Standardized Measurements for Elevated NEV and Energized Object Concerns

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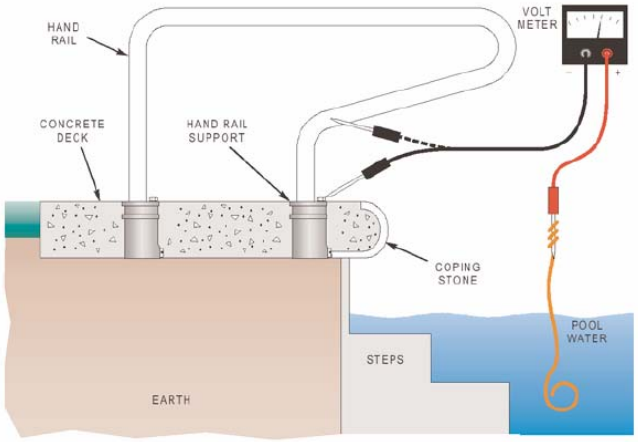


Presentation Summary

- Brief overview of past and present EPRI experiences related to contact voltages
- Brief overview of the 2005-2009 EPRI Stray Voltage Strategic Roadmap
- Some items where definitions will help support measurement protocols
- A few supporting examples of “induced voltages” and “harmonic NEV” that demonstrate the need for an IEEE guide that focuses at least “in part” on standardized measurement protocols
- Suggestions on Future Stray Voltage Work

Questions and Concerns Fielded by the EPRI Solutions Power Quality Hotline 1994-2006

- Personnel safety concerns related to touch potentials
- Animal contact area concerns related to health and productivity impacts
- Residential water and gas pipe shocking concerns
- Harmonic frequency voltages imposed on industrial gas lines
- Power circuit resonance conditions creating elevated NEV levels
- Shocking concerns with boat docks
- Insulated metallic pipe corrosion concerns
- Impacts of power line carrier communications technologies and other transient generating devices at contact locations
- Impacts of new gas and water line installations in power line right of ways
- Induced voltages onto fences and light poles
- Tingling sensations at swimming pools and outdoor water faucets
- Different opinions on measurement equipment specifications, measurement protocols and measurement durations

EPRI Stray Voltage Research Roadmap

- The prioritized research plan identified five areas of opportunity where supplemental or new research was needed:
  - Test and measurement protocols
  - Modeling and simulation guidelines
  - Test equipment and mitigation methods
  - Technology transfer Informational website
  - Regulatory guidance (NEV and MOEV baselines and what voltage levels are not a concern)

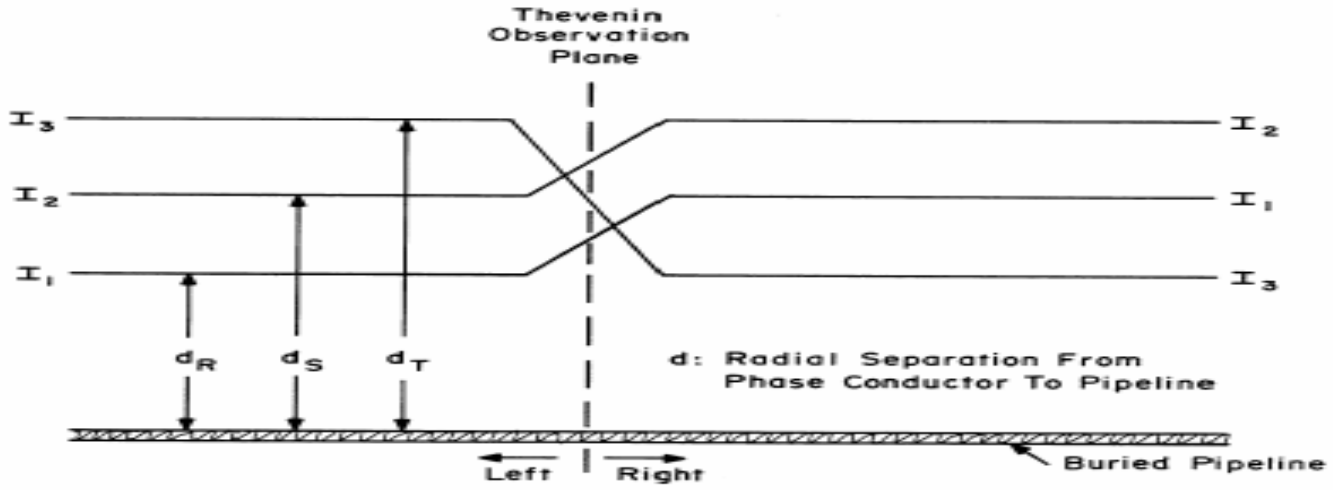
EPRI Program 128 Base Research Project Objectives and Solutions

