

SCOPE

This document provides a guideline that may be used when testing for stray voltage on livestock farms.

Electrically livestock farms vary widely in secondary on-farm wiring complexity and primary distribution system circuit characteristics. The individual performing the investigation must be allowed to make an on-site determination of the actual investigative procedure to be used. His/her analysis of the existing farm and distribution electrical systems based on verbal, visual, and recorded data, must remain the factor most important in deciding upon the direction and detail of any investigation. The investigator must exercise judgment in determining how much time should be spent, the amount of data that need be collected, and the action that should be taken to reduce, if necessary, levels of stray voltage. At farm locations where a detailed investigation is determined to be necessary adherence with the following will, in most cases, provide information sufficient to make informed decisions regarding stray voltage sources and appropriate reduction measures.

STRAY VOLTAGE INVESTIGATION FORMS

Attached to this document are the "Stray Voltage Investigation Forms". General information and test results specific to the farm being investigated can be documented on these forms. The investigator should decide which of the following test procedures are important to a determination of stray voltage levels, stray voltage sources, and, if necessary, appropriate mitigative action. The forms also provide a location for documentation of relevant observations and commentary.

A. Case History: Collect basic data and case history information. This data may become useful in assisting the investigator with testing and diagnostic activities.

B. Electrical System Review: Visually inspect and become familiar with both the farm electrical system¹ and the primary distribution system serving the farm. Document existing facilities and sketch the farm layout as specified in the Electrical System Review and Sketch sections of the Stray Voltage Investigation Forms. The sketch should: include farm buildings with appropriate labeling to identify the buildings; indicate the service wiring with wire size, type (copper vs. aluminum), length, and whether "3 or 4 wired"; and show the location of the reference rod, fencers, trainers, the setup location, and the panel used to bond the cow contact location. The sketch should also indicate locations of bolted connections, and may also note any defects in the fencer and/or trainer installation. If not identified on the sketch, defects in the fencer and/or trainer installation should be indicated elsewhere as a written note.

C. Record of Measurements:²

1. Meter Check:

Check the continuity of voltmeter leads and verify that the 500 Ohm resistor (used to represent a cow and its contact resistance in the measurement circuit) is connected across the meter input before making any stray voltage measurements. Doing so will help to ensure proper meter operation and accurate readings. This is accomplished by performing the following two steps.

¹ The purpose of the farm wiring electrical system review is not to identify existing violations of electrical code, but rather to familiarize the investigator with the electrical complexities of the farm being investigated, and to help identify possible on farm sources of stray voltage.

² It should be noted that it is preferable that all of the testing described be conducted with the primary neutral and secondary neutral connected at the farm (i.e. with the farm in a non-isolated condition). It may however be useful to conduct portions of the investigation, such as the "load box" test, with the farm both isolated and not isolated to determine the effectiveness of isolation.

a. Set the meter to enable resistance measurements. Connect the spring-clips of the meter leads together and flex each lead just above the point of termination on the spring-clip. The meter readings should go to near zero and remain there without fluctuation.

b. Set the meter to the proper resistance scale. Hold the meter leads apart so the spring-clips are not touching each other and note the reading on the meter. The meter should indicate a resistance of approximately 500 Ohms.

CAUTION: The 500-ohm shunt resistor should only be used when making voltage measurements at cow contact locations and when evaluating source and ground rod resistance. It should not be used to make line voltage measurements.

2. Barn/Parlor Sketch:

Indicate north and document spot-check and recorder placement locations for the barn, parlor, and/or other measurement location in the Spot Checks section of the Stray Voltage Investigation Forms.

3. Cow Contact Measurements before Bonding Improvement:

In an as-found condition, the investigator should first document animal contact voltage measurements at several locations within the animal confinement area. Documenting measurements under these conditions will provide an indication of internal structural and electrical bonding. An effort should be made to stabilize farm load while measurements are being made. A hair dryer may be used to help accomplish this. All measurements at cow contact locations should be made with and without a 500 ohm shunt, and should be recorded as indicated in the Spot Checks section of the Stray Voltage Investigation Forms.

