of Minnesota has continued to work with the electrical power industry to assess the operational and safety characteristics of these alternatives. Efforts are needed to continue to improve our understanding of electrical distribution systems as they relate to the creation of neutral-to-earth voltage.

The interdisciplinary scope of the University of Minnesota research and Extension team has allowed it to address the interfacing of animals and the electrical system in a highly productive manner. The project continues to develop and disseminate information needed by the agricultural and electrical industries to remove and prevent the detrimental effects of stray voltage in livestock facilities.

List of Appendices

Appendix 1 - Bibliography, University of Minnesota, Stray Voltage Publications, 1979-1984

Appendix 2 - Dairy Animal Sensitivity

Item 1 - Gustafson, R.J., T.M. Brennan and R.D. Appleman. 1984. Behavioral studies of dairy cow sensitivity to AC and DC currents. Paper No. 84-3504, American Society of Agricultural Engineers, St. Joseph, MI.

Item 2 - Appleman, R.D., and R.J. Gustafson. 1984. Sources of stray voltage and effect on cow health and performance. University of Minnesota Dairy Extension, Dairy Update 70, November, 1984. (Accepted for publication in Journal of Dairy Science.)

Appendix 3 - Swine Sensitivity

Appleman, R.D., R.J. Gustafson, M. Wehe and T.M. Brennan. 1984. Response of pigs to stray voltage. University of Minnesota Dairy Extension, Dairy Update 71, January, 1985. Reprinted from 1985 Minnesota Swine Research Report, pp. 62-65. University of Minnesota, Department of Animal Science.

Appendix 4 - Electrical Systems

Item 1 - Cloud, H.A., R.D. Appleman and R.J. Gustafson. 1980. Stray voltage problems with dairy cows. North Central Regional Extension Publication 125.

Item 2 - Gustafson, R.J. 1985. Understanding and dealing with stray voltage in livestock facilities. Paper for presentation at Rural Power Conference of Institute of Electrical and Electronics Engineers.

Item 3 - Gustafson, R.J. and D.J. Hansen. 1985. Single-Phase Distribution system Neutral-to-Earth Model. University of Minnesota, Department of Agricultural Engineering.

Appendix 1 - Bibliography, University of Minnesota,
Stray Voltage Publications, 1979-1984

APPENDIX 1

University of Minnesota

Stray Voltage Publications

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Appendix 2 - Dairy Animal Sensitivity

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Item 2 - Appleman, R.D., and R.J. Gustafson. 1984. Sources of stray voltage and effect on cow health and performance. University of Minnesota Dairy Extension, Dairy Update 70, November, 1984. (Accepted for publication in Journal of Dairy Science.)

PAPER NO. 84-3504

BEHAVIORAL STUDIES OF DAIRY COW SENSITIVITY TO AC AND DC CURRENTS

by

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SUMMARY:

Dairy cow behavioral responses to alternating and direct current were examined for three body pathways; mouth-to-all hooves, front-to-rear hooves and body-to-all hooves. At significant levels of response, a higher DC than AC current was needed to obtain the same response rate.

American Society of Agricultural Engineers

St. Joseph, Michigan 49085

BEHAVIORAL STUDIES OF DAIRY COW SENSITIVITY TO AC and DC ELECTRIC CURRENTS

INTRODUCTION

Recent studies have documented a condition existing in livestock facilities known as stray voltage. These voltages are generally of a low level (less than 10 volts). As a result of exposure to these voltages, animals can exhibit a wide range of behavior and health problems. For dairy cows, these include uneven milkout, reluctance to drink water, increased mastitis, and extreme nervousness while in the milking parlor (Cloud, Appleman, Gustafson, 1980). These symptoms could also be attributed to other factors such as animal mistreatment, disease, and nutritional disorders. Careful evaluation of herd management practices and health, as well as electrical sources, must be conducted to identify problem causes.

In this study, dairy cow responses to alternating (AC) and direct (DC) electrical currents were examined. Three body pathways; front-to-rear hooves, mouth-to-all hooves, and body-to-all hooves were used. These pathways were selected because animals may be exposed to front-to-rear currents when they stand or walk across an area of the barn or parlor where a floor voltage gradient exists. A mouth-to-all hooves shock can occur when an animal bridges the gap between a metallic feeder or water bowl and the ground. A body-to-all hooves current can occur when an animal bridges the gap between metal pipework that is connected to the grounded neutral system and a concrete floor or earth.

Three separate experiments were conducted with dairy cows. The overall objective was to develop cow response functions for a range of AC and DC current through each of the three pathways. Experiment 1 involved administering front-to-rear hooves currents, 0-5 ma AC and 0-6 ma DC. Experiment 2 involved administering mouth-to-all hooves currents, 0-5 ma AC and 0-6 ma DC. Experiment 3 involved administering body-to-all hooves currents, 0-7.5 ma AC and 0-9 ma DC.

REVIEW OF LITERATURE

The effect of a specific voltage on dairy cattle is influenced by many factors. When combined, these factors determine the current flow through the cow's body: 1) voltage magnitude and waveform, 2) the resistance of a cow's body pathway and the pathway current sensitivity, 3) condition of concrete, soil and metallic conductors affecting resistance to "true earth", 4) resistance of cow's contact points; 5) resistance of the electrical pathway to cow's contact points; and 6) impedance of the source (Gustafson, 1983).

The authors wish to acknowledge the assistance in statistical analysis received from Dr. Sandford Weisberg, Professor of Applied Statistics, and Matthew Mattison, Student, University of Minnesota.

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Several of these factors cannot be determined in the field, therefore current flow necessary to elicit a response is combined with resistance estimates to calculate probable voltage necessary to cause an animal to respond.

Available research data quantifying sensitivity by current level has been reviewed by Appleman and Gustafson (1984). In summary, they found three criteria have been used in judging cow responses to electric current: behavioral responses, endocrine responses, and changes in milking performance.

Endocrine Responses and Milking Performance

Lefcourt, et al. (1984) summarized their studies by concluding that "any negative effects of electrical shock on milk production or mammary gland health most likely are not directly related to shock, i.e., physiological responses to shock were minimal and milk yield was generally maintained at normal levels during the shock period. However, the severe behavioral responses to shock would almost assuredly result in management problems and the degree to which milk production would be affected would depend on how dairymen deal with the abnormal behavior." Similarly, Drenkard et al. (1984) found little or no physiological response to electric currents common in stray voltage problem herds. Thus, it appears the primary influence of stray voltage on dairy cow performance is one of behavior modification.

Behavioral Responses

While not directly studying behavior, physiological researchers have made useful observations of behavior while collecting data related to endocrine response and milking performance. Drenkard, et al. (1984) used an udder-to-all-hooves pathway on four cows being milked to obtain behavioral responses at 0, 2, 4 and 6 ma. Results suggest that some cows can be expected to exhibit a behavioral response at 2 ma, and most will respond to 4 ma.

Even though many of the observed cow behavior modifications are associated with the milking process, Gustafson et al. (1983) demonstrated that under normal conditions the milking equipment itself is not a likely path of problem currents to the animal. The minimum resistance for the milkline-claw path under milking conditions, for a 9 kg/min flow rate, would be above 47 kohms for a typical stall barn high line and above 26 kohms for a low line configuration. Resistance of the milk hose from the milkline (receiver) to the machine claw was inversely proportional to milk flow rate. Minimum resistance from the claw through the cow to the floor was 3 kohm.

A series of four experiments (Norell, 1983 and Norell, et al. 1983) were designed to study the effects of AC current on behavior of dairy cows. The first experiment involved a current contingent upon a muzzle-plate press by the cow. Six Holstein cows were trained to press the plate 30 times to receive a grain reward. Front-to-rear hooves currents up to 6 ma did not suppress plate pressing behavior. Subjective signs of annoyance such as hoof movement during plate pressing were occasionally observed. The current level which suppressed plate pressing for a muzzle-to-all hooves pathway varied between cows and sessions. Four of six cows were initially suppressed by 1.0 to 2.0 ma currents. Higher currents were required during later sessions. Currents of 4.0 or 4.5 ma were required to initially suppress the other two cows.

In a second experiment, seven Holstein cows were trained to raise a front hoof to avoid a continuation of a front-to-rear hooves shock. The observed escape response level for currents between 0 and 5 ma is summarized in Fig. 1. At currents less than 2 ma, the response level was equal to that of the random response level of twenty percent.

In a third experiment, an avoidance response curve for mouth-to-all hooves currents was developed. Mouth opening was a specific avoidance response, therefore, the curve shown in Fig. 1 continues to low current levels.

In the fourth experiment, twenty-five lactating Holstein cows were used in an experiment involving the cows walking across two electrically isolated metal grids upon leaving a preparation stall for the milking stall. Results indicated cows subjected to a 4.0 ma current required twice the time to cross the grid compared to the no current case. Two-minute milk yield, total milk yield, and machine-on time ratios were not significantly influenced by experimental treatments.

MATERIALS AND METHODS

The six Holstein cows utilized for all experiments were moved individually from their home tie stall to a stall that was specially built for these experiments. The stall used measured 1.2 x 3.6 m (4 x 8 ft) with a "cow catcher" neck hold in the front of the stall to hold the cow relatively still. On the base of the stall were two expanded metal grids. Placed under each grid and over a dividing "wall", was a continuous rubber sheet that acted as a barrier to moisture and effectively isolated the front hooves from the rear hooves. The grids were kept wet to ensure good contact. A large partition was constructed to use as a visual barrier between the cow and any activity in the barn. This partition also served to block the cows' view of the observer(s) as well. A radio was used for background sound. In this configuration, the cow was responding to the shock only and not the activity or sounds around her.

A schematic of the electrical current source circuit used for this study is shown in Fig. 2. For AC current applications, a 0-120 volt autotransformer was connected to a step up (1:2) isolating transformer. A 39 kohm resistor, in series with the cow, was used as a current limiting resistance.

The current level was adjusted by varying the voltage across the 39 kohm resistor. With the circuit set up as outlined, the maximum deliverable current is 6.2 ma AC. For this study, all currents were administered for a maximum 30 second period, with each current delivered in 0.5 s "on", 0.5 s "off" pulses. Initiation of the current is accomplished with one of the two stop/start switches in the circuit. Relays controlled not only the total period but also the on/off cycle within the period.

The design of the DC circuit was identical to that of the AC circuit, except for the substitution of a variable voltage DC power supply for the AC source and the substitution of a 20 kohm resistor for the 39 kohm resistor. The maximum deliverable current from this circuit was 15 ma DC.

The six cows were divided into two groups of three, with one group receiving AC current, and the other group receiving DC current via the same pathway. Then, the type of current was switched for each group so that at the end of each experiment all cows were subjected to both AC and DC current. This procedure was adhered to for each type of body pathway.

Experiment 1: Front-to-Rear Current Path

For Experiment 1, it was necessary to conduct training sessions for each cow to acquaint them with the desired response to current from their front-to-rear hooves. The training sessions consisted of exposing each cow to a 5.0 ma AC or 6.0 ma DC front-to-rear hooves current. A total of fifty exposures were presented. Each exposure, 0.5 s "on", 0.5 s "off" pulses, lasted for up to thirty seconds. If the cow gave the proper response, a front hoof raise, then the trial was terminated early. Intervals between trials varied from thirty to ninety seconds. A cow was considered trained if she gave the proper response 90% of the time over the last twenty trials. The training sessions were performed 24 to 48 hours before actual experimental testing took place.

An experimental session consisted of sixty AC trials, six current levels (0.0 to 5.0 ma in 1.0 ma increments) arranged randomly within ten blocks of time, or seventy DC trials; seven current levels (0.0 to 6.0 ma in 1.0 ma increments) arranged randomly within ten blocks of time. This random block design allowed for each current level to occur once within each block of time and ten blocked replicates. Preceding the experiment trials were 10 "warmup" trials similar to the training sessions. All the cows gave the trained response at least 70% of the time, with four of the six responding at 90% or better. This indicated a retention of the learned response from the training sessions conducted earlier.

Experimental trials were presented in a single blind experiment, that is, the animal observer was unaware of the current level being administered. Trials were replicated 24-48 hours later. As with the training sessions, if the cow raised her front hoof in less than thirty seconds, the trial was manually terminated. The interval between exposures was thirty to ninety seconds.

Experiment 2: Mouth-to-All Hooves Pathway

Experiment 2 used a mouth-to-all hooves pathway. The mouth contact was achieved by placing a metal bit in the cow's mouth. For experiment 2, the stall configuration, electrical equipment, and testing methodology were identical to that in experiment 1 except the front and rear floor grids were connected. The observation wall was placed near the front of the cow so that the observer could better view the cow's responses.

Cows were exposed to ten warmup trials prior to the actual experimental trials. Unlike experiment 1, no training sessions were necessary. Cows opened their mouths as a response to a current through the mouth without any prior training. All cows recorded an 80% or better positive response in these warmup trials, with both AC and DC currents. The same randomized block design and current levels used in the previous experiment were employed. Experimental trials were terminated early by the observer if the mouth opening response was detected before the thirty second duration of the current had expired.

Experiment 3: Body-to-All Hooves Pathway

The current pathway examined in this experiment was one of body-to-all hooves. The stall configuration, electrical equipment, and testing methodology were similar to those used in the previous experiments.

Approximating a body-to-all hooves path was achieved through the use of a canvas belt with a metal patch attached to the belt. The belt was placed around the shoulders of the cow and secured underneath by two D-rings. Attached to the inside of the belt was a brass metallic patch, measuring 5 cm (2 in) in width and 12 cm (5 in) in length. This patch delivered the current to the cow's body. The placement of the patch was critical in terms of how the cows reacted to a current of a given level. A cow could experience a body-all-hooves shock from any number of points on her body, depending on the orientation of her body to the source of the voltage. For this experiment, the patch was located on the shoulder area of a front leg. In order to ensure good contact at the cow's body, the metallic patch was coated with a conductive paste, "Liqui-Cor" ECG conductor. The hair was not shaved off.

A minimum of two training sessions were conducted for each cow for each current type. The response the cows were trained for was a front hoof raise. All six of the cows exhibited initial confusion as to exactly what type of response to give. Some shook their shoulders, others developed a muscle tremor, while still others lifted one of their front hooves. Hence, longer training sessions were required. Results from these training sessions were still below those of the other two pathways. Average cow responses were about 70% for training trials thirty through fifty, as opposed to over 80% for training trials thirty through fifty for the previous two pathways.

Experimental trials were preceded by ten warmup trials. The response from these warmups was about 70%, as with the training sessions. The random block design used for the previous experiments was followed.

However, the current ranges were 0.0 to 7.5 ma AC and 0.0 to 9.0 ma DC. The current level was stepped in 1.5 ma increments, therefore total number of applications remained the same. An experimental trial was terminated early if the cow expressed the trained escape response in less than thirty seconds.

ANALYSIS OF THE DATA

Analysis of the data required the use of a transformation. The data was binomial in nature, i.e. desired responses were coded as a 1 and no response was coded as a 0. Normal errors do not correspond to a zero/one response. As a result, variances along the binomial distribution are unequal. Data in this form renders standard regression techniques invalid.

The calculation of a response function to current level using binomial data was accomplished through the use of logistic regression. The logit being the natural logarithm of the odds of success, i.e. the ratio of the probability of success to the probability of failure. The program GLIM (Baker and Nelder, 1979) was employed to perform the necessary transformations and to obtain the maximum likelihood estimates, i.e. response functions. GLIM can be used to compare different submodels by examining the effects of adding/subtracting independent variables (current level, current type, and body pathway). In the analysis of data for all six experiments, both cow effects and replication effects were ignored.

The result of fitting this data to a logistic regression model available through GLIM can be expressed in two equivalent ways. First, we can fit a linear model to the logit scale. Fitting the linear model in the logit scale by using the transformation, yields:

$$\text{logit } T = \ln [T/(1 - T)] = B_o + B_1 X \qquad (1)$$

where T is the proportion of positive responses
X is the current level
B_o and B_1 are regression constants

This expresses the logistic regression model as a straight line on the logit scale. Solving for T using eq. (1), we arrive at:

$$T = \frac{e^{(B_o + B_X)}}{1 + e^{(B_o + B_1 X)}} \qquad (2)$$

Equation 2 expresses the model as an S-shaped curve in the original probability scale. GLIM calculates the estimates of the coefficients for use in the above equations. Depending on choice of submodels and independent variables, effects of these variables, collectively or individually, on the response rate, can be estimated.

A straightforward means of representing the results of the logistic regression analysis is to use as an index the value of current level that is required to obtain a response 50% of the time (Weisberg, 1980). Using the equation logit $T = B_o + B_1X$ we can find the value of X that gives T = 0.5, or logit T = 0. Hence, we must solve the equation $0 = B_o + B_1X$ for X. The estimated response rate will be 50% when the shock level is given by $B_o/B_1 = X$.

In an attempt to establish the current level(s) at which significant responses occurred, response frequencies were compared between each 1.0 ma pair (0.0 ma vs. 1.0 ma, 0.0 ma vs. 2.0 ma, etc.) with a chi-square test of proportions in two independent samples (Snedecor and Cochran, 1967).

This comparison was performed through the use of 2 x 2 contingency tables, each with one degree of freedom. The purpose of the chi-square test as applied to a 2 x 2 contingency table is to examine the hypothesis of independence between the two variables. The null hypothesis to be tested for all three experiments is; "Are the cows' response rates independent of current level?" If not, then at what current level does the response rate attain a level different from that at 0.0 ma.

RESULTS AND DISCUSSION

Experiment 1: Front-to-Rear Hooves Pathway

Table 1 contains base data and results of the chi-square analysis for both AC and DC currents through the front-to-rear hooves pathway. Response frequencies were not significantly different from 0.0 ma for AC current levels at 1.0 and 2.0 ma. However, at the 3.0 ma level, response rate difference becomes quite significant (ρ <.005). Response frequencies were not significantly different from 0.0 ma for a DC current level of 1.0 ma, but a significant (ρ<.008) difference occurred at the 2.0 ma level. At current levels of 1.0 ma and less for AC and DC, there is a base level of activity evident. This can be attributed to random front hoof movement, rather than an attempt to escape a shock (Norell, 1983).

As Table 1 indicates, significant increases in escape percentages occurred for each 1.0 ma increment above 2.0 ma AC and 1.0 ma DC. The cows were expressing the trained escape response in an attempt to avoid currents greater than 2.0 ma AC and 1.0 ma DC.

Closer examination of the data indicates an unusually low number of escapes at the 2.0 ma AC current level. This most certainly affected the chi-square analysis of the 0.0 ma - 2.0 ma paired sample, resulting in a higher significant current level. At the maximum current levels of 5.0 ma AC and 6.0 ma DC, the cattle were expressing the escape response 84% and 74.6% of the time respectively. These results were consistent with the ten "warmup" trials.

Table 1 - Data and Results of Chi-Square Analysis, Front-to-Rear Hooves

AC Current
Total Observations = 600
Observations/Current Level = 100

Current (ma)	Escapes (%)	Number of Escapes	χ^2_α, 1dof (0 - X ma)	Approx. ρ
0.0	27.0	27	NA	NA
1.0	31.0	31	0.22	0.66
2.0	24.0	24	0.11	0.75
3.0	62.0	62	23.40	<< 0.005
4.0	66.0	66	29.02	<< 0.005
5.0	84.0	84	63.48	<< 0.005

DC Current

Total Observations = 840
Observations/Current Level = 120

Current (ma)	Escapes (%)	Number of Escapes	χ^2_α, 1dof (0 - X ma)	Approx. ρ
0.0	21.6	26	NA	NA
1.0	31.6	38	2.58	0.10
2.0	39.1	47	7.27	0.008
3.0	42.5	51	11.01	<< 0.005
4.0	51.6	62	21.97	<< 0.005
5.0	63.3	76	40.94	<< 0.005
6.0	74.6	90	66.22	<< 0.005

Escape functions were calculated using logit regression analysis (Fig. 3). Individual cow escape percentages for all AC and DC current levels were used in the analysis.

If we assume an average pathway resistance of 744 ohms (Norell, 1983), we can calculate the average floor voltage gradient that would have to be present to evoke a certain response. For example, at a 50% response rate (2.6 ma AC, 3.4 ma DC) a voltage of 1.9 V AC and 2.6 V DC is indicated.

Experiment 2: Mouth-to-All Hooves Pathway

Table 2 contains base data and results of the chi-square analysis for the mouth-to-all hooves pathway. Response frequencies were not significantly different from 0.0 ma for AC current levels of 1.0 and 2.0 ma. However, a significant ($\rho << 0.005$) difference in response rate occurred at the 3.0 ma level. Significant differences in response rates for DC currents were markedly different. Response frequencies from 1.0 to 4.0 ma did not exhibit a significant ($\rho << 0.005$) difference from the response frequency at 0.0 ma. Between 4.0 and 5.0 ma, a significant difference in response rate did occur. At the higher current levels of 5.0 ma and 6.0 ma DC, the cow response rates were quite similar, 74.1% and 69.1%. However, this was lower than the response rates in the ten warmup trials, where the average response rate was 85% or greater.

Table 2 - Data and Results of Chi-Square Analysis, Mouth-to-All Hooves

AC Current

Total Observations = 720
Observations/current level = 120

Current (ma)	Escapes (%)	Number of Escapes	χ^2_α, 1dof (0 - X ma)	Approx. ρ
0.0	8.3	10	NA	NA
1.0	6.6	8	0.06	0.083
2.0	18.3	22	4.36	0.040
3.0	41.6	50	33.80	<<0.005
4.0	60.0	72	68.93	<<0.005
5.0	74.1	89	104.60	<<0.005

There was an unexpected level of response at 0.0 ma and 1.0 ma levels. Control, no shock experiments of this pathway conducted by Norell (1983) resulted in no observed mouth opening response during the control, suggesting the mouth opening was a shock elicited response. However, in this experiment, perhaps due to physical discomfort from the bit, the cows showed a distinct base level of activity at the zero current level.

A response function to a mouth-to-all hooves shock (Fig. 4) was calculated by logistic regression for AC and DC current.

Assuming an average mouth-to-all hooves pathway resistance of 360 ohms (Norell, 1983), the calculated voltages for 50 percent response (3.8 ma AC, 4.3 ma DC) are 1.4 V AC and 1.6 V DC.

DC Current

Total Observations = 840
Observations/Current Level = 120

Current (ma)	Escapes (%)	Number of Escapes	X^2_α, 1dof (0 - X ma)	Approx. ρ
0.0	15.8	19	NA	NA
1.0	18.3	22	0.12	0.75
2.0	20.0	24	0.45	0.50
3.0	25.0	30	2.56	0.10
4.0	28.3	34	4.75	0.03
5.0	57.5	69	43.08	<< 0.005
6.0	69.1	83	67.67	<< 0.005

Experiment 3: Body-to-All Hooves Pathway

Table 3 contains the base data and results of the 2 x 2 contingency tables and chi-square analysis of the body-to-all hooves pathway. A significant ($\rho << 0.005$) difference in response frequency, from 0.0 ma, occurs between 4.5 and 6.0 ma AC. For the DC current application, a significant ($\rho < 0.008$) difference in response frequency from 0.0 ma was not detected until the current interval between 4.5 and 6.0 ma. However, the response frequencies for each current level from 3.0 to 9.0 ma showed very little differences between one another. The range of the observed frequency responses over these current levels varied by only 11.8%.

The significance levels calculated from the chi-square test were all very close to one another and fluctuated higher and lower. This made it difficult to establish a particular current level at which one could expect to obtain a response frequency that was more significant than at any other current level. In addition, the observed response frequencies at the maximum current levels are lower than those obtained in the training sessions and in the warmup trials, where in both these cases the response rate was 70% or better.

The response functions generated by logistic regression were generally inconclusive (Fig. 5). The lines are positively sloped but show little if any of the expected S-shape that is characteristic of this type of exponential transformation. There is very little distribution of response throughout the range of current levels. The response frequencies increase and decrease with increasing shock intensity, never arriving at a clearly significant level.