- EPRIs present industry support plans related to elevated neutral to earth voltage and metallic object to earth voltage concerns
  - 2005 – Informational website, measurement protocols
  - 2006 – Develop distribution system modeling and simulation guidelines
  - 2007 – Testing on mitigation and measurement devices and perform survey of NEV levels on distribution systems
  - 2008 – 09 Regulatory informational support, design “best practices” and other R&D as directed by the project sponsors

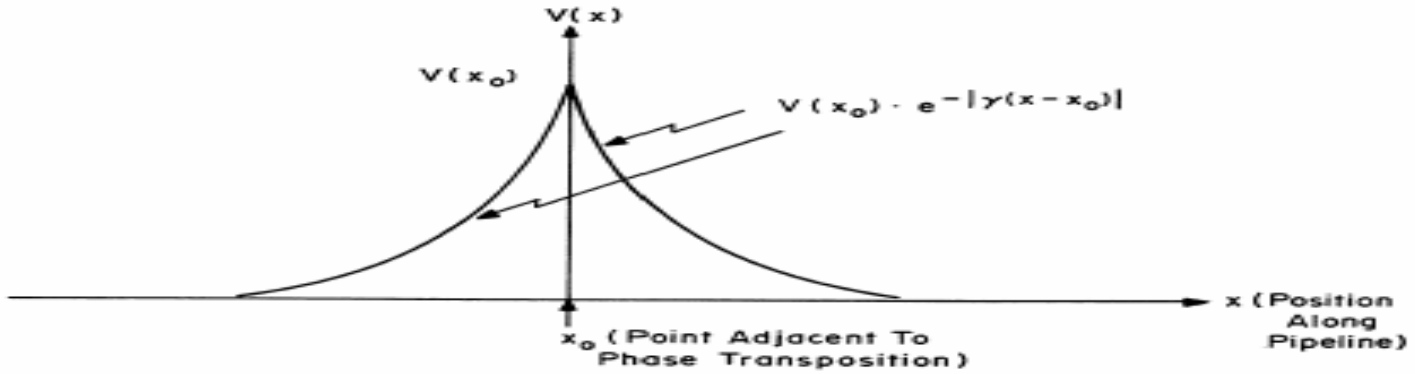
Some Examples of Past EPRI Research

- The subject is not new….. in fact research into suspected animal contact impacts go back to the 1940's and the range of issues cover the spectrum for current effects to advance mitigation strategies
  - EPRI TR 114340 "Stray Voltage Sensitivity Levels for Dairy Cattle, Swine, and Poultry"
  - Document Resolving Residential Pool Shocking Concerns
  - EPRI EL-3106 V1, V2, V3, V4 This report series addresses complex common corridor coupling problems for overhead electric power transmission lines and buried natural gas pipelines
  - Modeling and simulation results on the impact of automated meter reading technologies at animal contact points
  - Dozens of field investigations involving dairy farms, gas pipelines, swimming pools, hot tubs and other stray voltage sources
  - Distribution wide NEV assessment modeling
  - EPRI 1010652 Neutral to Earth Voltage and Urban Stray Voltage Measurement Protocols: Test Equipment and Procedures
  - Five wire distribution demonstration project in upstate NY