These as-found measurements are also used to select the stray voltage recorder set-up location. The preference is to set up the cow contact channel of the recorder at the location where the cow contact voltage during the spot check is the highest. However, consideration should also be given to the farm operator's preferred location, the possibility of animal interference, etc. While not always possible, the investigator should attempt to find a location where he/she can connect one meter lead to a copper plate on the floor in the vicinity of the animals rear hooves and at least 18 inches away from other metallic objects. A jack post, insulated from the copper plate, or other means of applying pressure to the plate should then be utilized. The plate contact area should be scraped clean and kept wet throughout the period of testing by placing a paper towel saturated with a salt-water solution under the plate. This will minimize contact resistance and helps to establish a worst case exposure scenario during the recording period. The other meter lead should be solidly connected to a metallic object that the cow could contact while standing on the plate contact area (e.g., water line, stanchion post, etc.). Milk lines, bulk tanks, metal conduit, and other objects that cannot come in contact with the cow should not be used for making cow contact measurements.

4. Cow Contact Source Resistance Measurements:

Source resistance can be determined by performing two cow contact voltage measurements. Making certain that the contact resistance of the meter connections is minimized; compare the voltage measured without a shunt resistor to the voltage measured with a 500 ohm meter shunt. If there is a significant (50%) reduction in voltage measured with the shunt, it may be an indication of inadequate structural/ electrical bonding or a high resistance floor contact. The investigator may need to choose another cow contact location or temporarily improve bonding before choosing this location to set the stray voltage recorder. If another location is chosen for the recorder, a source resistance assessment should be made at the new location. A formula for calculating actual source resistance can be found in the Calculations section of the Stray Voltage Investigation Forms.

5. Establish Reference Rod:

Determine an acceptable location and install a remote reference ground rod. If possible the ground rod should be installed in moist soil 100 feet or more from the barn and any conductive underground structures such as water pipes, the well casing, building grounds, etc. Make primary neutral to remote reference and secondary neutral to remote reference voltage measurements with and without a 500 ohm shunt resistor. If there is a significant (50 %) change in measured voltage an attempt should be made to

reduce the ground resistance of the remote reference rod before proceeding. However, too low of a ground resistance may be an indication that the rod is too close to underground facilities connected to the neutral/ground network.

The above procedure will ensure that an adequate isolated reference ground has been established. Its location should be shown on the farmstead sketch in the Sketch section of the Stray Voltage Investigation Forms.

6. Degree of Bonding:

Operate a 120 volt hair dryer at an outlet near the animal confinement area. Where practical other farm load should be turned off at this time. Measure the following voltages at the setup location to determine the degree of bonding between the metal work in the area that the cow may contact and the electrical system; barn metal (usually water line) to the ground bar of the barn electrical panel serving that location, barn metal to reference rod, and barn panel ground bar to reference rod. (If the farm is three wired, the neutral and ground bars are the same, and the measurement can be to either. If the farm is four wired, measurements should be to the separate ground bar and NOT to the neutral bar.) Record these measurements as “pre-bond” measurements in the Spot Checks section of the Stray Voltage Investigation Forms.

Because the possibility exists that intentional or inadvertent bonding to the electrical system may occur in the future, if necessary the investigator should attempt to temporarily improve this bonding before proceeding with the investigation. The "post-bond" measurements should also be recorded.

If inadequate bonding exists in the “as found” condition, the farm operator should be made aware of the hazards associated with inadequate bonding and the manner in which improvements may impact stray voltage levels. He/she should be encouraged to have a qualified electrician improve this wiring deficiency. In some cases it may be appropriate to record animal contact voltage for a 24-hour period in the "as-found" condition.

7. Cow Contact Measurements after Bonding:

Create voltage on the secondary neutral by operating a 120 volt hair dryer at or near the panel to which the barn metal bonding has been supplemented. Where practical, all other farm load should be turned off prior to making voltage measurements. Measure and record the voltage at the cow contact setup location in the Spot Checks section of the Stray Voltage Investigation Forms.

Adjust the voltmeter to measure DC Voltage. Measure and record DC voltage levels at the chosen measurement location with and without a shunt resistor. If DC voltage levels with shunt exceed 0.5 volts, further DC investigation may be appropriate. It should be noted that some level of DC voltage will always be present. A DC voltage reading is an indication of a natural galvanic cell created between the rear “copper” plate and other building metal (e.g. rebar). The actual reading is dependent upon a number of factors including what different metals are present. Use of a plate made of something other than copper will result in a different DC voltage reading.

