IEEE STANDARDS ASSOCIATION

IEEE Guide to Understanding, Diagnosing, and Mitigating Stray and Contact Voltage

IEEE Power and Energy Society

Sponsored by the
Transmission and Distribution Committee

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1695™-2016

IEEE Std 1695™-2016

IEEE Guide to Understanding, Diagnosing, and Mitigating Stray and Contact Voltage

Transmission and Distribution Committee
of the
IEEE Power and Energy Society

Approved 29 January 2016

IEEE-SA Standards Board

Abstract: Voltage conditions that may arise at publicly and privately accessible locations as a result of the delivery and use of electrical energy are addressed in this guide. This guide is not intended for use as a statement of cause and effect. It focuses primarily on the presence of power frequency related voltage conditions and discusses definitions, sources, testing techniques, and strategies that may be available to help reduce those conditions.

Keywords: contact voltage, IEEE 1695™, stray voltage

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

PDF:	ISBN 978-1-5044-0829-5	STD20882
Print:	ISBN 978-1-5044-0830-1	STDPD20882

Important Notices and Disclaimers Concerning IEEE Standards Documents

IEEE documents are made available for use subject to important notices and legal disclaimers. These notices and disclaimers, or a reference to this page, appear in all standards and may be found under the heading "Important Notice" or "Important Notices and Disclaimers Concerning IEEE Standards Documents."

Notice and Disclaimer of Liability Concerning the Use of IEEE Standards Documents

IEEE Standards documents (standards, recommended practices, and guides), both full-use and trial-use, are developed within IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association ("IEEE-SA") Standards Board. IEEE ("the Institute") develops its standards through a consensus development process, approved by the American National Standards Institute ("ANSI"), which brings together volunteers representing varied viewpoints and interests to achieve the final product. Volunteers are not necessarily members of the Institute and participate without compensation from IEEE. While IEEE administers the process and establishes rules to promote fairness in the consensus development process, IEEE does not independently evaluate, test, or verify the accuracy of any of the information or the soundness of any judgments contained in its standards.

IEEE does not warrant or represent the accuracy or content of the material contained in its standards, and expressly disclaims all warranties (express, implied and statutory) not included in this or any other document relating to the standard, including, but not limited to, the warranties of: merchantability; fitness for a particular purpose; non-infringement; and quality, accuracy, effectiveness, currency, or completeness of material. In addition, IEEE disclaims any and all conditions relating to: results; and workmanlike effort. IEEE standards documents are supplied "AS IS" and "WITH ALL FAULTS."

Use of an IEEE standard is wholly voluntary. The existence of an IEEE standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard.

In publishing and making its standards available, IEEE is not suggesting or rendering professional or other services for, or on behalf of, any person or entity nor is IEEE undertaking to perform any duty owed by any other person or entity to another. Any person utilizing any IEEE Standards document, should rely upon his or her own independent judgment in the exercise of reasonable care in any given circumstances or, as appropriate, seek the advice of a competent professional in determining the appropriateness of a given IEEE standard.

IN NO EVENT SHALL IEEE BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO: PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE PUBLICATION, USE OF, OR RELIANCE UPON ANY STANDARD, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE AND REGARDLESS OF WHETHER SUCH DAMAGE WAS FORESEEABLE.

Translations

The IEEE consensus development process involves the review of documents in English only. In the event that an IEEE standard is translated, only the English version published by IEEE should be considered the approved IEEE standard.

Official statements

A statement, written or oral, that is not processed in accordance with the IEEE-SA Standards Board Operations Manual shall not be considered or inferred to be the official position of IEEE or any of its committees and shall not be considered to be, or be relied upon as, a formal position of IEEE. At lectures, symposia, seminars, or educational courses, an individual presenting information on IEEE standards shall make it clear that his or her views should be considered the personal views of that individual rather than the formal position of IEEE.