Example of Coupling to a Pipeline EL-3106



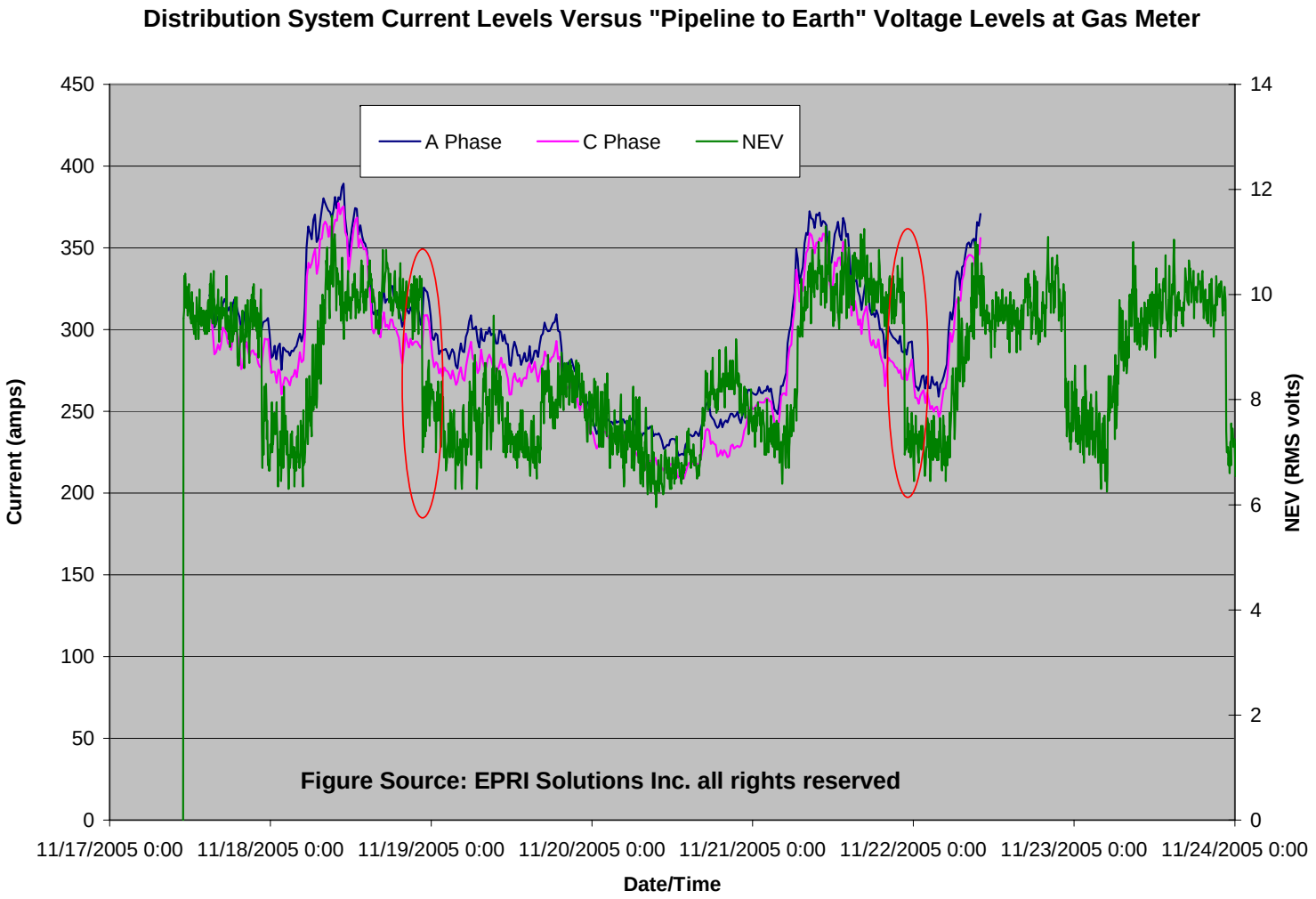
a) Phase Transposition Configuration



b) Induced Pipeline Potential

Source: EPRI EL-3106

Example Trending Correlation of Circuit Currents (yellow/pink) to NEV (green)



Example of Harmonic NEV Concerns

- The primary objectives of the EPRI research was to better understand the means of reducing neutral-to-remote earth voltage (NEV) levels on the primary power distribution circuits
- The results of the modeling efforts enable a better understanding of the methods and software programs that can be used to reduce NEV levels at customer connection points
- The results allow for simultaneous estimates of the NEV levels that at different points along distribution circuits
- This also provides *a way to compare solutions form both a cost and a relative improvement perspective*

Harmonic NEV is not new either…. Conrad et. al. assessed the problems 10 years ago!