Table 3. Data and Results of Chi-Square Analysis, Body-to-all Hooves

AC Current

Total Observations = 720
Observations/Current Level = 120

Current (ma)	Escapes (%)	Number of Escapes	χ^2_α, 1dof (0 - X ma)	Approx. ρ
0.0	25.8	31	NA	NA
1.5	30.0	36	0.75	0.44
3.0	43.3	52	6.93	2.01
4.5	39.1	47	4.27	0.40
6.0	49.1	59	12.96	<< 0.005
7.5	64.1	77	34.10	<< 0.005

DC Current

Total Observations = 770
Observations/Current Level = 120

Current (ma)	Escapes (%)	Number of Escapes	χ^2_α, 1dof (0 - X ma)	Approx. ρ
0.0	34.5	38	NA	NA
1.5	33.6	37	0	0
3.0	45.4	50	2.29	0.10
4.5	44.5	49	1.91	0.17
6.0	53.6	59	7.38	0.008
7.5	43.6	48	1.55	0.20
9.0	55.4	61	8.89	< 0.005

Several possible reasons exist for this lack of consistency in the response frequencies: 1) a training period that was too short; 2) confusion on the part of the cows as to what response to give to a current, despite the training sessions; 3) the utilization of current levels that were not high enough to evoke a consistent response from a majority of the cattle; or 4) inadequate technique of body contact.

Any of these could have contributed in part to the inconsistencies in the data. Although two training sessions were conducted for each cow, for each current type prior to the beginning of the experimental sessions, the response they were trained to give might have been an unnatural one for a current of this type. Three of the six cows exhibited a tendency to raise a front hoof upon experiencing the training current levels of 7.5 ma AC and 9.0 ma DC, while the other three cows gave varying responses including muscle contractions, startled jerks, and shoulder shakes.

Better response frequencies may have been obtained if the training sessions were longer or made allowances for these varying responses among cattle.

The only conclusive information from this particular pathway/current combination was that it seems a higher threshold current level than the previous two pathways is necessary to elicit a response from cattle. It is not possible to assign any values for the response voltages based on the results from this experiment.

SUMMARY

Experiments with three different pathways were intended to produce estimates of response rate as a function of current level with both AC and DC currents. For mouth-to-all hooves and front-to-rear hooves pathways, response frequency functions were obtained over a range of 0-5 ma AC and 0-6 ma DC. At significant levels of response, a higher DC current was needed to obtain the same response rate in both cases. At a 50 percent response rate a 34 percent higher DC current than AC was needed for the front-to-rear path and 22 percent higher for mouth-to-all hooves.

Front to rear hooves response rate was statistically greater than at the 0.0 ma level above 2.0 ma AC and 1.0 ma DC. Mouth-to-all hooves response rate was significantly greater than the 0.0 ma level above 2 ma AC and 4 ma DC.

Response rate for a body-to-all hooves pathway with currents from 0-7.5 ma AC and 0-9 ma DC were inconclusive. No reliable response pattern was obtained for this body pathway.

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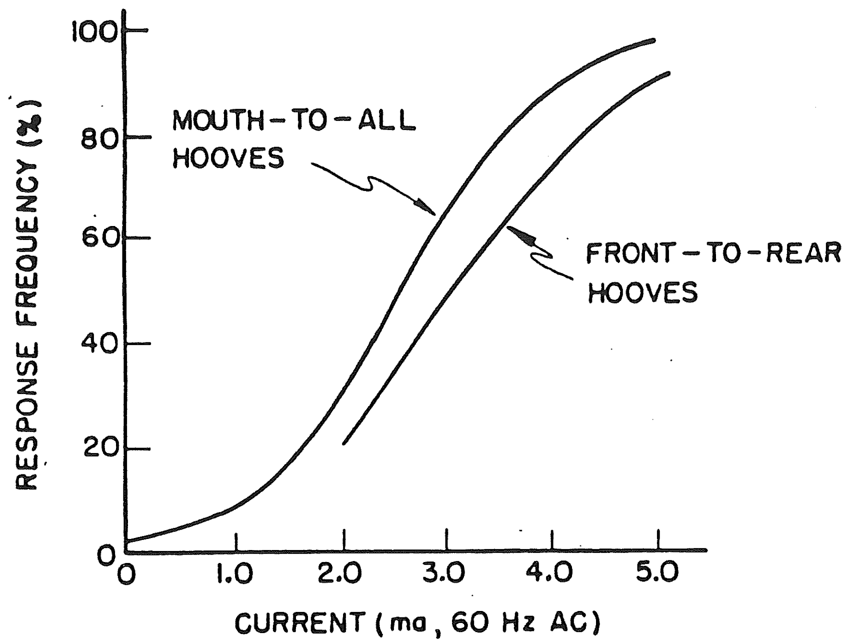

Fig. 1. Dairy Cow Current Sensitivity (Norell, et al., 1982)

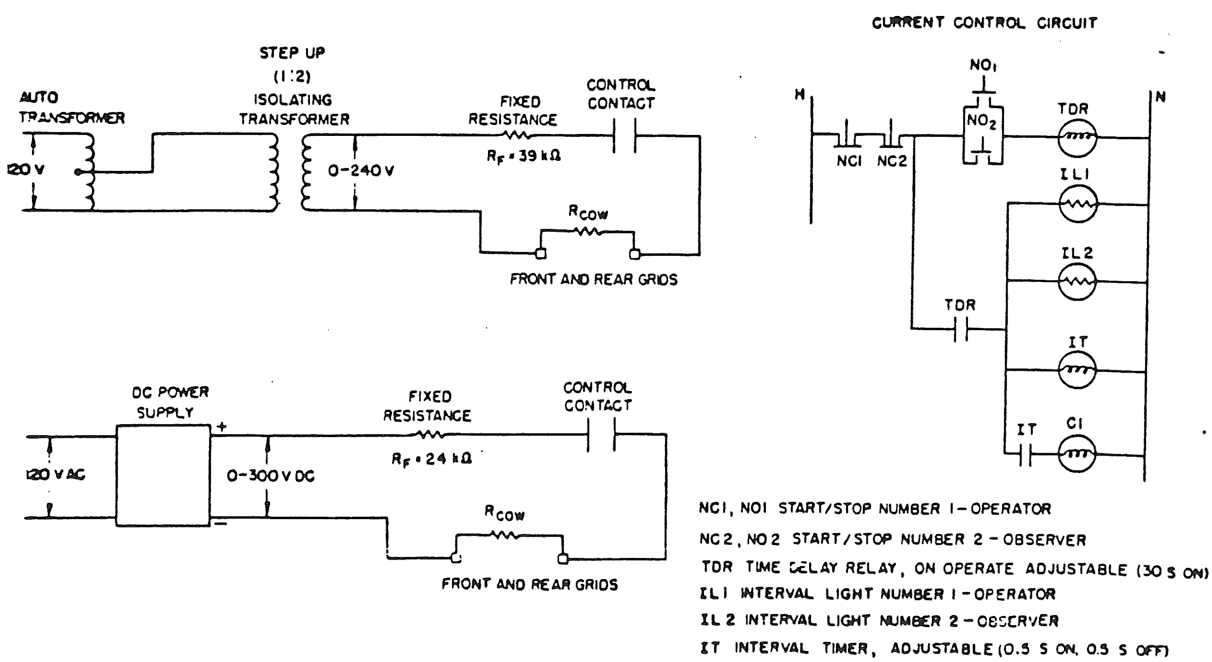

Fig. 2. Current Source and Control Circuits

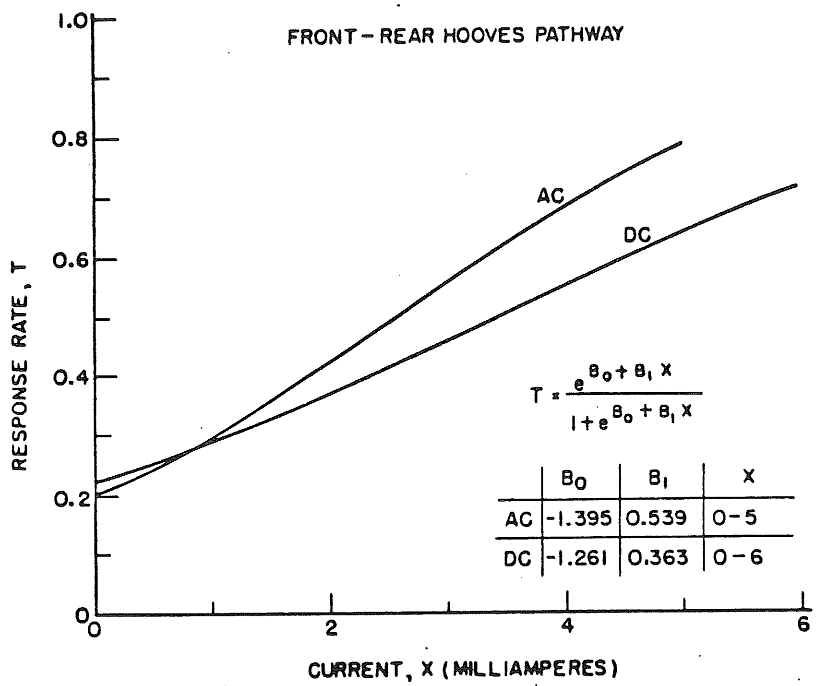

Fig. 3. Response Rate vs. Current, Front-to-Rear Hooves Pathway.

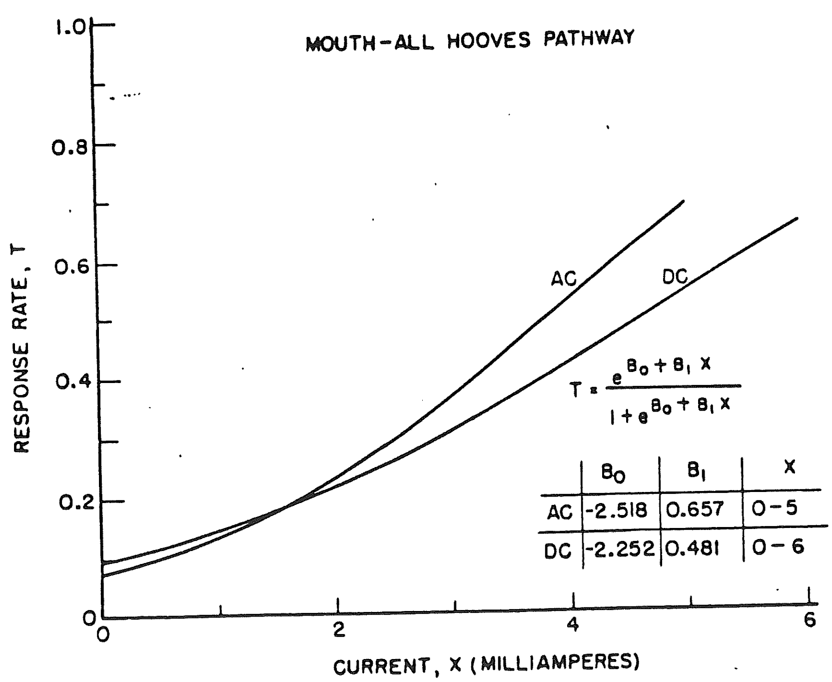

Fig. 4. Response Rate vs. Current, Mouth-to-All Hooves Pathway.

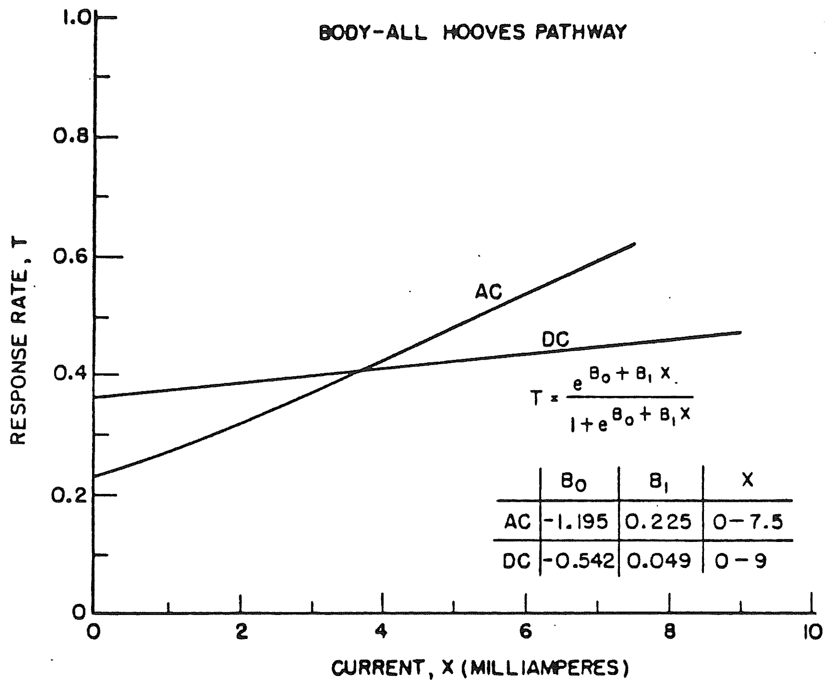

Fig. 5. Response Rate vs. Current, Body-to-All Hooves Pathway

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Dairy Update

SOURCE OF STRAY VOLTAGE AND EFFECT ON COW HEALTH AND PERFORMANCE[1]

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ABSTRACT

In dairy cows, two distinct and important aspects of the interrelationship between stray voltage problems on the farm and dairy cow productivity can be identified. One is behavioral modification that increases in intensity when currents associated with neutral-to-earth voltages above .7 V find a pathway through the cow. The other is immediate endocrine response. Results of research are less clear on the current necessary for the latter to occur; it may require 8 mA or more. This implies, depending on the pathway and the cow's pathway resistance, that voltage difference between two cow contact points must exceed 3 V. Resistance of different cow pathways range from 350 to 1700 ohms. Milk production is more likely to be affected adversely when cows are subjected to shock patterns that are both intermittent and irregular. Less than 10% of the dairy cow population are thought to perceive any electrical currents upon contact with conductive grounding equipment provided voltages on the farm electrical neutral system remain below .35 V. This paper also identifies various sources of stray voltage problems and discusses appropriate procedures for correction.

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Table of Contents

INTRODUCTION

Many different problems associated with management and milking of dairy cows occur when relatively small currents of electricity pass through cows' bodies. Producers are experiencing cow health problems and lowered milk production because of currents from "stray" voltages.

Stray voltage is known by several names: neutral-to-earth (NE) voltage, neutral-to-ground voltage, tingle voltage, extraneous voltage, transient voltage, and metal structures-to-earth voltage. The problem arises from a voltage at an undesirable intensity between two animal contact points.

The concept of stray voltage is relatively simple electrically although sources can be varied and complex. It is likely the number of stray voltage problems will increase as farm operations increase in size and sophistication, as farmstead electrical wiring systems deteriorate or become obsolete, and as electrical loads on rural distribution systems increase unless appropriate action is taken.

The purpose of this paper is to present problems reported, discuss briefly effective diagnostic and corrective procedures, identify what is known about effects of stray voltage on cattle, review briefly appropriate prevention and problem correction procedures, and discuss what still is unknown about its effect on livestock.

Location and Prevalence.

The national and worldwide nature of the problem has been recognized. An Australian researcher (4) implied in 1948 that current resulting from electrical equipment in the milking area may have affected cows negatively. Phillips (29), in New Zealand, published a similar statement in 1962. Craine et al. (9, 10) first reported stray voltages in the US (Washington) in 1969. Feistman and White (14) reported its presence in Canada in 1975.

About 1980, problems from stray voltages were being identified throughout much of the US and Canada (1, 7, 35). Cloud et al. (5) in 1980 and Williams (40) in 1981 estimated that 20% of all parlor operations probably were affected. Rodenburg (32) surveyed 131 Ontario dairy farms and concluded that 80% had voltages on the electrical neutral sufficiently high to be a potential problem. Based on current guidelines, from 29 to 36% of these farms had a voltage drop between cow contact surfaces sufficient to be of concern.

Field Observed Responses.

A variety of cow responses to stray voltages have been reported from farm case studies. A comprehensive list was developed by Williams (39). Other workers have verified the list through case farm studies (1, 12, 19, 24, 34, 37). Commonly cited cattle responses include: 1) intermittent periods of poor production; 2) unexplained poor production; 3) increased incidence of mastitis; 4) elevated somatic cell counts; 5) increased milking times; 6) incomplete milk letdown; 7) extreme nervousness while in the milking parlor; 8) reluctance to enter the milking parlor; 9) rapid exit from the parlor; 10) reluctance to use water bowls or metallic feeders; and 11) altered consummatory behavior ("lapping" of water from the watering device).

The observed effects of stray voltage can be classified into four general areas: effect on milking performance and behavior, effect on herd health, effect on nutritional intake, and effect on production. Pertinent research related to these four general areas is addressed later in this paper.

Other factors such as mistreatment, milking machine problems, disease, sanitation, and nutritional disorders can create problems which also manifest themselves in the above 11 symptoms. A careful analysis of all possible causes is necessary if the proper corrective procedure is to be found.

STRAY VOLTAGE SOURCES

Any electrical condition that sustains a potential difference of sufficient magnitude between any two animal contact points may create a stray voltage problem. Stray voltages associated with the electrical distribution network and the farmstead wiring system can be separated into several categories. 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 identified clearly and measured, the diagnosis is easy, and the appropriate corrective measures can be determined readily. However, a good understanding of sources and their interactions is necessary.

Seven potential sources of stray voltage are listed herein (16), and discussed in detail by Gustafson and Cloud (17). The first two problems discussed result from forces originating off farm. The remaining five causes originate on farm. Depending on the region, off-farm problems may be involved in approximately two-thirds of all problem farms. Rodenburg (32), in Ontario, found the principal sources of stray voltage on 76% of the farms surveyed were attributable to neutral resistance of the distribution system and 5% to on-farm sources. Bodman et al. (3), on the other hand, found that most Nebraska problem herds were the result of on-farm problems.

Off-Farm Causes:

1. Primary neutral current external to the farm.

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

2. Primary neutral currents from 240-volt on-farm loads.

As the electrical load on the distribution transformer of the problem farm increases, the increase of primary neutral current will result in increased primary NE voltages which again 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 of NE voltage associated with operation of equipment on the farm to an on-farm problem. An increase of NE voltage with the operation of "clean" 240-volt loads is a primary NE voltage.

On-Farm Causes:

3. Secondary neutral current in the farmstead wiring system.

A current in any portion of the secondary neutral from imbalance in 120-volt loads is accompanied by a voltage drop. Because 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 the primary NE voltage exists, an increase of out-of-phase secondary neutral current first will decrease the NE voltage at the barn. As this imbalance current continues to increase, the NE voltage at the barn may diminish to zero and then begin to increase 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 create 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 15 m of #12 copper conductor results in a potential difference of .8 volts. 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 neutral conductor on 120-volt equipment as a grounding conductor or interconnection of the neutral and grounding conductor at the equipment location.

In agriculture wiring systems the neutral (grounded conductor) and the equipment grounding conductors are bonded together only at the building service entrance. These also are bonded to an acceptable grounding electrode. 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 nonfault load current on the grounding conductors.

Reportedly, the practice of neutral and equipment grounding conductor interconnection beyond the service entrance is a relatively common practice in some locations where electrical code requirements are not enforced. This is a violation of the code and may create an additional serious stray voltage problem even though no lethal hazard exists. In this situation the load current will be carried by the grounding conductor (where it is improperly used as the neutral), or by the grounding conductor in parallel with the neutral (where they are interconnected at the device). The additional stray voltage component then is added to equipment equal to the voltage drop for the neutral current between the service entrance neutral bar and the equipment. This is of particular importance in circuits with 120 V motor starting surges as 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 must return to the center tap of the distribution transformer. Significant fault currents to earth are due to insulation breakdown on a conductor or in ungrounded faulty 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 in the area of the fault. These could be at a potential that creates a lethal hazard. They also will affect significantly the NE voltage on the farm and utility distribution system.

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 as measured with a very high impedence 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 electric field source can show a potential difference also.

Because of the high impedence of such a voltage source, the current producing capabilities are small. However, if the equipment is electrically well isolated and has sufficient electrical capacitance, it may provide a capacitive discharge of sufficient energy when an animal shorts it through a low resistance path to earth to cause stray voltage problems.

VOLTAGE PROBLEM VARIATION

Animals are not affected by voltage per se but by the electrical current produced by these voltages (27). The relation between voltage and current is the familiar Ohm's Law: $E = IR$,

where E is the voltage potential (volts)

I is the current flow (amperes)

R is the resistance of the total circuit (ohms).

Measuring the resistance of various pathways through the cow and calculating distributions is needed to discern variability of current flows from an applied voltage (26).

Resistance.

Resistance variability between cows and pathways is evident from the available data. Craine et al. (6, 10), Drenkard et al. (11), Lefcourt (21, 23), Norell et al. (27), Phillips and Parkinson (31), Whittlestone et al. (38), and Woolford (41) reported average resistances in the range of 300 to 1700 ohms for various pathways (Table 1). A combination of differences in methods of measurement, contact resistances, and actual pathway resistances likely explain the six-fold or more differences in resistances between specific pathways.

Norell et al. (27) determined the electrical resistance of eight defined cow pathways on 28 Holstein cows. Significant differences existed between pathways. Contrasts were used to compare pathway resistances including: two vs four hooves; front vs rear hooves; and mouth vs teat. Pathway resistances including four hooves were significantly less than those including two hooves. The resistance of pathways including front hooves only were greater than those including rear hooves only. Resistances of both pathways including mouth-hoof combinations were lower than those including teat-hoof combinations. The mouth-teat pathway was significantly lower in resistance than the teat-hoof pathway combinations. The front-rear hooves pathway resistance was larger than the mouth-hoof combinations but not as large as the teat-hoof combinations.

The lowest resistance for pathways (Table 1) was the front leg-rear leg pathway (21, 23). Metal electrodes plus conducting paste were applied to shaved front and rear hock. This pathway is unrealistic in comparison to on-farm situations because legs are shaved and hooves are not included in the circuit. Norell et al. (27) showed the front-to-rear leg pathway resistance is decreased by approximately 55% when the hooves are not included.

Considerable variation exists between cows for a given pathway (Table 1). Norell et al. (27) used selected percentile limits (10%, 25%, 50%, 75%, and 90%) for each pathway. These data are useful in illustrating differences in current flow between cows from an applied voltage. For example, for a mouth-all hooves pathway,

$$R_{10\%} = 244 \text{ ohms} \quad \text{and} \quad R_{90\%} = 525 \text{ ohms.}$$

In this case, 10% of the cattle exposed to a 1.0 V mouth-all hooves shock would receive a 4.0 mA or greater shock whereas 90% of the cattle would receive a 1.9 mA or greater shock. These data demonstrate a doubled difference in resistance and resulting current flow within the middle 80% of the population.

ANIMAL RESPONSE TO STRAY VOLTAGE

The effect of a specific voltage on dairy cattle is influenced by many factors which combined determine the distribution of current flow through the cow's body, namely: 1) voltage (what is measurable in the field); 2) the resistance of cow's body pathway (discussed previously) and the pathway current sensitivity; 3) condition of concrete, soil, and metallic conductors affecting resistance to "true earth"; 4) resistance of cow's contact points; 5) resistance of the electrical pathway to cow's contact points; and 6) impedance of the source (16).

Because these many factors can not be determined in the field, scientists have determined the current flow necessary to elicit a response, then applied the resistance estimates from research trials to calculate probable voltage necessary to cause an animal to respond.

Three criteria have been used in judging cow response to electric current, namely: behavioral responses, endocrine responses, and change of milking performance.

Behavioral Response.

Norell et al. (26, 27) reported that specific avoidance responses were exhibited 13.8% of the time at 1.0 mA of current. Significant increases (P < 4.0 vs 5.0 mA paired test, namely: 2.0 mA = 30.0% response; 3.0 mA = 69.2%; 4.0 mA = 92.3% response; and 5.0 mA = 98.4% response (Figure 1). No responses were observed during control (no shock) trials suggesting the mouth opening was a specific shock elicited response. Six cows were involved in this trial.