8. Stray Voltage Recorder Connections:

At this point in the investigation, a voltage recorder will have been set up to assist in the collection of data. The following discussion assumes that the stray voltage recorders used are digital voltage recorders that have four channels and an internal shunt in the fourth, cow contact, channel.

a. The principal voltage recording is to be made at the predetermined cow contact location. Prior to connecting the recorder the relative magnitude of the source resistance should be determined. This determination should be made, and the input of the recording channel with the internal shunt should be connected as described in #3 & #4 above.

b. A second recording channel should be installed to record secondary neutral to earth voltage between the single-phase secondary ground bar at the barn service entrance and the remote reference rod previously established.

c. A third recording channel should be installed to record voltage between the primary neutral (primary neutral ground lead at the utility transformer) and the remote reference rod previously established. If required, the primary neutral-to-earth voltage level recorded during the period of maximum cow contact voltage can later be estimated or artificially recreated with all farm load off in order to determine maximum primary neutral contribution to cow contact voltage (see Analysis of Collected Data).

d. The fourth recording channel should be set up to monitor the difference in voltage between the connection at the transformer (i.e. primary neutral connection) and the connection in the barn service entrance panel (i.e. the secondary ground bar connection).

e. Take adequate measures to ensure that leads are placed in a manner that will minimize the impact on farm operations.

f. Using a digital voltmeter, confirm the accuracy of voltage levels being recorded. Also confirm shunt resistance and continuity of all leads before leaving the recorder(s) unattended.

9. Equipment Signature:

Set the recorder for a high sampling rate, and start recording the voltage at the monitored points. As much as possible, this test should be conducted with minimal other farm load operating and/or switching on and off. Identify and momentarily energize individual pieces of farm equipment while monitoring the voltmeter or recorder for abnormal readings. The investigator should include in this signature test numerous types of equipment from various farm locations. The equipment location, type of equipment and on/off times should be recorded in the Signature section of the Stray Voltage Investigation Forms. If a significant on farm problem is found (e. g. defective equipment or high resistance neutral) and it cannot be immediately repaired, the livestock farmer should be urged to temporarily disconnect the equipment. The investigator should document all abnormalities.

10. System Assessment (Load Box Test):

An assessment of the distribution system neutral and its ability to contribute to stray voltage levels can be made using 240 volt single phase farm loads and/or a single phase 240 volt load box (multi-stage load box preferred). The use of 240 volt load (all 120 volt loads off) results in primary neutral current flow and increases the contribution from primary neutral stray voltage sources with minimal impact from the secondary neutral and its potential stray voltage sources.³

Starting with all farm load turned off (120 and 240 volt, single and three-phase), measure and record the current in the primary neutral conductor (both directions if necessary), the net secondary neutral current on the service(s) from the transformer (the current measured simultaneously on the line and neutral conductors as a bundle), and the primary neutral ground lead current at the transformer. Additionally, using the previously established remote reference, measure and record primary neutral-to-earth voltage, secondary neutral-to-earth voltage, the voltage difference between the transformer ground and the barn entrance panel ground/neutral bar (the “secondary neutral”), and the cow contact voltage. (These voltages may be monitored by the electronic recorder.) The resistance of the grounds at the pole should also be measured at this time.

As rapidly as possible, energize the first stage of the 240 volt load box to create 240 volt load, and measure/record the same voltages and currents. These measurements should be repeated and documented in the Load Box Test section of the Stray Voltage Investigation Forms for each of the three load box stages.⁴

After all of the load box stages are operating, and while still energized, turn the farm on. In addition to the other current and voltage measurements made when only the load box was operating, record the amount of current in both (or all) of the energized service conductors and the secondary neutral

³ When performing this test on a 240 volt three phase three wire service, use single phase 240 volt equipment (or the load box) connected between the ungrounded phases.

⁴ Artificial system loading should not exceed an amount that exceeds equipment rating if the load is applied through farm switches and equipment. (An analysis of circuitry and equipment, and/or a method of monitoring current at critical locations may be required.)

conductor. Finally, the load boxes are turned off and the same voltages and currents should again be measured with the farm still on.

