ELECTRIC POWER RESEARCH INSTITUTE

Neutral to Earth Voltage and Urban Stray Voltage Measurement Protocols

Test Equipment and Procedures

1010652

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Technical Update, December 2005

EPRI Project Manager

Ashok Sundaram

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1395 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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D. Dorr

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ABSTRACT

This measurement protocols document describes preliminary efforts to develop procedures and measurement equipment suitable for conducting consistent and repeatable stray voltage assessments. While useful measurement protocols and procedures exist for some situations such as animal contact area measurements, there are many inconsistencies and differences in the procedures used to conduct stray voltage assessments across many of the other areas of interest. To that end, this document provides preliminary recommended assessment protocols across three areas of interest. The first area includes residential concerns where elevated voltage potentials are experienced near swimming pools, hot tubs, faucets and other residential contact points. The second area includes dairy, swine and poultry farm concerns where elevated voltage potentials are experienced at animal feeding, production and other contact points. The third area includes concerns related to faulted secondary phase conductors coming in contact with a metallic object that can be subsequently contacted by humans or animals. Future efforts are expected to include protocols and procedures for telecommunications and cable service investigations as well as more detailed discussion of induced voltage measurement protocols for pipelines, fences and other metal objects not specifically covered in this technical update. The document contains some discussion, but does not distinguish between induced, radiated, and conducted voltage sources.

CONTENTS

1 **INTRODUCTION AND EXECUTIVE SUMMARY 1-1**
Definitions 1-1

2 **TEST AND MEASUREMENT EQUIPMENT 2-1**
Introduction 2-1
Voltage Measurements 2-1
Current Measurements 2-2
Additional Measurement Considerations 2-3
Trending Equipment vs Snapshots 2-3
Other Diagnostic Equipment 2-4
Calibration and Calibration Verifications 2-5

3 **GENERIC MEASUREMENT OBJECTIVES 3-1**
Safety Precautions 3-1
Basic Measurement Considerations 3-2
Identification of the Shock Complaint Location(s) 3-2
Determination of the Presence of a Voltage at the Shock Complaint Location 3-2
Identification of a “Common” Reference Point 3-2
Advanced Measurement Considerations 3-3
No Load vs Resistive Load Voltage 3-3
Current Flow 3-3
Spectral Content 3-3

4 **ANIMAL CONTACT AREA MEASUREMENTS 4-1**
Test Protocol 4-2
Objectives 4-2
Safety Considerations 4-2
Equipment/Materials Needed 4-3
Measurement Protocol 4-3

5 **RESIDENTIAL CONTACT AREA MEASUREMENTS 5-1**
Safety Precautions 5-1
Measuring Voltage Between Pool (or Hot Tub) Water and Ladder Steps or Handrail 5-2
Materials Needed: 5-2
Procedure: 5-2
Measuring Voltage Between Pool Water and Coping Stone 5-3
Materials Needed: 5-3
Procedure: 5-4
Measuring Voltage Between Pool Water and Concrete Deck 5-4
Materials Needed: 5-5

Procedure: 5-5
Measuring Voltage Between a Water Faucet and Earth 5-6
Materials Needed: 5-6
Procedure: 5-6
Measuring Voltage Between an Air Duct and Earth 5-7
Materials Needed: 5-7
Procedure: 5-8
Measuring Voltage Between Pole Ground and Earth 5-8
Materials Needed: 5-9
Procedure: 5-9

6 ENERGIZED METALLIC OBJECT CONTACT AREA MEASUREMENTS 6-1
Background 6-1
Safety Precautions 6-1
Objectives 6-2
Measuring Voltage Between a Metallic Pole and a Remote Earth Reference Point 6-3
Materials Needed: 6-3
Procedure When Gravel or Earth is Readily Available: 6-3
Procedure For Urban Investigations (No Gravel or Earth Readily Available): 6-4

7 EQUIPMENT MEASUREMENT ACCURACY VERIFICATION 7-1

8 REFERENCES 8-1

1

INTRODUCTION AND EXECUTIVE SUMMARY

In 2004 EPRI Developed a multi-year plan to evaluate concerns associated with voltage potentials that can appear at human and animal contact points. The prioritized research plan identified five areas of opportunity where supplemental or new research was needed. These five areas included test and measurement protocols, modeling and simulation guidelines, test equipment and mitigation methods assessments, technology transfer and regulatory guidance. Of these five areas, consistent and repeatable measurement protocols are a fundamental building block to each of the other areas of interest. The result is this measurement protocols report which defines procedures and measurement equipment suitable for conducting consistent and repeatable stray voltage assessments.

A major reason for this document is that while good measurement protocols and procedures exist for some situations such as animal contact area measurements, there are many inconsistencies and differences in the procedures used to conduct stray voltage assessments across many of the other areas of interest. To that end, this document provides recommended assessment protocols across three areas of interest:

- The first area includes, residential concerns where elevated voltage potentials are experienced near swimming pools, hot tubs, faucets and other residential contact points
- The second area includes, dairy, swine and poultry farm concerns where elevated voltage potentials are experienced at animal feeding, production and other contact points.
- The third area includes concerns related to faulted secondary phase conductors coming in contact with a metallic object that can be subsequently contacted by humans or animals.

To accomplish this effort, a literature survey was performed to identify and review all of the relevant documents related to the subject matter, a research task was undertaken to identify the manufacturers of the most useful measurement equipment and a number of subject matter experts were consulted to provide input and insights on their own field measurement experiences. There is discussion, but no distinguishing between induced, radiated, and conducted voltage sources.

Definitions

To make sense of the confusion surrounding the terminology associated with stray voltage, energized metallic objects, and neutral to earth potentials, this report will use the following terms:

- Remote earth
- Neutral grounding
- Neutral-to-earth voltage (NEV)
- Metallic-object-to-earth voltage (MOEV)
- Stray voltage

Each of these terms is defined in the following paragraphs, along with some insight into their most common causes. With an understanding of the terminology and what causes each condition, the remainder of the report will be easier to understand relative to the measurement terminology.

Remote Earth is defined as an earthing or grounding point that is at the same voltage potential as other points on the earth in the surrounding area. Electrical current flowing through grounding or neutral conductors, or even through earth itself, will cause voltage variation from point to point. The remote earth point is hypothetically "beyond" or outside of the influence of these current paths. Thus, the remote earth point is at zero potential with respect to the voltage source and provides a consistent and repeatable reference point.

Neutral Grounding - The IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems [1.], recommends limiting utility equipment to earth voltages by grounding the circuit neutral conductor at least four times per circuit mile, as well as at all utility hardware such as transformers, lightning arrestors, and capacitor banks. This tends to limit any developed voltages to less than 25 volts, which is generally accepted as a relatively non-lethal voltage level. The unavoidable consequence of grounding power system neutral conductors is that some currents will always be returning through the earth. Because of the current flowing through the earth impedance, any time the power system is energized there will be some level of voltage present relative to the remote earth point.

Neutral-to-Earth Voltage or NEV is a measure of the voltage potential between a neutral-to-ground (N-G) bonding point and a "remote earth" point. In essence, any time current is flowing through a neutral conductor, there will be a voltage potential with respect to the earth. This voltage potential can be metallically transmitted over to a remote earth point through "code-required" grounding and bonding of water pipes, neutrals and other conductive paths. It is important to note that NEV is a normal occurrence caused by the "intentional" grounding of the power system.

Metallic-Object-to-Earth Voltage or MOEV is caused by an accidental or "unintentional" energization of a metallic object. The most common scenario for MOEV occurs when an energized electrical conductor comes in direct contact with a metallic object, such as a streetlamp, a service box, a manhole cover, or virtually any type of metallic object, thereby energizing the object as well. MOEV potentials to remote earth can range anywhere from just a few volts to 120 volts or more, depending upon the source. MOEV can also occur when a pipeline or other insulated metallic object is close enough to an electric field from a power line to receive an induced voltage from that electric field.

Stray Voltage (from intentional actions) – The U.S. Department of Agriculture Publication 696 [2] defines stray voltage as "a small voltage (less than 10 volts) that can develop between two possible contact points." Contact points are generally considered to be points close enough between the voltage source and a remote earth path that would allow a current to flow through any human, animal, or other object that contacts both points simultaneously. Another important note about publication 696 is that the document summary states: "While stray voltage cannot totally be eliminated, it can certainly be reduced to an acceptable level." While this definition focuses primarily on NEV sources which result from the intentional grounding of the power system neutral conductor, many cases have been identified where improper wiring and load faults on the customer side of the meter contribute to the measured voltages.

<u>Stray Voltage (from unintentional actions) –</u> The New York Public Utility Commission uses the term stray voltage to describe the unintentional or accidental energization of manhole covers, street lamps and other urban street level metallic objects [3]. This definition focuses on MOEV sources such as contact with the power system phase conductor or in some cases as the result of induced voltages from electric fields.

While the previous two definitions have created some confusion the common element is that stray voltage could be considered an undesirable voltage potential across any two points that can be simultaneously contacted by an animal or a human. In summary, to develop a stray voltage we can consider the following sources: 1.) currents flowing on primary and secondary neutral conductors, 2.) faulted phase conductors, and 3.) induced voltages from currents flowing through power lines.

2
TEST AND MEASUREMENT EQUIPMENT

Introduction

The stray voltage investigator must be versatile and familiar with a wide assortment of test and measurement equipment in order to diagnose the source(s) of the voltage concern, a wide variety of measuring equipment is available to support the stray voltage investigator. The challenge is in selecting the most appropriate instrumentation for a given test or measurement. The intent of this chapter is to provide the reader with an overview of the types of measurements of interest, the available equipment, its functions, capabilities and field use suitability.

The chapter is subdivided into five main clauses:

- Considerations for performing voltage measurements
- Considerations for performing current measurements
- Considerations for taking single snapshots of the voltages and currents versus the value of longer term trending
- Supplemental measurement and diagnostic equipment that should be part of the stray voltage investigators toolkit
- Considerations surrounding accurate measurements and equipment calibration requirements.

Voltage Measurements

Accurate measurements of voltage potentials at human and animal contact points are essential to the stray voltage investigation. The challenge is that measurement resolution down to the tenths of a volt must be accomplished and just a few tenth of a volt error can result in the difference between no action required and expensive mitigation requirements. This section contains trademarked names and references to specific brands of metering equipment however these callouts are simply for reference and *in no way imply endorsement of that particular brand.*

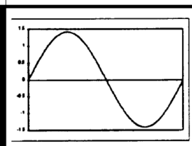
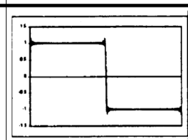
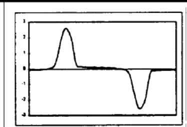
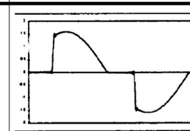
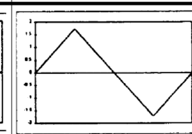
AC Voltmeters – It is ***recommended practice*** that all readings be taken with ‘true rms” responding voltmeters. True rms reading voltmeters indicate the square root of the sum of the squares of all instantaneous values of the cyclical voltage waveform. These meters will indicate the correct or true rms value for every type of waveshape from sinusoidal waves to pure square waves, and are therefore the preferred voltage measuring instrument for the stray voltage survey.

