United States
Department of
Agriculture

Agricultural
Research
Service

Agricultural
Handbook
Number 696

Effects of Electrical Voltage/Current on Farm Animals

How To Detect and Remedy Problems

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

5. Detection and Measurement

Pages 5-1 through 5-15

Pages 7-13 through 7-16

Lefcourt, A.M., ed. 1991. Effects of Electrical Voltage/Current on Farm Animals: How To Detect and Remedy Problems. U.S. Department of Agriculture, Agricultural Handbook No. 696, 142 pp.

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

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

Copies of this publication can be purchased from the Superintendent of Documents, Government Printing Office, Washington, DC 20402.

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Issued December 1991

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

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

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

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

Alan M. Lefcourt
Editor in chief

Warning

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

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

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5. Detection and Measurement

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Summary

This chapter addresses detection information, equipment, and investigative procedures for persons investigating or monitoring suspected stray voltage/current problems.

Detection information, instrumentation, and procedures to be followed by investigators of suspected stray voltage/current problems are described in some detail. Both equipment and procedures must be matched to the desired function and electrical expertise of the investigator. If carefully selected and used, standard electrical instruments are adequate for most types of measurements required for stray voltage investigations.

Voltage and current measurements of concern in stray voltage investigations should be made by persons knowledgeable about farm electrification, instrument characteristics, proper measurement procedures, and animal responses. These measurements must be interpreted by professionals skilled in stray voltage/current problems and capable of recommending mitigating solutions.

Instrumentation for stray voltage investigations can be categorized as to function of the equipment, level of electrical expertise required of the user, and location of equipment usage in relation to electrical hazards that may exist. Instrumentation suitable to different functions, locations, or levels of expertise is discussed in detail.

It must be recognized that problems, people, equipment, and suggested procedures will not fall neatly within single categories. Problems can be simple or complex. People may, through experience or training, acquire a broad range of capabilities. Some methods and equipment may be used by nearly anyone whereas others may be used only by appropriately experienced or trained persons. For highly complex problems, high levels of electrical expertise are required. *But whether the problem is simple or complex, measurements made between random points without an understanding of the intricacies of the problem and the meaning of the electrical quantities measured, or without knowledge of the characteristics of the instruments used, are of little value.*

Detection

Voltage is the easiest electrical quantity to measure and, as shown by experience, the most reliable first indicator of a possible stray voltage/current problem. Two methods are generally used to make stray voltage measurements: 1) point-to-point and 2) point-to-reference ground.

Point to Point

The point-to-point method simply involves measuring between points which may be contacted simultaneously by an animal or a person (fig. 5-1). The two most common points of contact are a metallic structure, such as a stanchion, and the floor or earth. The major drawback of this method is variability of readings due to the condition of the floor or earth at the time of measurement and the contact resistance of the meter probe with the floor or earth. If the floor is wet or damp from manure or water, the following method usually gives satisfactory results: Clamp (or clip) one of the test leads to the metal equipment, making sure that the electrical contact is good, and connect the other test lead to a hoof-area-size (16- to 36-square-inch) copper plate placed on the floor. Water or fresh manure should be used to improve contact of the plate with the floor. Two such plates can be used to measure step voltages, i.e., the voltage between an animal's front and rear hooves as it steps onto an equipotential plane. Determination of the possible existence of step voltages is an important, and necessary, part of any stray voltage investigation (fig. 4-4).

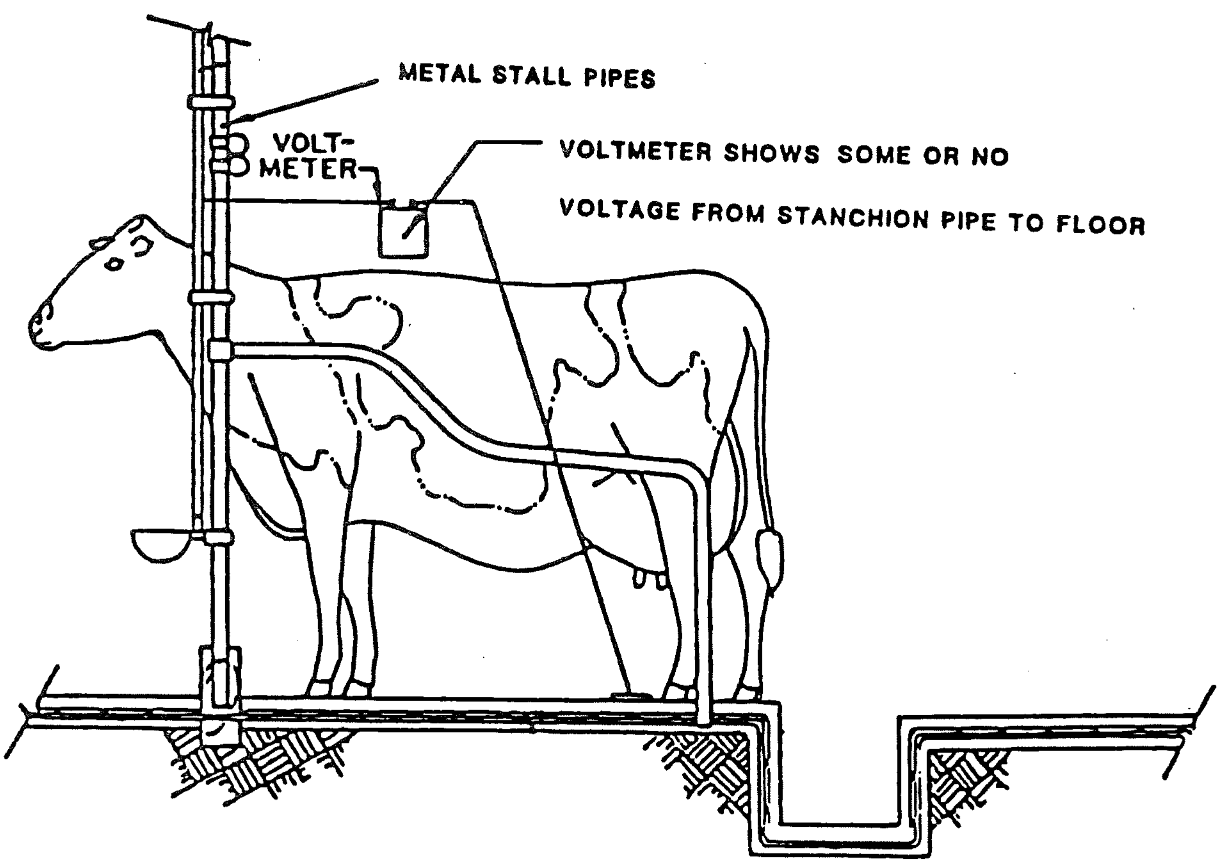

Figure 5-1. Point-to-point method of voltage measurement in cow contact area.

