Standardized Measurements for Elevated NEV Concerns

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***Abstract*— The range of sources as well as the frequency components for elevated neutral-to-earth and metallic-object-to-earth voltage concerns make it difficult to have just one standardized measurement protocol. The measurement devices and procedures for assessing elevated NEV levels at animal contact areas, distribution substations, pipelines, swimming pools and other contact points range from harmonics analyzers to oscilloscopes to simple multi-meters. For energized street level metallic objects the measurement devices can range from simple pen lights to custom designed equipment, while the protocols vary from precise documentation of voltage levels to simple detection of energized metallic objects. We will discuss the variables of interest surrounding accurate and consistent detection and measurement of any elevated voltage levels. This will include: instrumentation, time of day, seasonal patterns, and remote earth or ground reference selection points. Further, suggested initiation points for measurement protocols created via the standards development process are discussed. Efforts in the measurement protocol areas will insure that under situations where higher than expected voltage levels are present at human or animal contact points, the measurements taken to support these efforts are accurate and comprehensive of the range of elevated voltage that may exist at a given point.**

***Index Terms*—Neutral-to-earth voltage, metallic-object-to-earth voltage, stray voltage**

I. Introduction

Voltage potential between a metallic object and ground, or between a neutral conductor and ground—often called stray voltage, or elevated neutral-to-earth voltage (NEV)—can be a concern for electric utilities and their customers. Such concerns range from animal water troughs to streetlamps, manhole covers, gas lines, water pipes, swimming pools, and hot tubs. Complaints about humans or animals getting shocked are not new. In fact, these issues have been around since the inception of electric power. Although some useful measurement protocols and mitigation techniques are available, it can be difficult to correlate measured voltage levels to complaints about shocking sensations. In fact, sometimes during a shock complaint investigation the measured voltage levels are not large enough to correlate to the levels known to impact humans. This may be attributable to the variation in NEV levels that occurs at different times during the day and during the year. Such measurement issues present an opportunity within the IEEE to assist with development of protocols to better evaluate elevated NEV and MOEV concerns

To date, no states in the U.S. have recommended limits on voltage levels for human-contact areas. Some states such as Wisconsin have adopted very specific methods for assessing nuisance shocking at animal contact points and have defined thresholds above which remedial actions must be taken. Other states have considered or are in the process of passing regulations aimed at performing periodic measurements or at limiting the level of elevated voltage to which animals and humans may be exposed. This begins with adequate investigative and measurement protocols.

II. Definitions

To understand how measurement protocols will need to be structured it is important to define some of the common terms where confusion exists and then describe the necessary protocol criteria. For instance, "stray voltage" tends to be the catchall term that has been used to describe everything from energized manhole covers to swimming pool nuisance shocking. The primary distinctions among the sources of nuisance shocking are based on the type of problems encountered. For example, regardless of the cause, a voltage potential of less than 10 volts at an animal contact point is considered a stray voltage. An energized manhole cover, however, is more correctly characterized as a metallic-object-to-earth voltage and is sometimes characterized as "urban stray voltage."

To make sense of this sometimes-vague electrical phenomenon, the following five terms are defined as they are often employed in understanding and describing the sources of nuisance shocking:

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

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A. Remote Earth

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 the current path. Thus, the remote earth point is at reference potential with respect to the voltage source and provides a consistent and repeatable so called "zero reference" point. Finding this non-changing reference point is not always easy and thus measurement protocols need to incorporate guidance in terms of selection of the remote earth reference point.

B. Neutral to Earth Voltage (NEV)

The unavoidable consequence of grounding power systems for safety (and for the additional return path of fault current) 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 always be some level of voltage present relative to the remote-earth point. The elevated potential at the neutral grounding point with respect to remote earth is referred to as neutral to earth voltage or NEV. This voltage is typically measured between remote earth and the ground rod where the utility primary neutral is connected to that ground rod. The measurement can of course be made at any neutral grounding point and is typically defined with a subscript notation such as Vp for primary, Vs for secondary and so on.

C. Stray Voltage

The U.S. Department of Agriculture publication 696 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 cause a current to flow through any human, animal, or other object that contacts both points simultaneously. The typical scenario for the creation of such a voltage potential is when a metal wire, pipe, or other object is bonded at or near the neutral grounding point (placing it at the neutral voltage potential) and extends on to the contact point situated near a zero reference point.

D. Stray Current

If a resistance (human, animal or other) is placed between a stray voltage contact point and a remote earth contact point, a stray current will flow through the resistance path. In terms of measurement protocol, the significance of understanding how much stray current flows by using a specified resistor value defines whether or not the stray voltage source is capable of delivering a current level that is above human or animal perception thresholds.