Average responding rms voltmeters and peak responding voltmeters are not recommended as they assume a sinusoidal waveform and calculate the rms equivalent based on that assumption. With the average responding voltmeter, a multiplier called the “form factor” is used to convert the averaged value to the equivalent rms value. The 1.1 multiplier used by these instruments is based on the assumption that the rms value of a sine wave is 1.1 times the average value of the same rectified sine wave. With peak responding voltmeters, the peak value of the waveform is detected and a 0.707 multiplier is used to convert the peak value to the equivalent rms value.

Like the average responding circuit, the waveform must be sinusoidal or the displayed value will be erroneous.

The following table shows several waveshapes and the percent error recorded by the peak and averaging responding meters. This emphasizes the importance of using a true rms meter.

Table 2-1
Percent Error vs Type of Instrument Used for Differing Waveshapes

Meter type	Circuit	Sine wave	Square wave	Distorted wave	Light dimmer	Triangle wave
						
Peak method	Peak/1.414	100%	82%	184%	113%	121%
Average responding	Sine avg. 1.1	100%	110%	60%	84%	96%
True rms	RMS converter	100%	100%	100%	100%	100%

DC Voltmeters – The true rms voltmeters suitable for measuring AC voltage are typically suitable for measuring DC voltage as well. When performing a comprehensive stray voltage assessment, it is ***recommended practice*** to record both the AC voltage and the DC voltage across the contact points of interest.

Current Measurements

AC current measurements are slightly more difficult to perform during a site survey compared to voltage measurements, but there are many instruments available to simplify the process. As with voltage measurements, ***recommended practice*** is to use true rms-reading meters when performing a site survey. True rms ammeters include two types of indirect reading ammeters: current transformers and Hall-effect types.

Current-transformer (CT) ammeters – A transformer is commonly used to convert the current being measured to a proportionately smaller current for measurement by an ac ammeter. There is very little resistive loading with these ammeters, and when a split-core transformer is used, the circuit to be measured is not interrupted. Clamp on CT's cannot be used to measure DC currents. Caution is recommended when interpreting readings obtained with a CT-type device because some of these ammeters may not be true-rms-reading meters. Sensitivity wise, the CT must be capable of measuring accurately in the milliampere range. For current measurements the investigator may need multiple CT’s to cover a range of currents from one milliampere flowing into the earth via a ground rod to as much as a few hundred amperes on a circuit phase conductor.

Hall-effect ammeters – The “Hall-effect” is the ability of semiconductor material to generate a voltage proportional to the current passed through the semiconductor, in the presence of a magnetic field. This is a “three-dimensional” effect, with the current flowing along the x-axis, the magnetic field along the y-axis, and the voltage along the z-axis. The generated voltage is polarized so that the polarity of the current can be determined. Both ac and dc currents can be measured.

Additional Measurement Considerations

Spectral Content (Harmonics) – There are a number of documented cases where an elevated NEV concern is caused by harmonic currents flowing through the power distribution system neutral conductor and the earth. Since these currents do not cancel like the 60 Hz currents, they can be the dominant component in some NEV investigations. A true rms meter will quantify the total voltage, but a harmonic analyzer with resolution to capture frequencies out to at least the 50^{th} harmonic (3000 Hz) must be used to determine the harmonic content and the individual harmonic contributions. It is therefore ***recommended practice*** to measure the harmonic spectrum for stray voltage investigations where the suspected source is a multi-phase wye-grounded distribution system or where the suspected source of the elevated NEV is from customer equipment.

Peak versus RMS – Animals and humans respond to the peak of the voltage waveform in terms of the related current flow through the body. Most recommended limits or levels of concern are based on a conversion to the equivalent rms value. When capturing peak values it is ***recommend practice*** to either capture the associated waveform or if the meter is not capable of waveform capture to insure the meter is set to record the instantaneous millisecond peak and not an average over multiple cycles.

Event Duration Considerations – For the purposes of this document, the duration of a voltage or current variation will be defined per recommendations from IEEE std 1159-1995 Recommended Practice on Monitoring Electric Power Quality [3], for:

- Transients
- Short Duration RMS Variations
- Long Duration RMS Variations

where transient events are in the millisecond range and rms variations last at least one half of an electrical cycle. The rms variations are then subdivided into short duration variations lasting less than 2 minutes and long duration variations lasting 2 minutes or more. It is the rms variations and most particularly the long duration rms variations that are of most interest for the stray voltage investigator. It is a recommended practice to take when taking voltage readings, to take several readings over a few minutes to confirm that the readings are fairly consistent.

Trending Equipment vs Snapshots

Depending upon the type of investigation there may be a need to trend data over several weeks and a number of data loggers (either voltage or current) are available to accomplish this. In certain situations, a single snapshot of the voltage or the current is inadequate. For example, as the loading of a distribution system varies during the day, the NEV contribution from the distribution system can change proportionally. For distribution induced NEV, the major contribution is due to the non-canceling currents (unbalance and triplen harmonics) flowing on the distribution neutral conductor. By logging 15 minute snapshots at a contact point and comparing this to 15 minute loading data, comparisons can be easily made to rule out or to confirm potential causes. Example products that are useful to conduct snapshot measurements and data logging include the Metrosonics™ SRV-4 and the AEMC™ L205.

Other Diagnostic Equipment

The stray voltage investigator may sometimes find useful additional diagnostic equipment to accomplish the objectives of the audit. These other devices are described in the following section to include both function and suitability for various types of investigations.

Non-Contact AC Voltage Tester (Pen Light) – Several manufacturers supply non-contact capacitive voltage testers suitable to determine if AC voltage greater than the specified voltage is present on an object that can become energized. Care should be taken to closely evaluate the data sheets as each of the devices has a different sensitivity range (anywhere from 5 volts to 50 or 100 volts) but they do allow the investigator to detect and cautiously deal with objects that may become energized such as street lamp posts, manhole covers, service boxes, conduits, concrete and other objects.

The preferred units come with a test capability to insure that the indicator light glows or an audible alarm sounds when placed near an energized object. Example companies that manufacture low voltage (less than 24 volt sensing) versions of these non-contact AC voltage testers are Extech™ and Fluke™. These testers are suitable for determining the presence of AC voltage, but not suitable for accurately measuring the value of the AC voltage.

Load Boxes – For residential as well as animal stray voltage investigations, a load box capable of testing 240 volt and 120 volt secondary systems is useful. These load boxes contain switchable resistors and allow the facility load to be shut off while the box is connected to determine the value of neutral to earth voltage contributed as the load is varied. This method also enables a way to determine resistances of the secondary neutral conductor via phase to neutral loading and a way to determine facility load NEV contributions of the service transformer primary neutral grounding point via line to line loading.

Test Resistors – provide a means of determining if the voltage source is capable of driving adequate current between two contact points. The literature and the test protocols describe 500 ohm and 1000 and 20,000 ohm test resistor configurations. These are relatively easy to obtain and can be built into a switch-able configuration for banana jack connection to a voltmeter.

Metal Detectors – For location of metallic pipes, conduits and other potential sources of stray voltage the metal detector can provide the investigator with a useful tool for identifying these sources.

Earth Ground Resistance Testers – The resistance of the earth grounding electrode can be tested with a ground resistance tester. The ground resistance tester injects a known voltage at a known frequency and measures the current driven by the known voltage. With the voltage and current known, the resistance is easily calculated.

Miscellaneous Equipment – Other equipment that may be useful to the stray voltage investigator that is not detailed here include: Metallic Plates, Gauss Meters, Electric Field Sensors and Infrared Diagnostic Equipment.

Calibration and Calibration Verifications

To ensure that test instrumentation remains within calibration standards throughout all of the handling during annual field measurements, it may be useful to devise a set of calibration boxes. To serve as a reference, the signals from these calibration boxes can be measured by NIST traceable calibrated equipment not taken into the field. These boxes can provide reference signals for ac and dc voltages and currents at different levels to test resolution accuracy of the metering equipment. The box can then be used in the field to periodically validate the test instrumentation used throughout the year as a way to insure that the transported instrumentation remained in calibration. Resistance clamp-on meters such as those manufactured by AEMC usually come equipped with calibration-verification resistance loops. These resistance loops can be used in the field to verify the accuracy of the resistance measurements. “Field Calibration Data Forms” are also recommended to record measured data and to provide file-name references to saved waveforms associated with the periodic calibration-verification checks. These calibration checks and the associated forms should be completed and signed at every location where measurements are taken. An example of a calibration box and checksheet has been included for convenience in Section 7 or this document.

3
GENERIC MEASUREMENT OBJECTIVES

This section describes general considerations and the procedures for identifying the more detailed measurement protocol to be followed as found in section 4 (Energized Metallic Objects), section 5 (Residential Contact Areas), and section 6 (Animal Contact Areas). The following sections will detail the common elements of the investigation to include:

- Safety precautions to be used
- Methods to insure accurate measurements
- Considerations for measurements that can assist in defining the source

Generally speaking, nearly all investigations will begin with a complaint, some questions to identify whether or not the complaint is shock related and a determination of whether or not an investigation is warranted. Once a determination of investigation is warranted, the detailed investigation procedures found in 4, 5 and 6 may be followed.

Safety Precautions

Measurements of electrical quantities where the electric power system supplies the energization source have some common safety precautions as follows: Energized metallic object measurements should only be attempted by persons with appropriate electrical safety training and experience. It is a **recommended practice** to perform these measurements in pairs and only with proper safety gear. Workers involved in performing energized object testing should abide by the prescriptions of NFPA 70E, concerning appropriate protective equipment, as well as government regulation codified in OSHA CFR 1910 and CFR 1926 and in the National Electrical Safety Code® (NESC)® (Accredited Standards Committee C2).

Workers trained in performing any of the prescribed measurements throughout this document should be trained in and abide by the appropriate utility safety documents related to:

- Use of Proper Personal Protective Equipment
- Work Area Protection
- Hazard Communication
- First Aid CPR
- The proper use of voltage detectors and meters
- Working near electric sources
- Others as deemed necessary by local, state or federal regulations

When entering enclosure and manholes, there are other specific safety considerations that should be followed such as the use of barricades, gas detectors, etc.