In a separate experiment involving a different group of six Holsteins, cows were trained to press a plate to earn a grain reward. The typical response was a "touch-withdrawal" from the "live" metal plate. Currents between 3.0 and 4.5 mA consistently suppressed touching of the plate. These results suggest that cattle should not be exposed to voltages on farms capable of delivering a 3.0 mA shock.

In a third trial involving four groups of five cows each, cows were subjected to currents of .00, 1.33, 2.66, and 4.0 mA as they crossed a grid prior to entering their milking stall in a side-opening parlor. Cows subjected to the 4.0 mA current took twice as long to cross the grid compared to that required when no currents were present.

Three types of inhibited grid crossing behavior was expressed by cows in the 4.0 mA group. The first type was a brief pause halfway across the two grids (testing). A second type was a "cautious" placement of a front hoof on the front grid. The cow then either proceeded forward or stepped back off the front grid (awareness). The third type of inhibited grid crossing behavior was stepping back as the stall door opened (painful shock).

Drenkard et al. (11) used an udder-all hooves pathway on four cows being milked to obtain behavioral responses at 0, 2, 4, and 6 mA of current. Treatments consisted of current administered during 1 min with alternate on and off times of 5 s each. Scores assigned to each measurement were: 0 = no observed response; 1 = slight response characterized by muscle contraction or foot movement; and 2 = a strong or continuous reaction, such as jumping and kicking. Mean scores for 0, 2, 4, and 6 mA treatment groups were .00, .38, 1.50, and 1.50. These results suggest that some cows can be expected to exhibit a behavioral response to 2 mA currents, and most cows will respond to a 4 mA current.

In another trial (11), six cows received the same current for 14 consecutive milkings. Current treatment of 0, 4, and 8 mA were begun 5 min before cows were prepared for milking and continued for 5 s every 30 s until removal of the milking unit. As expected, each cow responded at least part of the time to 4 and 8 mA treatments. One cow responded similarly to both treatments, and five of six cows displayed stronger responses to the 8 mA treatment.

Lefcourt (21) used a front leg-rear leg pathway, and subjected five cows to an applied incremented current for 30 s. A mild response (cow flinched, became vocal, or showed behavioral changes at least half of four or more repeated trials) occurred, on the average, at 2.47 mA. A distinct response (startle response or raised a leg consistently in repeated trials) occurred at 3.8 mA. One cow reacted mildly at .7 mA current and exhibited an even stronger reaction at 1.0 mA current.

Lefcourt et al. (23) subjected seven cows for 14 milkings to a 3.6 mA shock and six cows to 6.0 mA current (5 s on, 25 s off) from starting preparation to milk until 9 1/2 min after the start of milking. The mean number of behavioral events per cow at 3.6 mA during the preshock, shock, and postshock period were .66, 3.90, and .73. At 6.0 mA, the mean numbers of behavioral events per cow were .67, 5.50, and .69. A seventh cow in the 6.0 mA group had to be removed from the study because of a severe behavioral response that prevented her from being milked. Prior to the start of this trial three cows were subjected to 12.0 mA currents. They could not be approached.

Even though many of the observed cow behavior modifications are associated with the milking process, Gustafson et al. (18) demonstrated that under normal conditions the milking equipment itself is not a likely path of problem currents to the animal. The minimum resistance for this milk line-claw path under milking conditions, for a 9 kg/min flow rate, would be above 47 kohms for a typical stall-barn high line and above 26 kohms for a low line configuration. Resistance of the milk hose from the milk line (receiver) to the machine claw was inversely proportional to milk flow rate. Minimum resistance from the claw through the cow to the floor was 3 kohm. Estimated voltages across this system required to obtain perceptible currents through the cow would be in the range of 25 and 50 volts AC for the low and high line.

In summary, independent research at three stations showed that behavior functions vary in response rate. An indication of the required voltage drop across the animal pathway for a given response can be obtained by combining the current response and pathway resistance data.

For example, because voltage is the product of current X resistance (E = IR), voltages expected to elicit a response from dairy cattle in the mouth-all hooves pathway are: 360 ohms X 3 mA = 1.08 V. A plot of voltage vs response rate for mouth-all hooves shocks is shown in Figure 2. The family of voltage response curves was drawn based on the pathway resistance percentile distribution (27). As an example, this plot indicates that at 1.0 V across the mouth-all hooves pathway, 90% of the population would respond 28% of the time; 50% would respond 50% of the time; and 10% would respond 92% of the time.

The front-rear hooves pathway represents conditions sometimes found when cattle are shocked entering a milking parlor. Figure 3 provides a similar plot of voltage vs response rate. In this case, there is a base response rate of approximately 20%. Above the base rate, effects of the current can be seen. For example, at 2.0 V, 50% of the population can be expected to respond 37% of the time. This represents a 17% response rate above base (27).

Endocrine Response.

Discomforting electric current flows were hypothesized to elicit endocrine responses in cows. Milk secretion and removal are influenced by changes of specific blood hormones. Because hormone concentrations are sensitive to stimuli, electric currents high enough to cause a cow discomfort were assumed also to cause an endocrine response. Thus, research on the effect electrical current has on hormonal response of dairy cows was undertaken at two experiment stations, USDA's Milk Secretion Laboratory at Beltsville MD and at Cornell University (11, 22, 23).

Lefcourt and Akers (22) first measured change of peripheral concentrations of norepinephrine, epinephrine, dopamine, oxytocin, and prolactin while animals were subjected to a 5 mA front-rear leg shock during a single milking. The voltage either remained on for 20 min starting 10 min prior to milking (three cows) or was on intermittently 5 of every 30 s (three cows). Lefcourt et al. (23) submitted 13 cows to intermittent shock for 14 consecutive milkings at either 3.6 or 6.0 mA of current. In both cases, a front-rear leg pathway was utilized.

Drenkard et al. (11), used an udder-all hooves pathway to subject four cows to 0, 2, 4, and 6 mA current that was alternately on and off every 5 s during 1 min. In another trial, they used the same pathway to subject six cows to 0, 4, and 8 mA. Current treatments were begun 5 min before cows were prepared for milking. Treatments consisted of 5 s of current stimulus every 30 s until removal of the milking unit. In the first trial, each treatment was for 2 days; in the second trial, treatments were applied during three 1-wk periods. Results are summarized in Table 2 and discussed herein.

1. Oxytocin. The posterior pituitary gland secretes oxytocin into the blood stream where it is transported to the udder and causes contraction of the myo-epithelial cells and milk ejection (2).

In the New York trial, oxytocin release was delayed during 8 mA current treatments, and applications of 4 mA current had no effect (11). In the first Beltsville trial (22), neither continuous nor intermittent voltage stimulation lowered differential oxytocin responses. On the contrary, intermittent electrical stimulation appeared to amplify peak oxytocin response. In longer experiments (23), oxytocin responses were essentially normal throughout except in the 3.6 mA group where peak oxytocin was delayed slightly. Because milking characteristics remained unchanged, it is difficult to ascribe meaning to small changes of oxytocin responses.

2. Epinephrine and Norepinephrine. The adrenal medulla, which is an extension of the nervous system, produces epinephrine and norepinephrine. Their major function is to regulate metabolic balance and homeostasis. Their secretion can result from stressful stimuli. Epinephrine increases blood glucose, liberates fatty acids from the fat depots, and stimulates adrenocorticotropic hormone (ACTH) release which in turn activates the adrenal cortex to discharge glucocorticoids. Both hormones increase heart rate and blood pressure. Both hormones may constrict the arterioles of certain tissues. Restriction of blood flow may account, in part, for inhibition of the milk-ejection reflex by epinephrine (2).

   According to Lefcourt and Akers (22), electrical stimulation had no effect on norepinephrine; and in their trials epinephrine concentrations were low, with only 5% of the samples showing concentrations sufficiently high to be assayed with the methods used. Furthermore, dopamine could not be detected.

3. Prolactin. The anterior pituitary secretes prolactin. Its major function is to promote mammary growth and initiate and maintain lactation. Milking causes prolactin to be released in the blood; this response probably lasts for less than 30 min; and its relationship to continuous occurring basal concentrations in the blood is unknown (2). It is hypothesized, however, that lowered blood concentrations might result in lowered production early in lactation.

Drenkard et al. (11) found no response of prolactin related to treatment in their short trials. In their longer trials, no significant treatment effects were discovered although there was a trend toward higher prolactin response during 8 mA treatment. Lefcourt and Akers (22) found lower prolactin in blood during milking of cows subjected to intermittent shocks. They suggested that milk loss might be intensified from chronic electrical stimulation on farms with stray voltage problems. Later, Lefcourt et al. (23) found opposite results in that prolactin concentration increased when cows were shocked. They concluded that prolactin in cows is not directly affected by electrical shock of the magnitude used.

4. Cortisol. Various stimuli such as fright, pain, or elevated temperature stimulate the outpouring of corticotropin-releasing factor (CRF) from the hypothalamus which, in turn, increases the anterior pituitary secretion of ACTH. High ACTH promotes increased cortisol production and also reduces milk production (2).

In the first New York trial (11), no significant effect on cortisol response was detected; and although there was variability in the data, it was suggested that currents as low as 2 mA may cause cortisol response. In the longer (1 wk) trial, there were significant treatment differences. Elevated cortisol may affect negatively milk production, especially when cows are exposed to 8 mA current for long times.

Milking Performance Response.

Results of milk yield, milking time, and peak milk flow rate for treatment groups in experiments at New York (11) and Beltsville (22, 23) are summarized in Table 3. Cows subjected to electrical currents produced significantly less milk in only one trial, that being the intermittent 5 mA current. Similar intermittent 6.0 or 8.0 mA currents failed to reproduce these results.

Changes of time required to milk cows followed trends expressed by milk yields. When milk yield decreased, milking times dropped; when milk yield increased, it required more time to milk cows. Peak milk flow rate increased in all experiments when milk yield increased.

Additional milking performance results indicated when cows were subjected to electrical currents, the time required to obtain maximum flow rate did not increase significantly (11, 23), and subclinical mastitis scores did not increase significantly (11, 23).

The New York workers (11) found no effect from increasing electrical current on the amount of residual milk remaining in the mammary gland. Furthermore, milk composition (percent fat and protein) was not altered in milk produced by cows receiving shocks.

Most research trials in the US have been designed to subject animals to electrical currents either continuously or on a prescribed intermittent schedule. Gorewit et al. (15) studied the effect of semirandomized AC current exposure on milk production, milk composition, feed and water intake, behavior and metabolic hormones of eight mid-lactation Holstein cows producing 15 kg milk/milking. Cows were assigned to groups receiving 0 or 4 mA current once every 4 h for 4 days in a semirandomized fashion with no individual cow receiving current at the same time every day. After 4 days groups were reversed. The trial was replicated so that all cows received the series of shocks twice. Current was applied for 30 s, then off for 30 s alternately for a total of 5 min. The pathway was two epidermal electrodes in the lumbar region, 15.2 cm from one another on either side of the spinal column. Cows never were milked during current exposure. Results are in Table 4. Milk production was lowered .16 kg/milking (-1.2%); somatic cell count increased (+7.3%), primarily because of one cow with clinical mastitis; water consumption increased 1.6%; and fat percentage, protein percentage, and feed intake were maintained while cows were subjected to 4 mA currents. There were no statistically significant changes in any of the variables.

Behavioral responses (cows arching their backs and moving side to side in the stanchion) occurred upon initial exposure to current. Cows became accustomed to the shock within 24 h of exposure, and behavioral responses were almost extinct by the fourth (96 h) period of exposure. No relationship between concentrations of cortisol and thyroid hormones and current exposure was discerned.

Overmier (28) suggested response to a constant shock may decay rapidly following shock onset. Thus, several short shocks may be more bothersome to the animal than a long shock of the same intensity.

Phillips (30), in New Zealand, discussed his unreported data showing that an irregular, as well as an intermittent, shocking pattern is more likely to be disruptive to normal cow behavior and to lower production. He subjected cows to five shocks during each of 14 milkings and found no difference in production compared to controls. On the other hand, five random shockings applied on only 3 of 14 random milkings resulted in a 6 to 15% drop of milk production. Cows appeared to be bothered as much, or more, by anticipation of the shock treatment as by the shock itself. In these trials, a 3 V shock was applied to a rump-rear hooves pathway.

Summary of Animal Response.

Lefcourt et al. (23) summarized their studies by concluding that "any negative effects of electrical shock on milk production or mammary gland health most likely are not directly related to shock, i.e., physiological responses to shock were minimal and milk yield was generally maintained at normal levels during the shock period. However, the severe behavioral responses to shock would almost assuredly result in management problems and the degree to which milk production would be affected would depend on how dairymen deal with the abnormal behavior." Similarly, Drenkard et al. (11) found little or no physiological response to electrical currents common in stray voltage problem herds. Thus, it appears the primary influence of stray voltage on dairy cow performance is one of behavior modification (11, 21, 23, 26, 27).

Stray voltage problems are minimal in herds where neutral-to-earth voltages during full load conditions (at milking time) remain below .7 V. A reasonable and attainable goal on farms needing correction would be to maintain neutral voltages on the farm grounding system below .35 V. Based on research results to date, less than 10% of the population would perceive the presence of any electrical currents upon contact with conductive grounding equipment at this potential.

PREVENTION AND CORRECTION OF 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 equi-potential plane that will keep all possible animal contact points at the same potential. Numerous papers address these solutions (3, 5, 13, 16, 17, 24, 35, 37, 42).

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.

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. The power supplier also should check the imbalance in the three-phase feeder which serves the farm, either directly or through a single-phase distribution tap. 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 are 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. Decreasing the length 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 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 requirements of the National Electrical Code on the secondary wiring systems will help to minimize on-farm sources of stray voltage.

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 effectively will remove the contribution of the secondary neutral voltage drop in the barn service neutral.

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 noninterconnected 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 noninterconnected neutrals if properly done. However, many power suppliers, because of safety and operational considerations (17), will not operate with noninterconnected neutrals.

Another means of primary neutral isolation is 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 also may be effective in minimizing a secondary neutral contribution due to imbalance currents. With either option the isolating transformer should have overcurrent protection and should have its case grounded to the source side. All load side conductors should be insulated from the transformer case.

When isolation is used to solve stray voltage problems, it is necessary to remove all conductive interconnections which effectively may bypass the isolation. Some common interconnections are telephone grounding conductors, metal water lines, 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 reportedly have been solved (primarily in stanchion barns) by isolation of all conductive equipment (pipes, stanchions, etc.) in the barn from the electrical grounding system at the barn service entrance. THIS CAN CREATE A POTENTIAL ELECTRICAL HAZARD. Any electrical fault to this isolated conductive equipment, because it is not electrically grounded, may create a lethal condition. In the interest of electrical safety, all conductive equipment should be grounded electrically through an equipment grounding conductor to the service entrance, particularly if there is electrical equipment involved.

3. Installation of equipotential planes.

The concept of equipotential planes or grounding mats as a solution to stray voltage problems is simple and practical. 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 equipotential planes can be effective in solving stray voltage problems in milking parlors. Animal access to equipotential planes should be through a voltage ramp installed in the access areas.

The use of equipotential systems will solve stray voltage problems in the area they cover, regardless of the source, if they are successful in maintaining the same potential at all possible animal contact points. In addition, they improve electrical safety characteristics of the installation. Equipotential planes are an extension of good electrical wiring and grounding practices. They should be included in the design of all new milking facilities. They also should be considered for all areas where electrically grounded equipment is located in space occupied by livestock or exposed to livestock traffic.

RESEARCH NEEDS

Much has been learned in a relatively short time about the effect of stray voltage on animal behavior and productivity. Physiological responses to relatively small shocks are minimal, and milk yield generally may be maintained. Still, several unanswered questions remain. These include:

1. Is there a carry-over effect after cattle have been exposed to stray voltages for several months before the problem was corrected? Some producers feel that such cattle are stressed and that physiological functions are impaired. Based on results of short research trials with dairy cattle, one would not suspect this to be the case. Still, research with laboratory animals (20, 25, 36) suggests this is a distinct possibility. Long trials involving a full lactation are recommended.

2. To what extent do cattle habituate or become sensitized to electrical shock? Both adaptation processes may occur on farms. Response frequency may change as a result of either adaptation process. Research results thus far suggest that random, intermittent shock applications more nearly simulate field conditions and observations.

3. Do "sensitive" cows have conditions that predispose them to lower resistance and greater sensitivity to current? For example, do cracked or abscessed hooves, open sores on joints or other body surfaces, etc. provide entry points of low contact resistance resulting in current density problems? Perhaps cattle in well managed research herds are not typical of those on the average farm suffering from prolonged exposure to stray voltage.

4. How frequently and to what extent do stray voltages affect other species of farm animals? Are there differences in the pathway resistance and sensitivity among dairy and beef cattle, hogs, sheep, chickens, and turkeys?

Spencer (33) indicates there is a need for more research on the problem, but wonders if it might not be more cost effective and humane if research resources were spent on developing less costly methods of preventing the problem, rather than continuing research on the effect of stray voltage on animals. Animal research related to this problem is expensive. On the other hand, agricultural industries using electricity are faced with litigation establishing liability associated with lowered animal productivity (8). Undoubtedly, industry will determine if more research involving animals will be conducted by their continuing financial support of animal related stray voltage research.

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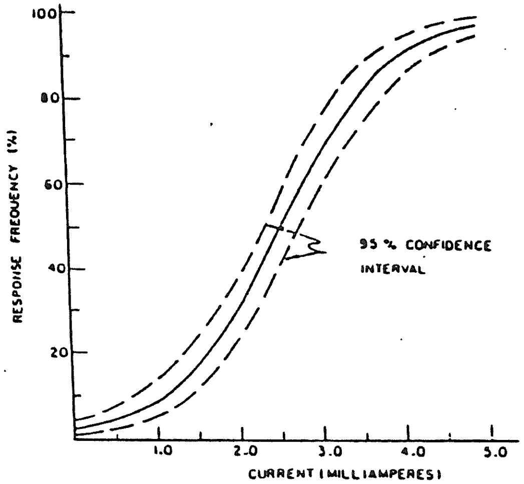

Figure 1. Response rate vs current flow for mouth-all hooves shock (27).

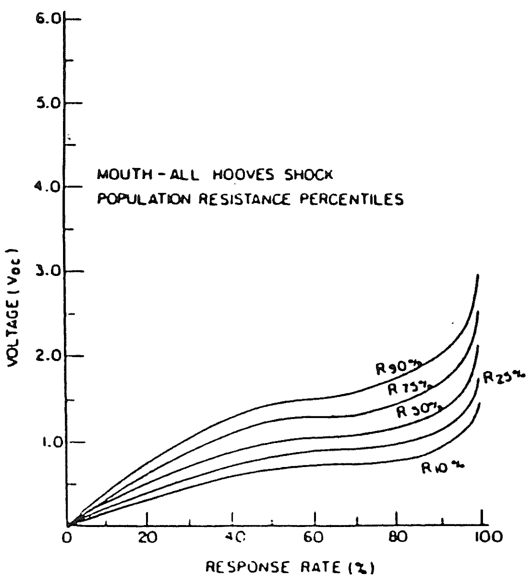

Figure 2. Voltage vs response rate for mouth-all hooves shock (27).

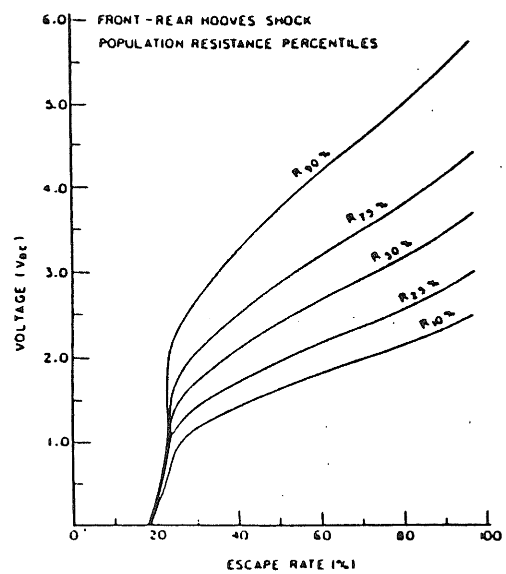

Figure 3. Voltage vs response rate for front-rear hooves shock (27).

Table 1. Summary of measured resistance of various electrical pathways through the cow.

Animal pathway	n	$\overline{x}$ (ohms)	Range (ohms)	Current Frequency (Hz)	Authors
Mouth-all hooves	70	350	324-393	60	Craine (6)
	28	361	244-525[a]	60	Norell et al. (27)
Mouth-rear hooves	28	475	345-776[a]	60	Norell et al. (27)
Mouth-front hooves	28	624	420-851[a]	60	Norell et al. (27)
Front leg-rear leg	5	300	250-405	60	Lefcourt (21)
	13	362	302-412	60	Lefcourt (23)
Front hooves-rear hooves	28	734	496-1152[a]	60	Norell et al. (27)
Rump-all hooves	7	680	420-1220	50	Whittlestone et al. (38)
Chest-all hooves	5	980	700-1230	50	Whittlestone et al. (38)
	NS[b]	1000[c]	NS[b]	50	Woolford (41)
Teat-mouth	28	433	294-713[a]	60	Norell et al. (27)
Teat-all hooves	28	594	402-953[a]	60	Norell et al. (27)
	4	880	640-1150	50	Whittlestone et al. (38)
Teat-rear hooves	28	710	503-1203[a]	60	Norell et al. (27)
Teat-front hooves	28	874	593-1508[a]	60	Norell et al. (27)
All teats-all hooves[d]	6	1320	860-1960	50	Whittlestone et al. (38)
	NS[b]	1000[c]	NS[b]	50	Phillips & Parkinson (31)
Udder-all hooves[d]	12	630	510-980	60	Drenkard et al. (11)

[a] Ranges given are for the 10% and 90% percentile, or percent of cows with measured resistance below the reported limit.

[b] NS = not specified.

[c] Approximate average stated by the author.

[d] Measured during milk flow.

Table 2. Summary of endocrine responses by cows subjected to various electrical currents.

Hormone	Major Functions (2)	Beltsville Trials (22, 23)		New York Trials (11)	
		1 Milking	14 Milkings	2 Days	7 Days
Oxytocin	Milk ejection	Increased concentrations	3.6 mA = delayed response 6.0 mA = no effect	---	4 mA = no effect 8 mA = delayed release
Epinephrine	Stress response	No response	---	---	---
Norepinephrine	Stress response	No response	---	---	---
Prolactin	Mammary growth; Initiation & maintenance of lactation	Trend toward lower levels during intermittent shock	Increased release	No response	4 mA = no effect 8 mA = trend toward increased production
Cortisol	Involved glucose, fat & protein metabolism	---	---	Non-significant trend toward increased concentrations	4 mA = no effect 8 mA = significant increase from baseline

Table 3. Comparison of change in milk yield, milking time, and peak milk flow rate in various stray voltage research trials (11, 22, 23).

	Change from .0 mA current control, %[a]					
	Beltsville				New York	
	Stimulation		mA			
Measurement	Continuous	Intermittent[b]	3.6	6.0	4.0	8.0
Milk yield, kg						
Shock	-2.4	-13.2[.1]	-0.1	+3.3	+2.5	+3.2
Postshock			+1.1	+1.7		
Milking time, min						
Shock	-5.2	-17.6[.01]	+1.1	+3.6	+3.0	+6.3
Postshock			+1.7	+5.5		
Peak flow rate (kg/min)						
Shock	---	---	+1.7	+6.3	+2.2	+3.0
Postshock	---	---	+1.0	-1.1		

[a] Data adapted from published kg measurements, and expressed as a percentage for comparison

[b] .1 and .01 indicates statistical significance. All other measurements are statistically not significantly different.

Table 4. Effects of randomized alternating current exposure on milk production, milk composition, and feed and water intake (11).