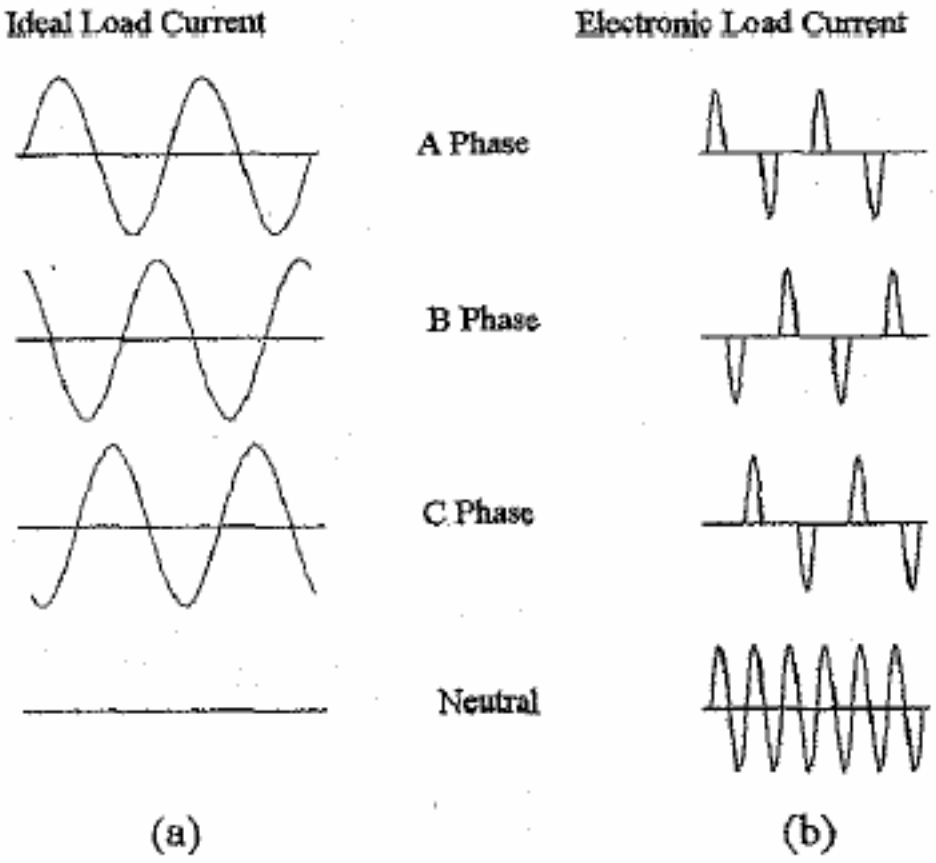


Fig. 3. (a) Ideal Load Current (b) Electronic Load Current

Balanced Three Phase Circuit

$$\bar{I}_A = |I_a|\sin(\omega t)$$
$$\bar{I}_B = |I_b|\sin(\omega t - 120^\circ)$$
$$\bar{I}_C = |I_c|\sin(\omega t + 120^\circ)$$
$$\bar{I}_N = \bar{I}_A + \bar{I}_B + \bar{I}_C = 0$$

Balanced Circuit with Single–Phase Loads

$$\bar{I}_{3rdA} = |I_{3rda}|\sin(3\omega t)$$
$$\bar{I}_{3rdB} = |I_{3rdb}|\sin[3(\omega t - 120^\circ)]$$
$$\bar{I}_{3rdC} = |I_{3rdc}|\sin[3(\omega t + 120^\circ)]$$
$$\bar{I}_{3rdN} = \bar{I}_{3rdA} + \bar{I}_{3rdB} + \bar{I}_{3rdC} = 3*|I_{3rda}|\sin(3\omega t)$$

Source: L. Conrad et. al., Electric Shock and Elevated EMF Levels Due to Triplen Harmonics' IEEE Transactions on Power Delivery, Volume 11, No. 2, April 1996

Modeling and Simulation – What parameters were varied or evaluated in the models?

- Neutral conductors
- Grounding
  - Resistance of the substation grid
  - Resistance of the circuit pole ground
- Capacitor Banks
  - Grounded versus ungrounded
- Circuit Loading
  - Winter loading vs summer loading
- Harmonic filter configurations

NEV Mitigation Priorities

- Individual Customer Bonding/Grounding/Isolation
- Load Balancing (10 percent? – 5 percent?)
- Neutral Impedance Assessment
- Harmonic Resonance Assessment
  - Ungrounded Capacitors
  - Tuned Harmonic Filters
- Neutral Impedance Reduction
- Grounding Assessment
  - Earth Resistivity?
  - Average Ground Rod Resistance
  - Aggregate Services and Customer Ground Resistance
  - Substation Ground Grid Resistance

Generic NEV (and MOEV) Evaluation Priorities

- Adequate call handling and response procedures
- Safe and accurate measurement protocols
- Adequate instrumentation and personnel training
- Consistent documentation for reporting and analysis
- Understanding of all the possible causes
- A procedure for “peeling the onion” start with all possibilities and systematically narrowing down the list
- Preventive maintenance and spot monitoring
- Design guidelines

Measurement Protocols

- Much of the work in the area of diagnosing and resolving undesirable contact voltage potentials requires accurate and repeatable measurement protocols
- The IEEE WG on Stray Voltage has an opportunity to assist the industry in this area
- The protocol is not simply a three page spreadsheet to fill in the blanks
- Considerations range from training personnel to selecting the correct, equipment for the task at hand, and implementing the proper measurement and documentation procedures

Measurement Protocols

- If done properly, a consistent and repeatable measurement protocol should answer a lot of the questions that may arise during an investigation
  - Why did the voltage I measured last week disappear?
  - What is the source of the elevated contact voltage?
  - Why did the voltage go away when I measured with a resistance in the circuit?
  - Why do I get different readings with two different instruments?
  - Why does the selected reference point change my voltage reading?