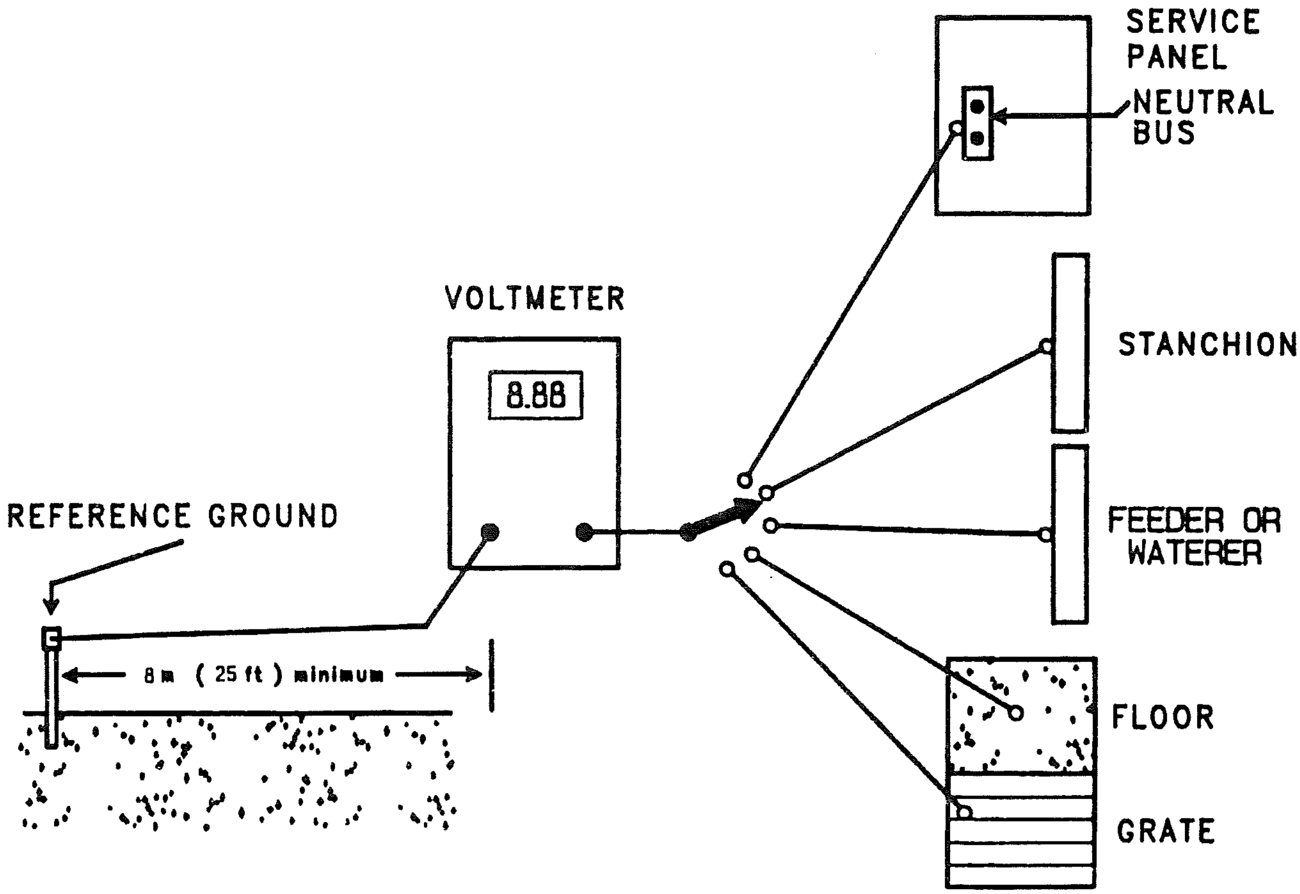

Figure 5-2. Point-to-reference-ground method of voltage measurement.

Point to Reference Ground

The first step in using the point-to-reference-ground technique is to drive a ground rod to a depth of at least 1.3 m (4 ft) into moist soil at a distance of at least 8 m (25 ft) from any electrical-system grounding electrode or grounded metal equipment in contact with the earth (fig. 5-2). Such metal equipment includes underground power lines, gas lines, and metallic water lines. An insulated conductor is then run from this reference ground into the building housing the equipment to be tested and connected to one terminal of the meter. The other meter lead is used to measure voltages between the reference ground and various metal equipment and the floor. This method usually yields higher voltage readings than the animal-contact point-to-point method. The voltages measured by the reference ground method are *not* those the animals contact. The advantage of this method is that it is more useful in identifying specific sources and gives more repeatable readings. The major disadvantages are the necessity to install a reference ground and the length of test leads (conductor) that must be transported about to make the measurements. Also, as the voltages measured may be larger than the actual cow-contact voltages, some lay persons may not interpret the readings properly.

Interpreting Measurements

Animal sensitivity to stray voltage/current is based on the effective (root mean square, or rms) current flow, and not on the voltage differential before animal contact (chapter 3). Therefore, it is important to verify that any voltage source has the capability to produce sufficient current to affect animal behavior. A general measurement/exposure circuit (fig. 5-3) would include the source impedance, the resistances of the paths to the contact points, the contact resistances, and the equivalent body resistance of the animal. *Quantifying or reproducing the actual values of each of the resistances is not feasible under field conditions. Therefore, adequate knowledge of current-producing capability must be gained by other means.*

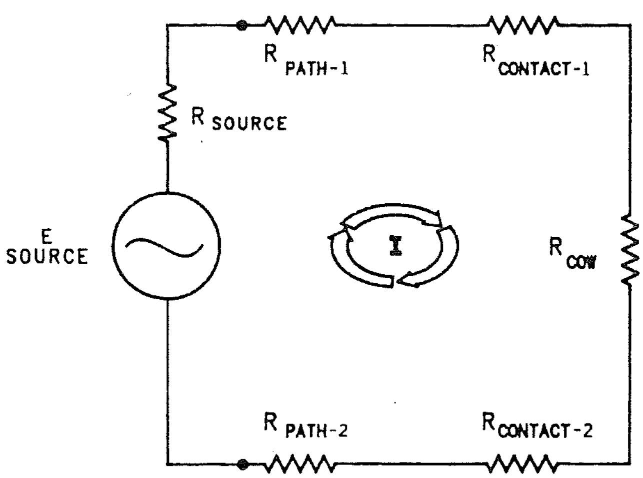

Figure 5-3. General animal-path measurement circuit.

When a high-impedance voltage-measuring device, which most voltmeters are, is placed in a circuit, the voltage measured does not indicate the quantity of current available. If, for example, the circuit is one like that shown in fig. 5-4, where the leakage resistance in the path of the 120-V source is 290 megohms (MΩ), a meter with a 10-MΩ input impedance will indicate a 4-V potential. However, the current-producing capability will only be 0.4 microampere (μA). Therefore, since current through the animal, not the open circuit voltage, is the principal concern, voltage measurement alone is inadequate. Another way of looking at this example is to replace the voltmeter in the circuit with a low impedance load, such as a cow; the voltage across that low impedance load would approach zero.

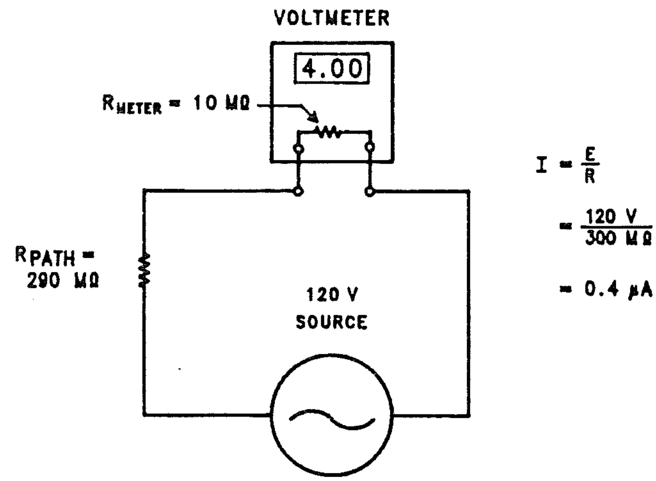

Figure 5-4. Voltage measurement using a high-impedance meter and a leakage path.

It might seem logical to measure the current with an ammeter. However, an ammeter has a very low internal resistance, and the path resistance will effectively determine the current level. As shown in figure 5-5, if the path resistance is low, a very low voltage source having a low source impedance can produce a relatively large current. In the example, the source, path, and meter resistances add to 0.13 Ω, so a 0.1-V source would produce 0.77 A of current flow. In contrast, if the ammeter were replaced by an animal, assuming a 500-Ω animal resistance, the current would be less than 0.2 mA.