Basic Measurement Considerations

Common measurement considerations for performing the voltage investigation involve the following:

- Identification of the shock complaint location(s)
- Determination of the presence of a voltage at the shock complaint location
- Identification of a "common" reference point

Identification of the Shock Complaint Location(s)

This can typically be accomplished before the assessment takes place based on a question and answer session. Dependent upon the identified location, the equipment lists described in the appropriate section of sections 4, 5 and 6 will allow the investigator to have a check list of materials and equipment to bring along. It is important to set some communication expectations regarding what will be done and how the results of the investigation will be recorded or reported.

Determination of the Presence of a Voltage at the Shock Complaint Location

It should be emphasized that the level of voltage present on an energized object or at a neutral/ground bonding point will vary with weather conditions, circuit loading, intermittent contact of a faulted conductor and even the photo sensors in lighting systems. When a complaint is received, every attempt should be made to thoroughly investigate the complaint area to determine the possibility of an intermittent problem. A voltage logger may be needed to further quantify intermittent voltages. Specific examples where voltage may be intermittently present include:

- High impedance faults due to power system conductors touching an object that can become energized
- Photo sensors in street lights that only allow voltage to appear when the photo-eye is in the closed "on" position
- Power system neutral conductor loading levels where an objectionable NEV exists only during peak times of the day

Identification of a "Common" Reference Point

The remote earth reference point can be variable depending upon currents flowing through the earth at the point selected as the remote reference. The general rule is to select a remote reference point at least 3-4 times the distance of the neutral/ground bonding ground rods length for NEV measurements. Alternatively one can move the remote earth meter probe further away from the point of connection of the other probe connection point until a non-changing reading is obtained.

For Energized Objects, the distance is not significant as long as a clean, bare metallic connection to a reference ground such as a fire hydrant, neutral lug or solidly grounded metallic object is located.

Advanced Measurement Considerations

Advanced measurement considerations when a voltage source has been identified include:

- No Load vs Resistive Load Voltage
- Current Flow
- Spectral Content

No Load vs Resistive Load Voltage

It is a recommended practice to use a 500 ohm, 1000 ohm or a 20,000 ohm resistor (depending on the protocol) to confirm that a measured voltage actually has a source impedance that is low enough to drive currents through the resistor.

Current Flow

A properly rated current transducer in conjunction with the measured voltage on a pole down ground can accommodate some useful determinations of earth resistances, relative NEV values, and possible broken or high impedance neutral connections along a circuit. Additionally, knowing the currents and phase angles of the current carrying phase conductors and knowing the neutral current value will yield a good representation of the current flowing in the earth at the measurement point.

Spectral Content

The use of a harmonics analyzer to record rms and harmonic content of the voltages and currents has been found to be extremely valuable in terms of understanding sources of elevated voltage levels and potentially even some energized object related conductor faults. The next phase of this report will incorporate a section to expand on this important diagnostic development.

4
ANIMAL CONTACT AREA MEASUREMENTS

The impact of stray voltage on animals has been suspected since the 1950s. According to the U.S. Department of Agriculture (USDA) Handbook Number 696 [2], the earliest reported complaints about nuisance electrical currents flowing through dairy cows and possibly affecting production date back to 1948.[4] However, it was not until the late 1970s and early 1980s that the subject began to receive national attention. Most of the basic investigative and measurement procedures emerged during the 1980s, although learning and refinement continues.

Efforts to understand and prevent the shocking of farm animals have been very comprehensive, including animal testing, field measurements, recommendations on levels of concern, implementation of solutions, and many technology-transfer workshops. Much of the research has centered on dairy cows because of the high costs associated with the loss of milk production, but there have also been studies on swine facilities and poultry farms.

Certain states (as listed in Table 4-1) have published levels of concern upon which remedial actions must be pursued. For example, the Wisconsin Public Service Commission (PSC) has recommended maximum voltage levels for animal-contact areas, based upon substantial dairy cow testing which suggests that the perception threshold for nearly all dairy cows tested was greater than or equal to 4 milliamps (derived from a 60HZ ac voltage source). The level of concern is translated based on a 500 ohm specified animal resistance to yield 2 Vac rms as the published level of concern. With this level in mind, the PSC has set the level of concern at one half of that value or "one-volt ac rms." When more that one-half volt as measured at an animal contact point can be attributed to the utility primary system remedial actions should be implemented to reduce the level of stray voltage. With such a small level of concern, it is important to insure that proper measurement protocols are used and calibration verifications on the measurement equipment are implemented.

Table 4-1
State by State Published Levels of Concern for Farm Animals

State	Primary Contact	Standardized Test Procedure?	Level of Concern?	Mitigation Requirements
Wisconsin	Public Service Commission of WI	Yes	1 Vac rms	Isolation optional
New York	New York State Stray Voltage Committee	Yes	No level specified	Isolation at 30V or less available on request
Michigan	Michigan Dept of Agriculture Food and Dairy Inspectors	Yes	2 Vac or Greater 10 Vac Immediate Action Required	Isolation upon Request
Pennsylvania	Pennsylvania Dept of Agriculture	No	0.5 to 2 Vac rms – Depending on Utility	Isolation on Request
Vermont	Vermont Dept of Agriculture	Yes	0.5 Vac rms	Isolation above the level of concern

Test Protocol

The test protocol as published by the Public Service Commission of Wisconsin has been thoroughly tested and review by the EPRI team responsible for developing this report. Recommended practice is to use the Wisconsin test protocol for Farm related investigations. A copy of this document is available at the following url: http://psc.wi.gov/utilityinfo/electric/newsInfo/document/strayVoltage/ph2paper.pdf

The detailed protocol in the Wisconsin publication provided the procedures and forms for the investigation. The following sections provide supplemental information to use in conjunction with the protocol to assist the investigator.

Objectives

The basic objectives of the investigation are to ultimately determine:

1. The presence or absence of a stray voltage and or NEV at various locations on the farm
2. The presence or absence of proper bonding at the subject locations
3. The sources of the measured voltages at the subject locations
4. The requirements if any to perform remedial actions to reduce voltage levels

Safety Considerations

Energized metallic object measurements should only be attempted by persons with appropriate electrical safety training and experience. It is a **recommended practice** to perform these measurements in pairs and only with proper safety gear. Workers involved in performing energized object testing should abide by the prescriptions of NFPA 70E, concerning appropriate protective equipment, as well as government regulation codified in OSHA CFR 1910 and CFR 1926 and in the National Electrical Safety Code® (NESC)® (Accredited Standards Committee C2).

Workers trained in performing any of the prescribed measurements throughout this document should be trained in and abide by the appropriate utility safety documents related to:

- Use of Proper Personal Protective Equipment
- Work Area Protection
- Hazard Communication
- First Aid CPR
- The proper use of voltage detectors and meters
- Working near electric sources
- Others as deemed necessary by local, state or federal regulations

Equipment/Materials Needed

Recommended equipment for the on-farm investigation includes:

Basic:

- Resistors: 500 ohm and 1000 ohm
- True RMS meters capable of, AC and DC voltage/current measurements
- Remote earthing rod
- Metal plate
- Ground resistance meter
- Several 200 ft wire spools
- 120V/240V load box
- Recording forms

Advanced:

- Voltage trending equipment
- Harmonics analyzer
- Gauss Meter

Measurement Protocol

Following the PSC Wisconsin Protocol the investigator should complete the measurements required to fill in the values for Table 4-1 based on the defined terms in the same table.

The procedure essentially established baseline and worst case measurements where the objective is to be able to determine the utility primary neutral contribution to the stray voltage at the animal contact point, the farm load contribution, possible equipment contributions.

The basic measurements involved in the protocol will define:

1. The voltage for the utility primary neutral with respect to a remote earth reference
2. The voltage for the neutral of the building under investigation with respect to the remote earth reference
3. The animal contact point voltage

Table 4-2
Terms, Definitions and Electrical Measurement Input Form.

Vcc		Cow contact voltage, same as Vcr[1]. If not otherwise noted, Vcc represents the voltage measured across a 500 ohm resistor placed in series between a water pipe (pr other cow contact surface) and a copper plate placed on the floor of the milking parlor. Vcc measurements are not made with any direct connection to remote ground.
Vpr		Primary neutral to remote ground voltage, same as Vp[2]. The primary neutral connection is typically made to the neutral grounding electrode conductor associated with the distribution transformer serving the farm under test.
Vsr		Secondary neutral to remote ground voltage, same as Vs[3]. The secondary neutral connection is typically made to the ground bus in the service panel associated with the milking parlor or other farm building under test.
K factor		The "ratio of the animal contact voltage to the secondary neutral-to-earth voltage.[4]" K factor or K = Vcc/Vsr
Rt		Rt is the primary source impedance based on a Thevenin equivalence calculated based on the ratio of the change in primary voltage to the change in primary current into the distribution transformer from high load to low load. The formula is present in "Appendix A-2a," of the "PSC Staff Report[5]."
Rpn		Rpn is the primary neutral source impedance based on a Thevenin equivalence calculated based on the ratio of the change in primary voltage to the change in primary neutral current associated with a distribution transformer from high load to low load. The formula is present in "Appendix A-2a," of the "PSC Staff Report[6]."
Kp		Kp is the "ratio of the animal contact voltage (Vcc) to the primary neutral to remote earth voltage (Vpr). It is assumed that without any line to neutral secondary farm loads, Kp = K factor. Kp =Vcc/Vpr

[1] ASAE meeting presentation, "Relationships Between Secondary Neutral and Cow Contact Voltages," Page 3, measurement points 4 and 5, Paper No. 963072, July 1996 [5].
[2] ASAE meeting presentation, "Relationships Between Secondary Neutral and Cow Contact Voltages," Page 3, measurement points 1 and 2, Paper No. 963072, July 1996 [6].
[3] ASAE meeting presentation, "Relationships Between Secondary Neutral and Cow Contact Voltages," Page 3, measurement points 1 and 3, Paper No. 963072, July 1996 [7].
[4] ASAE meeting presentation, "Relationships Between Secondary Neutral and Cow Contact Voltages," Page 4, Paper No. 963072, July 1996 [8].
[5] "PSC Staff Report: The Phase II Stray voltage Testing Protocol," Richard S. Reines and Mark A. Cook, Rural Electric Power Services Public Service Commission of Wisconsin, February 1999 [9].