Measure	Treatment 0 mA	4 mA	% Change[a]
Milk production, kg/milking	13.74	13.58	-1.2
Fat, %	4.52	4.51	-0.2
Protein, %	3.27	3.28	0.3
Somatic cell count, 10^3	855.74	917.02	+7.3
Feed intake, kg	42.16	42.08	-0.2
Water intake, l	80.88	82.19	+1.6

[a] Differences between means statistically not significantly different.

Appendix 3 - Swine Sensitivity

Appleman, R.D., R.J. Gustafson, M. Wehe and T.M. Brennan. 1984. Response of pigs to stray voltage. University of Minnesota Dairy Extension, Dairy Update 71, January, 1985. Reprinted from 1985 Minnesota Swine Research Report, pp. 62-65. University of Minnesota, Department of Animal Science.

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Dairy Update

RESPONSE OF PIGS TO STRAY VOLTAGES

January, 1985
Issue 71

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Summary

Stray voltages, resulting in small electrical currents flowing through pigs' bodies, can adversely affect performance and profits on swine operations. Water consumption was lowered 25 percent when growing pigs were exposed to a 4.0 milliamp current by accessing an electrically charged watering nipple. A voltage reading of 3.7 V elicited this response.

Introduction

Stray voltages have caused serious problems on livestock farms. While most of these have been dairy farms (300 or more in Minnesota), we are aware of four swine operations that have been affected. Symptoms reported were similar to those observed in dairy cattle. Sows were characterized as having an aggressive behavior, reduced appetite, lowered water consumption, and uneven milking (increased rate of starve-out per litter). Anorexia post-farrowing, along with some constipation, was a major complaint.

The concept of stray voltages is relatively simple electrically, although the sources can be varied and complex. As hog operations increase in size and sophistication, as farmstead electrical wiring systems become obsolete or deteriorate, and as electrical loads on rural distribution systems increase, it is likely that stray voltage problems also will increase. Any electrical condition that sustains a potential voltage drop of sufficient magnitude between any two animal contact points may create a stray voltage problem.

Voltage is the product of current times resistance. The algebraic equation is:

$$E = IR, \text{ where } \begin{aligned} E &= \text{voltage potential (volts)} \\ I &= \text{current flow (amperes)} \\ R &= \text{current resistance (ohms).} \end{aligned}$$

It is important that people making stray voltage measurements understand this relationship. At a given voltage, one of two interpretations can be made: (1) high current flow and low pathway resistance, and (2) low current flow and high

Reprinted from the 1985 Minnesota Swine Research Report, pp. 62-65

pathway resistance. The first is much more likely to be a problem, resulting in poor performance in a swine operation.

Experimental Procedure

Two experiments were conducted in the summer of 1984 at the University of Minnesota. Eight growing pigs (about 100 lbs) were subjected to various current levels. An electrical current was applied to the watering nipple. The pig stood on a grounded, metallic pad (floor). The electrical pathway through the pig's body was completed whenever the pig's mouth made contact with the watering nipple. All pigs were withheld from water for 2 hours prior to conducting these experiments to insure thirst and a desire to drink water. Each pig was then allowed to access the watering nipple(s) for 30 minutes.

In Experiment 1, the pig's sensitivity to low level currents was assessed by the pig having a choice of three watering nipples available. Two of the nipples had different current levels applied; the remaining nipple was not energized. Measurements obtained included: (1) water consumption; (2) number of attempts to drink; (3) number of drinks; and (4) average drinking time.

In Experiment 2, the pigs had only one watering nipple available. On day 1, half of the pigs could obtain water only by accessing an energized watering nipple while the other half received no shock while drinking. On day 2, the pigs were reversed. In this manner, each pig was its own control and day affects (climatic temperature, etc.) were effectively removed. Data collected was identical to that described for Experiment 1.

The levels of current applied are shown in Table 1. They ranged from 0 to 4.0 mA (milliamps) in Experiment 1, and 0 to 5.0 mA in Experiment 2. Resistance measurements were obtained on each pig during the course of the experiments, averaging 930 ohms. Thus, the calculated voltage applied was .93 V for each 1 mA current increment, reaching a high of 4.65 V when a 5 mA current was applied. Typically, a 6 to 10 V shock is required before humans can detect a "tingle" from an electrical current.

TABLE 1. CURRENTS (mA) APPLIED IN EXPERIMENT 1 (SENSITIVITY DETERMINATION) AND EXPERIMENT 2 (AVERSION LEVEL)

Trial	Experiment 1[a]	Trial	Experiment 2[b]
1	0, 2, 4 mA	1	0, 0.5 mA
2	0, 1, 2 mA	2	0, 1.0 mA
3	0, .5, 1 mA	3	0, 1.5 mA
4	0, .25, .5 mA	4	0, 2.0 mA
		5	0, 2.5 mA
		6	0, 3.0 mA
		7	0, 3.5 mA
		8	0, 4.0 mA
		9	0, 4.5 mA
		10	0, 5.0 mA

[a] Three watering nipples available simultaneously, each with a different current.
[b] One watering nipple available; currents differed on successive days.

Results and Discussion

Pigs are sensitive to, and can detect the presence of, low level currents. When given a choice of waterers with different current levels applied, all water was consumed from nipples with a current of 0.5 mA or less (Table 2). However, these pigs did attempt to drink water from the other (higher current level) nipples.

TABLE 2. WATER CONSUMPTION, ATTEMPTS TO DRINK, NUMBER OF DRINKS, AND AVERAGE DRINKING TIME OF EIGHT PIGS IN SENSITIVITY TRIALS

		Current (mA)					
Measurement	Trial	0.0	0.25	0.5	1.0	2.0	4.0
Water consumed (ml)	1	392				0	0
	2	1497			0	0	
	3	1446		35	0		
	4	1202	1011	1135			
No. unsuccessful attempts to drink	1	.04				1.24	1.74
	2	.00			2.55	1.89	
	3	.15		2.76	2.33		
	4	.57	1.19	1.45			
No. successful drinks	1	2.54				0	0
	2	4.98			0	0	
	3	5.85		.24	0		
	4	2.81	2.21	1.36			
Time per drink (min)	1	2.71				0	0
	2	2.63			0	0	
	3	2.44		.82	0		
	4	1.78	1.18	1.21			

The "avoidance response", defined as that point when behavior was modified as indicated by: (a) a marked change in pigs' attempts to consume water, and (b) a meaningful decrease in total water consumed, appeared to begin when current through the pig's body approached 2 mA of current (Table 3). The response was even more dramatic at the 4.0 mA level. Water consumption was reduced by one-fourth, even more at the 4.5 mA level. Further, the number of successful drinks were reduced, but countered to some extent by an increase in the time spent consuming water during each drink.

These results are in general agreement with that observed in dairy cattle. However, due to species differences in the resistance of the mouth-all hooves pathway (pigs = 930 ohms; dairy cattle = 360 ohms), a much higher voltage drop is required in swine operations to elicit a response.

It appears some pigs may exhibit a behavior modification when voltage measurements exceed 1.86 V (2 mA x 930 ohms). A significant change in typical water consuming habits, however, doesn't occur in most pigs until measured voltage drops exceed 3.72 V. These changes are reflected in: (a) more unsuccessful attempts to drink; (b) fewer successful drinking events; (c) increased time per drink; and (d) lowered water consumption.

TABLE 3. WATER CONSUMPTION, ATTEMPTS TO DRINK, NUMBER OF DRINKS, AND AVERAGE DRINKING TIME OF EIGHT PIGS IN "AVOIDANCE RESPONSES" TRIALS

Current (mA)		Water Consumed (ml)			No. of Unsuccessful Attempts to Drink	
Control	Experimental	Control	Experimental	% of Control	Control	Experimental
0	0.5	1148	1054	91.8	.13	.78
0	1.0	1180	1242	105.2	.03	1.13
0	1.5	1567	1360	86.8	.03	.84
0	2.0	1103	981	88.9	0	2.31
0	2.5	1997	1962	98.2	.03	3.34
0	3.0	1773	1693	95.5	0	1.57
0	3.5	1787	1518	85.0	.09	1.72
0	4.0	2215	1649	74.4	0	1.84
0	4.5	2323	1131	48.7	.03	2.22
0	5.0	2401	1785	74.3	.56	.56

Current (mA)		No. of Successful Drinks		Time/Drink (min)	
Control	Experimental	Control	Experimental	Control	Experimental
0	0.5	3.44	2.09	2.09	1.88
0	1.0	3.28	1.91	2.17	2.48
0	1.5	1.88	1.59	1.94	1.78
0	2.0	2.13	1.06	1.40	1.26
0	2.5	3.22	2.03	2.39	2.84
0	3.0	1.98	1.23	2.32	2.35
0	3.5	2.56	0.72	2.12	2.24
0	4.0	2.56	1.03	2.58	3.48
0	4.5	2.03	0.59	2.88	2.36
0	5.0	2.72	0.59	2.95	2.19

Note: 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. Contact your local power supplier for advice and/or assistance in determining if a stray voltage problem exists, its cause, and an appropriate corrective procedure. We refer you to the popular University of Minnesota publication entitled "Stray Voltage Problems With Dairy Cows" (Extension Folder 552) for a tested and proved procedure to diagnose the source of existing stray voltage problems.

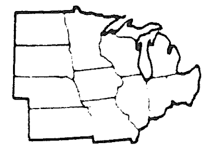
Appendix 4 - Electrical Systems

Item 1 - Cloud, H.A., R.D. Appleman and R.J. Gustafson. 1980. Stray voltage problems with dairy cows. North Central Regional Extension Publication 125.

Item 2 - Gustafson, R.J. 1985. Understanding and dealing with stray voltage in livestock facilities. Paper for presentation at Rural Power Conference of Institute of Electrical and Electronics Engineers.

Item 3 - Gustafson, R.J. and D.J. Hansen. 1985. Single-Phase Distribution system Neutral-to-Earth Model. University of Minnesota, Department of Agricultural Engineering.

North Central Regional
Extension Publication 125

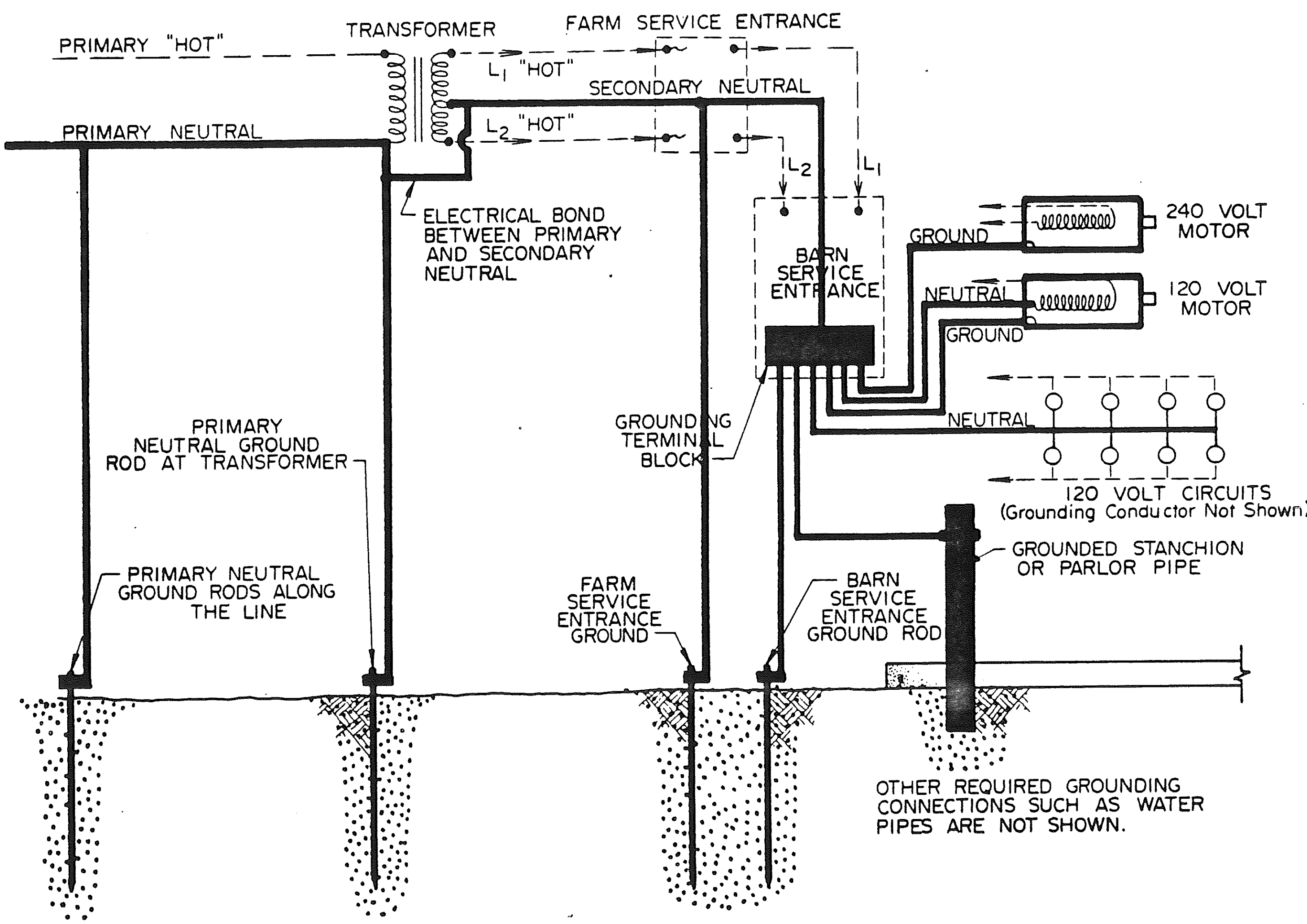


STRAY VOLTAGE PROBLEMS WITH DAIRY COWS

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

Sponsored by the Extension services of Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin, in cooperation with SEA-Extension, USDA.

Figure 1. The grounded neutral network (in red) on a single-phase distribution line



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Agricultural Extension Service University of Minnesota Extension Folder 552—1980

Many dairymen are losing milk production and experiencing cow health problems at milking time due to small currents of electricity passing through the cows' bodies. This condition may be caused by low voltages existing on the grounded neutrals of the farm electrical system. 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 the required current through the grounded neutral system. The last case is the most difficult to correct because this voltage is a necessary part of delivering and utilizing electrical energy. It is an inherent characteristic of the electrical distribution system and will exist in varying degrees on all grounded neutral systems.

At least 300 herds in the North Central region states have suffered from this problem. Some experts feel that 20 percent or more of all parlor barn operations may be affected. Numerous stall barn dairy farms are also affected, especially the larger ones.

Many dairymen have been successful in eliminating stray voltage problems. Others have at least reduced the severity of their problems. But the causes of stray voltages often are difficult to locate. This can be very frustrating since the condition may exist even with no electrical faults. In these cases, it requires the cooperation of the power supplier because its solution may involve an alteration in the system.

The response of dairy cattle to corrective measures will vary considerably. An immediate, dramatic response is probable if a severe problem is completely solved. However, a more gradual improvement is likely with some cows or some herds depending on severity of the problem, degree of solution, and individual characteristics of the animals. The mammary glands of cows affected by stray voltages may have become infected with mastitis and, depending on severity, both production and milking characteristics could be permanently hampered. Experience indicates some cows respond more rapidly than others. Also, there is some indication that once some cows have been subjected to a severe case they may remain fearful of stray voltages and exhibit some of the symptoms after the solution has been implemented. This publication is intended to explain the problem, describe how to determine its source, and give recommendations on what to do to correct the problem.

TERMINOLOGY

The problem has been identified by several different names. Among dairymen, stray voltage or tingle voltage is the most common. The most correct terminology, and that used by most power suppliers, is neutral-to-ground or *neutral-to-earth* voltage. Another name sometimes used, but one that has an altogether different meaning among electrical engineers, is transient voltage. The term *neutral-to-earth (N-E)* voltage will be used here and refers to the voltage existing between the neutral system and zero-potential earth.

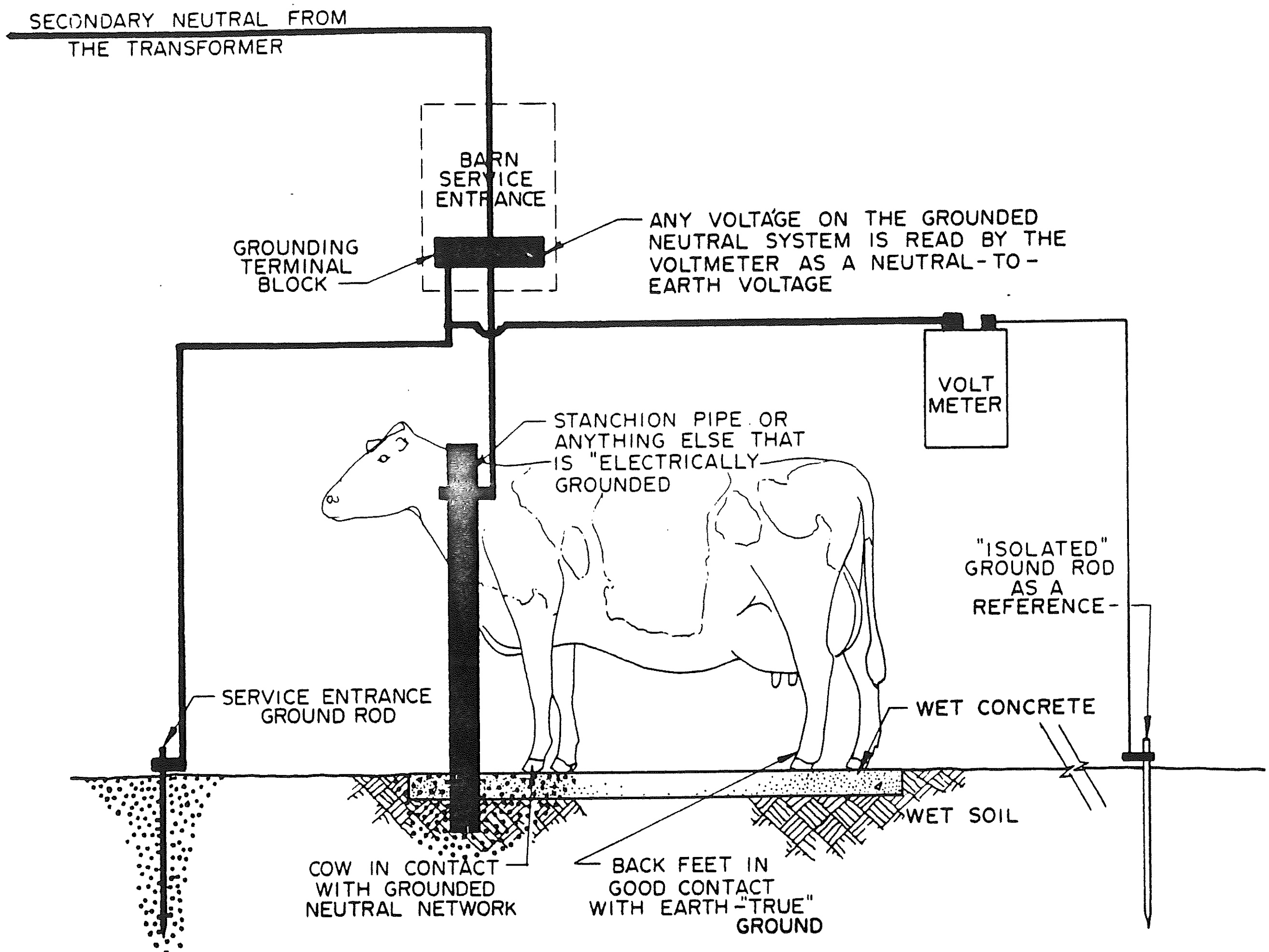
SYMPTOMS OF STRAY VOLTAGE PROBLEMS

Animal reactions will vary depending upon the severity of the problem. If one or more of the following symptoms persists, stray voltages may be contributing to the problem:

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

Figure 2. A dairy cow subjected to a neutral-to-earth (N-E) voltage



WHAT CAUSES STRAY VOLTAGE?

All modern dairy facilities depend on electrical energy supplied over rural distribution networks. The primary distribution system together with the secondary farmstead wiring and all electrical equipment and grounded components form a complex network. All parts of this network are interconnected through an electrically conductive system consisting of the primary and secondary neutrals and all grounded equipment and facilities. The grounded neutral system is connected to earth through "ground rods" driven into the soil and through electrically grounded equipment and facilities in contact with the soil.

Figure 1 (see cover) shows part of the grounded neutral system with examples of neutral and grounding conductors. All neutrals and all grounding conductors in the barn are bonded to the grounding terminal in the barn service entrance which, in turn, must be grounded according to the provisions of the National Electrical Code. The grounding terminal in the service entrance is bonded to the secondary neutral which is bonded to the primary neutral at the transformer.

Figure 1 shows only the neutral and grounding circuits. The dashed-line and arrows indicate the primary and secondary high voltage connections. This circuitry will have no direct effect on the grounded neutral system unless there is a "ground fault" electrically connecting the high voltage conductors to the grounded network. However, as we will see later, loads added to the system create various effects on the grounded neutral network.

Every part of the grounded neutral network including the conductors, the connections, the earth, and the contact between the ground rods and the 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 to all parts of the interconnected network and, if they are sufficiently high, may be detected by an animal. They exist as neutral-to-earth (N-E) voltages and will cause a current flow through the body of an animal bridging the gap between the neutral network and the earth, as shown in figure 2. In this case, the cow's back feet provide a connection to "true ground" through the wet concrete and the wet soil underneath. The front portion of her body is in contact with the grounded neutral system through the pipe, wet concrete, feeder, etc. She may be subjected to the same N-E voltage read by the voltmeter in figure 2. This voltage causes a current to flow through her body and can result in serious problems when it is high enough to cause discomfort.

Neutral-to-earth voltages result from the voltage differential created by current flowing in any part of the neutral network. The voltage depends on the resistance of, and the current flowing in, all parts of the interconnected neutral system. Many factors affect this:

1. loads on all parts of the distribution system
2. length and size of the primary neutral
3. grounding resistances on the primary neutral
4. resistances of all connections on the primary neutral
5. grounding resistances on the farm
6. length and size of all secondary neutrals
7. current in the secondary neutrals, as affected by balancing of line-to-neutral loads (120 volts)
8. resistance of connections on the secondary neutrals
9. ground fault currents

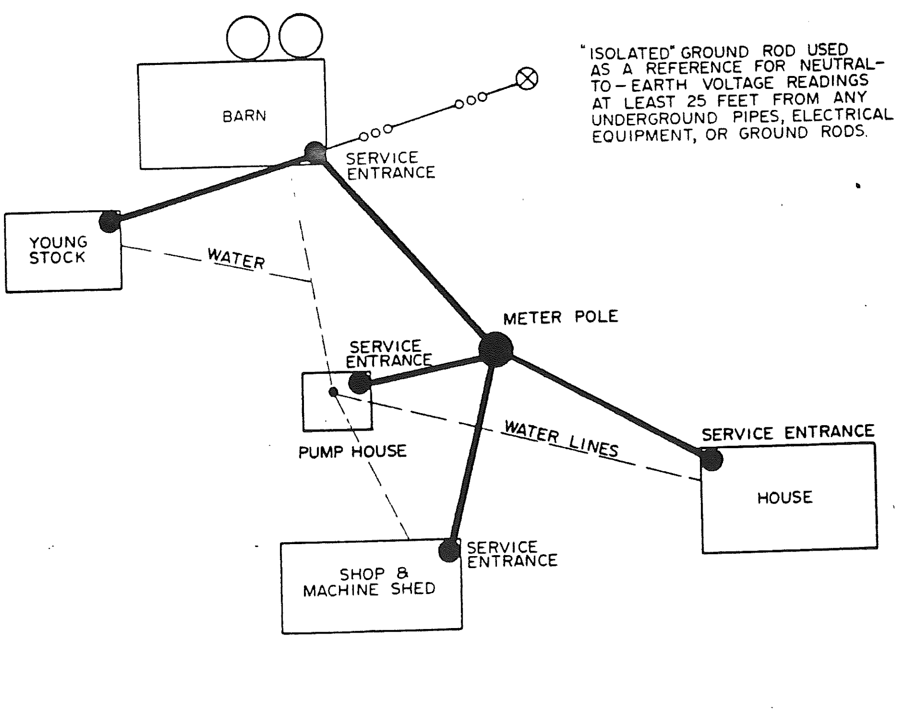
The effect of these voltages on dairy cattle is influenced greatly by other conditions. The current through a cow's body depends on the voltage as well as the resistance of the current path through her body to "true" ground. This depends on:

1. resistance of the cow's body
2. resistance of her contact points
3. the soil moisture conditions affecting the "grounding" resistances
4. the soil-concrete contact
5. conductivity of the concrete and the soil

Soil moisture conditions affect both the N-E 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 N-E voltage, as well as the reaction of the cow to these voltages, partially explains the intermittent "here today, gone tomorrow" nature of the problem.