One possible way to avoid the inadequacy of measurements made with only a voltmeter or ammeter in the circuit would be to place a resistance simulating that of an animal (perhaps 500 Ω) in parallel with the voltmeter or in series with the ammeter. However, using a resistor to simulate animal resistance can produce erroneous results. For point-to-point measurements, the errors introduced by the resistor will be small, so the meas-

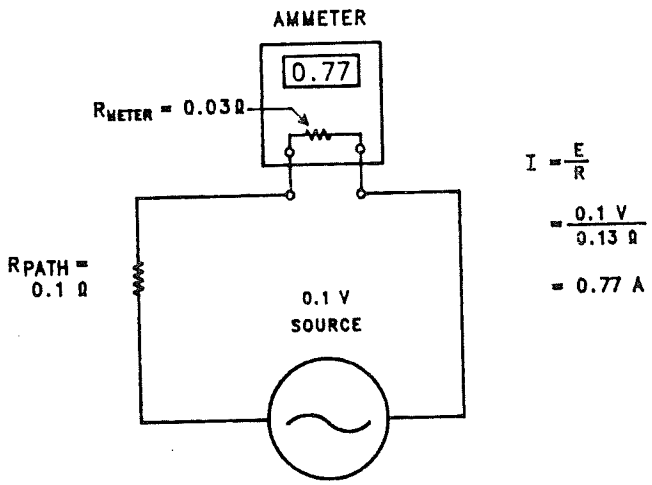

Figure 5-5. Current measurement with an ammeter and a low-impedance-source path.

urements will give a reasonable indication of the severity of a stray voltage/current problem. The errors will be due to differences in contact resistances and variability in body resistance of cows. The metal-to-metal contact resistances of the measurement circuit will likely be very different from cow contact resistances, e.g., the contact resistance of dry fur touching a metal stanchion is significantly greater than the resistance of metal-to-metal contact. In addition, the body resistance of cows varies among animals and according to points of contact, e.g., mouth to four hooves or front leg to rear hock. Estimates of body resistance for cows can be found in chapter 3. Even under experimental conditions it is difficult to separate contact resistances from body resistance; after all, no measurements can be made without some form of contact. For evaluation purposes, it is often sufficient to consider the worst case resistance, i.e., the lowest resistance likely to be encountered. We consider 500 Ω for the sum of contact and body resistances to be a very conservative estimate of the worst case, or minimum, resistance that is likely to be encountered.

For point-to-reference ground measurements, the errors introduced are serious, and a simulated animal resistance should not be used. When a 500-Ω resistance is placed across the voltmeter, the resistance to earth of the reference electrode can affect the measured value. For example, figure 5-6 shows that if a voltage source of 2.5 V with no path resistance and 500-Ω resistance to earth is measured with a high impedance meter, placing 500 Ω across the meter will reduce the voltage reading from 2.5 V to 1.25 V. In this example the voltmeter is measuring the voltage across only a component of a voltage divider (made up of the resistor and the resistance to earth of the reference electrode). Since the animal will never be in series in the reference electrode circuit, this is not a valid measurement of a voltage or current source for the animal.

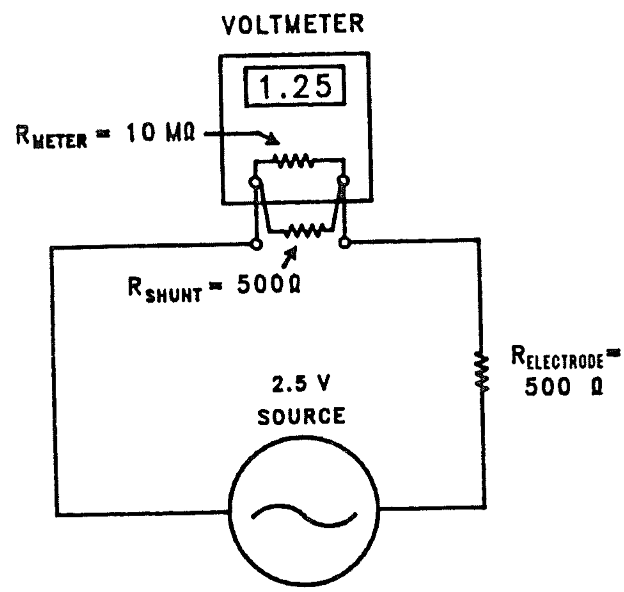

Figure 5-6. Voltage measurement with shunt and a high-impedance reference ground showing voltage divider effect.

A combination of readings will provide the most meaningful information when a high impedance (greater than 1 MΩ) voltmeter is used for stray voltage investigations. Generally the combination consists of two voltage measurements: 1) with no loading and 2) with a (1- to 10-Kohm) loading resistor across the voltmeter. For both measurements, good contact between meter leads and contact surfaces must be made. Using a 10-K loading resistor across the meter gives a sufficient indication of whether or not the source truly has a high impedance (low current capability). We consider that the 10-K resistance is large enough that the resistance of a reference electrode will have little effect on point-to-reference ground measurements or, when carefully done, on point-to-point measurements.

Stray-voltage/current problems exist only if the following two conditions are met: 1) A voltage can be measured between two animal contact points and 2) the current that flows, when a resistance equivalent to that of an animal and its contact resistances is connected across the contact points, is greater than the threshold current needed to elicit a response from an animal.

Instruments

When making measurements, instrument characteristics and monitoring points are significant considerations. The instrument must be able to separate alternating current (ac) and direct current (dc) and must have a resolution of 0.1 V. If the instrument is to be operated in place over extended periods, it must be able to withstand the harsh physical environment of the farm (wet, dirty, corrosive) or be protected from it. The instruments must also be protected against electrical extremes, such as faults or lightning.

As shown in figure 5-2, one suggested location for a monitoring device is from the neutral bar of the service entrance panel to a reference electrode away from the building. For a more visible location, the device may be placed between metallic equipment known to be bonded to the service panel and the reference electrode if careful consideration is given to path resistances. Alternatively, if the instrument, connecting leads, and contact points can be protected from damage, voltages can be monitored in a point-to-point area of concern.

Measurements

Several types of measurements may be necessary to identify and confirm the presence of a problem voltage on a dairy facility. Measuring instruments may include an indicating portable voltmeter, recording voltmeter, oscilloscope, clamp-on ammeter, recording ammeter, ground resistance tester, and insulation tester. Each of these instruments and its applications are discussed. *Some measurement procedures can be hazardous and should only be performed by qualified personnel with adequate training in safety procedures. Also, regardless of the complexity of a stray voltage/current problem, measurements made between random points without an understanding of the intricacies of the problem and the meaning of the electrical quantities measured, or without knowledge of the characteristics of the instruments used, are of little value.* Please give careful consideration to the **warning** at the beginning of this handbook.

Voltage

One of the most common variables measured in stray voltage investigations is voltage. Generally voltage is measured with a voltmeter, e.g., an analog volt-ohm meter (VOM), a digital multimeter (DMM), or an oscilloscope. For use in stray voltage investigations, a voltmeter must meet three major requirements: 1) It must be able to separate alternating current (ac) and direct current (dc) voltages, 2) it must have a minimum voltage resolution of 0.1 V, and 3) it must have an impedance of at least 5,000 Ω/V.

If the meter reads on the ac scale when connected to a flashlight battery, it does not separate ac and dc (fig. 5-7). A capacitor of at least 5 microfarads (μF) with a voltage rating of at least 50 V (use 200 V if it is possible that an inexperienced person might try to measure a 120-V circuit) must be placed in series with one lead of the meter for reasonable ac readings (fig. 5-8). A meter with an input impedance of less than 5,000 Ω/V may unduly load the circuit it measures. Most quality voltage instruments have a high internal-input impedance (resistance). Such voltmeters characteristically produce very little load on the circuit or device where the voltage is being measured and, thereby, have a minimal effect on the circuit. A high internal resistance means that only an extremely small current is needed to measure a large voltage. In accordance with Ohm's law (voltage (V or E) equals current (I) times resistance (R)), a DMM with a 10-MΩ internal resistance used to measure a 1-V source draws a current of only 0.1 μA.