E. Metal-Object-to-Earth Voltage

An additional source of voltage potential at a contact point is metallic-object-to-earth voltage (MOEV). When the energized object is located at the street level where pedestrians or their animals may come in contact, it is sometimes referred to as "urban stray voltage." MOEV potentials to remote earth can range anywhere from just a few volts to 120 volts or more, depending upon the source. The most common scenario for MOEV is 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 causing the object to become energized as well. MOEV may 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.

III. Measurement Protocol Areas of Interest

To develop consistent and repeatable measurement protocols the specific areas where a protocol will be useful as well as some background on documents that may be useful in defining the protocol are described in the following sections. While there are a number of additional topical areas, the most common complaints stem from:

- Farm Animal Contact Areas
- Urban Stray Voltage Contact Points
- Swimming Pools
- Metallic Pipelines

A. Farm Animal Contact Areas

According to the U.S. Department of Agriculture (USDA) Handbook 696, the earliest reported complaints about nuisance stray voltage impacting dairy cows and possibly affecting production date back to 1948.[1] Methods for the prevention of "perception level" exposure to dairy animals still tend to be very much specific to location. Resolving a site's issues generally requires a thorough investigation to identify the sources of stray voltage and the level of voltage experienced at the animal-contact points. The Wisconsin Public Service Commission (PSC) has recommended maximum voltage levels for animal-contact areas. The PSC also has a very solid measurement protocol that can serve as the basis for IEEE work. In this particular area, the measurement protocol needs are mostly in improved way to define the source of elevated voltage levels.

B. Swimming Pools

Reports of shocking at swimming pools and hot tubs have been common since the 1970s. Most of the investigative and measurement procedures were developed in the 1980s, and refinements continue today. Key causes of nuisance shocking complaints 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

Needs in this area include recommendations for how to determine whether or not proper bonding and grounding has been accomplished at contact areas, how long to monitor to insure the capture of maximum NEV levels during the monitor period and determining the exact source of the elevated voltage at the contact points.

C. Metallic Pipelines

Issues involving subterranean workers getting shocked while working with gas and water pipelines have been reported for over 40 years. In fact, EPRI and the Gas Research Institute co-sponsored comprehensive research into this issue back in the 1970s and early 1980s to address some known concerns with longitudinal electric fields inducing voltage onto pipelines in the vicinity of power lines. Most research has been focused primarily on long pipelines in transmission or distribution right of ways.

Not as much is known or readily available regarding industrial pipelines and lengths of pipes feeding customer locations. Just as in the swimming pool area, needs in this area include recommendations for how to determine whether or not proper bonding and grounding has been accomplished at contact areas, how long to monitor to insure the capture of maximum NEV levels during the monitor period and determining the exact source of the elevated voltage at the contact points.

D. Urban Stray Voltage Contact Points

Nuisance voltages on metallic objects occur for reasons much different from the causes of stray voltages or NEV. Generally, a wiring error or contact between a bare conductor and a metallic object causes the problem. There is research ongoing in this area to define levels of concern, standardize measurement methods, develop new testing devices, and even assess new techniques for locating faulted wires. Some unique measurement devices have been developed for this surveying effort, including light meters, handheld meters, voltage probes and even rolling carts equipped with voltage pickups.

Needs in this area include recommendations for how to determine whether or not a given object has become inadvertently energized, what to use as the remote earth reference point and exactly what type of metering is useful in defining the level of voltage present as well as determining the exact source of the elevated voltage at the contact points.

E. Harmonic Impacts on NEV Levels Near Substations

The most recent area of interest in terms of elevated NEV stems from triplen harmonic currents flowing on neutral/ground return paths. Because these currents add in the neutral/earth return path on three-phase wye configured utility distribution systems, they contribute to elevated NEV levels and cannot be reduced by load balancing. In order to characterize elevated NEV sources, meters capable of measuring both true RMS and harmonic contributions are necessary. In terms of accuracy, CT's must be accurate for measurements in the tenths of amperes for pole down grounds and up to 100 amperes for circuit phase and neutral conductors. The measurement protocols must define ways to insure that measurement represent true NEV levels between neutral grounding points and remote earth reference points. Measurement devices must have the ability to capture and record not only the harmonic content of the currents but also the phase-angle relationships for the different phase conductors. Similarly, power factors and load-unbalance conditions must be captured at the same time if the full extent of NEV related concerns are to be understood.