The cause of excessive N-E voltages often is very difficult to locate. Its source may be on the farm, off the farm, or a combination of the two. The problem occurs whenever the combination of neutral resistances and currents creates a voltage large enough to cause the cattle discomfort. This condition can exist because of the inherent characteristics of the electrical distribution system and is not necessarily the result of electrical faults or poor wiring.

Figure 3. Location of an "isolated" ground rod used as a reference in neutral-to-earth voltage measurements



The following examples show several N-E voltage conditions and will help develop a better understanding of the problem. Figure 3 shows the location of an "isolated" ground rod 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 2, and the other lead is attached to the "isolated" ground rod, it will read the N-E voltage existing on the network at this location. The location and use of this "isolated" ground rod and voltmeter will be discussed in the section entitled "Standardized Measurements." In this position the voltmeter reads the maximum voltage to which a cow could be subjected if one contact point is touching the grounded neutral system and another is in good contact with the earth.

Figure 4 illustrates how the N-E voltage on a farm can be affected by the electrical load of other farms on the same distribution system. The load on the neighboring farm is accompanied by a current in the primary neutral. The voltage required to move this current through the grounded neutral system is partially reflected onto the secondary neutral on the farm system and exists as N-E voltage. Experience indicates that farms near the end of the distribution line are more likely to suffer from N-E voltages.

Figure 5 illustrates how added farm loads increase N-E voltage on the same farm. The added load is accompanied by an increased current in the primary neutral at the transformer. The increased voltage accompanying the increased current is reflected onto the farm neutral system through the bond between the primary and secondary neutrals at the transformer.

Figure 6 illustrates how the N-E voltage at the barn can be affected by the current in the secondary neutral from the transformer. An increase in unbalanced line-to-neutral (120-volt) loads at the barn is accompanied by an increase in neutral current. The increased voltage to move this current through the neutral is reflected onto the grounded neutral system at the barn service

Figure 4. Neutral-to-earth voltages on a farm due to other farm loads on the same line

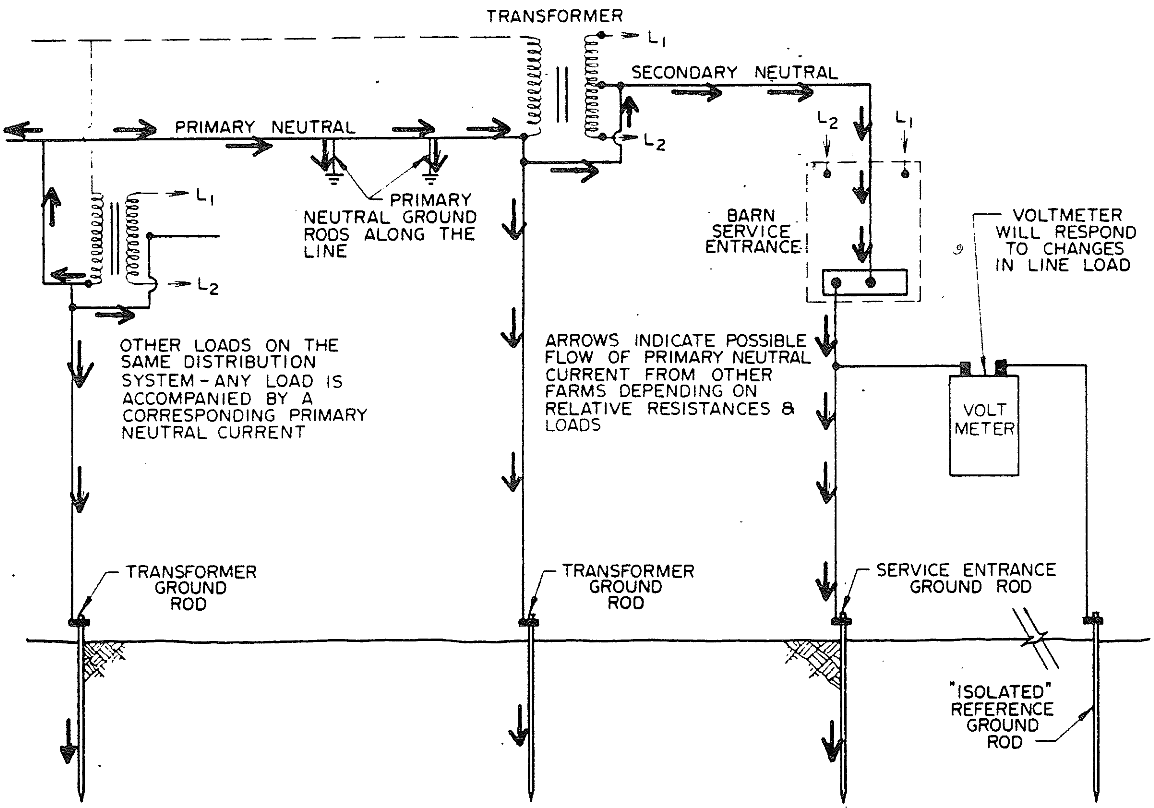


Figure 5. Increase in neutral-to-earth voltage due to increasing loads on the same farm

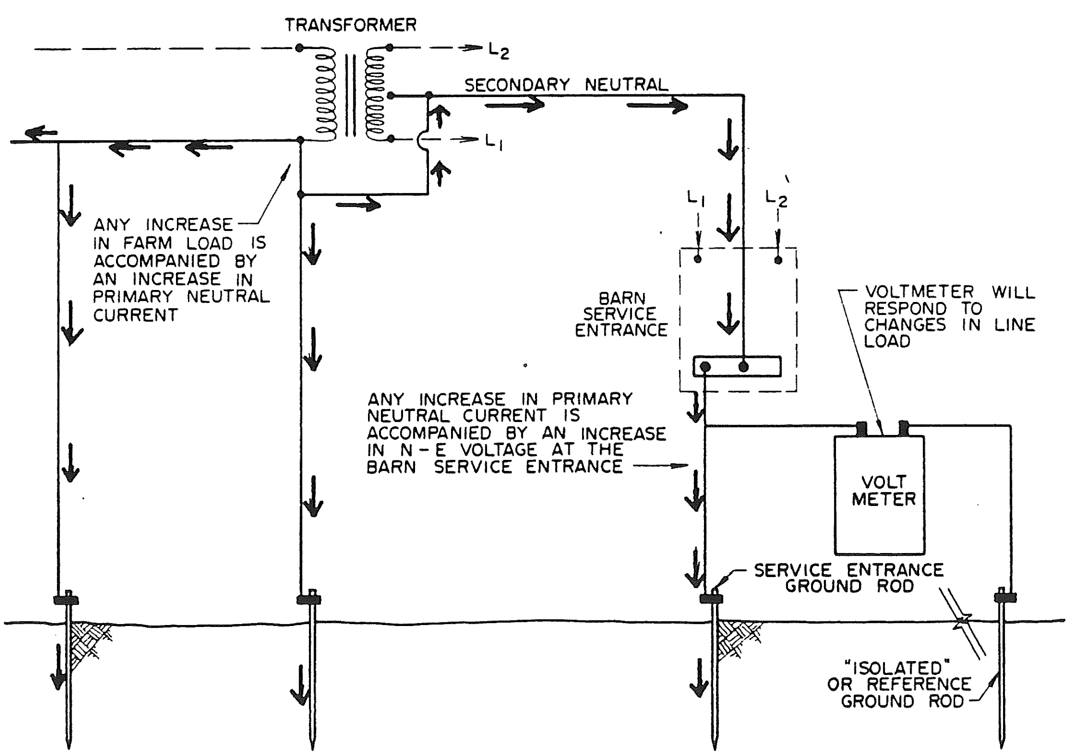
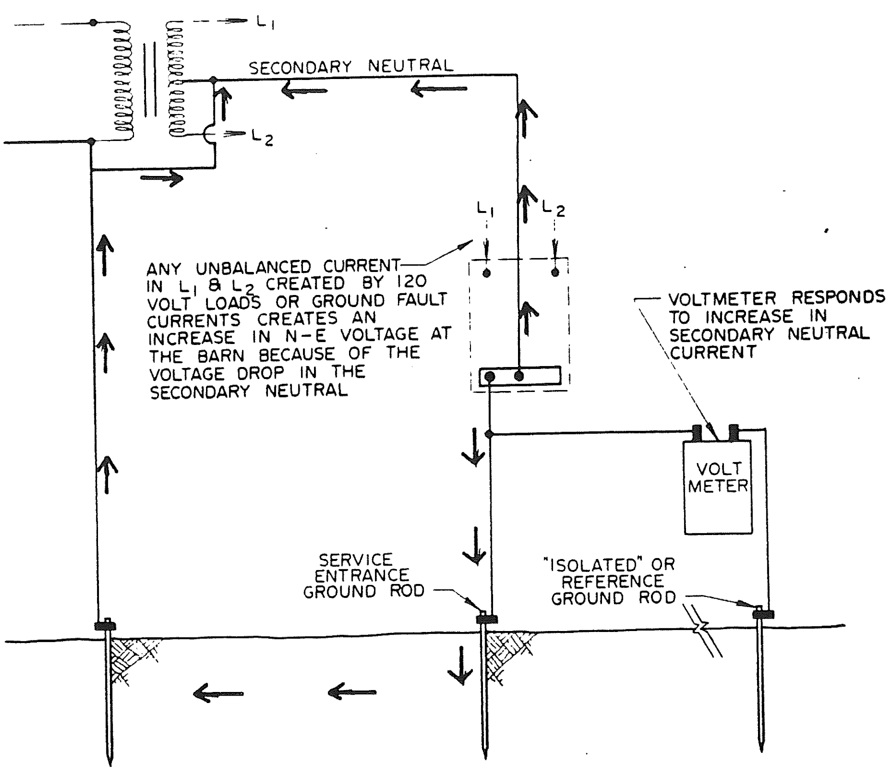


Figure 6. Neutral-to-earth voltages created by the voltage drop in the secondary neutral to the barn



entrance. Excessively high N-E voltages at the barn can be created by large, unbalanced 120-volt loads and high neutral resistances caused by poor connections, long secondary neutrals, or conductors that are too small. These create increased voltages on the secondary neutral at the barn and can cause an excessive N-E voltage at the barn service entrance.

Ground fault currents in the barn will increase the N-E voltage as a result of the increased load on the primary neutral and the increased current in the secondary neutral.

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 are connected to the neutral system, 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, stanchion, metal stall, metal grate, milk pipeline, 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. 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 N-E voltage exceeds 1.0 volt (using the test procedure described later) during milking, some corrective action may be necessary. Large 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.

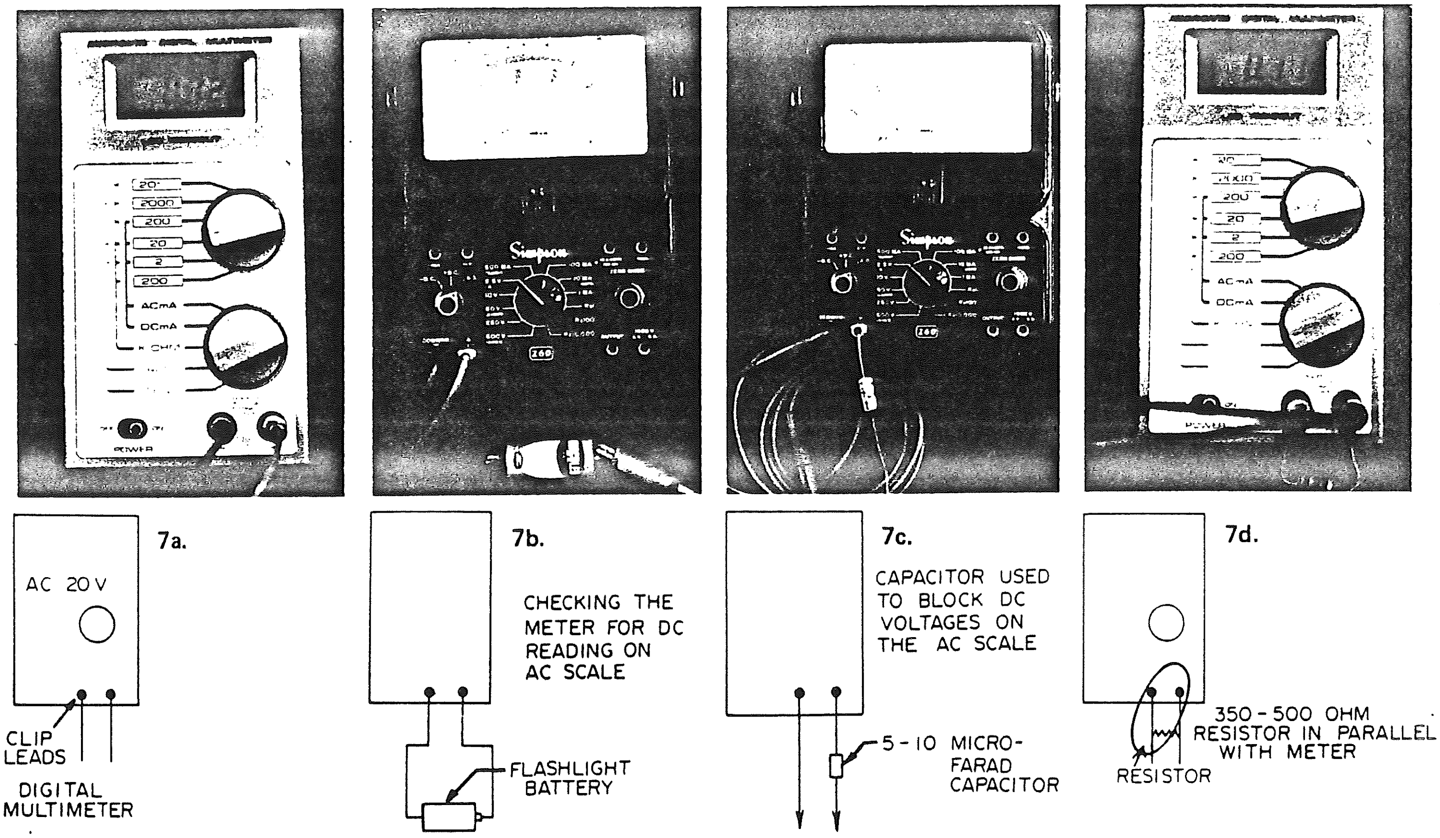
If N-E voltages do not exceed 0.5 volts during milking there is generally no cause for concern. Voltage measurements taken at other than milking and feeding times will generally be lower and may not indicate a problem. However, testing during hours other than milking time (using the test procedures described later) will be helpful in isolating the source of a stray voltage problem if it exists. Whenever 0.5 or more volts are observed between milkings, further checks should be made at milking time.

VOLTMETER REQUIREMENTS TO MEASURE STRAY VOLTAGE

Confusion exists because inappropriate and poor quality voltmeters sometimes are used to determine whether a problem exists. The voltmeter should:

1. be equipped with an AC voltage scale having a full scale reading of 2 to 5 volts, with the capability of reading to the 0.1-volt level, as shown in figure 7a.
2. 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 detection of induced voltages on electrically isolated components (described later) may require meters with much higher impedance.
3. *not read DC voltage on the AC scale.* To test this capability, connect the two voltmeter leads to each terminal of a conventional dry cell battery (1½ to 6 DC volts), as shown in figure 7b. If a positive reading is obtained, install a 5 or 10 micro-farad capacitor "in series" with one of the leads from the voltmeter, as shown in figure 7c.

Figure 7. Equipment for measuring stray voltages



4. be able to estimate the potency of the voltage source and the resistance of the "isolated" ground rod. To accomplish this, a 350- to 500-ohm resistor must be available to parallel the input leads of the voltmeter as shown in figure 7d.

Any voltmeter meeting the above specifications and adapted to read only AC voltage on the AC scale will generally be satisfactory. However, the overall convenience, ease of reading, and high input impedance of several digital multimeters have shown them to be well adapted to the analysis of stray voltages. One such digital multimeter (Radio Shack Cat. #22-198) is shown in figure 7. These multimeters can be purchased for $75 to $125.

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.

Most milking machine company representatives, many power supplier employees, some milking equipment dealers, and some veterinarians and county extension agents have equipped themselves with suitable voltmeters and are prepared to lend assistance. *Someone familiar with electrical systems, wiring, and equipment should be consulted and, if possible, be present when measurements are made.*

STANDARDIZED MEASUREMENTS

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 the barn and isolated from any other component such as water piping. The ground rod should be at least 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 (see figures 2 and 3).

This voltage is measured rather than voltages within the milking parlor itself because generally this voltage is the maximum expected between any two locations in the milking parlor, unless an electrical fault exists. If this voltage reaches a problem level, as discussed earlier, it is possible it exists in the milking parlor or barn and may be difficult to locate.

When measuring N-E voltages, the effect of the resistance of the "isolated" ground rod can be determined by placing a 350- to 500-ohm resistor across the input terminals of the voltmeter (resistor in parallel with meter) as shown in figure 7d. 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.

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 if a problem exists 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 and connecting the voltmeter as described in "STANDARDIZED MEASUREMENTS," read the N-E voltage at the barn.	Voltmeter Reading (AC volts) ________ Time ________	The voltmeter will now read the N-E voltage at the barn. This voltage 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.
Step 2. N-E voltage without the barn load: Open the main disconnect at the barn service entrance. If the N-E voltage in Step 2 is low (below 0.25 volt) skip Steps 3 and 4 and go to Step 5.	Voltmeter Reading ________	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 3. Removal of loads from other farm buildings: Leaving the main disconnect at the barn open, record the N-E voltage at the barn after opening each of the other service entrances on the farm. Leave the service disconnects open until all have been disconnected.	Service Disconnected / Voltmeter Reading ________ / ________ ________ / ________ ________ / ________ ________ / ________ ________ / ________	After each service entrance is disconnected, the N-E voltage at the barn should drop slightly if there are any loads operating on that service entrance. If the voltmeter reading at any step is relatively high (above 0.5 volts) and drops to a much lower value (less than 0.2 volts) when the service entrance is disconnected, the loads on that service entrance should be checked out later. This drop in voltage could be caused by a faulty load on that service entrance or it may be the result of a heavy load on the entrance at the specific time.
Step 4. Complete removal of farm load: Open the main disconnect to the farm and record the N-E voltage at the barn. Be sure the well is also disconnected if it is powered ahead of the main disconnect. After Step 4 is completed reconnect the main service and all building services.	Voltmeter Reading ________	The voltage recorded at the barn when all services are open is due to N-E voltage on the primary neutral created by loads at other locations on the main distribution system. When the main disconnect is opened the voltage reading should be the same as when all building services were disconnected.
Step 5. Checking 240-volt loads in the barn: Place a clamp-on ammeter around the neutral to the barn service. Be sure no 120-volt loads are added or dropped during this test. Record the voltmeter and ammeter reading after each of several 240-volt loads are added to the previous load. Also read the voltmeter and ammeter as each load is turned off in reverse sequence.	Load Added / Voltmeter Reading / Ammeter Reading None / ________ / ________ ________ / ________ / ________ ________ / ________ / ________ ________ / ________ / ________ ________ / ________ / ________	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. 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.

Step 6. Checking 120-volt loads in the barn: Open all 120-volt circuits in the barn. Record the voltmeter and ammeter readings as each of the 120-volt circuits is reconnected and the loads on that circuit are operating.

Carefully observe the effects of starting and stopping 120-volt motors. They can cause serious N-E voltages when starting.

Circuit Number	Loads	Voltmeter Reading	Ammeter Reading

The secondary neutral current to the barn (read by the clamp-on ammeter) and the N-E voltage readings will increase and decrease as the unbalanced load on the secondary neutral to the barn changes.

If the N-E voltage increases significantly (perhaps 0.3 volts or higher) with a maximum unbalanced load on the barn neutral, the voltage drop in the neutral may be causing problems. The problems may be a high neutral resistance created by poor connections or the resistance of the wire itself. Improving connections, better balancing of the line-to-neutral loads, and/or a larger neutral wire may help relieve the problem. Making sure the current in the barn neutral is minimized during milking (by selection of offsetting 120-volt loads) may help solve the problem.

It is possible for the N-E voltage to decrease with an increase in secondary neutral current. This is caused by the voltage drop in the secondary neutral counteracting (subtracting from) the primary N-E voltage. This occurs when the unbalanced current is created by loads on the 120-volt leg that is 180 degrees out of phase with the primary voltage.

Step 7. Circuit checks for other farm buildings: If in Step 3 one or more of the other building services seemed to produce an excessive voltage repeat Steps 5 and 6 for that building.

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

Peak	Voltmeter Reading Static	Time

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 is 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 N-E 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 N-E voltage should be monitored to see if it is periodic due to weather, soil moisture conditions, or other systematic fluctuations.

Step 9. 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 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 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. (Primary and secondary neutral systems have not been isolated).

If the tests outlined show an N-E voltage problem, the results should indicate whether the problem originates on the farm, off the farm as a result of an excessive primary N-E voltage, or a combination of the two.

STRAY VOLTAGES NOT RELATED TO N-E VOLTAGES

If these tests do not indicate a problem originating from the N-E voltage, further checks are necessary. Voltages can be induced on electrically isolated (non-grounded) conductors located in the barn or milking parlor.

Two such cases have been documented, both involving cow trainers in stanchion barns. In one case a voltage was induced on a non-grounded, stainless steel milk pipeline running parallel to the cow trainer. In the other case a voltage was induced on a water pipe paralleling the cow trainer about 2 feet away. The pipe was isolated from the well and pump by a section of rubber garden hose. In each case a voltage of 2 to 4 volts was measured between the pipes and the floor or other grounded surface. When a 350-ohm resistor was inserted across the input terminals to the voltmeter the voltage dropped to near zero. This indicates the source is not capable of delivering significant current. However, the current flow when the cow made initial contact was enough to cause discomfort. In the case of the water line, the cows were reluctant to contact the waterers to drink. However, the farmer noted, if one cow was drinking the others would drink with no apparent discomfort.

Induced voltages of this type may not be indicated by voltmeters with low input impedance. In both of the above cases the voltages were detected by meters with input impedances of 10 megohms.

Another potential problem voltage source is leakage from improperly grounded, faulty electrical equipment. *In this case, a hazardous condition exists to both humans and animals.*

The only way to detect these stray voltages is to measure the voltage between the equipment or facilities and earth. A voltmeter reading between the equipment and the floor may be adequate. However, the best measurement is between the equipment and the "isolated" ground rod used as a reference for measuring N-E voltages.

If the voltage is an "induced" voltage, grounding the isolated equipment should solve the problem. If the problem is faulty, non-grounded electrical equipment *the fault must be corrected and the equipment properly grounded.*

Voltages imposed on milk pipelines by electrical circuits controlling the operation of the milk pump, pulsator, or other electrical components of the milking system can cause problems. If the problem appears only when placing the milking equipment on the cow and during milking, these control circuits should be checked to see that they are properly installed and wired.