Digital Meters

Many DMM's meet the three requirements listed above. They may have either light-emitting-diode (LED) displays or liquid crystal displays (LCD's). LCD's are much easier to read than LED displays except in dark areas. Most digital meters have an input impedance of 10 MΩ or greater. A distinct advantage is that they provide good resolution at low voltages. Many are small and lightweight, and can be read quickly and accurately.

Some potential problems are associated with digital meters. One is that because of the high input impedance, the meter will measure capacitively coupled or leakage voltages. Most coupled or leakage voltages do not cause stray voltage/current problems. If an ac voltage greater than 0.5 V is found, the voltage measurement should be repeated with a 1,000- to 10,000-Ω resistor shunted across the voltmeter leads (fig. 5-9). This procedure allows low impedance sources, such as a neutral-to-earth voltage, to be separated from high impedance sources, such as voltage due to resistive leakage or capacitive coupling. A high impedance meter is advantageous because measurements without and with the loading resistor can be used to distinguish between low and high impedance sources. This determination is important in solutions to stray voltage/current problems. When the digital voltmeter is used with a 1,000-Ω shunt, the current can easily be estimated by using Ohm's law, $I = E/R$. For example, a 2-V reading with a 1,000-Ω shunt resistor represents 2 mA.

Another problem characteristic of some digital voltmeters is the method used by the instrument to measure the voltage. The instrument samples the input voltage over a short interval and then displays the value obtained. If the input voltage waveform is changing in value, the digital meter may not respond rapidly enough to accurately register the change or may show changing readings.

Analog Meters

It is important to obtain an analog meter with a voltage scale sensitive enough to measure less than 1V of alternating current (Vac). The meter illustrated in figure 5-10 has a 2.5-Vac scale. A scale of 0 to 5 V is acceptable; however, a scale of 0 to 10 V may be too coarse and insensitive for accurate stray voltage measurements. The internal resistance of the meter is generally printed on the scale. The meter of figure 5-10 has a resistance of 5,000 Ω/V on the ac scale, or a total of 12,500 Ω of input resistance for the 2.5-V range setting.

It is important to know how to read the scale. The meter in figure 5-10 is indicating 1.6 V on the 2.5-Vac scale. With multiscale instruments, some scales are non-linear, so accurate readings are difficult to make, and it is easy to make an error by reading the wrong scale.

One of the advantages of analog meters is the ability to respond to transients. Many analog meters will respond reasonably well to transient voltage changes that occur, as for example, when a motor is starting. For this reason, the needle "kick" response of an analog meter is preferred by some investigators of stray voltage/current problems. An oscilloscope, however, is the best instrument for making transient measurements.

Accuracy

The accuracy of an instrument must be known if the validity of the measurements is to be correctly interpreted. For digital meters, accuracy is determined by the number of digits in the display and is normally stated in terms of expected variation in the least significant digit(s). For analog meters, accuracy is more difficult to interpret, and it is commonly stated as a percentage of the full scale value. Thus, accuracy will depend on the actual scale used to make the measurement. For example, if the full scale accuracy of a meter is 3 percent, the accuracy of a 50-V scale will be ± 1.5 V while the accuracy of a 2.5-V scale will be ± 0.075 V. When using an analog meter, for greatest accuracy, readings should be made using the most sensitive scale possible.

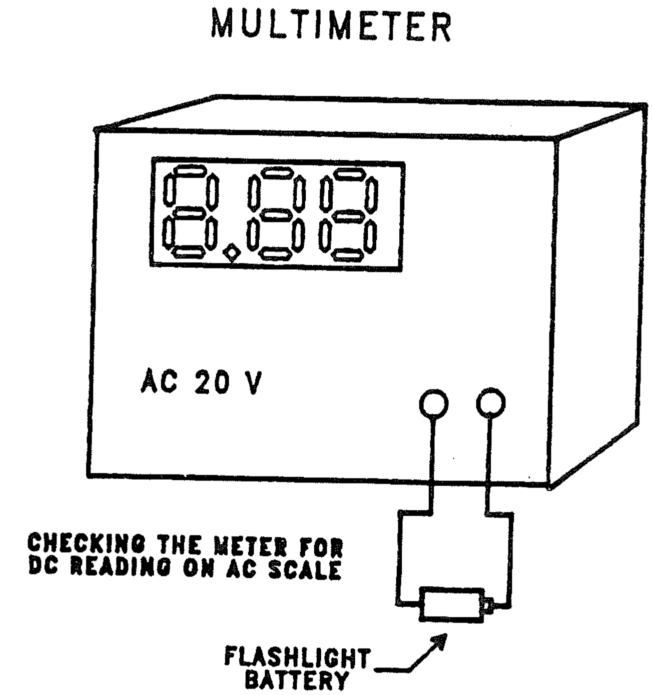

Figure 5-7. Checking a meter for the ability to separate ac and dc voltages.

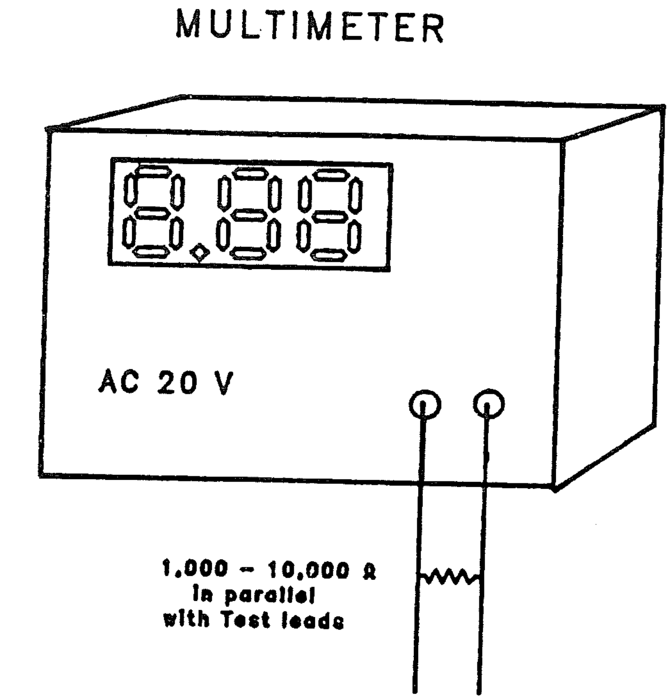

Figure 5-9. Voltage measurement using a shunt resistor to test the current-producing capacity of a source voltage.

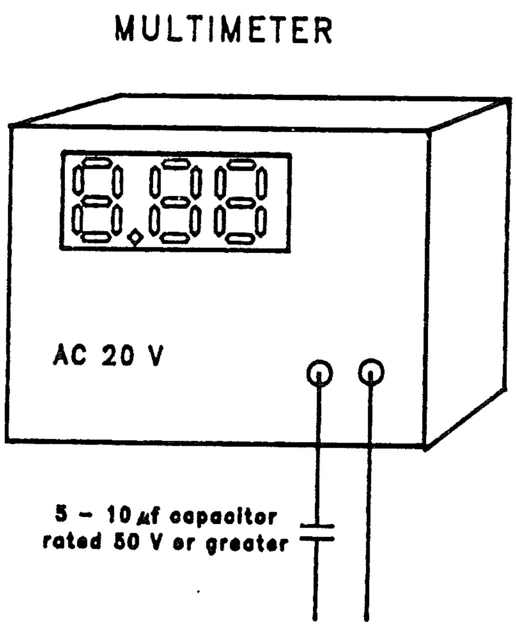

Figure 5-8. Use of blocking capacitor when meter does not separate ac and dc voltages.