Comments on standards

Comments for revision of IEEE Standards documents are welcome from any interested party, regardless of membership affiliation with IEEE. However, IEEE does not provide consulting information or advice pertaining to IEEE Standards documents. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments. Since IEEE standards represent a consensus of concerned interests, it is important that any responses to comments and questions also receive the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to comments or questions except in those cases where the matter has previously been addressed. For the same reason, IEEE does not respond to interpretation requests. Any person who would like to participate in revisions to an IEEE standard is welcome to join the relevant IEEE working group.

Comments on standards should be submitted to the following address:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
Piscataway, NJ 08854 USA

Laws and regulations

Users of IEEE Standards documents should consult all applicable laws and regulations. Compliance with the provisions of any IEEE Standards document does not imply compliance to any applicable regulatory requirements. Implementers of the standard are responsible for observing or referring to the applicable regulatory requirements. IEEE does not, by the publication of its standards, intend to urge action that is not in compliance with applicable laws, and these documents may not be construed as doing so.

Copyrights

IEEE draft and approved standards are copyrighted by IEEE under US and international copyright laws. They are made available by IEEE and are adopted for a wide variety of both public and private uses. These include both use, by reference, in laws and regulations, and use in private self-regulation, standardization, and the promotion of engineering practices and methods. By making these documents available for use and adoption by public authorities and private users, IEEE does not waive any rights in copyright to the documents.

Photocopies

Subject to payment of the appropriate fee, IEEE will grant users a limited, non-exclusive license to photocopy portions of any individual standard for company or organizational internal use or individual, non-commercial use only. To arrange for payment of licensing fees, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; +1 978 750 8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

Updating of IEEE Standards documents

Users of IEEE Standards documents should be aware that these documents may be superseded at any time by the issuance of new editions or may be amended from time to time through the issuance of amendments, corrigenda, or errata. An official IEEE document at any point in time consists of the current edition of the document together with any amendments, corrigenda, or errata then in effect.

Every IEEE standard is subjected to review at least every 10 years. When a document is more than 10 years old and has not undergone a revision process, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE standard.

In order to determine whether a given document is the current edition and whether it has been amended through the issuance of amendments, corrigenda, or errata, visit the IEEE-SA Website at http://www.ieee.org/publications_standards/index.html or contact IEEE at the address listed previously. For more information about the IEEE-SA or IEEE's standards development process, visit the IEEE-SA Website at http://standards.ieee.org.

Errata

Errata, if any, for all IEEE standards can be accessed on the IEEE-SA Website at the following URL: http://standards.ieee.org/findstds/errata/index.html. Users are encouraged to check this URL for errata periodically.

Patents

Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken by the IEEE with respect to the existence or validity of any patent rights in connection therewith. If a patent holder or patent applicant has filed a statement of assurance via an Accepted Letter of Assurance, then the statement is listed on the IEEE-SA Website at http://standards.ieee.org/about/sasb/patcom/patents.html. Letters of Assurance may indicate whether the Submitter is willing or unwilling to grant licenses under patent rights without compensation or under reasonable rates, with reasonable terms and conditions that are demonstrably free of any unfair discrimination to applicants desiring to obtain such licenses.

Essential Patent Claims may exist for which a Letter of Assurance has not been received. The IEEE is not responsible for identifying Essential Patent Claims for which a license may be required, for conducting inquiries into the legal validity or scope of Patents Claims, or determining whether any licensing terms or conditions provided in connection with submission of a Letter of Assurance, if any, or in any licensing agreements are reasonable or non-discriminatory. Users of this standard are expressly advised that determination of the validity of any patent rights, and the risk of infringement of such rights, is entirely their own responsibility. Further information may be obtained from the IEEE Standards Association.

Participants

At the time this Guide to Understanding, Diagnosing and Mitigating Stray and Contact Voltage was completed, the Working Group on Voltages at Publicly and Privately Accessible Locations had the following membership:

Chuck DeNardo, *Chair*
Jim Bouford, *Vice Chair*

Yanhia Attianese
Bryan Beske
Anthony Cedrone
Mythili Chaganti
Daniel Chen
Jim Cole
Larry Conrad
John Dagenhart
Doug Dorr
Fred Friend
Dave Gilmer
Stuart Hanebuth
Harry Hayes
Ray Hisayasu
Mark Isom
Robert Johnson
David Kalokitis
Scott Kruse
Frank Lambert
Sal Martino
John McDaniel
Laurie Miller
Francisco Munoz
Matthew Norwalk
Ed Paluch
Jeffrey Parker
Jens Schoene
Matt Seeley
John Shipman
Rusty Soderberg
Casey Thompson
Betty Tobin
Val Werner
Marv Wessel
Brian Wong

The following members of the individual balloting committee voted on this guide. Balloters may have voted for approval, disapproval, or abstention.