WHAT TO DO IF THE PROBLEM ORIGINATES ON THE FARM

The results of the tests outlined in the previous sections should help identify the problem if it occurs on the farm. If these tests suggest faulty equipment or large voltage drops on the secondary neutral, corrective action should be taken as indicated. The following guidelines will help reduce the effect of problems created on the farm:

1. Have a licensed electrician or a representative of the power supplier check the electrical system to make sure all farmstead wiring meets the proper code requirements.
2. Check to make sure all service entrances are properly grounded.
3. Establish and maintain good neutral circuits and connections. Heavy use, high humidity, corrosive silage acids, urine, and manure make dairy farms poor environments for electrical wiring and equipment.
4. Look for faulty equipment that may have leakage currents by measuring the current draw of operating equipment and by checking the currents in the ground and neutral wires.
5. Make every effort to balance, as well as possible, the line-to-neutral (120-volt) loads on the barn service entrance in operation during milking.
6. If possible, convert all motors in the barn to 240 volts. If 120-volt motors are used they should not be starting and stopping during milking. When 120-volt motors start, the high starting current flows in the secondary neutral. The voltage drop resulting from this momentarily large current increases the N-E voltage at the barn.
7. If the problem is created by excessive voltage drop in the secondary neutral and better balancing of 120-volt loads is not feasible, install a larger diameter neutral wire to reduce its resistance. Another proposed solution is to separate the neutral (grounded conductor) from the grounding conductors at the barn service entrance and run a separate, insulated grounding conductor to the transformer. *This modification must be checked out with the proper authorities.* It is discussed in Section 250-21 of the National Electrical Code and may or may not be acceptable.
8. Ground all electrical equipment such as manure pumps, silo unloaders, water heaters, and pumps to the service entrance ground. Use large wire (number 10 or larger). Insulation is not needed on these grounding wires. Spot weld or use pressure clamps rather than soldering or wrapping connections. *Improperly grounded equipment is extremely dangerous in milking parlor and dairy barn environments.*
9. Provide adequate power circuits. Too many services become overloaded as more and larger equipment is installed.
10. If it is possible, consider converting to three-phase service.

WHAT TO DO IF THE PROBLEM ORIGINATES OFF THE FARM

If the problem originates off the farm it is a result of excessively high N-E voltage on the primary neutral. *In this case the solution must be a cooperative effort between the* *power supplier and the dairy farmer.* The following steps should be considered if the problem originates off the farm:

1. The power supplier should thoroughly check the primary neutral on the entire distribution system to be sure of proper grounding, no high resistance connections, and no large-fault loads on neighboring farms.

   A procedure for checking the primary neutral has been developed by the Tennessee Valley Authority. It is described in a paper "Ground Potentials and Currents" (IEEE Paper No. 80CH1532-1TA-C2) by Walter J. Szelich, Jr., presented at the 1980 Rural Electric Power Conference in Rapid City, SD, April 27-29, 1980.
2. The power supplier should check the load balance on the three-phase service serving the single-phase distribution line.
3. Consult with the power supplier about leaving the farm neutral disconnected from the primary neutral at the transformer. This procedure will provide relief if the problem voltage originates on the primary neutral. *Operation under these conditions must be under the direction of the power supplier.* Section 97D of the National Electrical Safety Code provides for this if interconnection is made through a proper spark gap and the secondary neutral is properly grounded (shown in figure 8). However, some power suppliers, because of company safety policies, will choose not to operate with non-interconnected neutrals.
4. After consultation with the power supplier have a licensed electrician install a general purpose insulating transformer (standard dry type) to isolate the primary neutral from the barn neutral. It can be installed to isolate the total farm or just the barn service. If installed on the barn service, the grounded neutral system at the barn must be electrically isolated from the grounded neutrals at the other service entrances on the farm. This can be checked prior to installation of the transformer by measuring the N-E voltage at the barn with service to the barn, including secondary neutral, disconnected. If it is isolated from the rest of the farm, the N-E voltage should remain very low and increase very little as electrical load is added to the rest of the farm.

   The general purpose insulating transformer must use the 240 volts from the distribution transformer as its input and have a 120-240 volt 3-wire output. These transformers will cost from $400 to $1,200 (not including installation) for capacities from 15 to 50 KVA. When this type of transformer is installed, the dairyman assumes responsibility for maintaining proper grounding on the isolated system. Complete isolation is required, and tests should be run to document this by showing very little increase in N-E voltage at the barn when 240-volt loads are operated.
5. Provide an equi-potential plane as shown in figure 9. This procedure is practical in milking parlors but probably is impractical in stall-barn facilities. If the entire milking parlor—including floor, stalls, and feeders—is at the same potential, there can be no electrical

Figure 8. Interconnection of the primary and secondary neutrals through a spark gap with the secondary neutral grounded at the transformer (Section 97D, National Electrical Safety Code)

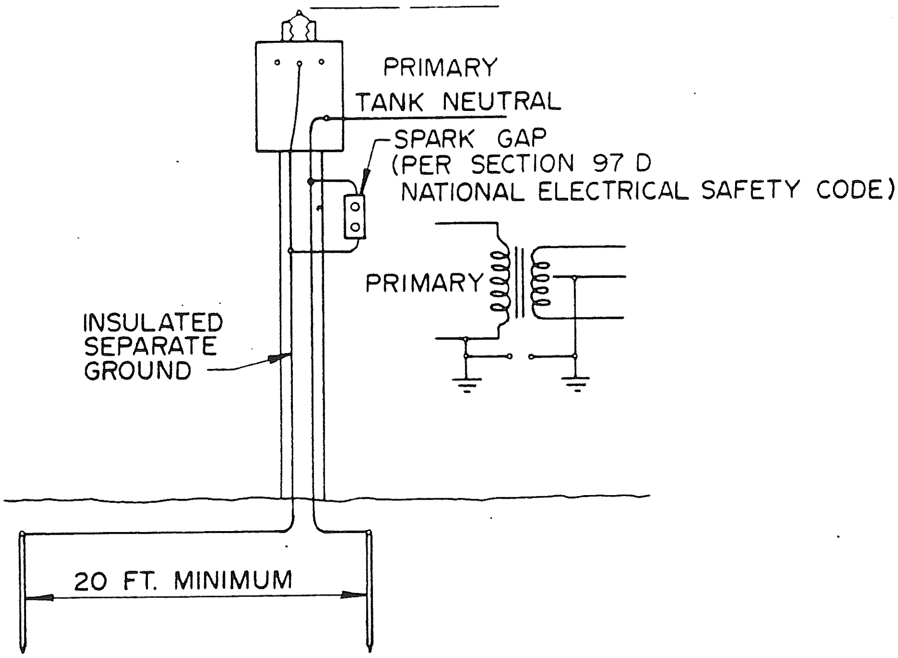
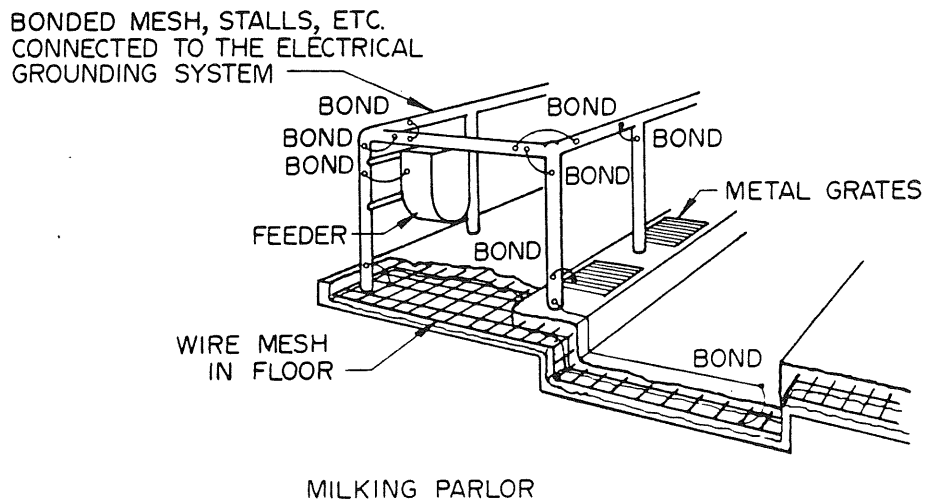


Figure 9. Bonded wire mesh used to form an equi-potential plane



shock (as in the "bird on a wire" phenomenon). A heavy welded wire mesh (9 or 10 gauge) is embedded in the concrete floor over the entire milking parlor including cow stalls and operator pit. Any common size up to a 6-inch by 6-inch mesh should be satisfactory. The wire mesh should be covered with a layer of concrete not thicker than 2 inches. Weld or clamp the mesh at all possible locations to other conductors such as stalls, floor grates, and feeders. It is important that the complete interior of the milking parlor be electrically connected. Use stainless steel clamps when connecting to stainless steel milklines. *Installation of an equi-potential grounding material is highly recommended in all new milking parlors.*

An equi-potential mat when installed correctly removes the shock potential for the cow in the parlor. It does not prevent a differential voltage from occurring when the cow enters the parlor from the holding corral, which is not a part of the equi-potential plane. In these cases, there may be a reluctance for cows to enter the milking parlor.

It is desirable to provide a gradual voltage transition from earth conditions in the holding corral to the equi-potential plane in the milking parlor. To do this weld steel mesh or rods (no more than 6 inches apart) to the equi-potential plane at the entrance to the milking parlor and extend them 15 to 20 feet into the holding corral and gradually embed them deeper (to 2 to 3 feet) in the concrete and earth.

6. An equi-potential plane can be approximated by placing a heavy metal base over the concrete portion of the cow platform and electrically bonding it to all metal structures in the parlor. Another way is to embed 10-gauge, or heavier, bare copper wire in slots cut in the floor and grout them over. These must be bonded together and to all metal structures in the parlor.

This publication is the result of several years of experience and study related to stray voltage problems with dairy herds in Minnesota. Numerous people have contributed, through their writings and personal contact, including Lloyd B. Craine, Department of Electrical Engineering and Grady F. Williams, Cooperative Extension Service, Washington State University; Leo Soderholm, USDA-SEA-AR, Ames, Iowa; Fred J. Feistmann, Agricultural Engineer, British Columbia Department of Agriculture; and William Fairbanks, Cooperative Extension Service, University of California.

The authors thank Vern Albertson, Department of Electrical Engineering, University of Minnesota, for his help in reviewing the manuscript as well as his consultation over the last several years.

HOW TO PROCURE ASSISTANCE

Proper measurement techniques, identification of stray voltage sources, and appropriate corrective action provide the most satisfactory approach for eliminating stray voltage problems. Up to now, progress has been occasionally hampered by the lack of cooperative interchange between involved parties.

Initial contact for assistance should be made to both your local licensed farm electrician and the engineer representing your local power supplier. In addition, some milking equipment dealers and creamery fieldmen have quality voltmeters and can provide valuable help in identifying the source of the problem. Similarly, they may have information available regarding recommended bonding procedures during construction of new milking parlors.

If you have difficulty in securing the expertise and cooperation necessary for proper diagnosis and corrective action, your local county agents can help you locate qualified assistance. The state extension service specialists listed below have agreed to serve as contact personnel whenever special problems occur:

State	State Agricultural University	Ag. Engineering	Dairy or An. Sci.
Illinois	Univ. of Illinois, Urbana	Wm. H. Peterson	Ralph V. Johnson
Indiana	Purdue Univ., Lafayette	Bruce A. McKenzie	Willard M. Dillon
Iowa	Iowa State Univ., Ames	Vernon M. Meyer	Ronald L. Orth
Kansas	Kansas State Univ., Manhattan	Elwyn S. Holmes	James R. Dunham
Michigan	Michigan State Univ., East Lansing	Ext. Ag. Eng.	Roger Mellenberger
Minnesota	Univ. of Minnesota, St. Paul	Harold A. Cloud	Robert D. Appleman
Missouri	Univ. of Missouri, Columbia	Robert George	Barry J. Steevens
Nebraska	Univ. of Nebraska, Lincoln	Gerald R. Bodman	Phillip H. Cole
North Dakota	N. Dakota State Univ., Fargo	Harvey Hirning	George R. Fisher
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UNDERSTANDING AND DEALING WITH STRAY VOLTAGE IN LIVESTOCK FACILITIES

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Abstract - Dealing with stray voltage has become a significant problem in livestock facilities. In this paper, a general description of sources is given. Currently available procedures for problem mitigation and avoidance of future problems (source reduction, gradient control and isolation) are outlined. Numerical modeling is used to show the effects of system parameters and modifications on neutral-to-earth voltage.

I. INTRODUCTION

Low level voltages existing between the grounded neutral system and "true earth" are causing serious problems in livestock facilities. These voltages have been termed: 1) stray voltage, 2) tingle voltage, 3) neutral-to-earth (NE) voltage, 4) neutral-to-ground voltage, 5) metal structures-to-earth voltage, and 6) extraneous voltage. On multi-grounded electrical distribution systems, it is normal to have some potential difference between all electrically grounded equipment and "true earth". As shown in Figure 1, these voltages can force a current through any conductor such as an animal's body, which provides a pathway to earth. The effect on the animal is influenced by many factors which combined, determine the current flow: 1) the voltage, 2) the resistance of the animal's body, 3) the concrete and soil moisture conditions affecting the resistance to "true earth", 4) resistance of the animal's contact points, and 5) resistance of the electrical pathway to the animal's contact point(s) (impedance of the source).

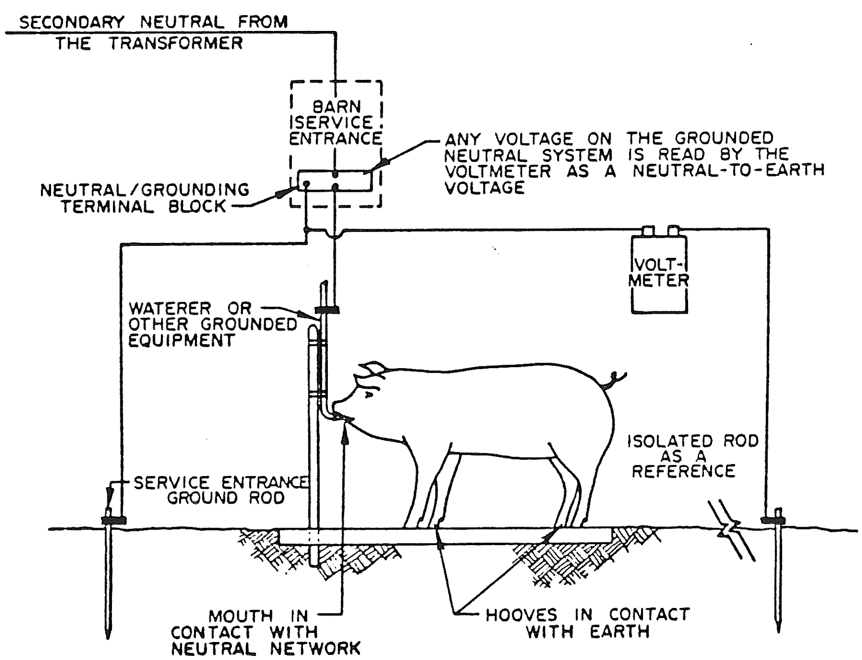

Fig. 1. Animal exposure to neutral-to-earth voltage.

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A. Animal Sensitivity

Animals, because of their relatively low body resistance, are annoyed by voltages at a level generally below human perception. Figure 2 summarizes data on t response of dairy cows to a mouth-to-all hooves current (1)(2). Since path resistance for the mouth-to-all hooves path averages only 360 ohms (2), a voltage of only 0.9 Vac could be expected to produce a 50 percent response rate.

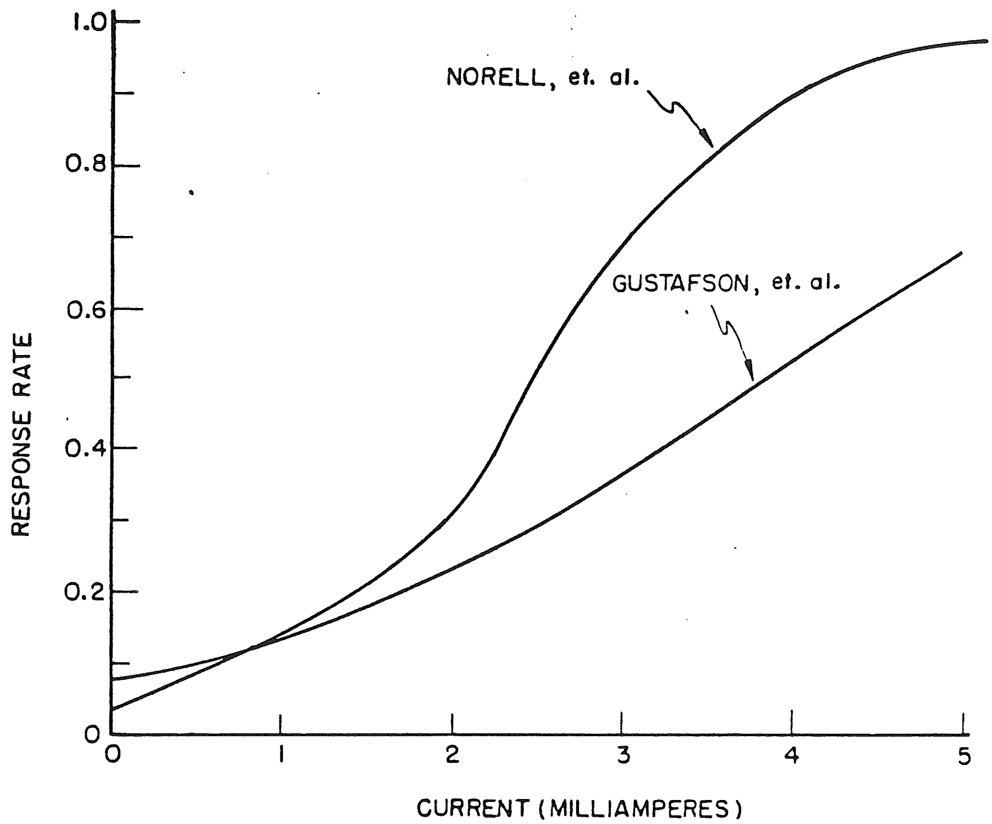


Fig. 2. Animal response rate to mouth-to-all hooves shocks.

Animal reactions will vary depending on the severity of the problem. The following symptoms are commonly reported with stray voltage in dairy operations: 1) uneven milkout, 2) cows extremely nervous while being milked, 3) cows reluctant to enter barn, 4) increased mastitis, 5) reduced feed and water intake, 6) increased manure deposition in the parlor, and 7) lower milk production. It must be recognized that other factors such as mistreatment, milking machine problems, disease, sanitation and nutritional disorders can create problems which manifest themselves in the same symptoms.

B. Prevalence of Problems

Prevalence of problems on farms is not fully known. Early estimates were that 20 percent of the dairy farms in the United States may be experiencing herd problems due to stray voltage (3)(4). Problems across the United States, in Europe, in Australia, and New Zealand have been reported (5). Three surveys have recently given more insight as to the magnitude of the problem in the dairy industry.

A 1983 study of 140 Ontario (Canada) Dairy Farms (6) reported,

"On 40 percent of the farms studies, tingle voltage was absent because stabling was not bonded to the neutral; a situation which creates electric shock hazard and is not in compliance with the Electrical Safety Code. About 60 percent of the remaining farms had levels above 0.75 volts between stabling and the cow platform. Based on these results, it is likely that 50 to 60 percent of Ontario dairy herds with properly bonded stabling would benefit from eliminating tingle voltage from the environment of the milking cows."

In stray voltage investigations on 59 Michigan dairy farms (7), sources of stray voltage greater than 0.5 V were detected on 32 farms. When voltage exceeded 1 V, statistical analysis showed that there was increased abnormal behavior and increased prevalence of clinical mastitis. Recovery from the stray voltage-induced abnormalities was related to the type of abnormality and the magnitude of the exposure voltage.

In a random survey of 162 barns in Alberta (8), it was found that 53 percent of the farms had voltages on the neutral above 0.5 V and 21 percent above 1 V. As with other surveys, lack of bonding was found to reduce the number of cases where voltages actually reached the cow contact points.

II. STRAY VOLTAGE SOURCES

A. Categorizing Sources

Stray voltages associated with the distribution network and the farmstead wiring system arise from relatively simple electrical conditions and can be easily separated into 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, the appropriate corrective measures can be readily determined. However, good understanding of the source and their interactions is necessary.

AC stray voltage sources can be placed in the following seven categories (9):

1) Primary neutral current from loads on other farms
2) Primary neutral current from on-farm loads
3) Secondary neutral current in the farmstead wiring system
4) Fault currents on equipment grounding conductors
5) Improper use of the neutral conductor on 120 V equipment as a grounding conductor or interconnection of the neutral and grounding conductor at the equipment location
6) Ground fault currents to earth through faulty insulation on energized conductors or ungrounded equipment
7) Induced voltages on electrically isolated conductive equipment.

This paper is dealing with alternating (ac) sources. Direct current (dc) voltages are also commonly present in livestock facilities.

Often the source of these voltages, in the range of 0.5 Vdc or less, is simple electrolytic action between dissimilar metals. These have not been shown to be a problem source. However, higher levels of voltages have been reported by some investigators due to: 1) use of the grounding system as return for dc control circuits or electric fencers, 2) faulty telephone systems, or 3) faulty cathodic pipeline (natural gas) protection systems in the area.

Few attempts have been made to quantify the relative frequency of each type of source. In the Ontario study (6), a subjective assessment of voltage source showed the main source to be primary neutral resistance (load dependent) on 62.1 percent of farms, primary neutral resistance and off-farm faults (load independent) on 15 percent of farms, secondary neutral resistance on 1.4 percent of farms, a combination of the first three on 9.3 percent of farms. On-farm faults were found on 3.6 percent of the farms. The Michigan survey (7), showed that of 32 farms, source was on-farm for 9 (28 percent), off-farm for 17 (53 percent), and a combination for 6 (19 percent).

B. Source Identification

In dealing with existing problems, it is imperative that the sources of stray voltage in the facilities be clearly identified. In design of new facilities, it is important to understand the potential sources. Publications describing the sources and identification procedures (4),(9),(10), can be used by persons knowledgeable in electricity to clearly identify the vast majority of problem sources. Instrumentation and procedural needs for persons of varied electrical expertise have also been discussed (11).

III. MITIGATION AND AVOIDANCE

Both the elimination of existing stray voltage problems and design for prevention of future problems demand careful consideration of sources; animal sensitivity threshold; and characteristics of the mitigation procedures or devices. With understanding of these items, one or more of the following three categories of approaches can be matched to the situation.

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

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

3) Isolation of portion of the grounding or grounded neutral system accessing the animals, so that they will not be subjected to objectionable currents due to stray voltages existing on the remainder of the grounded neutral system.

In the author's opinion, all of the devices and procedurues to be discussed in the following sections are theoretically sound. All have their particular advantages and disadvantages. Any mention of a specific manufacturer is not intended to imply endorsement of that manufacturer or their devices. It will be the responsibility of the industry to select the appropriate approach that meets the needs of a specific situation.

Some of the concepts and devices are still under development, therefore, their specific design may change. However, the concepts under consideration have been clearly identified.

IV. VOLTAGE REDUCTION

A. Elimination or Reduction of Sources

If a systematic analysis shows that a substantive component of the NE voltage is originating due to such items as: high resistance connections (either on or off the farm); excessive neutral imbalance currents on the farm; undersized neutrals; or faults to earth or equipment grounding, corrections can be made and the subsequent remaining voltage assessed. Clearly, such items as faulty connections and faults to earth can lead to serious problems. The proper procedure for such situations must be to correct the faults, and thereby eliminate the source.

If design of the farmstead system requires unusually long secondary neutrals, an option of using a four-wire service to the building has been clarified in the 1984 National Electrical Code (NEC) (12). Figure 3 shows the four-wire system schematically. This system eliminates the portion of secondary neutral drop on the four-wire segment from appearing at the barn. For this system, all neutral and grounding circuits in the building and all feeders from the service must be competely separated. (No neutral-to-ground interconnects or grounding connections between buildings.) NE voltage from off-farm sources, faults and other secondary drops will remain.