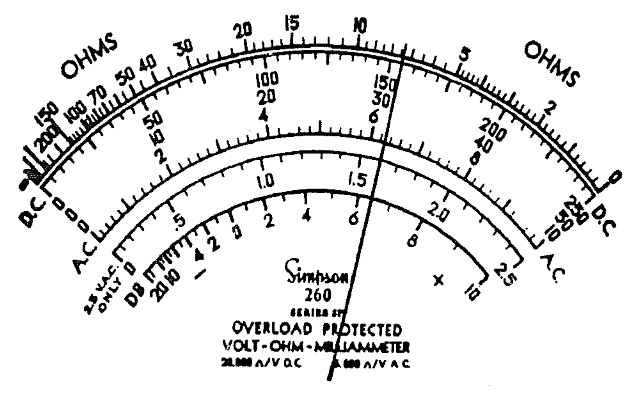

Figure 5-10. An analog volt-ohm-milliammeter. The meter indicates 1.6 V on the 2.5-Vac scale.

Voltage Measuring Techniques

Voltmeter test probes must make good electrical contact with the two points between which a voltage may appear. Often the existence or absence of a stray voltage/current problem cannot be resolved by one or several individual voltage measurements. One solution is to attach the leads of a portable voltmeter between the critical points of concern and have an observer record numerous readings over a period of time. Several voltmeters can be used with an observer for each. Some meters have a memory feature which will save maximum and minimum readings until they are retrieved and the meters reset.

Recording Meters

Another means for determining the existence or absence of a problematic voltage is to use a recording voltmeter. A recording voltmeter should have the same characteristics as an indicating voltmeter, i.e., high impedance, separation of ac and dc voltages, and capability to resolve a minimum of 0.1 V. Transient response time could also be important if rapid voltage variations occur. In addition, it is desirable that a recording meter be able to record voltage between two or more points (multiple channels).

Multiple-channel voltmeter recorders are available in both continuous (analog) and digital types. The continuous types have a specific voltage range, while the digital recorders are autoranging. Each may have an advantage, depending on the intended use and the knowledge level of the user. Recording voltmeters can gather voltage information for several days or weeks. This capability is especially important when problem voltages are suspected but not found at the time of single voltage measurements, as some problems occur infrequently. Recording voltmeters can also be used to record test results as specific loads are operated or other tests are conducted.

Oscilloscopes

A portable oscilloscope can be used to measure peak voltages and display actual voltage waveforms. The oscilloscope may be used alone or in parallel with an indicating or recording voltmeter to detect transient voltages. It should be noted that most VOM's and DMM's are calibrated to indicate the *effective* value of a sine wave of the voltage/current (by rms or measurement averaging methods) and not the peak-to-peak value. Peak-to-peak values measured using an oscilloscope can be converted to rms values by multiplying by 0.707 or average values by multiplying by 0.636. The oscilloscope allows the simultaneous measurement of both ac and dc components of a waveform. It will reveal whether a dc source is pure dc or has been rectified from ac. It will indicate whether an ac source is 60 hertz or has other frequency components. Such information can provide valuable clues as to where to look for the source of the voltage. The oscilloscope can also reveal if the current producing the voltage changes phase as specific loads are operated. The oscilloscope should be battery operated or operable in a differential mode (two inputs balanced to ground). Most line-voltage-operated oscilloscopes have one terminal connected to the equipment grounding conductor; thus, this terminal is normally at the neutral-to-earth voltage. This connection makes it difficult to properly measure the voltage between two animal contact points.

Current

In stray voltage investigations, it may be necessary to make several current measurements. These measurements commonly include current producing capability of circuits involving animal or human contact points, normal load current, and fault or leakage currents. The current requirements of motors, lights, and other equipment can be measured to determine whether the equipment is operating properly. The current in an equipment grounding conductor can be measured to check for fault or leakage currents. The total current requirements of a building or set of buildings may be measured to determine adequacy of the electrical service. To help diagnose neutral voltage drop, measuring the neutral current during periods of peak power usage is useful. Neutral current measurements also aid in determining whether or not the electric loads are balanced or when imbalance occurs.

For many current measurements, clamp-on-type ammeters or recording ammeters are used. Some types of ammeters require opening of the circuit to connect the ammeter in series with the circuit or to install a current transformer. Either such installation can be hazardous. Ammeters used in series circuits are accurate but have a fixed current range. There are many styles and jaw types of clamp-on ammeters to choose from. Some digital clamp-on ammeters or DMM accessory clamp-ons have autoranging from 1 to 999 A and are easily and accurately read. They may also have a locking function to measure peak amperages from rapidly changing loads such as motor-starting current. Clamp-on ammeters are generally not accurate at levels below 1 A.

Detection of currents less than 1 A in grounding conductors can be of significant value in locating sources of stray voltage. An AC AMP CLIP (Wm. H. Swain Co., Sarasota, FL), which is a clamp-on ammeter and has ranges from 1 mA to 20 A full scale, can be used for quick measurements of low currents.

For safety reasons, use of clamp-on ammeters is preferred. Extreme care must be taken when maneuvering the clamp in crowded electrical enclosures. To use series ammeters, the circuit must be opened, and doing so can result in dangerous voltages appearing across the open circuit.

During an investigation it may be desirable to determine the ability of the stray voltage source to deliver current. The ac milliammeter range of a multimeter can be used for this measurement. To avoid damaging the meter, it is important to begin with the highest value scale. The meter can then be switched to successively lower scales until a reading is obtained. The ammeter has a very low input resistance; therefore, a resistor must be placed in series with one lead, as illustrated in figure 5-11. A 500-Ω resistor is shown to approximate the minimum contact and body resistance of an animal. An animal contacting the two measuring points can therefore be assumed to conduct about the same level of current.

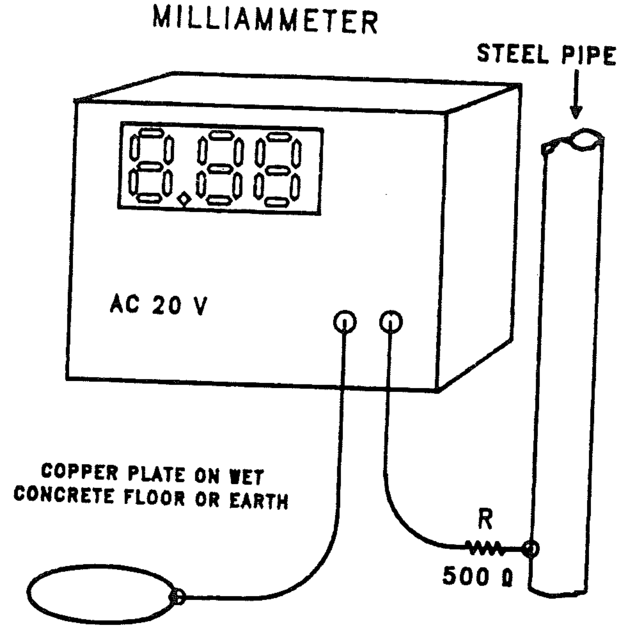

Figure 5-11. A current reading with a 500-ohm resistor in series to approximate the minimum contact and body resistance of an animal.

Resistance

Resistance is the opposition offered by a body or substance to the passage through it of a *steady* electric current. Impedance is the apparent opposition in an electrical circuit to the flow of an *alternating or time-varying* electrical current. If the opposition to current flow for a given body or substance does not vary when the flow of current varies, resistance is equivalent to impedance. Under most conditions, little error is introduced by assuming that all loads are resistive. However, it is important to consider impedances, including phase angles, when dealing with motors and load balancing. Measuring resistance is important because for any given voltage, resistance helps determine the path and magnitude of current flow.