William Ackerman
David Baron
Frank Basciano
Bryan Beske
Richard Bingham
James Bouford
Jeffrey Brogdon
Bill Brown
William Byrd
Thomas Campbell
Mythili Chaganti
James Cole
Larry Conrad
Johnny Dagenhart
Davide De Luca
Charles DeNardo
Douglas Dorr
Charles Fijnvandraat
Keith Flowers
Fredric Friend
Robert Gettier
Joseph Grappe
Randall Groves
Stuart Hanebuth
Lee Herron
Robert Hoerauf
Laszlo Kadar
David Kalokitis
Yuri Khersonsky
Scott Kruse
Jim Kulchisky
Michael Lauxman
Sal Martino
Neil Matthes
John Mcalhaney Jr.
Thomas Mc Carthy
John McDaniel
Sujeet Mishra
Edrin Murzaku
Joe Nims
Matthew Norwalk
Gregory Olson
Thomas Overman
Marty Page
Christopher Petrola
Dean Philips
Iulian Profir
Charles Rogers
Daniel Sabin
Bob Saint
Robert Schaerer
Kevin Schnack
Robert Schuerger
Kenneth Sedziol
Robert Seitz
Andra Shaughnessy
Jerry Smith
Gary Smullin
Rusty Soderberg
Eriks Surmanis
David Tepen
Wayne Timm
Mark Voigtsberger
Carl Wall
Daniel Ward
Yingli Wen
Val Werner
Kenneth White
James Wikston
Jian Yu
David Zech
Donald Zipse

When the IEEE-SA Standards Board approved this guide on 29 January 2016, it had the following membership:

Introduction

This introduction is not part of IEEE Std 1695-2016™, IEEE Guide to Understanding, Diagnosing, and Mitigating Stray and Contact Voltage.

For many years the term stray voltage had been primarily used to discuss the power frequency voltages present at animal contact locations in and around animal confinement facilities. With the widespread availability of inexpensive and user friendly voltage measurement and recording devices, there has been a growing awareness that the general public and their pets are also regularly exposed to these voltages at many publicly and privately accessible locations. Until recently there has been little recognition of the important difference between the presence of small voltages related to normal electrical system operation (customer and utility) and the presence of potentially harmful and even lethal voltages related to un-cleared electrical faults. This guide has been created because there are few easy to understand public documents that describe the phenomena, their causes and effects, and actions that may help identify and reduce potentially dangerous voltage conditions.

This guide does not reflect the views of any one contributor or source and is not intended for use to advance a specific scientific, public health, security, environmental, or legal position attributed to, or propounded by, any user or third party. While it is impossible to give recognition to all those who have contributed to the content of this guide, the assistance of past and present members of the IEEE PES T&D Stray and Contact Voltage Working Group should certainly be acknowledged. The efforts of the Electric Power Research Institute (EPRI) and the National Electric Energy Testing Research and Applications Center (NEETRAC) should also be acknowledged. Much of the work these organizations have performed on this important topic is reflected in this guide.

Contents

List of Figures

List of Tables

IEEE Guide to Understanding, Diagnosing, and Mitigating Stray and Contact Voltage

IMPORTANT NOTICE: IEEE Standards documents are not intended to ensure safety, security, health, or environmental protection, or ensure against interference with or from other devices or networks. Implementers of IEEE Standards documents are responsible for determining and complying with all appropriate safety, security, environmental, health, and interference protection practices and all applicable laws and regulations.

This IEEE document is made available for use subject to important notices and legal disclaimers. These notices and disclaimers appear in all publications containing this document and may be found under the heading "Important Notice" or "Important Notices and Disclaimers Concerning IEEE Documents." They can also be obtained on request from IEEE or viewed at http://standards.ieee.org/IPR/disclaimers.html.