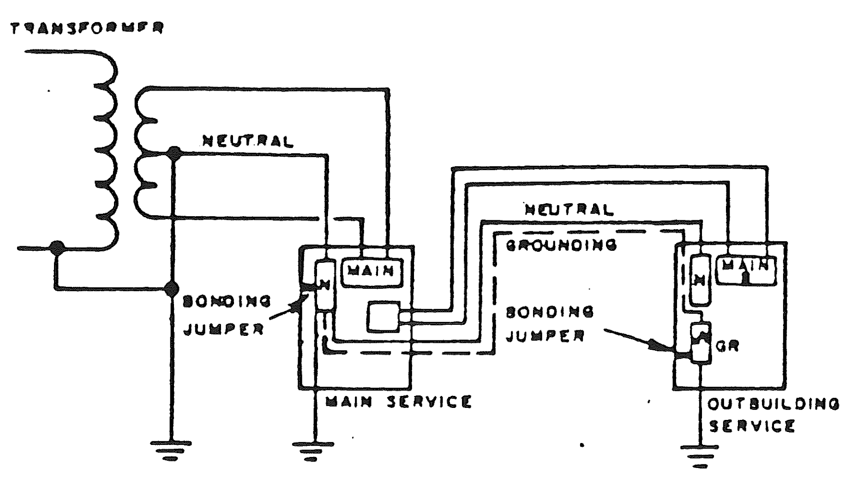


Fig. 3. A four-wire feeder from farm main to outbuilding.

B. Active Voltage Suppression

Since NE voltage is created by current flow through a system impedance, it is possible to create a potential source in opposition to the original source such that the effect can be nulled or cancelled at that point in the system. Two concepts for such an active voltage suppression approach have been developed.

The first suppression concept is the use of a controlled current to earth (Figure 4).

Voltage between a point in the neutral system and an isolated reference ground is used as the sensing input to a differential amplifier. Current to the remote electrode is then adjusted to null out the voltage sensed. This approach has been developed by ITT Blackburn Co., of St. Louis, MO (13).

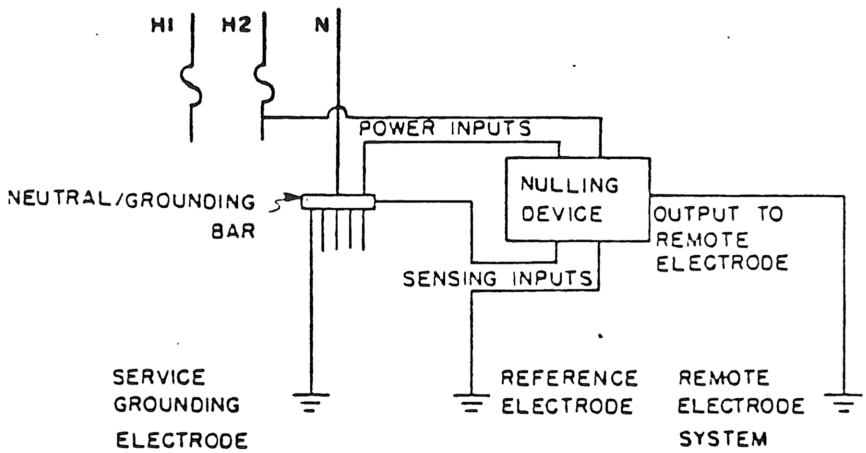


Fig. 4. Voltage suppression by controlled current to earth.

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, 2) nulling the NE voltage at a point lowers the level of NE voltage on the distribution system. The latter advantage has the opposite effect of isolation techniques.

Disadvantages include: the possible increased maintenance problems inherent to an active (amplifier system) type device; initial cost may be high relative to other approaches; and the potential exists for offsetting of problem sources which might more properly be corrected by other means. 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. The developers have units under field test at this time. Experience as to operational characteristics in a field setting, energy costs and installation problems will be helpful.

A second active suppression approach has been presented by a private inventor (Figure 5). Service conductors pass through a heavy iron core forming one side of a transformer. Current in a set of windings around the core, controlled by a differential amplifier, can offset the NE voltage at this point. Offset can be accomplished at the point of a building service or farmstead service. This approach has been demonstrated with a prototype device by the inventor (Mr. William Bickner, 410 W. Elm St., Stillwater, MN 55082).

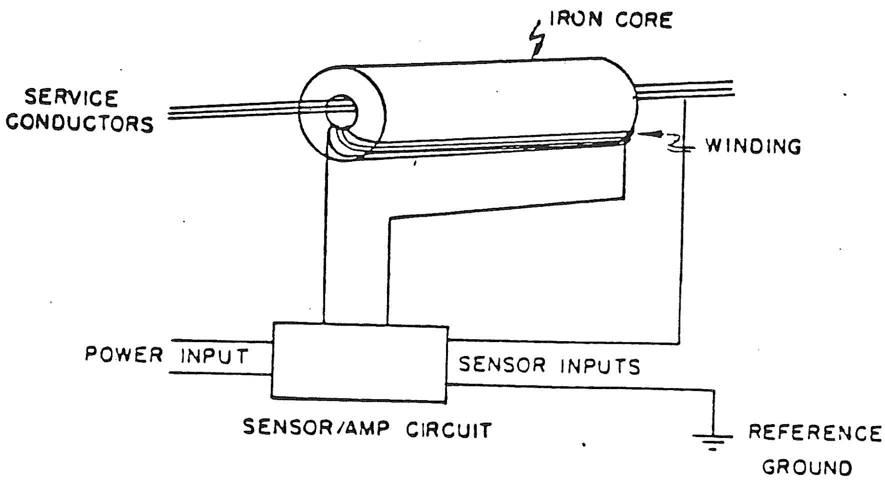


Fig. 5. Voltage suppression by transformer method.

This approach has similar installation advantages and disadvantages to the first suppression approach in that it does not require change in design of the wiring system and should not significantly affect fault currents. However, its effect on the distribution system, raising the NE voltage, will be the same as that of isolation.

V. GRADIENT CONTROL

Gradient control by equipotential planes will negate the effects of NE voltages in livestock facilities if they reduce the potential differences at all possible animal contact points to a sufficiently low level. The concept of gradient control is recognized in the electrical industry as a means of minimizing the risk of hazardous step and touch potentials under fault conditions at substations and around electrical equipment.

In addition to the objective of protecting persons, animals and equipment under fault conditions, equipotential planes in livestock facilities are an attempt to reduce problems arising from naturally occurring potentials, to levels well below those causing direct harm. Equipotential planes will improve the electrical safety with regard to lightning protection and clearing of faults without harm to people or animals. The plane represents an excellent grounding electrode for the system.

Limited description of procedures for installation in new facilities have been presented (4)(14)(22). However, all of these are based on engineering judgement with little validation of their effectiveness in actual situations. Ontario Hydro (23) reports that their analysis of grid size demonstrates that meshes up to 30 cm (12 in) square are effective in producing an acceptable plane. In a study of transition design for access and egress areas (24), it was found that the transition step potential could be reduced up to a factor of two by a properly installed transition.

Equipotential planes can successfully minimize stray voltage problems independent of source. However, consideration must be given to all areas where electrically grounded equipment is located in space occupied by livestock or exposed to livestock traffic. Additional methods other than equipotential planes may be needed in certain areas.

VI. ISOLATION

Isolation of part of the grounded neutral or grounding systems can eliminate access to NE voltages by animals in contact with the isolated system. If isolation is selected, on a conventional single-phase grounded neutral system, there are two points which lend themselves to isolation. The first is: isolation of the whole farmstead from the primary distribution system; the second is isolating the grounding or grounded neutral system at a single building service. For all isolation procedures, careful consideration must be given to both the safety and operational effects.

A. Whole Farm Isolation

Three procedures are currently being used for whole farm isolation: 1) isolated neutrals at the distribution transformer with a surge arrestor, 2) isolated neutrals at the distribution transformer with a switching/reconnect device for fault conditions, and 3) isolation transformers in series following the distribution transformer. In all cases the system grounding of the isolated portion is removed from the distribution system, at least during non-fault conditions.

Whole farm isolation can be accomplished by removal of all bonds between the primary and secondary neutrals at the distribution transformer. The National Electric Safety Code (NESC) (25) Section 97D2 requires "interconnections of the neutrals shall be made through a spark gap or a device which performs an equivalent function. The gap device shall have a 60 Hz breakdown voltage not exceeding 3 kV."

Some power suppliers are reluctant to use the spark gap approach. With the spark gap installation, a primary-to-secondary transformer fault below the breakdown voltage of the gap would be dependent on only the farmstead grounding for clearing the fault rather than both distribution system and farmstead system grounding. However, other devices have been developed to alleviate this problem, these will be discussed later.

Isolating transformers have been used extensively 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 losses of the transformer. Care must be exercised in proper installation to meet prevailing codes and recommendations, particularly for overcurrent protection and bonding.

Both the spark gap and isolating transformer approach rely on an arrestor to interconnect the two systems during an overvoltage situation such as a lightning strike. Because of the disadvantages of both the spark gap and isolating transformer approaches, other alternative devices have been developed.

They are based on the concept of placing, at a key point in the system, a device which presents a high impedance under normal conditions but reduces to a low impedance uner fault conditions. These devices can replace the simple spark gap as an interconnect between primary and secondary neutrals at the distribution transformer.

Two concepts for these devices are available at this time. One uses a saturating reactor, which is a conductive coil with a core that magnetically saturates when the current through the coil increases. This means the device presents a high impedance at low currents, but saturates and presents a low impedance at high currents. The available devices reach saturation at potentials in the range of 10 to 24 Vac. The saturating reactor blocks most of the NE voltage under normal operating conditions by acting as the higher impedance in a voltage divider with the farmstead grounding system. However, under fault conditions where the potential across the device would increase, the reactor saturates and presents a very low impedance. Figure 6 shows characteristic 60 Hz ac impedance curve for these devices. Saturating reactors do not conduct (saturate) for steep transients such as lightning. Therefore, all these devices have a surge arrestor across their terminals to prevent damage by lightning or switching transients.

A second isolating device, patented by Dairyland Industries of Oregon, WI, consists of a solid state switch. The switch consists of oppositely-directed thyristors in parallel, which are fired when the voltage across them reaches a preset value. This effectively returns the bond during fault conditions, while blocking the NE voltage with a high impedance below the triggering threshold. In contrast to the coil, which presents only a low resistance to dc currents, the solid state switch will block both ac and dc currents below the triggering threshold.

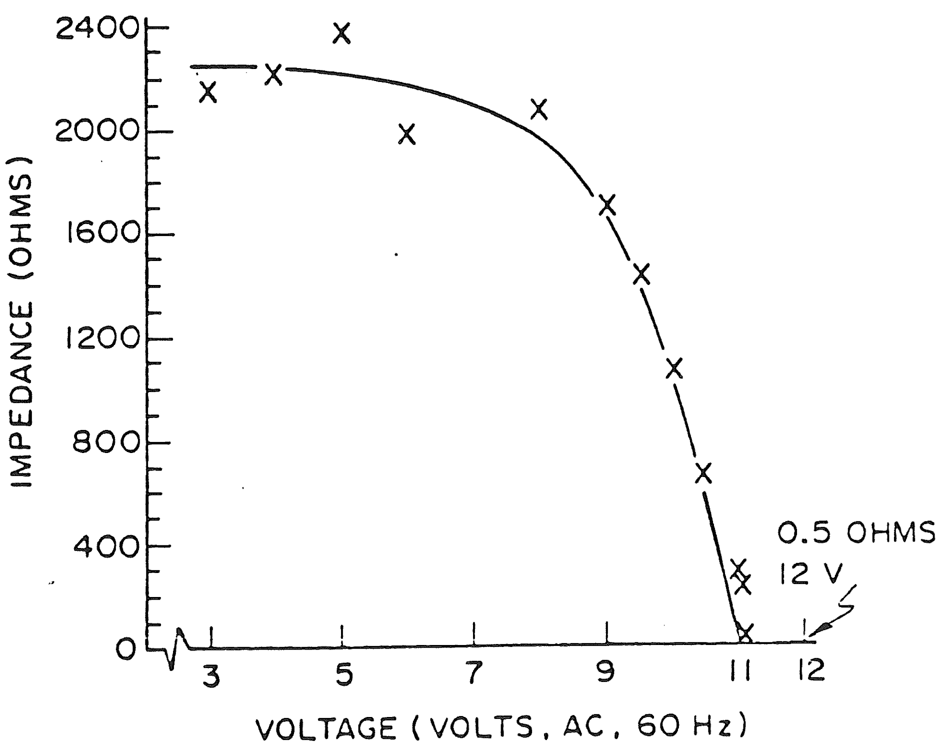


Fig. 6. Impedance curve (60 Hz ac) for one saturating reactor.

These devices will reduce the risk of operating with non-interconnected neutrals to a lower level when compared to the spark gap at a cost much lower than the isolating transformer approach. However, they will raise the NE potential on the distribution system during normal operation.

B. 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. 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 may be a result of the services needing isolation. When an isolating transformer is installed, assurance is necessary that no conductive interconnections are bypassing the transformer. Common interconnections are metallic gas or water pipes, metal feeders, fences and connected metal buildings. Any conductive bypass will negate the isolation of the transformer. Prevailing codes and recommendations, particularly for overcurrent protection and bonding, must be followed.

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

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

Devices for this approach have not received listing by Underwriter's Laboratory for such an application. The concept has not been determined to be acceptable under the National Electric Code, therefore its use in the US at this time can not be recommended unless approved by appropriate electrical inspection authorities on an experimental basis.

VII. MODELING FOR IMPROVED UNDERSTANDING

Both physical and numerical models have been used in stray voltage work (26). The function of the models in general has not been to describe a specific installation or line, but rather to (1) describe types of sources and their interaction and (2) test the effect of changes in system parameters or configuration.

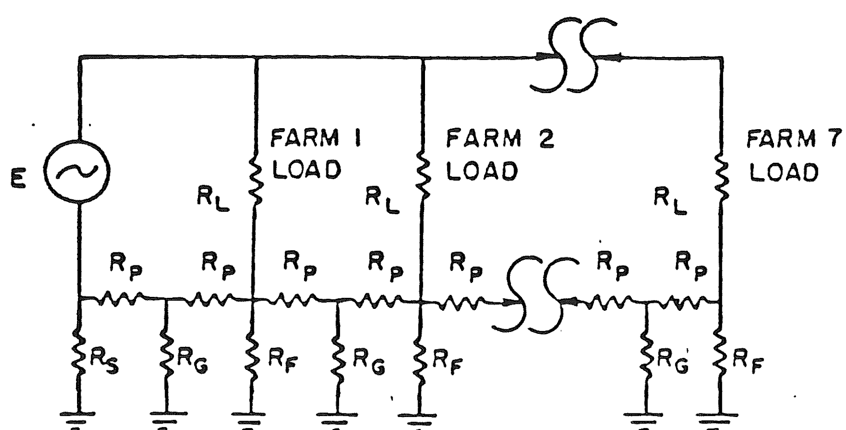
The most frequent function of modeling of electrical transmission and distribution lines has been to establish system capabilities for reliable power delivery with ample ability to handle large fault currents due to surges, such as lightning and direct conductor-to-conductor or conductor-to-earth faults.

For this purpose, it is assumed that the resistance of the connections to earth, such as tower grounds, are zero. This assumption is unsuitable for determining neutral potentials, since it implies the existence of no neutral potential. In understanding NE voltage, the characteristics of the distribution system under mal loading (including both normal load and ground fault currents from consumers) and the resulting potentials between the grounded neutral system and the earth itself, are the principal concerns. Hence the resistance of the grounding connections must be taken into account. With grounding resistance values included, the effects of NE voltage and fault current capabilities can be assessed.

A. System Characteristics With A 1Ø Resistive Network Model

A seven-farm, single-phase line model, shown schematically in Fig. 7, can be used to demonstrate the effects of a series of parameters related to the primary and farmstead grounded neutral systems under steady state conditions (27). In the model, the voltage drop across the system grounding components represents the NE voltage at their locations. As a base case situation, the model assumes a very uniform line with the following characteristics:

(1) purely resistive components throughout
(2) an equivalent system grounding of 2.5 ohms at each farm
(3) system grounding of 12.5 ohms at the midpoint between farms and between the first farm and the substation
(4) a substation system grounding resistance of 0.5 ohms
(5) primary neutral conductor resistance of 0.66 ohms between farms (approx. equivalent to 475 m or 1,660 ft of No. 6 AWG Cu)
(6) a farmstead load producing 1 ampere per farm of primary load.



E = System Supply Voltage = 7200 V
R_L = Farmstead Load Resistance = 7200 ohms
R_S = Substation Grounding Resistance = 0.5 ohms
R_P = Primary Neutral Conductor Resistance = 0.33 ohms
R_G = Primary Neutral System Grounding = 12.5 ohms
F_F = Farmstead and Transformer System Grounding = 2.5 ohms

Fig. 7 Seven-Farm, Single-Phase Line Model

A system of twenty-one loop equations was established from the circuit description. A matrix solution program on an Apple IIe was used to solve the equation system. A solution time of approximately sixty seconds was required for each solution. By changing a single parameter or a series of parameters, the effects of these changes relative to the base case can be easily demonstrated.

As described earlier, one approach to elimination of off-farm NE voltage sources at a particular farmstead, is through isolation of all, or a part of, the grounded neutral system of the farmstead. Figure 8 displays, by comparison with the base case, the effect of neutral isolation (full farmstead, individually) at two locations along the line.

Figure 9 shows the effect of a change in system grounding and the interaction of isolation with system grounding. The farmstead grounding resistances are reduced by 50 percent, from 2.5 to 1.25 ohm per farmstead. Although with the lower farmstead grounding resistances the voltage at the substation was nearly identical, the peak voltage at the end of the line was reduced by 43 percent (2.0 to 1.3 V).

However, the increases due to isolation as a percentage of the base case increased. At Farm 4, the percentage increase due to isolation rose from 29 percent to 48 percent. Similarly, at Farm 7, the percentage increase due to isolation rose from 56 to 96 percent.

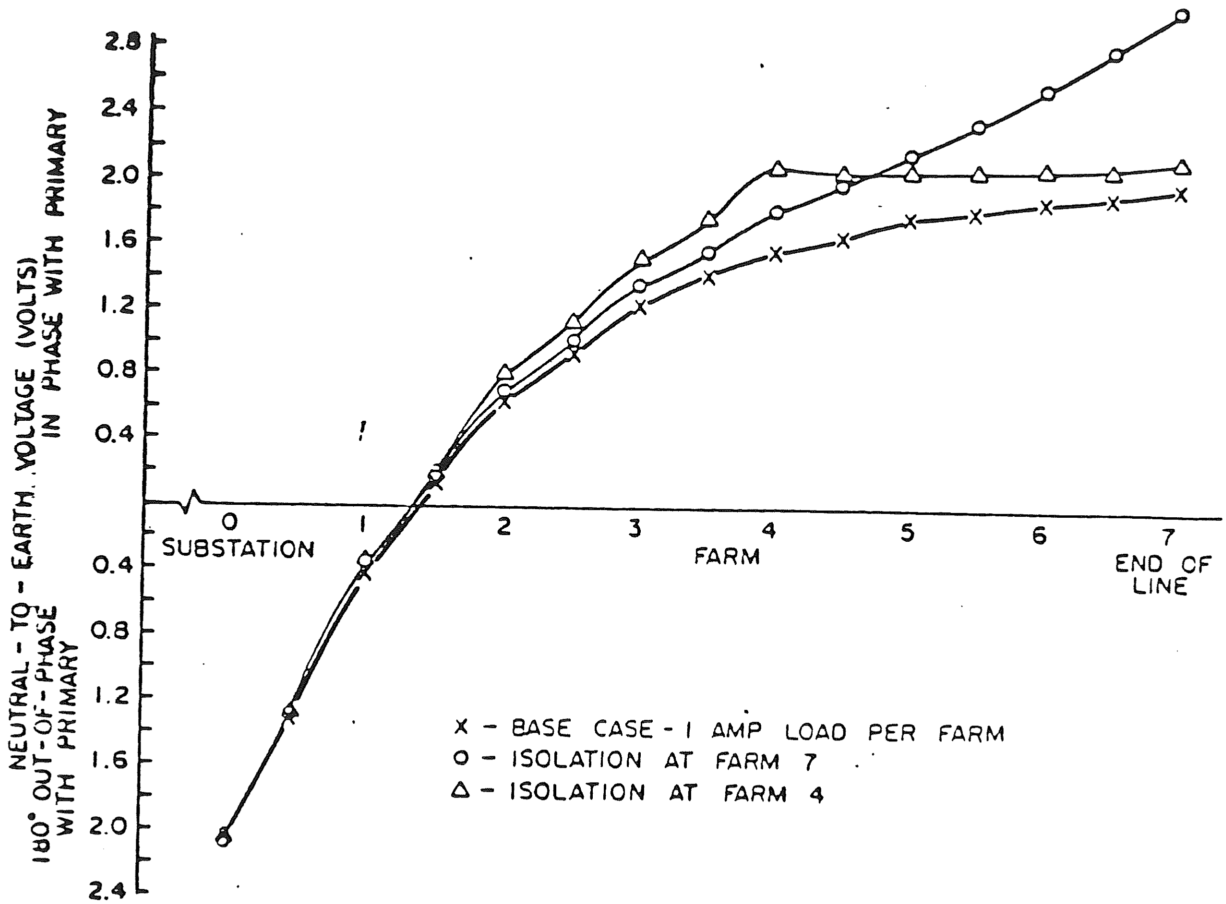


Fig. 8. NE voltage with improved farmstead grounding.

Figure 10 demonstrates the effect of wire size or increased distance between farmsteads. An increase in primary neutral wire resistance of 67 percent is used, combined with the base load. Isolation at Farm 4 and Farm 7 is also shown. The increased neutral conductor resistance resulted in the largest percentage effect in the central portion of the line. A 79 percent increase in NE voltage (0.66 to 1.18 V) occurred at Farm 2. The effect of isolation was amplified at both the point of the isolated farmstead and adjacent farmsteads.

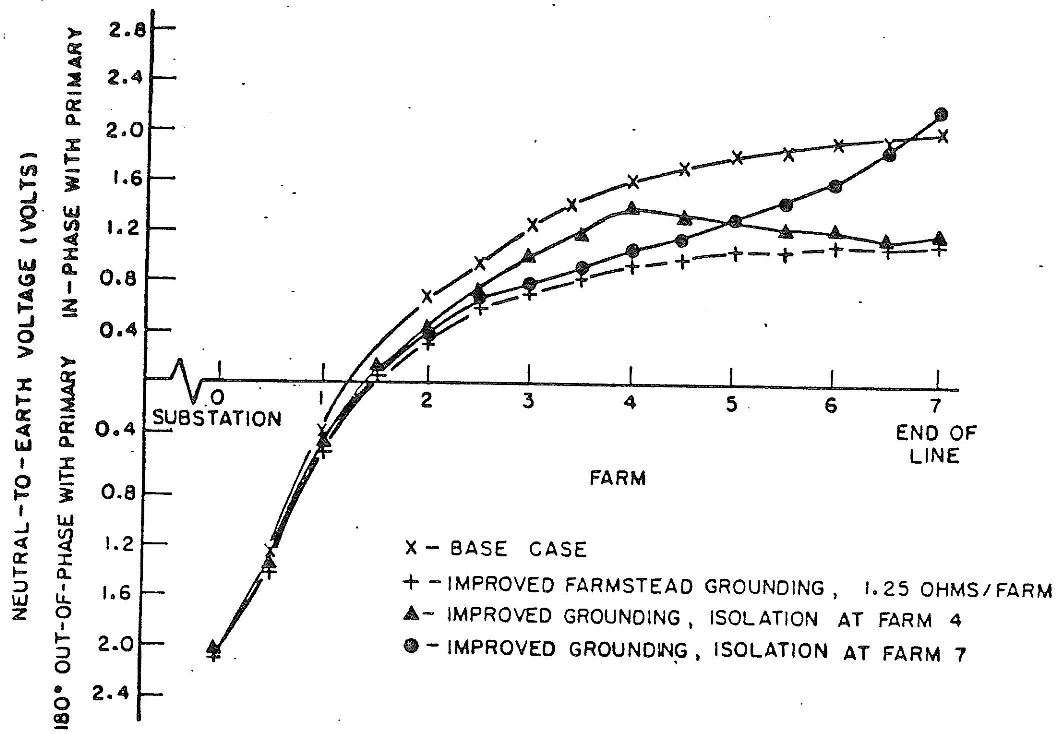


Fig. 9. NE voltage with improved farmstead grounding.