Measurement of Resistance

VOM's or DMM's are often used to measure the resistance between two points. The measured value may at times be in error, as there is sometimes a small dc voltage between the two points being measured. Most instruments to measure resistance utilize dc currents, and any extraneous dc signal will alter readings. It is always a good practice to measure ac and dc voltages between the two points of interest before measuring resistance. If only a low (0.5 V) dc voltage is present, two resistance measurements should be made, one with the test leads reversed, and the two readings averaged to yield a good approximation of the actual resistance. *If an ac or a higher (>0.5 V) dc voltage is present, direct readings of resistance are impossible and should not be attempted.*

Equipment Grounding

If voltages to earth appear on equipment or along an equipment grounding conductor, it is often necessary to track down the reason for the voltage. If there is a bad (high resistance) connection in the equipment grounding circuit, even low leakage currents can produce measurable voltages on supposedly grounded equipment. These bad connections often occur where flexible or rigid conduit or metallic raceways are used for the equipment grounding conductor. The fastening nuts, screws, etc., may not cut through the paint on the equipment, and may loosen, rust, or otherwise develop a high resistance joint. The testing technique is to measure the voltage across each joint or connection. If necessary, a low voltage transformer providing several amperes of current can be connected to force a current from various points on the grounding system to the junction of the grounding conductor and neutral at the service entrance. *For safety reasons, the transformer output voltage should be less than 25 V.* This increased current will allow easier detection of bad connections. The apparatus may need to be moved or shaken while the current magnitude is observed to find intermittent poor grounding connections.

Grounding Electrodes

Measuring the resistance to earth of ground rods or structures such as stanchions can add important information concerning the relative effectiveness of various ground paths. These measurements can be used to determine whether the on-farm and service grounds are adequate or need to be supplemented. The relative impedance values of the on-farm grounding system and the utility grounding systems may also be of importance.

The grounding system on a farm usually consists of several electrodes. Each building should have a grounding electrode as part of the electrical service. Grounding and bonding of metal structures such as stanchions, metal water pipes, buildings, and equipment in contact with the earth adds additional equivalent electrodes.

The resistance to earth of an electrode can be measured by the three-point or the three-terminal fall-of-potential method, as shown in figure 5-12. A current is injected into the earth from a low-voltage, high-current source, and the voltage between the potential probe and the ground rod is measured. The resistance is determined from Ohm's Law, $R = V/I$, where I is constant and V is measured. The placement of the two auxiliary electrodes P_2 and C_2 is important. The distance from C_1 to P_2 should be at least six times the depth of the grounding electrode C_1. The distance C_1 to C_2 should be at least 10 times the depth of C_1. These distances minimize the effects of the fields from each of the electrodes. A triangulation method is used to determine resistance to earth (Fink and Beaty 1971). The resistance can also be registered directly by earth resistance testers.

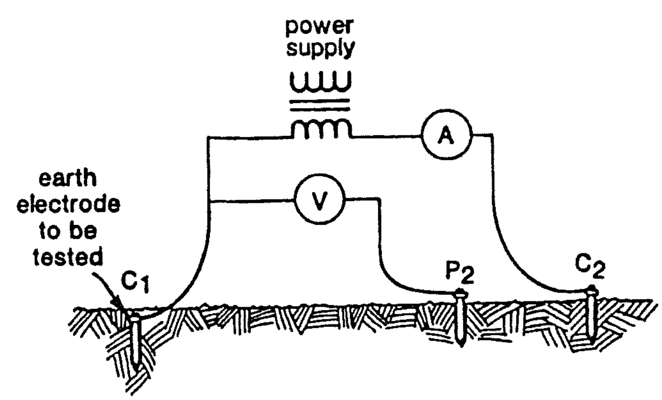

Figure 5-12. Test setup for measuring grounding electrode resistance by the fall-of-potential method. V = voltmeter, A = ammeter, C_1 = electrode to be tested, C_2 = current injection electrode, and P_2 = voltage measurement electrode.

The earth's resistivity varies with location and can also be measured, but measurement and injection from four points would be required. For most stray voltage applications, earth resistivity should not have to be measured. *An ohmmeter uses a dc source and will not accurately measure grounding or earth resistance, because of polarization in the soil.*

Ground Faults

Insulation failures or broken conductors or connections may cause a circuit conductor to contact a grounded surface. These accidental or unplanned faults are often called ground faults. When the faults are not obvious, ground fault testers are used. *Ground fault or insulation testers for equipment or circuits should only be used on deenergized circuits.* If the circuit is not deenergized, the meter will be damaged. Circuit analysis or voltage and current measurements may identify circuits or equipment that should be tested for current leakage. An ohmmeter may be used; however, it may only identify circuits which have short circuits, as it applies a very small voltage. An insulation tester, which applies a high voltage to measure circuit resistance, will identify not only short circuits but also circuits or equipment with current leakage through faulty insulation. Insulation may develop leakage paths due to deterioration, moisture, or dirt. It may be necessary to disconnect portions of the deenergized circuit to determine the specific location of faults. For example, a 240-V water-heater element that has shorted to ground near the center of the heating coil will not draw excess current and may show the appropriate terminal resistance as determined by ohmmeter measurements; however, an insulation tester will detect the grounded circuit. If insulation is suspected to have been damaged, one probe of the tester is connected to the suspect wire, with the other to the metal enclosure. The meter will display the resistance. Wire insulation that is still sound will have a resistance of several million ohms. Figure 5-13 illustrates the use of an insulation tester.

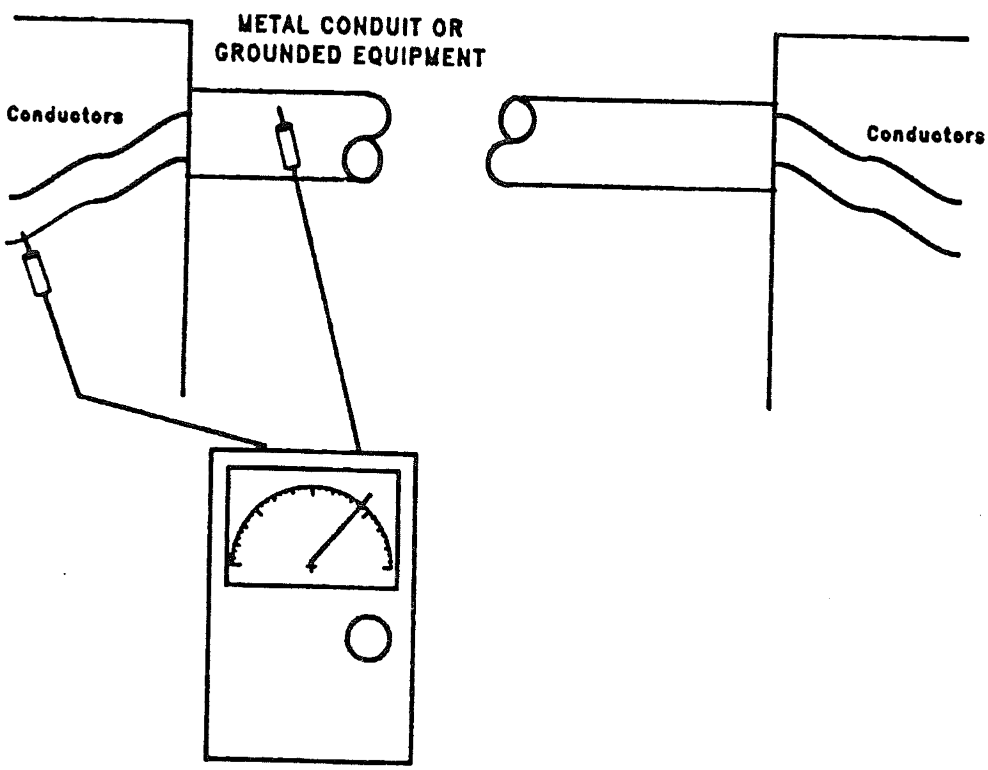

Figure 5-13. An insulation or ground fault test on deenergized systems.

Conductor insulation can be damaged during installation or by vibration, animals, or even lightning. Equipment such as motors, transformers, and controllers can also be tested for ground faults. *Special care must be taken when testing circuits which normally supply power to electronic equipment; the voltages generated by an insulation tester may damage the equipment.* It may be necessary to remove a neutral connection for some tests because of the bond between the neutral and the equipment grounding conductors.