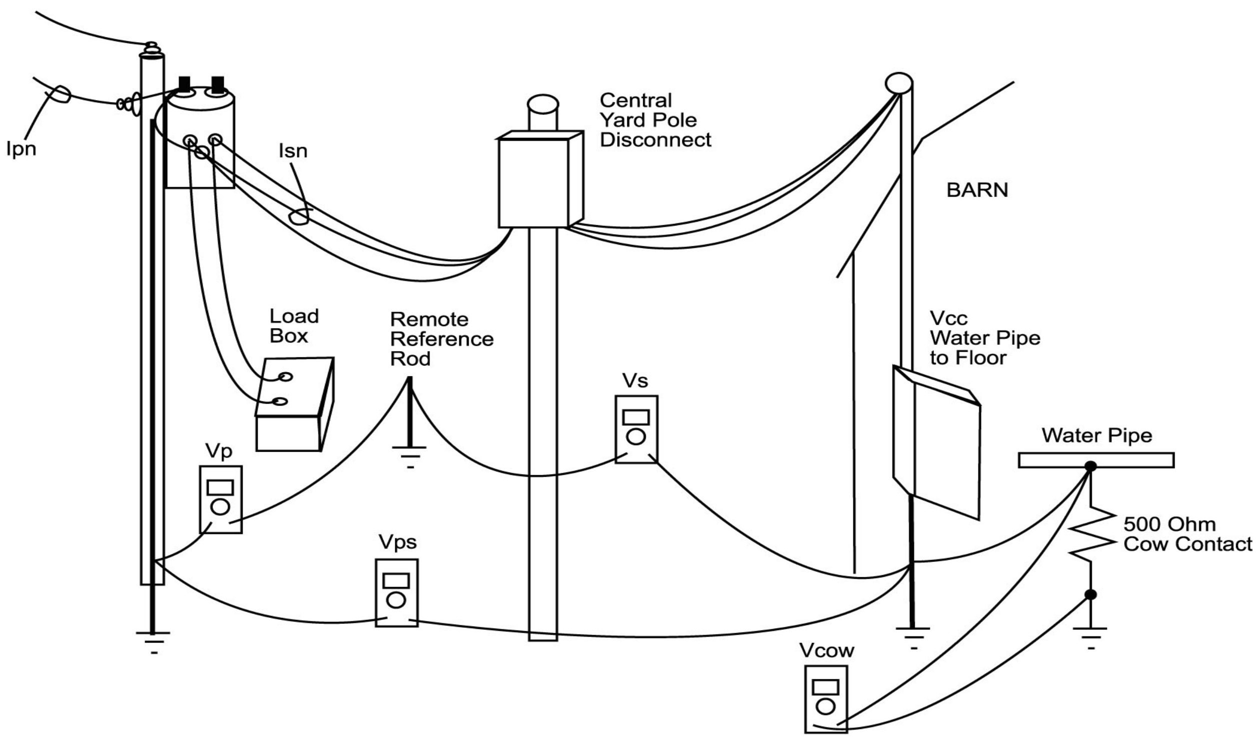


Figure 4-1
Test Setup for Baseline 60Hz and Harmonic Snapshot Field Tests

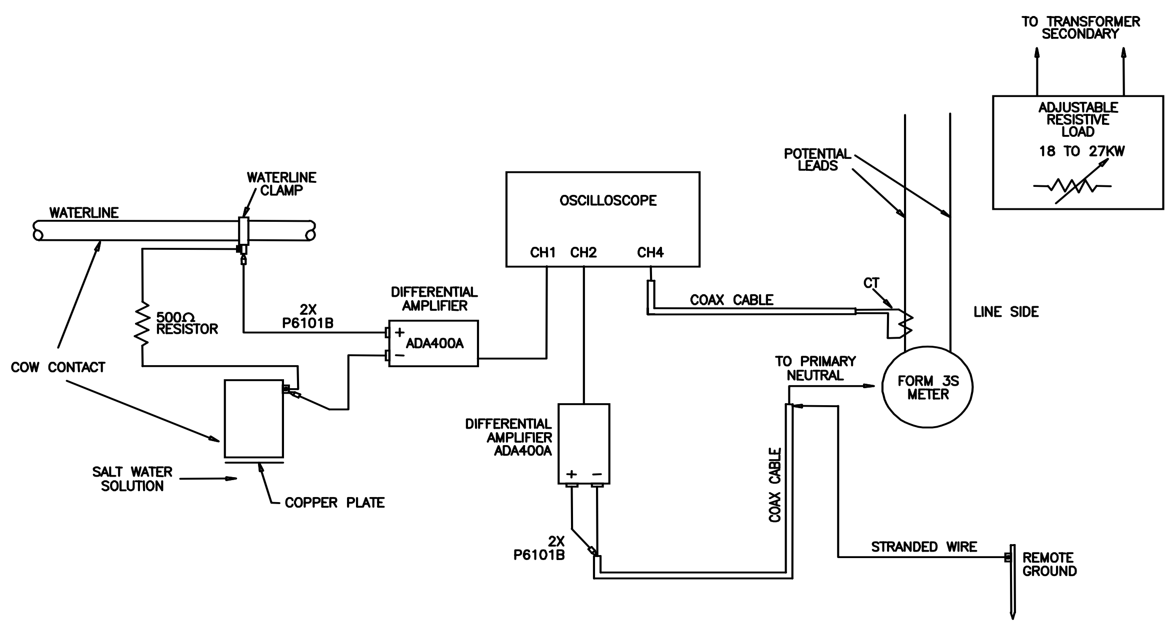


Figure 4-2
Test Setup for Transient Voltage Assessment Field Tests

5

RESIDENTIAL CONTACT AREA MEASUREMENTS

Reports of shocking at swimming pools, hot tubs, showers and faucets have been common since the 1970s, but the subject was not readily discussed in a collaborative way and utilities did not share cases until the 1990s. Most of the investigative and measurement procedures were developed in the 1980s, and refinements continue today. Key causes of such shock hazards include:

- Metallic parts not being properly bonded per requirements of the National Electrical Code (NEC)
- Unbalanced voltages on the distribution circuit
- High currents through a neutral impedance
- Customer load faults
- Open neutral conductors and connections

The efforts to identify and resolve shock hazards at swimming pools and hot tubs include field measurements, information on human perception (levels of concern), implementation of solutions, and a number of papers and documents related to cause and remedy.

This section details the measurement protocols and procedures for measurements at service panels, swimming pools, hot tubs, water faucets and conduits. The procedures follow the basic techniques described in the 1999 EPRI Document TR113566 "Identifying and Diagnosing Residential Shocking Complaints with some noted supplemental materials related to some of the more advanced diagnostic measurements using harmonics analyzers.

Safety Precautions

Energized metallic object measurements should only be attempted by persons with appropriate electrical safety training and experience. It is a **recommended practice** to perform these measurements in pairs and only with proper safety gear. Workers involved in performing energized object testing should abide by the prescriptions of NFPA 70E, concerning appropriate protective equipment, as well as government regulation codified in OSHA CFR 1910 and CFR 1926 and in the National Electrical Safety Code® (NESC)® (Accredited Standards Committee C2).

Workers trained in performing any of the prescribed measurements throughout this document should be trained in and abide by the appropriate utility safety documents related to:

- Use of Proper Personal Protective Equipment
- Work Area Protection
- Hazard Communication
- First Aid CPR
- The proper use of voltage detectors and meters

- Working near electric sources
- Others as deemed necessary by local, state or federal regulations

Measuring Voltage Between Pool (or Hot Tub) Water and Ladder Steps or Handrail

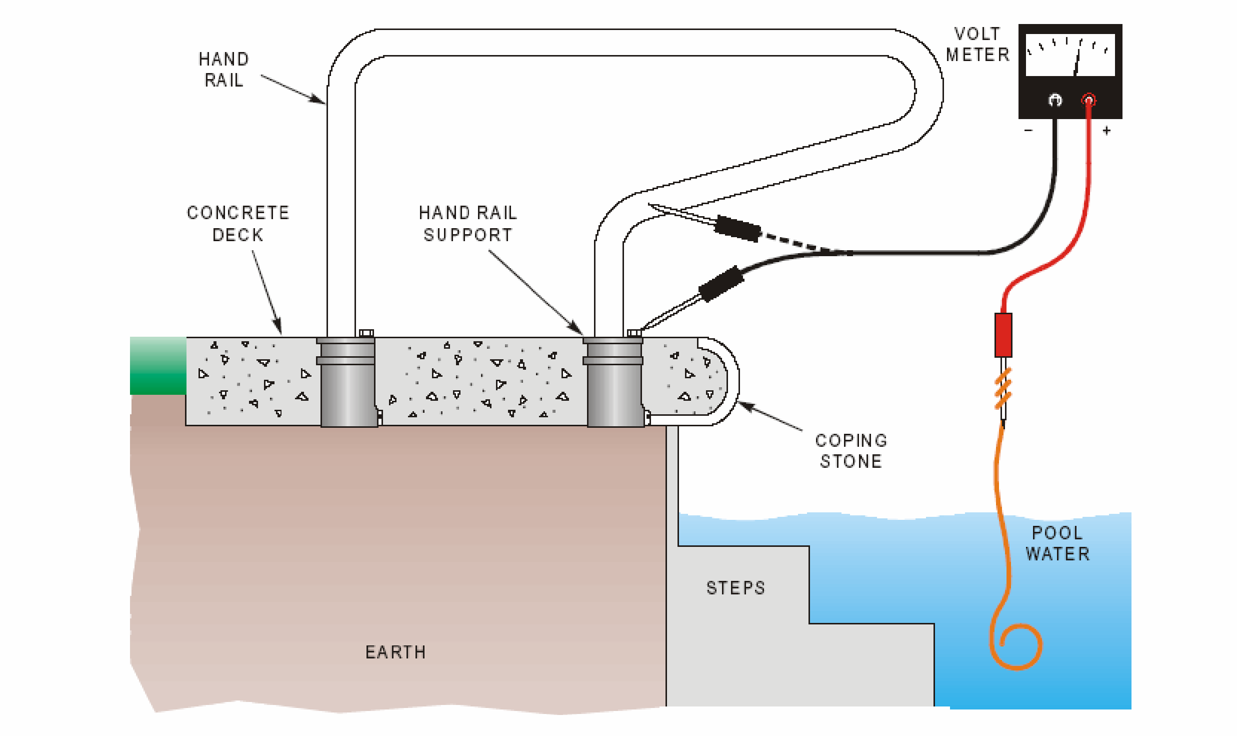


Figure 5-1
Measuring Voltage Between Pool Water and Ladder Steps or Handrail

Materials Needed:

- High-impedance AC voltmeter
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure:

1. Wet the concrete area around the ladder or handrail supports.
2. Drop the "+" probe of the AC voltmeter in the pool water. Caution: To prevent damage to the volt meter probe, use a short length of wire attached to the "+" probe to dip into the water.
3. Place the "-" meter probe against the metal of the ladder or handrail to measure the voltage between it and the pool water.

4. Measure the voltage between the pool water and the ladder/handrail supports.
5. Record the measurements and time of day they were taken.
6. Repeat steps 1, 2, 3, 4 & 5 for each ladder or handrail indicated as a shocking voltage location by the customer.
7. Repeat entire process with DC voltmeter.
8. Repeat entire process with a Harmonics Analyzer and save the voltage spectrum info.