If the secondary neutral-to-remote voltage level (with farm load operating) DOES NOT indicate the presence of an electrical system problem, obtain the farm owner's permission to leave all existing isolation devices bypassed for the period of initial testing (generally 24 hours). If the secondary neutral-to-remote voltage level (with farm load operating) DOES indicate the presence of an electrical system problem, and this voltage cannot be immediately attributed to a malfunctioning piece of equipment or some other obvious cause, attempt to reduce the level of voltage by lowering the farm and/or primary neutral resistance to earth (e.g. create well casing bond, repair poor primary neutral splice, etc.). If this cannot be easily accomplished, the farm should be temporarily isolated or restored to isolated status to allow time to find the voltage source and implement reduction measures.

At those locations where primary neutral-to-earth voltage levels appear to be abnormal, distribution system repair or modification, and/or isolation may be necessary prior to additional testing.

For most three phase transformer connections, three phase loads will not generate current in the primary neutral and are not suitable for use in conducting a load box test. Where a farm is served solely from a three phase service, other measures may have to be used to generate current on the primary neutral, such as applying the load at a neighboring transformer. Load box testing cannot be adequately performed at all farm locations.

11. Secondary Neutral Voltage Drop:

The purpose of this test is to determine the effect of secondary neutral voltage drop on stray voltage levels. A 120 volt test load is operated at the load end of each of the on-farm services, and a measurement is made of the voltage drop on the farm grounding system caused by that load. The farm wiring examined includes the service from the transformer to the farm's main distribution point, and then individually all of the farm services from that distribution point to the various farm buildings. This may include numerous segments of wire of varying size and material, connections, and segments that may extend past and through the various farm buildings.

Although the ideal would be to do this test with all farm loads off, it is acceptable to conduct the test with other loads operating and note the change, or step in voltage between when the load is turned on and when it is turned off⁵. A 1200 watt or larger 120 volt hairdryer with two heat settings is ideal for use as the test load. The preset stray voltage recorder may again be used to assist in capturing data.

To conduct the test, the test load should be energized at the building being served by the service drop under consideration. Record in the Voltage Drop section of the Stray Voltage Investigation Forms the test load current magnitude and the change in voltage drop between the equipment ground bar (for a three wire service this may be the neutral bar) at the building entrance panel and the ground at the central distribution point. Simultaneous to measuring the change in voltage drop, measurement should be made of the change in ground bar to earth voltage at the test building and neutral to earth voltage at the source end (e. g. the main distribution point to the reference rod, and from the "building under test" panel ground bar to the reference rod). Additionally, the change in the cow contact voltage, and the voltage change at all other measurement points monitored by the voltage recorder should be documented along with the time of each test. These voltages measurements may be taken from the preset recorder or a separate voltmeter(s) may be used.

The service drop of a properly wired "four wire" system has an equipment grounding conductor (fourth wire) that is separate from the neutral (grounded) conductor. Although 120 volt load current will flow on the neutral, there should be little or no current on the equipment grounding conductor. Therefore, if a

⁵ With existing load on the service it may be necessary to determine whether the 120 volt test load current is additive or subtractive to the current that may already be on the neutral. This can often be accomplished by repeating the test with the hairdryer set on the lower setting. If the hairdryer current is out of phase with the existing neutral current, the voltage drop would also be out of phase. This could result in a voltage shift that appears to be lower than it actually is. By repeating the test with the hairdryer on a low setting, the investigator will be able to determine whether the change under the higher load condition was additive or subtractive, and its magnitude.

service is properly four wired, there will be little or no change in voltage drop between the building's ground bar and the main distribution point neutral when the test load is applied. If there is an identifiable voltage drop change associated with the operation of the test load, a current is flowing on the equipment grounding conductor, the equipment grounding conductor and the neutral conductor are in parallel, and the system is NOT properly four wired.

For a 240 volt three-phase three wire service, the voltage drop on the grounded B-phase should be measured in much the same way as the voltage drop on the neutral of a single phase service. A 240 volt hair dryer should be used instead of a 120 volt device, and it should be connected A to B or C to B to allow the test current to flow on the grounded phase conductor. For a three-phase four wire 208 GrY/120 volt service, a 120 volt hairdryer may be used between any of the individual legs and the neutral to generate a current in the neutral. For a three-phase four wire 480 GrY/277 volt service this test can not be easily conducted because of the lack of a suitable load and commonly available receptacles.