Investigation Procedures

The investigation should begin by gathering and recording evidence to indicate that a stray voltage/current problem really exists on the farm. Information requested in the following questionnaire should be obtained with help from the farm operator:

1. Names, addresses, titles, telephone numbers of persons present, and location and date of the stray voltage investigation.
2. Names, addresses, professions, and telephone numbers of others who may have previously made an investigation and their remarks.
3. When did farmer first suspect there was a voltage problem and why?
4. Do some or all animals react?
5. Where are the reactions observed and what kinds of reactions are they?
6. Is reaction continuous or periodic?
7. At what times of the day is problem most noticeable?
8. Is problem more noticeable in wet or dry conditions, or is it seasonal?
9. What changes have been made in farm electrical systems, operators, or animal handling procedures?
10. Does operator receive shocks or see sparks?
11. Have both voltage and current measurements been taken? Where? When? By whom?
12. What recommendations were made as result of previous investigations, and what actions were taken?
13. Sketch the farm layout showing locations of all distribution lines, transformers, services to buildings, and grounding electrodes. Note: Service voltages, single- or three-phase, delta or wye, sizes of equipment.
14. Have neighbors had electrical problems of any kind? If they have, what details are available?
15. Has lightning struck in the vicinity of the farm? Where? When?
16. Note the overall condition of the wiring and electrical equipment on the farm. Look for unsuitable equipment, lack of maintenance, leakage paths, corrosion, and type and extent of neutral and equipment grounding conductors and grounding of main and building service-entrance equipment.
17. Note persons and organizations that have made wiring installations on the farm (electrical contractor, equipment installer, farmer, other).
18. What information or assistance has been obtained from the electric power supplier, electricians, or equipment suppliers?

Visual inspection should discern the farmstead's electrical system layout, adherence to electrical codes, obviously unsafe equipment, or wiring conditions and maintenance needs. However, it must be recognized that visual inspection alone cannot confirm that existing, electrical safety hazards are indeed potential sources of stray voltage/current problems.

Farm Secondary Systems

Electrical measurements are necessary to show whether any source or sources of voltage capable of being contacted by the animals exist at the site. Use of the detection methods described earlier in this chapter can reveal the existence of problem level voltages capable of supplying sufficient current to be of concern. When such voltages are detected, specific source identification and mitigation will be required, as described in other sections of this handbook. Installation of a monitoring system and instruction of the farmer/operator in use of the monitoring system may be needed to detect intermittent problems.

Farm Equipment Suppliers

Farmstead electrical equipment is often installed and serviced by equipment suppliers. These suppliers have a special knowledge about the operating characteristics of their equipment and may provide valuable assistance in solving stray voltage/current problems.

Electricians and Installers

Electricians who are knowledgeable of prevailing electrical codes, qualified to do farmstead wiring, experienced with measurement instruments, and trained or experienced in stray voltage investigation are needed to deal with stray voltage/current problems. They should be called upon to do the testing, and they should also be able to identify specific sources of problems, make necessary on-farm repairs and changes, and work with utility personnel if off-farm sources are identified.

The impedance/resistance bridge and insulation testing equipment would be used by electricians to verify the adequacy of grounding electrodes, test equipment grounding, locate neutral-to-ground interconnections and ground faults, and test for insulation leakage or capacitively coupled paths. Multichannel recording (ac) voltmeters connected to points of concern can be particularly helpful in detecting recurring or random electrical events which may not occur at the time of controlled testing.

Electrical Professionals

Electrical professionals (consultants and utility engineers), generally engineers dealing in electrical power, will play a role in 1) the training of others involved in stray voltage investigations, 2) source identification in particularly complex situations, 3) specific quantification of voltage sources, 4) assessment of electrical system characteristics, and 5) recommendation of mitigation techniques. These persons must possess a complete understanding of the electrical circuits both on and off the farm, animal sensitivity, and measurement equipment and techniques.

Engineers actively involved in stray voltage field investigations will need not only the equipment commonly used by electricians and others but also, at times, more advanced tools, such as an oscilloscope, recorders, and disturbance monitors. The oscilloscope can be used for study of both phase relationships and waveforms, which cannot be done with standard voltmeters.

Primary Distribution Systems

Should a voltage investigation show the need for making changes to the distribution transformer or distribution system leading to the farmstead, the changes must be made by utility personnel trained and equipped to deal with high voltage systems. Safety and legal considerations dictate that other persons should not approach or attempt to modify the utility system. Utility personnel can be readily grouped into three categories on the basis of their levels of electrical expertise.

Power Use Advisers

Power use advisers are nonelectrical professionals or customer service personnel who would likely be mostly involved in initial on-farm discussions.

Line Maintenance Crews

Line maintenance crews are knowledgeable about primary system configurations and may be trained to interact with and support persons doing on-farm work and can investigate the location of primary system sources such as faulty connectors. However, they are generally not qualified, and may not be authorized, to do on-farm electrical inspection or work.

Power Utility Engineers

Utility engineers are professionals who are knowledgeable about electrical circuits and electrical systems. A cooperative effort of the utility engineer and the on-farm investigator is often necessary.

Use of the standard electrical tools (voltmeter, ammeter, oscilloscope, earth resistance bridge, and insulation tester) and procedures can help the investigator determine whether a possible source is on the primary distribution side or on the farm secondary system. It may be necessary for the utility personnel to temporarily disconnect the farm secondary neutral from the primary distribution neutral to remove interactions between possible on-farm and off-farm problems. Taking these actions may enable trained utility personnel to make recommendations on mitigation. Most often line personnel with skills and access to sophisticated electrical equipment will be working under the supervision of a utility engineer.

Additional Sources of Information

For additional information on investigative procedures, see Surbrook and Reese (1981), Gustafson (1983c), Stetson and Bodman (1985), and Cloud et al. (1987).

a 50/60-Hz waveform whose peak is above the threshold, the device triggers during each half cycle and remains closed for the remainder of the half cycle. This device also has a surge arrester in parallel to assist in passing fast rising transients.

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

Single Building Service Isolation

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

Isolation of Grounded Equipment Within a Single Service

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

Detection and Measurement

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

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

Warning

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

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

Basic Measurement Procedures

Voltage is the easiest electrical quantity to measure and experience has shown that voltage is the most reliable first indicator of a stray voltage/current problem. Two methods have been used to make voltage measurements: point to point and point to reference ground. In the point-to-point method measurements are simply made between two points which may be contacted simultaneously by an animal. In the point-to-reference ground method, one of the two measurement probes in connected to a reference ground. The advantages of the point-to-reference ground method are that it is more useful in identifying specific sources and is more repeatable (see chapter 5, "Detection and Measurement"). Two requirements must be met when using either measurement technique. The first is that the investigator make certain that there is good *electrical* contact between the instrument probes and the points of contact. Generally, a metallic surface should be scratched with the probe. When the floor is one point of contact, a 16- to 36-square-inch metal plate should be used to make contact with the floor. To ensure good *electrical* contact, the floor and metal plate should be wet.

The second requirement is that the investigator reliably estimate the current-producing capability of the voltage source. Recall that cows respond to the current generated by a voltage and not to that voltage directly. A general measurement/exposure circuit (fig. 7-1) includes source, pathway, contact, and body impedances. Quantifying or reproducing the actual values of each impedance is not feasible under field conditions. Therefore, adequate understanding of current producing capability must be gained by other means.