Measuring Voltage Between Pool Water and Coping Stone

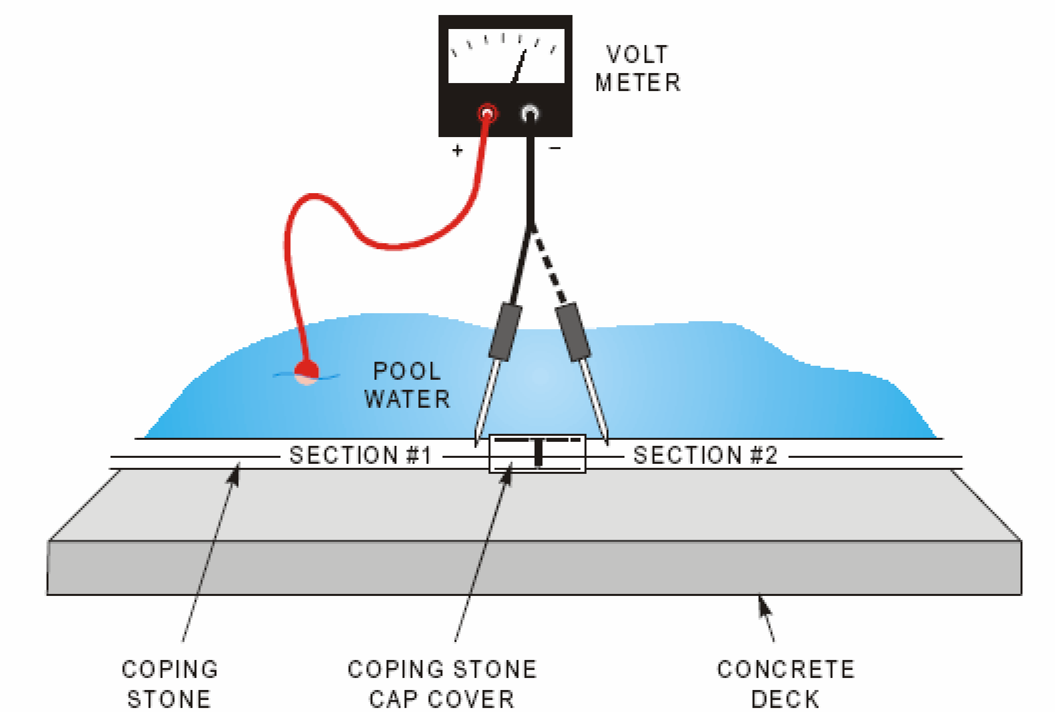


Figure 5-2
Measuring Voltage Between Pool Water and Coping Stone

Materials Needed:

- High-impedance AC voltmeter
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure:

1. Make a top-view (or plan view) sketch of the swimming pool, noting each section of coping stone around its edge.
2. Find a scratch or small spot of exposed metal on a section of coping stone.
3. Drop the "+" probe of the AC voltmeter in the pool water. Caution: To prevent damage to the voltmeter probe, use a short length of wire attached to the "+" probe to dip into the water.
4. Measure the voltage between the pool water and the bare spot on the coping stone.
5. Record the reading and time of day on your sketch.
6. Repeat for each section of coping stone in areas indicated as shocking voltage locations by customer.
7. Repeat steps 2, 3, 4, 5 & 6 with a DC voltmeter.
8. Repeat steps 2, 3, 4, 5 & 6 with Harmonics Analyzer and save the voltage spectrum info.

Measuring Voltage Between Pool Water and Concrete Deck

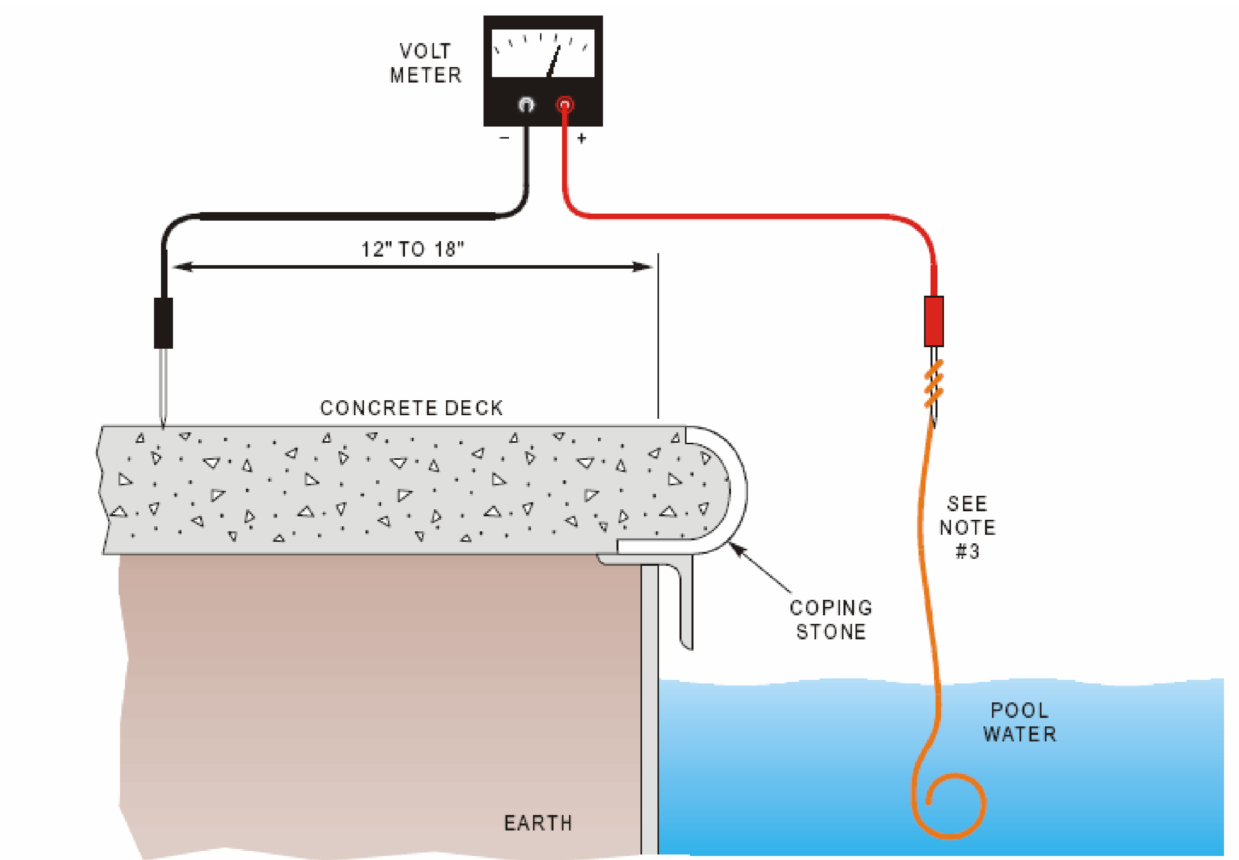


Figure 5-3
Measuring Voltage Between Pool Water and Concrete Deck

Materials Needed:

- High-impedance AC voltmeter
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure:

1. Wet the concrete deck.
2. Drop the “+” probe of the AC voltmeter in the pool water. Caution: To prevent damage to the voltmeter probe, use a short length of bare wire attached to the “+” probe to dip into the water
3. Place “-“ voltmeter probe on wet concrete deck, 12” to 18” from edge of pool (clear of coping stone).
4. Measure voltage from the pool water to the wet concrete deck.
5. Record voltage reading and time of day it was taken.
6. Repeat steps 2, 3, 4 & 5 with a DC voltmeter.
7. Repeat steps 2, 3, 4 & 5 with a Harmonics Analyzer and save the voltage spectrum info.

Measuring Voltage Between a Water Faucet and Earth

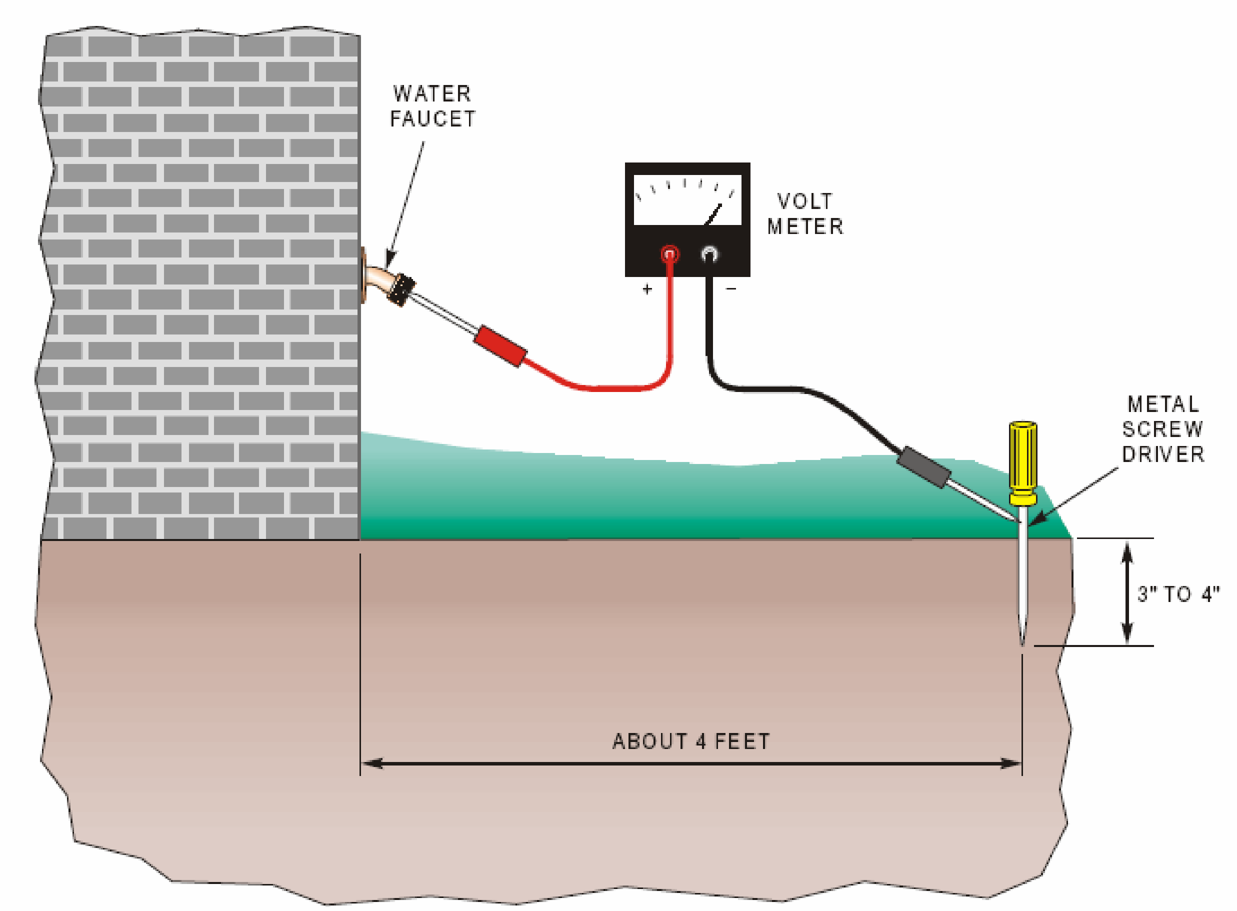


Figure 5-4
Measuring Voltage Between a Water Faucet and Earth

Materials Needed:

- High-impedance AC voltmeter
- Screw Driver
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure:

1. Push a metal screwdriver into the ground to a depth of 3” or 4”, approximately 4 feet from the water faucet.
2. Place the “-“ probe of the AC voltmeter against the screwdriver, and the “+” probe on the faucet.