From the information concerning service lengths and wire sizes previously noted on the site sketch, calculate the approximate anticipated voltage drop using the resistance values for that wire size and material. If there is an indication that secondary neutral or B-phase voltage drop may be a concern (higher than anticipated readings coupled with lengthy service, small conductor, numerous split bolt connectors, etc.), the investigator may perform additional tests and/or make recommendations to the farm owner regarding necessary secondary system modifications.

12. Voltage at Feed Bunks and/or Stock Water Tanks:

There are sometimes locations outside of the animal confinement facility where animals may be exposed to stray voltage (e.g. metallic stock waterers, metallic bunk feeders, etc.). The investigator should identify the areas of concern and make appropriate cow contact voltage measurements with and without a shunt resistor. The measurements should be noted in the Waterer/Bunk Feeder Test section of the Stray Voltage Investigation Forms. At the start and end of these measurements, notation should also be made of the secondary neutral to reference rod voltages. Again, the preset voltage recorder may be used to assist the investigator by monitoring the secondary neutral to reference rod voltages while making the spot measurements at these locations.

Based on levels of voltage present and the animal's ability to avoid the energized surface, the investigator and the livestock owner must make a determination regarding the need for mitigative action. If mitigative action is necessary, a decision must be made regarding what type of mitigative effort is most appropriate.

13. Primary Profile:

In the Primary Profile Test section of the Stray Voltage Investigation Forms record the pole ground current and pole ground resistance of each of 10 grounds distributed on either side of the farm being investigated. Calculate, using Ohms Law, the pole ground voltage (primary neutral to earth voltage) at each pole. Use the comments section of the form to annotate the condition at each location such as whether the pole has equipment mounted on it, a primary or secondary riser, is close to a telephone pedestal, etc.

14. 24 Hour Recording:

Before leaving the farm, slow the sampling rate of the recorder(s) to ensure that there is sufficient storage capacity to record voltages for the remainder of time the recorder will be left to monitor voltage levels on the farm. Allow the recorder(s) to operate for at least 2 milking cycles or a 24-hour period. Remove the recorder(s) and analyze collected data. If existing neutral separation devices had been bypassed for testing, the jumpers should be removed until the data has been analyzed, discussed with the farm operator, and a decision regarding future isolation status has been reached.

15. Recorded Data:

After review of the recorded data, document dates and times, weather conditions, voltages at the time of maximum cow contact voltage, and any other relevant information in the End of Test Information section of the Stray Voltage Investigation Forms.

16. System Resistance Analysis:

Using the data collected in #10 "System Assessment," the farm and distribution system neutral-to-earth resistances can be calculated using the formulas provided in the Calculations section of the Stray Voltage Investigation Forms. This information may be important to a determination of appropriate mitigative action.

17. Comments:

This section of the "Stray Voltage Investigation Forms" can be used to document important findings and issues discussed with the livestock farm's owner/operator.

ANALYSIS OF COLLECTED DATA

A. Animal Contact Voltage Levels: At this point in the investigation there should be sufficient data, and farm "as is" documentation, to provide necessary information about the distribution and farm electrical systems. This data will be the basis for determining the need for, and direction of, further investigation or action. Additionally, if required, it will provide the investigator with valuable information for determining the most effective means of reducing cow contact voltage.

If the maximum recorded steady state cow contact voltage did not exceed 0.5 volts, the level of stray voltage resulting from the combination of both on and off farm sources is not sufficiently high to warrant isolation from the primary neutral. The investigator may, however, offer to utilize collected data to work with the farm owner to further reduce levels of stray voltage from on farm sources if possible. If a neutral separation device is currently in place, the livestock farmer should be informed that the device is no longer required.

If the maximum recorded steady state cow contact voltage was greater than 0.5 volts, it will be necessary for the investigator to determine maximum off-farm contribution to cow contact voltage. This is necessary so that a decision regarding temporary neutral separation can be accurately made. In addition, quantifying the off-farm contribution will provide information necessary for the eventual determination of the best technique(s) for reducing cow contact voltage.