When a high impedance device such as a voltmeter is placed in a circuit, the voltage reading alone does not indicate the current producing capabilities of the source (figure 7-3). When the point-to-point measurement technique is used, a second voltage measurement should be taken with a resistance (impedance) simulating that of an animal (perhaps 500 ohms) placed across the leads (probes) of the voltmeter (fig. 7-4). This second measurement will then allow a reasonable estimate to be made of the actual cow contact voltage. However, body impedances of cows vary and

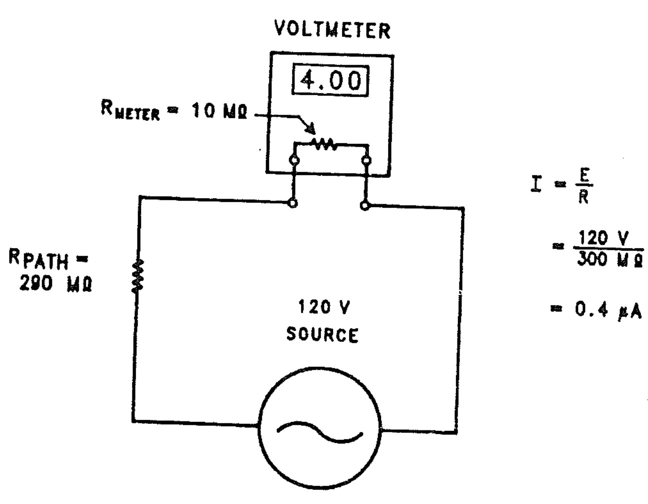

Figure 7-3. Voltage measurement using a high-impedance meter and a leakage path.

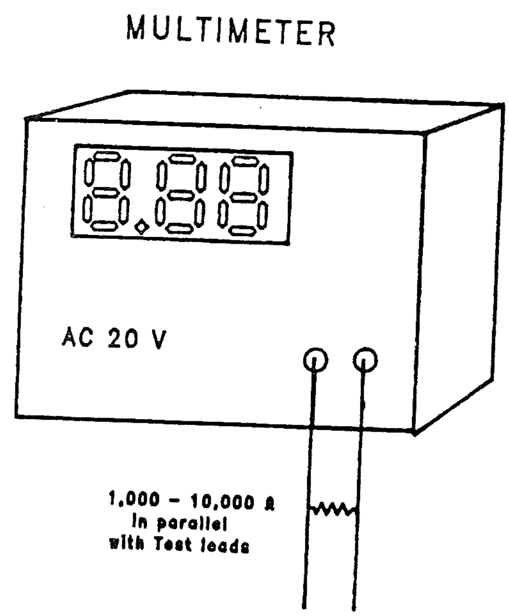

Figure 7-4. Voltage measurement using a shunt resistor to test the current-producing capacity of a source voltage.

metal-to-metal contact resistances of the measurement circuit will likely be very different from the actual contact resistances of an animal, e.g, hooves to floor or body to stanchion. These differences create errors where the measured voltage may be somewhat different from the voltage the animal actually experiences.

The above is really an overly simplistic description of the point-to-point measurement technique. To ensure that measurements are made properly, a thorough understanding of chapter 5 is necessary.

Instrumentation

When making measurements, instrument characteristics and monitoring points are the significant considerations. Generally, the instrument must be able to separate alternating current (ac) and direct current (dc). If the instrument is to be operated over extended periods, it must be able to withstand the harsh physical environment of the farm (wet, dirty, corrosive) or be protected from it. It must also be protected against electrical extremes such as faults or lightning. The following is a description of the types and characteristics of instruments commonly used in stray voltage investigations. For more detailed information, see chapter 5.

Voltmeters

One of the most common variables measured during stray voltage investigations is voltage. Generally this measurement is made using a voltmeter, e.g., an analog volt-ohm meter (VOM), a digital multimeter (DMM), or an oscilloscope. The instrument must have a resolution of 0.1 V and an input impedance of at least 5,000 ohms per volt. Other considerations are the ability to monitor transients and to record voltages (or currents) over time, i.e., to detect events that occur only at specific times and/or for short periods. It may also be necessary to use an instrument such as a differential oscilloscope to monitor the exact waveform of voltages.

As excessive neutral-to-earth voltages are the most common source of stray voltages, it may be advantageous to permanently install a voltmeter to monitor the voltage differential between the neutral bar of the service entrance panel and a reference electrode driven into the ground at least 30 feet from the building and away from any underground pipes or wires.

Ammeters

In stray voltage investigations, it may be necessary to make several current measurements. These measurements commonly include normal load currents and fault or leakage currents. The electrical current requirements of motors, lights, and other equipment can be measured to determine whether the equipment is operating properly. The current in an equipment grounding conductor can be measured to check for a fault or leakage current. The total current requirements of a building or set of buildings may be measured to determine adequacy of the electrical service. To help diagnose neutral voltage drop, monitoring the neutral current during periods of peak power usage is useful. Neutral current measurements also aid in determining the degree to which electric loads are balanced.

For many current measurements, clamp-on-type ammeters or recording ammeters are used. Other types of ammeters require opening of the circuit to put the ammeter in series or to install a current transformer. Opening the circuit can create a safety hazard.

Insulation Testers

Insulation failures or broken conductors or connections may cause a circuit conductor to contact a grounded surface. These accidental or unplanned faults are often termed "ground faults." When the faults are not obvious, use of ground fault testers is appropriate. *Ground fault or insulation testers for equipment or circuits should only be used on deenergized circuits.* An insulation tester that applies a high voltage to measure circuit resistance will locate circuits or equipment with current leakage through faulty insulation as well as through short circuits. *High voltage testers must not be used on low voltage circuits.*

Investigation Procedures

The investigation should begin by gathering evidence of the suspected stray voltage/current problem. Knowledge of the history and circumstances surrounding stray voltage/current problems can be critical to their solution. Chapter 5 contains a detailed questionnaire that should be completed before any measurements are made.

Identification of Sources

Source identification involves considerable knowledge of electrical systems in general and of the farm and local distribution systems. Often, source detection necessitates consultations among many specially trained electrical personnel. For example, farm equipment suppliers often have special knowledge about the operating characteristics of their equipment and may provide valuable assistance in solving stray voltage/current problems. Electricians and installers are normally called upon to do the testing; but they should also have the capability to identify specific sources, make necessary on-farm repairs and changes, and work with utility personnel if off-farm sources are identified. Electrical professionals (consultants), generally engineers dealing in electrical power, will play a role in 1) the training of others involved in stray voltage, 2) source identification in particularly complex situations, 3) specific quantification of sources, 4) assessment of electrical system characteristics, and 5) recommendation of mitigation techniques. These professionals must possess a complete understanding of the electrical circuits both on and off the farm, animal sensitivity, and measurement equipment and techniques.

Line maintenance crews may be trained to interact with and support those persons doing on-farm work and to investigate the location of primary system sources such as faulty connectors. Utility engineers can provide a more thorough understanding of problems with the distribution system.

Future Research

Research on the effects of stray voltages/currents on farm animals has been conducted at a number of institutions in several different countries over the past 20 years. The problems that may arise from the use of electric power on farms and the principles that apply to the mitigation of particular problems that may affect animal productivity, health, or reproduction are well understood. However, there are several areas where possible problems requiring careful examination may still exist and where definitive research to better describe the problems and provide solutions is recommended.

Physiology

Research comparing the physiological bases of responses to electric currents by dairy cattle with those by other species would allow data collected for other species to be used to predict the responses of dairy cattle more accurately than is presently possible. In addition, establishing the variability of sensitivity and response to current for a large number of dairy animals would allow construction of a more precise model of responses. This model could then be used to more accurately assess the most cost effective methods for improving herd performance.

Power Systems

The U.S. electrical power system is a huge network and is based on a specific transmission, distribution, and utilization philosophy. Modern uses of electricity have strained the capabilities of power suppliers to meet user needs. It may become necessary in the future to more clearly specify the power characteristics that the utilities are to provide at delivery points, the limits to which a consumer's type of usage can be allowed to affect other customers and the utility, and who is to monitor and require conformance to these specifications. The ability of power suppliers to continue providing power of reliable quality in the future will depend on the success with which the suppliers and consumers cooperatively solve numerous economic, technical, and legal problems.

Load Growth

The increase in neutral currents due to electrical load growth on a farm or along a distribution line and leakage or uncleared fault currents to earth