3. With a high-impedance AC voltmeter, measure the voltage from the screwdriver to the water faucet.
4. Record the measurement and time of day it was taken.
5. Repeat steps 2, 3 & 4 with a DC voltmeter.
6. Repeat steps 2, 3 & 4 with a Harmonics Analyzer and save the voltage spectrum info.

Measuring Voltage Between an Air Duct and Earth

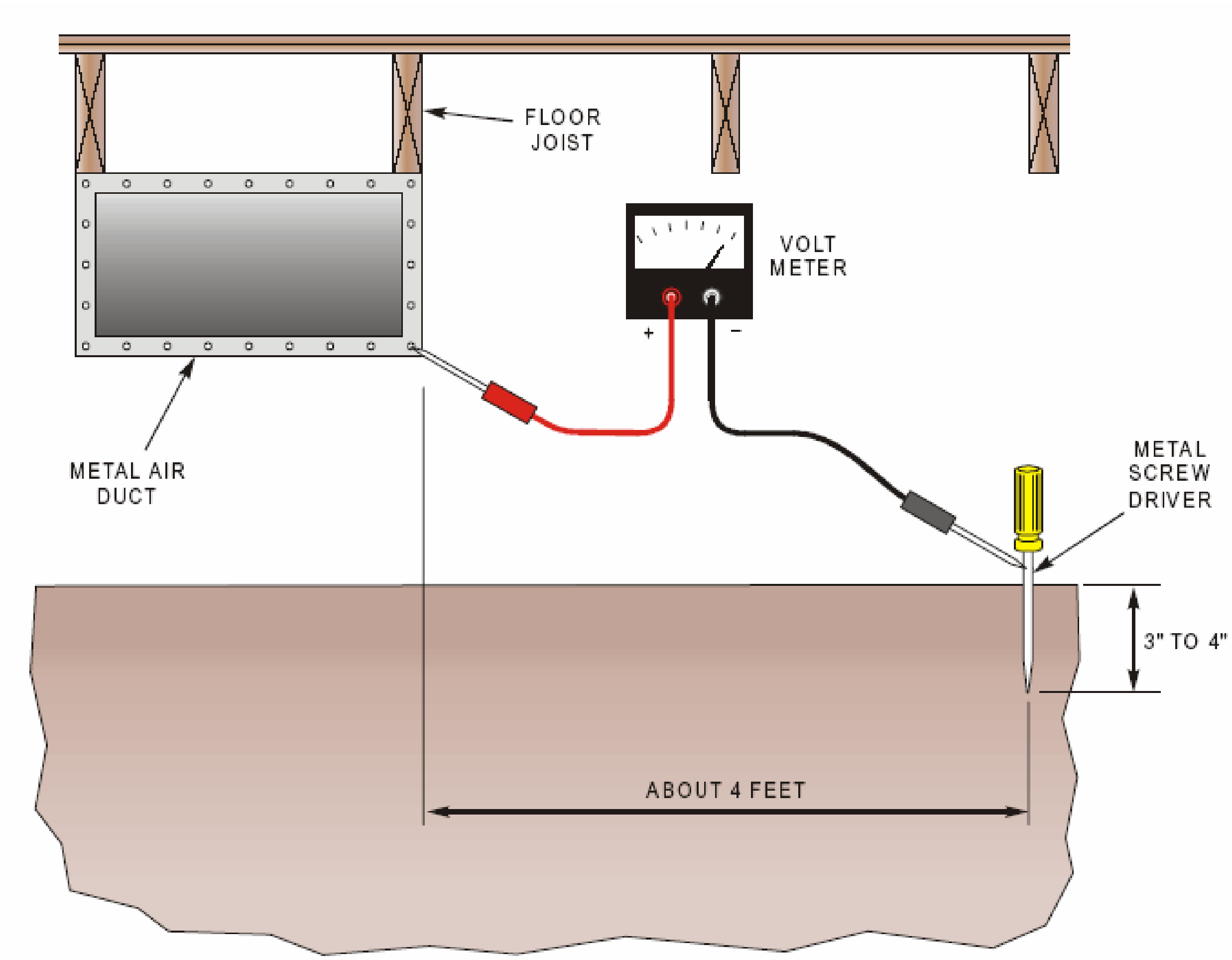


Figure 5-5
Measuring Voltage Between an Air Duct and Earth

Materials Needed:

- High-impedance AC voltmeter
- Screw Driver
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure:

1. Push a metal screwdriver into the ground to a depth of 3" or 4", approximately 4 feet away from the metal air duct.
2. With a high-impedance AC voltmeter, measure the voltage from the screwdriver to the air duct ("-" probe on screwdriver, "+" probe on air duct).
3. Record the measurement and the time of day it was taken.
4. Repeat steps 2 & 3 with a DC voltmeter.
5. Repeat steps 2 & 3 with a Harmonics Analyzer and measure and save voltage spectrum info.

Measuring Voltage Between Pole Ground and Earth

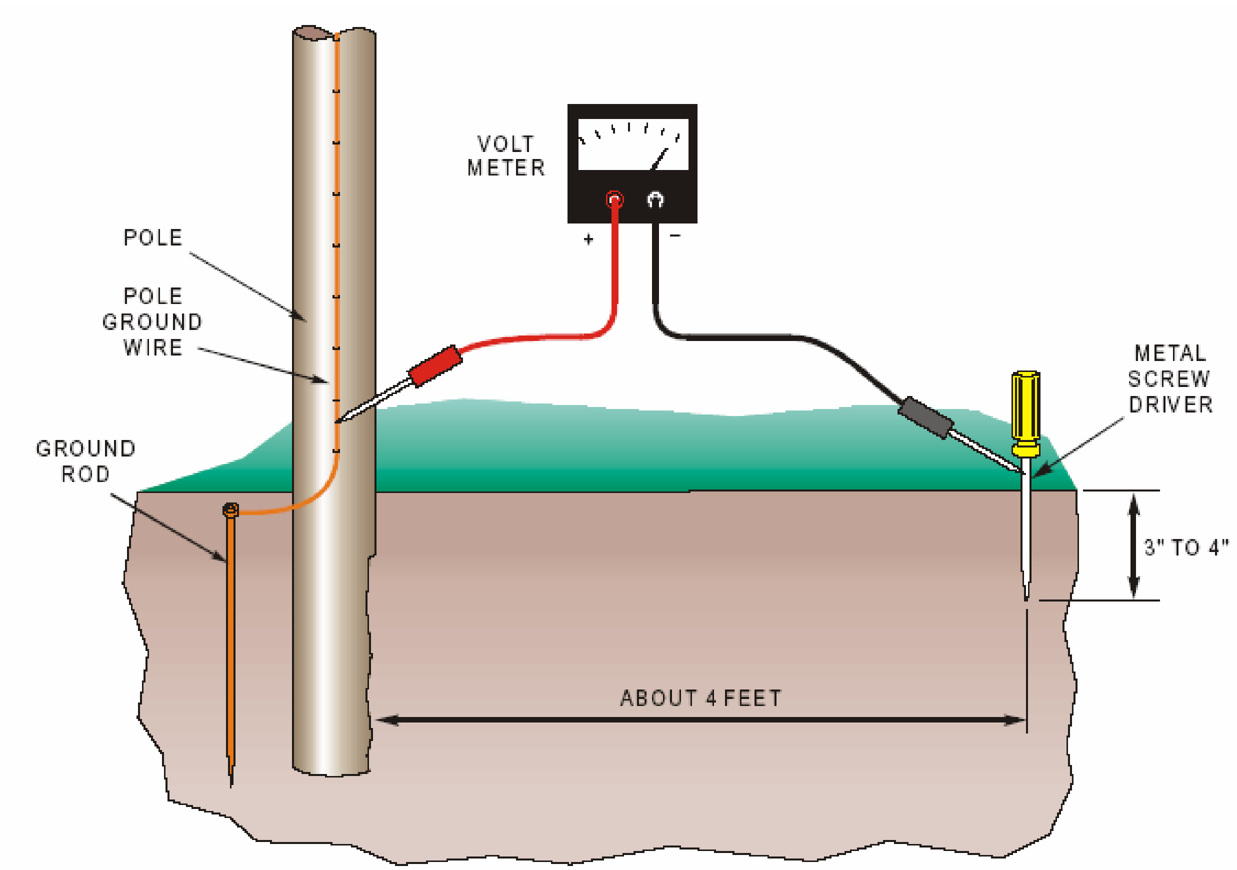


Figure 5-6
Measuring Voltage Between a Pole Down Ground and Earth

Materials Needed:

- High-impedance AC voltmeter
- Screw Driver
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure:

1. Push a metal screwdriver into the ground to a depth of 3” or 4”, approximately 4 feet away from the power pole. Note: When pushing the screwdriver into the ground, do not let it contact the pole’s ground rod, down guys, primary & secondary cables, metal pipes, or any other obstructions that might influence the voltage measurement.
2. With a high-impedance AC voltmeter, measure the voltage from the screwdriver to the pole ground.
3. Record the measurement and the time it was taken.
4. Move the screwdriver 45 degrees around the pole from its initial location, push it into the ground, and take another voltage measurement to verify the first one.
5. Record the second measurement and the time it was taken.
6. Repeat steps 2, 3, 4 & 5 with a DC voltmeter.
7. Repeat steps 2 & 3 with a Harmonics Analyzer and measure and save voltage spectrum info.