Test and Measurement Equipment

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.

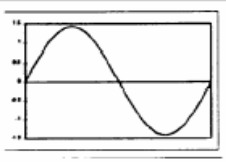
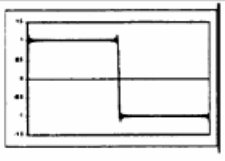
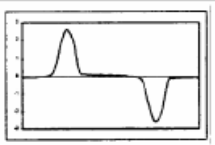
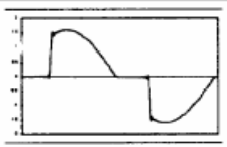
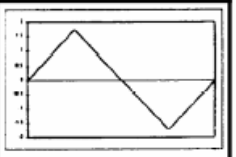
The chapter is subdivided into five main clauses:

- 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.

Measurement Section Should Focus on "Recommended Practice"

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.

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.

Figure source: IEEE Std 1100 – 2006 Recommended Practice on Powering and Grounding Electronic Equipment

Measurement Section Should Detail the Equipment and "Other" Considerations used in the Assessment

- Use of trending versus snapshot for time of days and source correlations
- Harmonics and the importance of understanding the spectral content of the NEV
- Pen Lights
- Hand Held Meters
- Data Loggers
- Multi Channel Recorders

Measurement Objectives

Procedures may require different actions based on the levels measured

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

Source: ***Neutral to Earth Voltage and Urban Stray Voltage Measurement Protocols: Test Equipment and Procedures.*** **EPRI, Palo Alto, CA: 2005. 1010652**

Procedures should include grounding and bonding assessments

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

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.

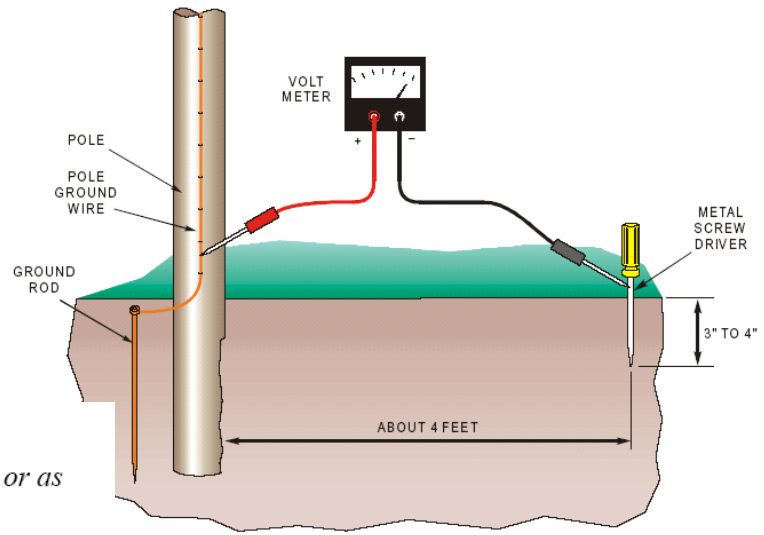
Procedures may have some differences when unintentional energization occurs

6
ENERGIZED METALLIC OBJECT CONTACT AREA MEASUREMENTS

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.

Equipment and Step by Step and Procedures



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.

Materials Needed:

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

Source: ***Neutral to Earth Voltage and Urban Stray Voltage Measurement Protocols: Test Equipment and Procedures.*** **EPRI, Palo Alto, CA: 2005. 1010652**

Equipment Calibrations

Equipment Measurement Accuracy Certification

Location:_____

Tester Name:_____

1. Voltage Reading Instruments:

easure 4.3 Volts DC

_____

easure 0.6 Volts

_____

nts 100 kHz at 1 Volt Pea

easure 1 Volts

The peak amplitude measurement should read within 2% of _____

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 _____

The frequency should read within 2% of _____ kHz

Actual Value Measured:_____

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.

- Chapter Concept:
  - Develop a simple means of checking your equipment and documenting it's accuracy before doing any *"for the record"* testing

Final Comments

- IEEE Stray Voltage Working Group is in a position to assist the industry with:
  - Measurement procedures and guidelines that result in accurate repeatable results
  - Information on equipment specifications, calibration procedures, and measurement point connection and reference consideration to promote correct measurements
  - Case studies and examples that promote application of optimized mitigation techniques when necessary