B. Primary Neutral Contribution: Using the 24 hour recording and data collected during the "System Assessment" tests (see #10 above), an estimate of the maximum utility contribution to voltage at cow contact can now be made. This is possible because of the relative linearity between increasing levels of primary neutral-to-earth voltage and stray voltage when on-farm factors are eliminated. The maximum contribution to stray voltage levels (CCmv) will be the ratio of primary neutral-to-earth voltage at the time of maximum recorded cow contact voltage (Pnev@ccvmax), to primary neutral-to-earth voltage as created by the 240 volt farm load and/or load box test (Pnevlb); times the cow contact voltage as created by the load box test (CCvlb).

$$CCmv = (Pnev@ccvmax/Pnevlb) \times CCvlb$$

While adherence with the described procedure will generally provide a reasonable estimate of the maximum utility contribution to stray voltage, there are several factors capable of skewing results (e.g. large on-farm secondary voltage drop can either increase or decrease primary neutral to earth voltage during the 24 hour recording period). The investigator should use his/her experience and all available test results when making a contribution determination.

1. Less Than 0.5 Volts

a. Neutrals Bonded: If the maximum off-farm contribution to voltage at cow contact locations with neutrals tied is less than 0.5 volts, and the primary and secondary neutrals have not been separated, the investigator may offer to utilize collected data to work with the farm owner in an attempt to further reduce stray voltage from on farm sources.

b. Neutrals Isolated: If the maximum off-farm contribution to voltage at cow contact locations with neutrals tied is less than 0.5 volts, and a neutral separation device(s) is currently in place, the farm owner

should be informed that the isolation device is not necessary. The investigator may offer to utilize collected data to help the farm owner further reduce stray voltage levels from on farm sources.

2. Greater Than 0.5 Volts

If the maximum off-farm contribution to voltage at cow contact locations with neutrals tied is greater than 0.5 volts, the investigator must take whatever action is necessary to lower utility contribution to voltage at cow contact points to a level below 0.5 volts. This must be done regardless of whether the primary and secondary neutrals are presently tied or separated. A determination regarding the best on and/or off-farm method(s) by which this is to be accomplished should be based on an analysis of previously collected data as well as any necessary additional testing. When an existing neutral separation device must continue to be utilized temporarily, or a new device must be installed to allow time for implementing necessary changes, it should be made clear to the farm owner that the neutral separation device installation will be temporary. Following a reduction of off-farm stray voltage contribution to levels below 0.5 volts, the investigator may offer to utilize collected data to help the farm owner further reduce stray voltage levels from on-farm sources.

Resolution of the stray voltage concern in this situation does not necessarily require that the existing off-farm voltage contribution be lowered. Voltage at cow contact may be reduced by on-farm changes such as grounding improvements or the installation of an equipotential plane. In many cases a combination of on-farm and off-farm modification may be required.

C. General

1. Where the new installation of a neutral separation device is required, the investigator should assess its impact on neighboring non-isolated livestock farms located within five spans (~1000ft) of the newly isolated farm. If necessary, temporary isolation may be performed at neighboring livestock farms, but only after a stray voltage investigation and a determination that temporary isolation is necessary.
2. If the farm owner has expressed a concern regarding personal shocks (tingle voltage) at locations other than cow contact, the investigator should make measurements where necessary in an attempt to determine the source(s) of the voltage. Because tingle shocks can be an indication of secondary wiring or equipment failure, the customer should be encouraged to contact a qualified electrician immediately. Voltage levels, specific measurement locations, and recommendations/action should be documented.
3. At the completion of the investigation the farm owner should be encouraged to monitor voltage at cow contact locations.
4. The investigator should visually inspect the electric fencer/trainer installation at all farms investigated. Where appropriate modify or make modification recommendations. Where problems are found they should be documented in the Stray Voltage Investigation Forms along with repair recommendations that have been explained to the farm owner/operator.
5. If the primary and secondary neutrals of a farm service are separated, the telephone and/or cable television companies serving the farm should be notified of the separation. Notification procedures vary between the various communication companies. Should the stray voltage investigation reveal that the telephone or cable television systems provide a parallel path for off-farm contribution, and, this path prohibits effective isolation from off-farm sources, the investigator should seek immediate assistance from the appropriate communication company.