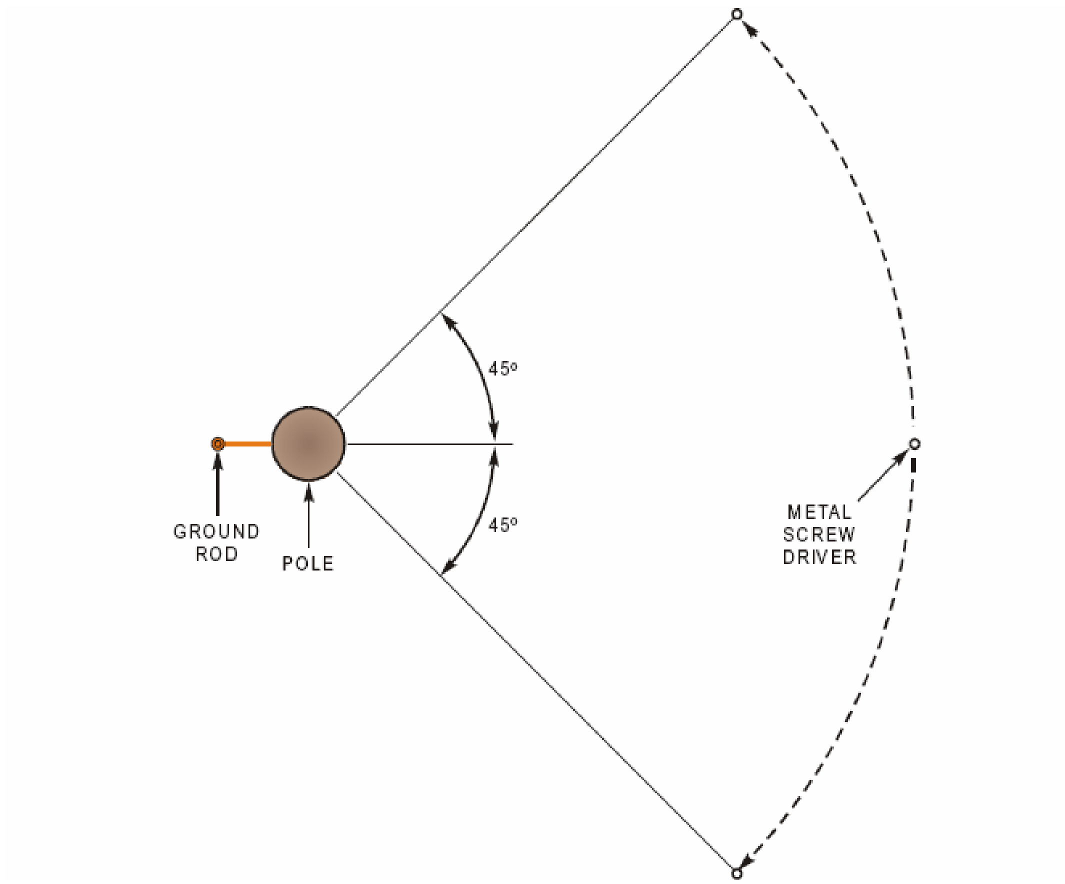


Figure 5-7
Making Multiple Measurements to Insure Accuracy in the Readings

6
ENERGIZED METALLIC OBJECT CONTACT AREA MEASUREMENTS

Background

Test and Measurement procedures for identifying electrically energized objects vary considerably depending upon the objectives of the investigation. For example, performing checks of energized objects as part of a recurring maintenance survey process typically requires only verification of the presence of voltage with a capacitive light tester. Once an accidental energization has been identified, More sophisticated diagnostic and metering equipment is required to quantify the voltage and source characteristics. It is also important to follow proper testing and measurement protocols in order to adequately document the level of voltage found, the source, and the level of voltage after remediation efforts have been taken.

When identifying energized metallic objects, the first objective is to assume that an electrical hazard is present unless the metering equipment provides an indication that it is not. If an electrical hazard is present, it is important to secure the area with warning or caution barriers such that humans and animals are unlikely to contact the energized object(s) until they can be de-energized and repaired.

This protocol focuses on determining the presence of the energized object and measuring the voltage related parameters associated with the object. Future efforts will supply measurement techniques that will aid the investigator in determining whether the source of the voltage is induced, radiated or conducted.

Safety Precautions

Measurements of electrical quantities where the electric power system supplies the energization source have some common safety precautions as follows: Energized metallic object measurements should only be attempted by persons with appropriate electrical safety training and experience. It is a recommended practice to perform these measurements in pairs and only with proper safety gear. Workers involved in performing energized object testing should abide by the prescriptions of NFPA 70E, concerning appropriate protective equipment, as well as government regulation codified in OSHA CFR 1910 and CFR 1926 and in the National Electrical Safety Code® (NESC)® (Accredited Standards Committee C2).

Workers trained in performing any of the prescribed measurements throughout this document should be trained in and abide by the appropriate utility safety documents related to:

- Use of Proper Personal Protective Equipment
- Work Area Protection
- Hazard Communication
- First Aid CPR
- The proper use of voltage detectors and meters
- Working near electric sources
- Others as deemed necessary by local, state or federal regulations

When entering enclosure and manholes, there are other specific safety considerations that should be followed such as the use of barricades, gas detectors, etc.

Objectives

Defining the objectives of the investigation will define the procedure to be followed. The generic objectives are as follows:

1. Energized Object Survey: When the objective is to quickly assess the presence of electrically energized objects throughout a service territory, the requirement is fairly simple requiring only recording forms and voltage indicators or volt meters.
2. Voltage Source or Level Quantification Survey: When complaints are received or an energized object is detected during a routine survey, more detailed investigation is typically useful to insure that statistical objectives may be met when analyzing the information from a database. More detailed recording forms plus instrumentation capable of voltage and or current quantification is required.

Measuring Voltage Between a Metallic Pole and a Remote Earth Reference Point

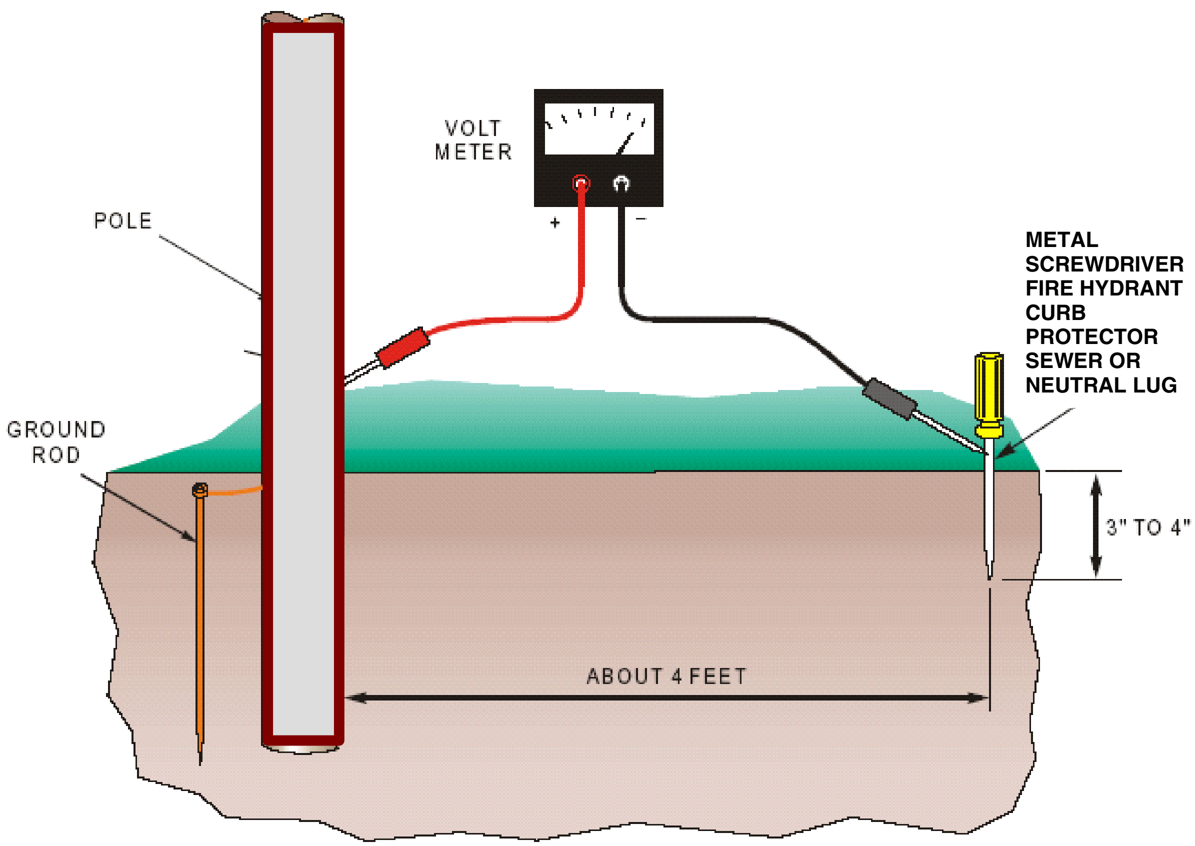


Figure 6-1
Measuring Voltage Between a Metallic Pole and a Remote Earth Reference Point

Materials Needed:

- Capacitive voltage tester
- High-impedance AC voltmeter
- Screw Driver (or paint scraper)
- Harmonics Analyzer
- DC voltmeter
- Recording Forms
- Watch

Procedure When Gravel or Earth is Readily Available:

Note: Depending on the survey objective, this procedure may be as simple as step one only or as complex as the complete set of steps 1 through 8.

1. Using an operational non-contact voltage indicator, such as a the EXTECH LM5™, position the unit within 6 inches of the object under test. If the unit indicates the presence of a voltage, go to step 2.
2. Push a metal screwdriver into the ground to a depth of 3” or 4”, approximately 4 feet away from the metallic object. Note: When pushing the screwdriver into the ground, do not let it contact the pole’s ground rod, down guys, primary & secondary cables, metal pipes, or any other obstructions that might influence the voltage measurement.
3. With a high-impedance AC voltmeter, measure the voltage from the screwdriver to the pole ground.
4. Record the measurement and the time it was taken.
5. Move the screwdriver 45 degrees around the pole from its initial location, push it into the ground, and take another voltage measurement to verify the first one.
6. Record the second measurement and the time it was taken.
7. Repeat steps 2, 3, 4 & 5 with a DC voltmeter.
8. Repeat steps 2 & 3 with a Harmonics Analyzer and measure and save voltage spectrum info.

Procedure For Urban Investigations (No Gravel or Earth Readily Available):

Note: Depending on the survey objective, this procedure may be as simple as step one only or as complex as the complete set of steps 1 through 9.