IV. Measurement Techniques

Finding more accurate methods of assessing elevated voltage levels and in particular characterizing the defined terms in section 2 of this document is of significant interest because, improper measurements have led to incorrect conclusions and mitigation solutions that failed to solve the problem. For example, measuring the NEV at a substation neutral bus can be challenging. Selecting remote earth reference point at 10 feet outside the substation versus 200 feet outside the substation, measured NEV values measured between a neutral riser and the remote earth reference can differ by more than 100% because of the currents flowing in the earth near the substation.

The protocols for measuring stray voltages at animal contact points are well documented and are fairly comprehensive. However, this is not the case in the other concern areas, for example, when third-harmonic current returning on a utility primary neutral conductor presents an elevated NEV problem. In general, different measurement techniques are appropriate for different nuisance shocking scenarios, depending upon whether they are residential, commercial, agricultural, or pedestrian. Specific items that cause deviations in the measured data include the following:

A. Time of Day

When investigating a distribution system and assessing voltage at multiple points at customer sites, all of the measurements cannot be taken simultaneously, so variations associated with time of day and day of the week must be considered. Because customer loading varies with the time of day and day of week, measured NEV levels can also vary accordingly.

B. Time of Year

Earth impedance varies depending on the ambient temperature and moisture content of the soil. In general, dry summer conditions are typically the worst case because of the higher earth-impedance values and because system load current is the greatest during hot summer days.

C. "Remote Earth" Reference Point

As previously stated, NEV measurements are influenced by current flows in the earth. Ideally, remote earth is defined as a point where zero current flows, and the earth is therefore at a reference potential. The remote-ground probe for the voltmeter needs to be a sufficient distance away from the neutral-grounding point. In some cases, right-of-way constraints make this difficult to achieve.

D. Phase Angle Reference

For harmonic spectrum measurements care must be taken to obtain phase and neutral measurements using the base reference.

V. Summary – Stds. Development Needs

Given the previous discussion on measurement considerations and voltages/frequencies of interest for NEV, elevated MOEV and urban stray voltage investigations, there is an opportunity for IEEE standards development to improve and enhance the protocols and equipment requirements necessary for comprehensive and accurate elevated voltage assessments. There are three specific areas where the standards development process will be useful to the power industry. These are:

- Measurement and Documentation Protocols
- Instrumentation (Measurement Device) Requirements
- Application Guidelines/Case Studies

A. Measurement and Documentation Protocols

Outside of measurement and documentation protocols for animal contact areas there is a substantial need for IEEE standards support to refine and gain industry consensus on protocols surrounding the areas discussed in this paper such as swimming pools and other residential contact points, street level metallic objects, pipelines, and possibly non electric conductors in the same right of ways such as cable or telecommunication line shields and even railways. Each of these areas present an opportunity to better understand and resolve elevated voltage concerns as they relate to human and animal exposure.

B. Instrumentation (Measurement Device) Requirements

Given the range of measurement considerations described in section 4, there is an opportunity for an IEEE working group to assist in characterizing the requirements for instrumentation capable of performing impedance, voltage, current, phase angle and spectral content measurements. Further, because measurement probes may sometimes be placed hundreds of feet apart, there is a value to the industry to understand how lead length and impedances may impact some of the measurements of interest.

C. Application Guidelines/Case Studies

Development of measurement protocols and instrumentation criteria is best supported with some real world examples. Once the protocols and specifications are completed, it will be useful to provide guidance and examples of how these protocols and measurement devices are applied in the field. The standards development process may be able to fulfill this need assuming some of the experts in this area are interested in supporting the industry with their practical experiences.

VI. References

[1] A.M. Lefcourt, "Effects of Electrical Voltage/Current on Farm Animals: How to Detect and Remedy Problems," USDA Handbook 696 (Washington, D.C.: U.S. Dept. of Agriculture, 1991). Available from National Technical Information Service, Technology Administration, U. S. Department of Commerce, Springfield, VA 22161, phone (703) 605-6000. NTIS Order No. PB92-172873.

VII. Biographies

Douglas S Dorr is a Director with EPRI Solutions, Inc. He manages and supports many of the EPRI research initiatives surrounding elevated neutral to earth voltage and urban stray voltage. He has been involved with power quality and distributed generation projects for the past 15 years including power conditioning device testing/application, surge/lightning protection, and monitoring/field demonstration of distributed resources. Mr. Dorr is the Chair of the IEEE Emerald Book working group and is Vice Chair of the IEEE Surge Protective Devices Committee. He has authored over 50 technical publications in the above mentioned research areas. Mr. Dorr received his Bachelor of Science degree in Engineering from Indian Institute of Technology in Fort Wayne, Indiana.

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