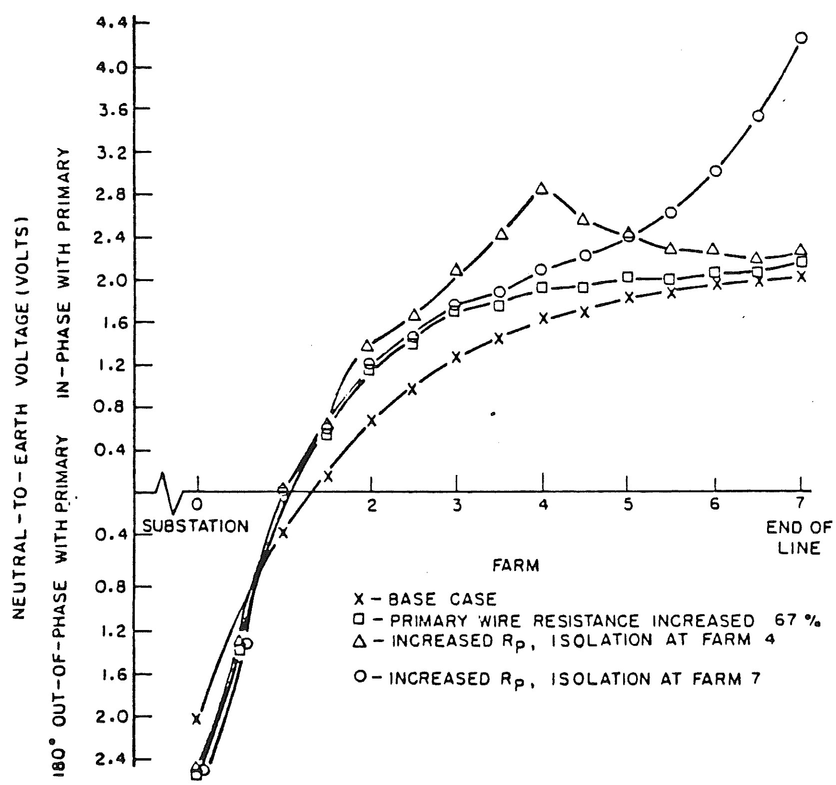


Fig. 10. NE voltage with increased primary conductor resistance.

The voltage suppression approach (13) can be modeled by the addition of one more source loop. One more equation was inserted in the model to represent this current offset device. The source was placed between true earth and a selected point in the grounded neutral systems. Figure 11 shows the effect of implementing such a nulling device at three locations along the system. Power required from the compensating circuit depends on the requisite current and resistance of the remote grounding electrode to earth. In the model cases, power required for nulling at the last farm was 261 W for a 55 ohm electrode system, and 52 W for an 11 ohm system.

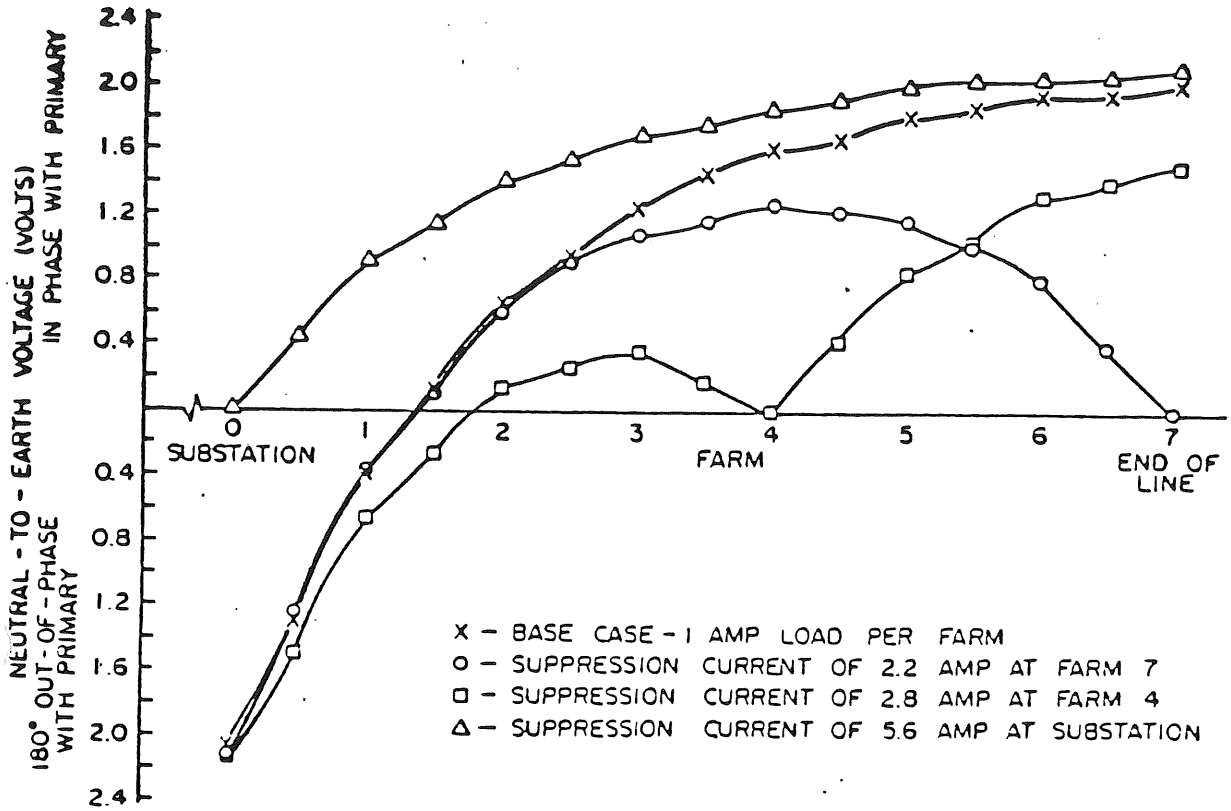


Fig. 11. Voltage suppression at selected locations.

Poor connections in the primary neutral conductor can dramatically change the apparent resistance of the conductor. Figure 12 allows comparison of two cases where a 40 ohm resistance was placed at a selected point in the primary neutral conductor. When placed near the substation, the effect was largest on those farms near the substation. The highest value, at the end of the line, was not changed significantly. When the resistance was placed near the midpoint of the line, some farms ahead of the poor connection had reduced levels of NE voltage, while those further along saw increased levels.

Figure 12 also shows the effect of variation in the resistance to earth of the substation. As the substation grounding resistance is increased, the voltage near the station increases and the zero point along the line is moved further down the line. The effect diminishes with distance from the substation.

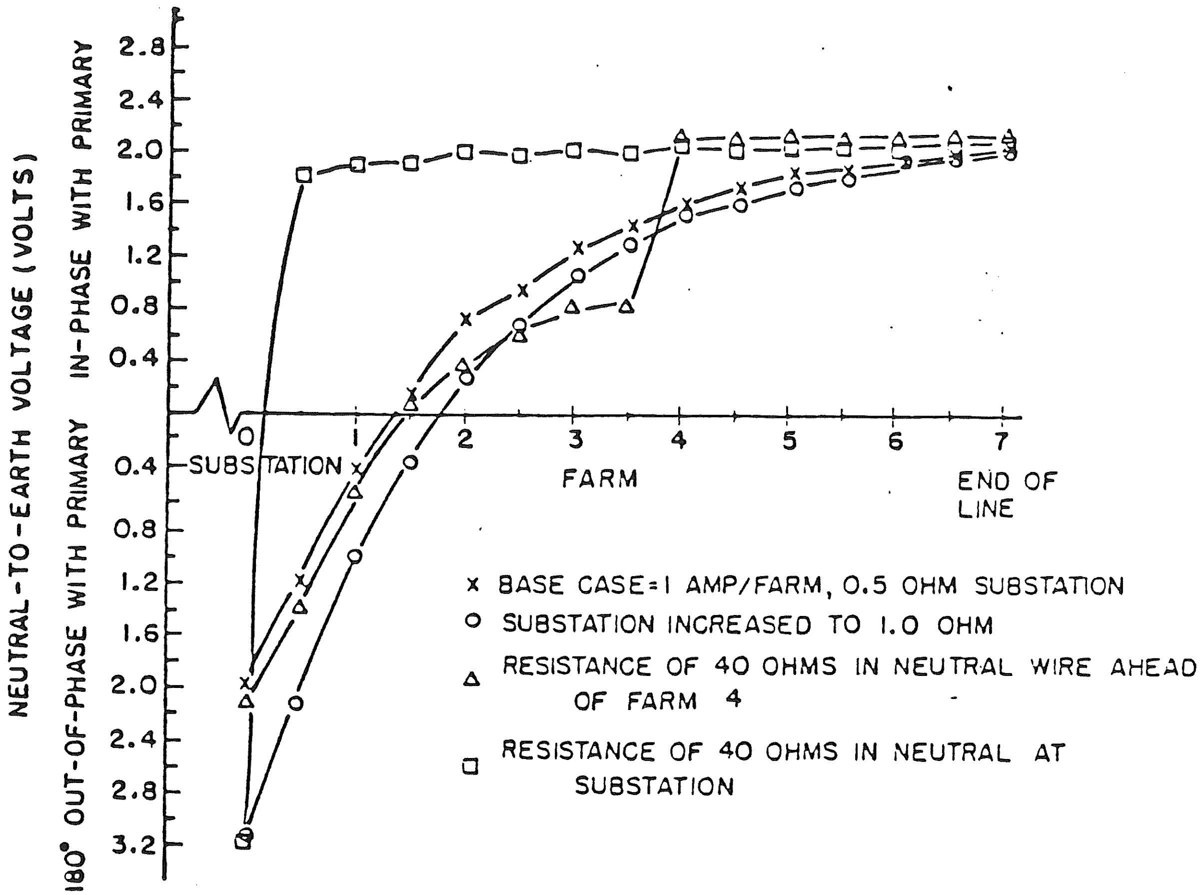
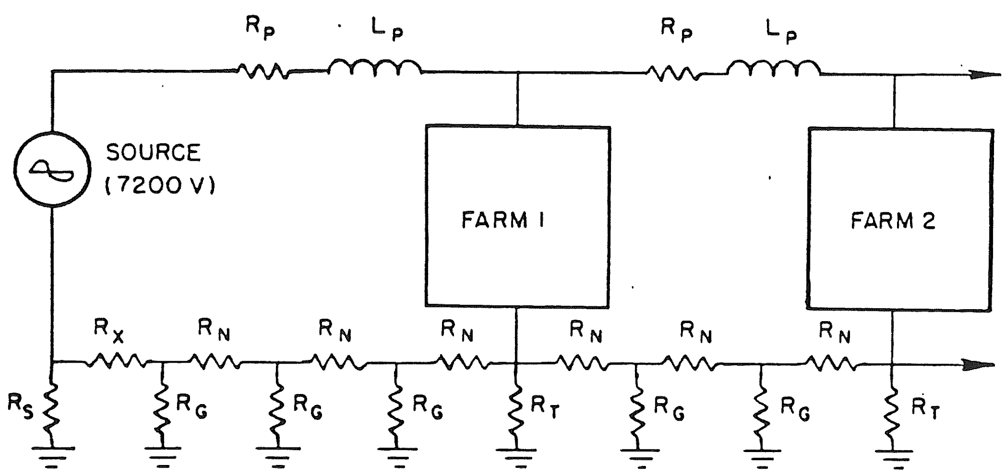
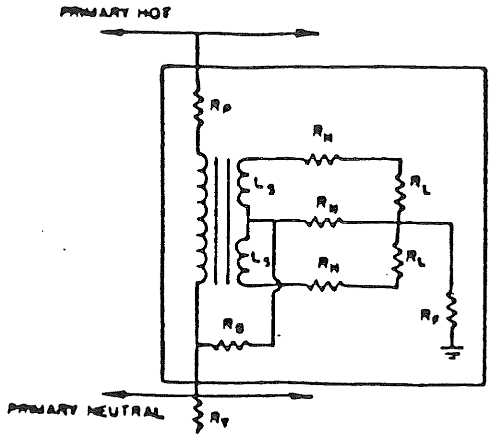


Fig. 12. Bad connection and substation grounding variation effects.



Rp = Primary Hot Resistance = 1.42 ohm
Rn = Primary Neutral Resistance = 0.473 ohm
Rt = Transformer Grounding Resistance = 25 ohm
Rg = Neutral Grounding Resistance = 25 ohm
Rs = Substation Grounding Resistance = 0.25 ohm
Rx = Substation Connector Resistance = 1.0 E-4 ohm
Lp = Primary Hot Inductance = 1.08 mH

Fig. 13a. Schematic of single-phase line model, primary.



Rp	=	Transformer Primary Resistance	= 41 ohm
Rt	=	Transformer Grounding Resistance	= 25 ohm
Rh	=	Secondary Hot Resistance	= 6.4 E-3 ohm
Rn	=	Secondary Neutral Resistance	= 6.4 E-3 ohm
Rb	=	Neutral Bonding Strip Resistance	= 1.3 E-4 ohm
Rl	=	Secondary Load Resistance	= 1.54 ohm
Rf	=	Farm Grounding Resistance	= 1.25 ohm
Ls	=	Transformer Secondary Inductance	= 8.3 E-2 mH

Fig. 13b. Schematic of single-phase line model, farmstead.

B. Three-Phase Substation System

The ten-farm, single-phase line model, shown schematically in Fig. 13 a & b, was used to demonstrate three single-phase lines (on separate phases of a three-phase system) served from a substation. Solution of the system, via the Electromagnetic Transients Program (EMTP), (28) included inductive characteristics of the system. The power supply at the substation is a three-phase wye connected system.

For comparison with earlier models, Fig. 14 shows the magnitude of NE voltages when only one single phase line is connected to the substation. Figure 14 also shows the results when two more identical lines (each from a different phase of the three-phase system) are added. Since the three-phase system is now balanced at the substation, the resulting NE voltage at the substation is zero. In this case the magnitudes of the NE voltage on each line are equal although they would be 120 degrees out-of-phase with each other.

A maximum imbalance case results from removing all the load on one of the three single-phase lines. Figure 15 shows the magnitude of the NE voltage resulting on each of the lines.

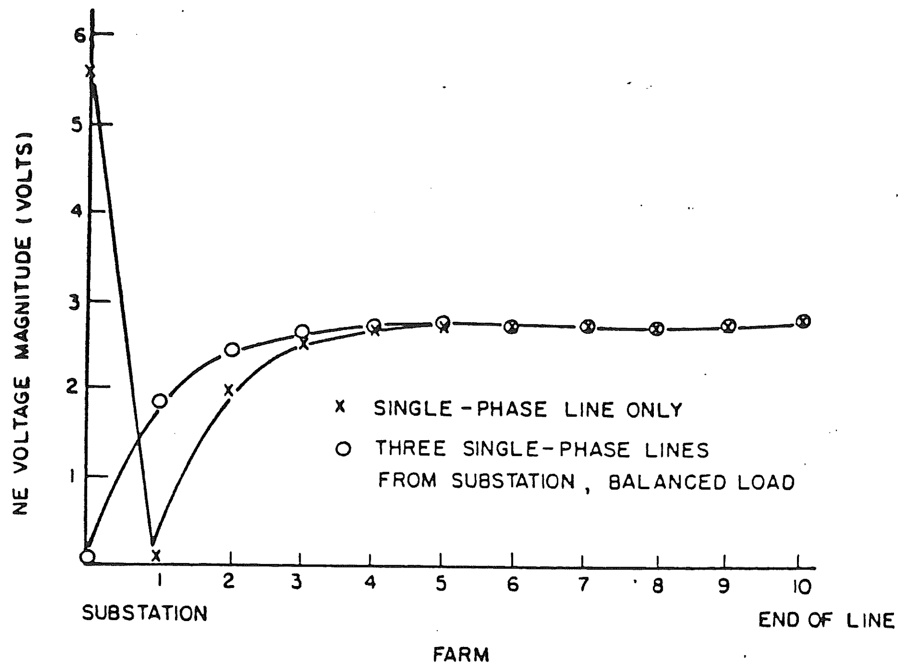


Fig. 14. NE voltage for single-phase and balanced three phase systems.

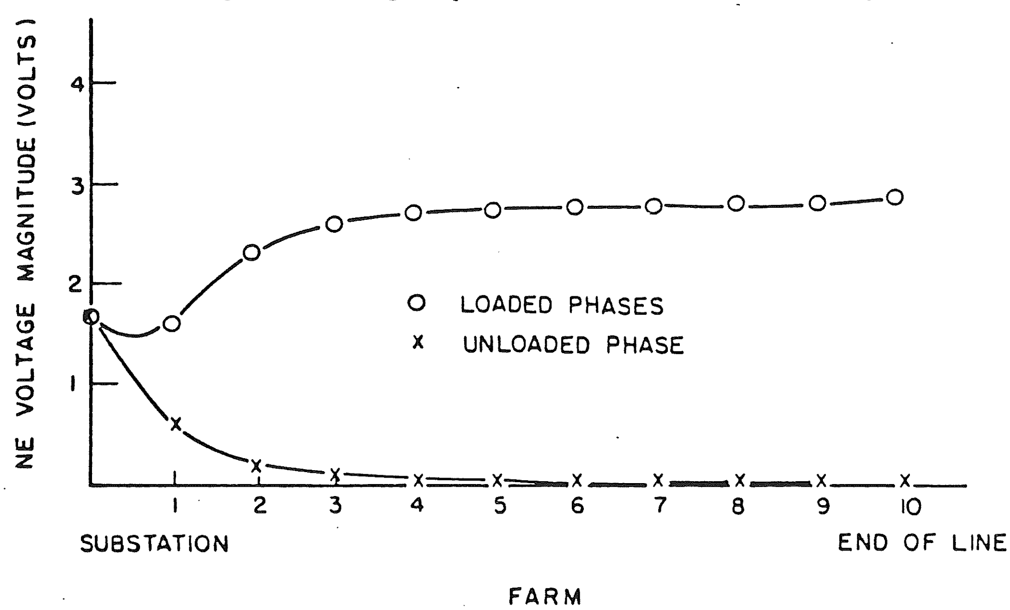


Fig. 15. NE voltage for imbalanced three phase system.

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SINGLE-PHASE DISTRIBUTION SYSTEM
NEUTRAL-TO-EARTH MODEL

UNIVERSITY OF MINNESOTA
DEPARTMENT OF AGRICULTURAL ENGINEERING
1390 ECKLES AVENUE
ST. PAUL, MN 55108
(612) 373-1359

Requirements: Apple II with 64K of memory and one disk drive.

The Single-Phase Distribution System Neutral-to-Earth Model is an interactive BASIC program which allows you to select voltage, wire sizes, grounding, resistances and loads for the system you wish to solve, and then calculates the resulting neutral-to-earth voltages. The program is divided into two parts; one which allows you to create a system by entering the appropriate data and another which lets you edit the data, print it out, or solve the system. In the edit/solve module, it is possible to solve a system, make changes, and solve again to compare the differences.

When the program is booted, several screens of general information are displayed before the menus appear. Make sure that the caps lock key is depressed on an Apple IIe or IIc before entering any information. Throughout the program, pressing the RETURN key will move you on to the next page, or will select the default value.

Part 1 allows you to create a file of data specific to the system you wish to model. These parameters can then be saved on the program disk, and recalled at another time if desired. The first time the program is run, no data file will exist on the disk. You may only choose option 1 - Create a new file. After you have saved a file, you may recall it by choosing option 2 - Retrieve an old file. The catalog of the disk will then be displayed and you may type in the name of the data file you wish to load. If the file you want is not there, hitting RETURN will allow you create a new file instead.

If you create a new file, the program will display a series of questions about your system. You may enter a value as an answer, or hit the RETURN key to accept the displayed default value. Some of the questions will require yes or no answers. For these a Y or N is sufficient. After the data has been entered, you may save the data to the disk. At this point you must enter a name for the data file. The name must be less than 30 characters long and must begin with a letter, as specified by APPLE. If the name has been already used, you will be given the choice of specifying a new name or replacing the file which already exists.

After the data has been entered, the solution module for the program is loaded. At this point you may display or edit the data already entered, print the data on a printer, or solve the model.

If you display/edit the parameters, the program will display the data on screen "pages". If the parameters are acceptable, hit RETURN to go on to the next page, or enter Y to the query "ANY CHANGES?" to edit the data. The cursor will move to the first line of data, and you may use the RETURN key to position the cursor at the line to be edited. Enter the correct value and use the RETURN key to pass through the other parameters. When you are satisfied with the display, hit RETURN to go on to the next page of data. When the editing is complete, if you answered Y to "ANY CHANGES?" during the edit display, the program will ask if you wish to save the data again, otherwise you will be returned to the menu.

If you have a printer you may print the parameters out. WARNING - choosing this option without a printer may kill the program.

When you solve the model, the program will go through a process of setting up the solution calculations and finding the solution. This may take up to 30 seconds. The neutral-to-earth voltages for the substation, each farm in the system, and the midpoints between the farms will then be displayed on the screen. If the list is too long, only a portion of it will be displayed. Press RETURN to display the rest of the voltages. When you have finished viewing the voltages you have the option of printing the solution on a printer. The final part of the solution is a plot of the voltages versus the distance of the location from the substation. The plot may also be dumped to a dot matrix printer, if your APPLE is equipped with a graphics dump interface. As it stands, the program will work with a card similar to the Orange Micro GRAPPLER™. You are then returned to the menu, where you may change the parameters and solve again, or quit the program. If you have made any changes in the data and have not saved them on the disk, you will be again be given the option of saving the data before exiting the program.

(Line 4168 in program SOLUTION is the location of the graphics screen dump. To dump the graph it may be necessary to change this line to fit your interface).

PARAMETERS

TITLE: enter a description of 40 characters (one screen line) or less or hit RETURN for no title

SUBSTATION MODULE

1. Primary system voltage (phase to ground voltage)
2. Resistance of substation grounding mat in ohms
3. Number of farms in the model

SUBSTATION TO FIRST FARM

1. Distance from the substation to the first farm in feet
2. Wire size of the primary neutral conductor
   (#8 CU, #6 CU, #4 ACSR, #2 ASCR, #0 ACSR, #00 ACSR)
3. Average resistance of a ground rod in this segment in ohms
4. Number of ground per mile in this segment

REMAINING SEGMENTS OF THE LINE (Nth FARM to N+1th FARM)*

1. Length of this segment in feet
2. Wire size of the primary neutral conductor (#8,#6,#4,#2,#0,#00)
3. Average resistance of a ground rod in this segment in ohms
4. Number of grounds per mile in this segment

FARMSTEAD (FOR N FARMS)*

1. Load on farm in amps at 240V
2. Resistance to earth of the total farmstead grounding system

FAULT TO EARTH FOR 1 FARM (OPTIONAL)

1. Number of farm with fault
2. Current level of fault in amperes
3. In phase or 180° out of phase with primary

BAD CONNECTOR (OPTIONAL)

1. Number of farm following bad connector
2. Resistance of bad connector in ohms

PRIMARY-TO-NEUTRAL ISOLATION (OPTIONAL)

1. Number of farms to be isolated
2. Farm numbers of the isolated farms

*When entering data for these sections, you may choose to make all or some of the parameters equal for all segments or farms. If you choose to make the values the same for all segments, you will not be questioned about that parameter again.