1. Using an operational non-contact voltage indicator, such as a the EXTECH LM5, position the unit within 6 inches of the object under test. If the unit indicates the presence of a voltage, go to step 2.
2. Located one or more suitable ground reference points. These ideal reference points are clean, unpainted metallic surfaces such as curb protectors at least 10 feet in length, neutral lugs, bare metal locations on fire hydrants, uninsulated, water pipes, earthed metallic conduits etc.
3. With a high-impedance AC voltmeter, measure the voltage from the object under test to the ground reference.
4. Record the measurement, time it was taken, the ground reference object used and the condition (rusty, painted, scraped metal point, etc.)
5. Select a second suitable ground reference point and confirm the initial reading.
6. If a second suitable ground reference point is unavailable, select other local metallic objects and measure between those objects and the object under test. Attempt to verify the readings taken in 11.
7. Record the second measurement and the time it was taken.
8. Repeat steps 2, 3, 4 & 5 with a DC voltmeter.
9. Repeat steps 2 & 3 with a Harmonics Analyzer and measure and save voltage spectrum info.

Figure 6-2
Sample Measurements Between a Metal Light Pole and a Reference Ground

Figure 6-3
Sample Measurements Between a Gas Service Point and a Reference Ground

Figure 6-4
Sample Measurements Between a Grounded Meter Base and a Reference Ground

Figure 6-5
Sample Measurements Between a Pole Down Ground and a Reference Ground

7

EQUIPMENT MEASUREMENT ACCURACY VERIFICATION

It is necessary to establish a reasonable amount of confidence in the accuracy of the equipment used to perform electric power measurements. Normally this is satisfied through traceable NIST calibration certification stamps on the equipment. Because the equipment involved in stray voltage investigations is portable and may be subject to environmental changes and physical shock conditions during transportation, it is important to field validate the accuracy of the subject measurement equipment.

This may be accomplished by taking one metering device and comparing it to the reading obtained from a second device connected to the same measurement points. Alternatively it is useful to develop a means and procedure to accomplish quick equipment measurement verifications at each test site using a signal and voltage verification device. The device is designed for this application and provides a means of comparing the field equipments accuracy to that of NIST traceable calibrated laboratory equipment. Comparing the field equipment measurement values to the values listed in the attached procedure before the field measurements are taken for the record provides an easy way to certify the field equipment measurement accuracy. The following figure and associated measurement spreadsheet provide an example of such a method.

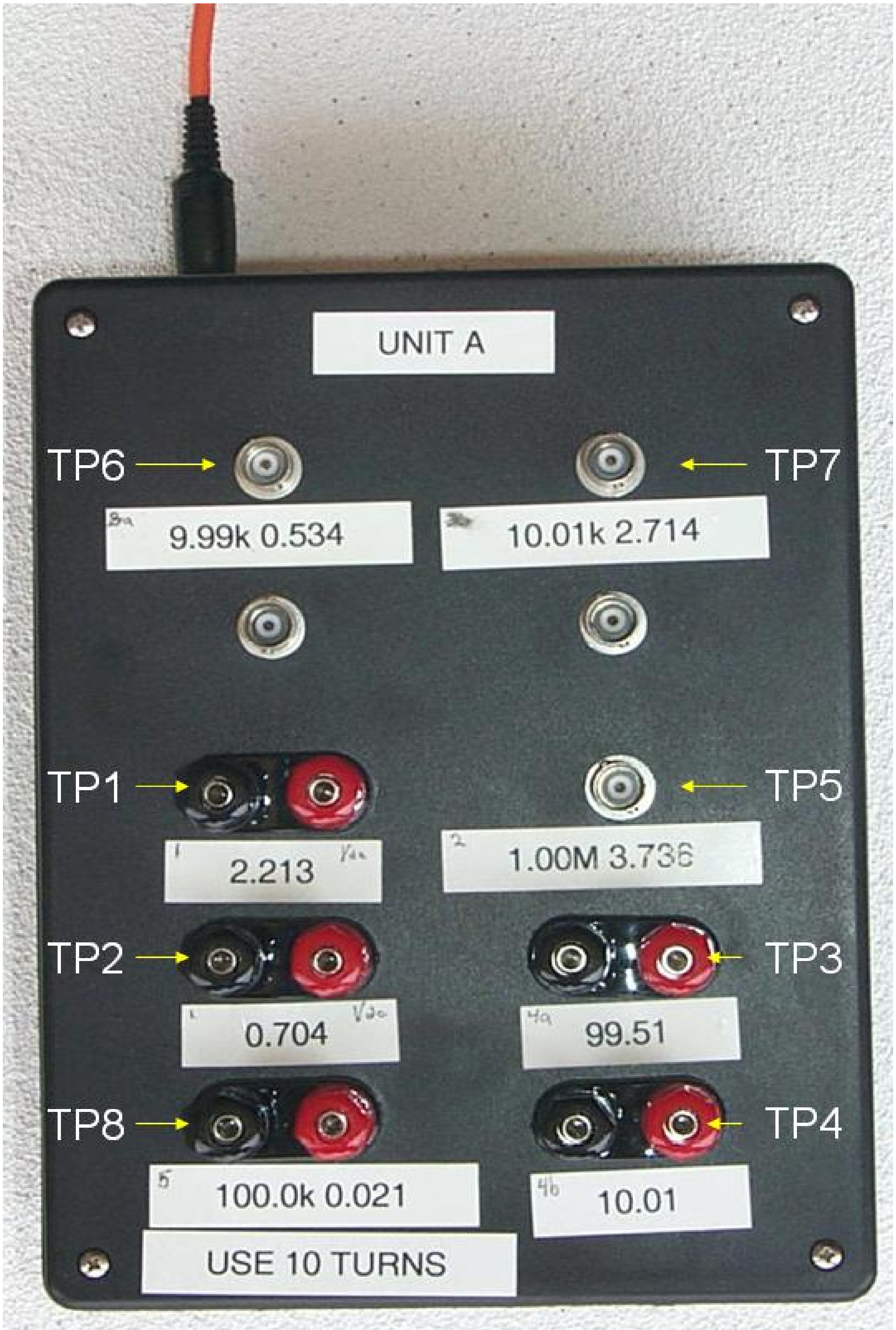


Figure 7-1
Example Field Calibration Verification Box

Equipment Measurement Accuracy Certification

Location:_________________________

Tester Name:_____________________

1. Voltage Reading Instruments:

1. Select the appropriate scale if required to measure 4.3 Volts DC
2. Connect the Voltage Input HI to TP1
3. Connect the Common to TP1 Common

The measurement should read within 2% of ___________

Actual Value Measured:_________________

4. Select the appropriate scale if required to measure 0.6 Volts
5. Connect the Voltage Input HI to TP2
6. Connect the Common to TP2 Common

The measurement should read within 2% of ___________

Actual Value Measured:_________________

2. Voltage and Time-Domain Reading Instruments 100 kHz at 1 Volt Peak:

1. Select the appropriate scale if required to measure 1 Volts
2. Select the time base for ____ µs
3. Connect the Voltage Input HI to TP3
4. Connect the Common to TP3 Common

The peak amplitude measurement should read within 2% of __________ V_{pk}

Actual Value Measured:_________________

The frequency should read within 2% of _______ kHz

Actual Value Measured:_________________

5. Select the appropriate scale if required to measure 0.6 Volts
6. Connect the Voltage Input HI to TP4
7. Connect the Common to TP4 Common

The peak amplitude measurement should read within 2% of __________ V_{pk}

The frequency should read within 2% of _______ kHz

Actual Value Measured:_________________

3. Voltage and Time-Domain Reading Instruments 10 kHz at 0.6 Volt Peak:

1. Select the appropriate scale if required to measure 0.6 Volts
2. Select the time base for ____ μs
3. Connect the Voltage Input HI to TP5
4. Connect the Common to TP5 Common

The peak amplitude measurement should read within 2% of __________ V_{pk}

Actual Value Measured:_________________

The frequency should read within 2% of _______ kHz

Actual Value Measured:_________________

5. Select the appropriate scale if required to measure 0.6 Volts
6. Connect the Voltage Input HI to TP6
7. Connect the Common to TP6 Common

The peak amplitude measurement should read within 2% of __________ V_{pk}

Actual Value Measured:_________________

The frequency should read within 2% of _______ kHz

Actual Value Measured:_________________

4. Resistance Reading Instruments:

1. Select the appropriate scale if required to measure 100 ohms
2. Connect the Voltage Input HI to TP7
3. Connect the Common to TP7 Common

The resistance should read with in 2% of __________ Ω

Actual Value Measured:_________________

4. Select the appropriate scale if required to measure 500 ohms
5. Connect the Voltage Input HI to TP8
6. Connect the Common to TP8 Common

The resistance should read within 2% of __________ Ω

Actual Value Measured:_________________

5. Current Transformers Burden or Self Burden 100 kHz at 50 milliamperes:

1. Select the appropriate scale if required to measure 0.05 Volts
2. Select the time base for ____ µs
3. Connect the 10 ten loop TP9
4. Connect the Common to TP9 Common
5. Insert the CT in the ten-turn loop.

The peak amplitude measurement should read within 5% of ______ mV_{pk} when corrected for CT ratio.

Actual Value Measured:_________________

The frequency should read within 2% of _______ kHz

Actual Value Measured:_________________

6. Current and Time Reading Instruments 100 Hz at 50 milliamperes:

1. Select the appropriate scale if required to measure 0.05 Volts
2. Select the time base for ____ µs
3. Connect the 10 ten loop TP10
4. Connect the Common to TP10 Common
5. Insert the CT in the ten-turn loop.

The peak amplitude measurement should read within 5% of ______ mV_{pk} when corrected for CT ratio.

Actual Value Measured:_________________

The frequency should read within 2% of _______ kHz

Actual Value Measured:_________________

7. Resistance High Frequency Current Clamp

Resistance Current Clamps such as those manufactured by AEMC usually come equipped with calibration verification resistance loops.

1. Select the appropriate scale if required to measure 25 ohms
2. Connect the CT across the 25 ohm loop.

The resistance should read within 5% of __________ Ω

Actual Value Measured:_________________

3. Select the appropriate scale if required to measure 45 ohms
4. Connect the CT across the 45 ohm loop.

The resistance should read within 5% of __________ Ω

Actual Value Measured:_________________

5. Select the appropriate scale if required to measure 100 ohms
6. Connect the CT across the 100 ohm loop.

The resistance should read within 5% of __________ Ω

Actual Value Measured:_________________

The undersigned certifies that the appropriate certification tests from those listed in the preceding sections were conducted on the field instruments and the recorded results were within the specified limits.

Name:____

Signature:____________________________ **Date**________________

8
REFERENCES

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5. ASAE meeting presentation, “Relationships Between Secondary Neutral and Cow Contact Voltages,” Page 3, measurement points 4 and 5, Paper No. 963072, July 1996.
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9. “PSC Staff Report: The Phase II Stray voltage Testing Protocol,” Richard S. Reines and Mark A. Cook, Rural Electric Power Services Public Service Commission of Wisconsin, February 1999.

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3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com