1. Overview

1.1 Scope

This guide addresses voltages that exist at publicly and privately accessible locations as a result of the delivery and use of electrical energy. This guide is not intended for use as a statement of cause and effect. It focuses primarily on the presence of power frequency related voltages and discusses definitions, sources, testing techniques, and mitigation strategies.

1.2 Purpose

While some jurisdictions have implemented local rules concerning stray and contact voltage, there is presently no industry-wide guide or standard that describes the variety of publicly and privately accessible voltages resulting from the delivery and use of electrical energy. The purpose of this guide is to provide information regarding the potential for risk and recommend actions taken in respect to the presence of either stray or contact voltage. This guide is also intended to help dispel misinformation surrounding this topic and enhance public safety.

2. Definitions, abbreviations, and acronyms

2.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* can be consulted for terms not defined in this clause. [1]

contact impedance: The impedance between any two conductive objects making contact (e.g., test probe and lamp post, cow muzzle and water bowl). Because contact impedance is primarily resistance at extremely low frequency (i.e., 1 Hz to 300 Hz), this term is often referred to as Contact Resistance in stray voltage literature.

contact resistance: Contact impedance with resistive component and no reactive component (*see:* Contact Impedance).

contact voltage: A voltage resulting from electrical faults that may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or animals. Contact voltage can exist at levels that may be hazardous.

earth current: Once electrical current leaves the structure of a grounded object or made electrode to flow within the three dimensional soil structure of the earth itself, it becomes an earth current. (*see also:* Ground Current, Return Current and Neutral Current)

equipotential plane: A grid, sheet, mass, or masses of conducting material that, when bonded together, offer a negligible impedance to current flow and significantly reduce step and touch potentials within the plane.

fault: A partial or total local failure in the insulation or continuity of a conductor.

ground current: Electrical system current that is on a grounding conductor, a grounding electrode, or some other conductive pathway between the neutral (grounded) conductor and the earth. (*see also:* Earth Current, Neutral Current and Return Current).

neutral current: Electrical system current that flows in the neutral conductor. (*see also:* Return Current, Earth Current and Ground Current).

neutral-to-earth voltage (NEV): A voltage measured between the neutral conductor or an extension of the neutral conductor (e.g., primary or secondary grounding conductor, bonded metallic water pipe, or bonded swimming pool water) and remote earth.

qualified reference: A measurement reference point that has been verified to be at zero potential relative to remote earth and have a low impedance pathway to the earth.

reference rod: A metal rod driven into the earth at a remote earth location that is verified to be a low impedance connection to the earth. The reference rod can be used as a common reference point for the measurement of voltages (e.g., neutral-to-earth voltage) on earth-referenced electrical systems.

remote earth: The distant point on the earth's surface where an increase in the distance from a ground electrode will not measurably increase the impedance between that ground electrode and the new distant point.

return current: Electrical system current that returns to its source by way of grounded and grounding conductors, the earth, and any other parallel conductive pathway (e.g., cable messenger) between the location of the load or fault and the current source. (*see also:* Neutral Current, Earth Current and Ground Current).

[1] *IEEE Standards Dictionary Online* is available at: http://ieeexplore.ieee.org/xpls/dictionary.jsp.

stray voltage: A voltage resulting from the normal delivery or use of electricity that may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or animals. Stray voltage is not related to electrical faults.

2.2 Abbreviations and acronyms

CVD	contact voltage detection
DMM	digital multimeter
DVM	digital voltmeter
ESR	electric-shock report
GFCI	ground-fault circuit interrupter
NEV	neutral-to-earth voltage
PPE	personal protective equipment
THD	total harmonic distortion
VOM	volt-ohm meter

3. General discussion

3.1 The nature of publicly and privately accessible voltages

Every time electricity is used, electric current is present in the device being used. It is also present in the wires of the building where the device is being used, and in the wires that belong to the utilities that deliver the electrical energy to the building. Because the majority of electrical energy is delivered using alternating current (ac), expanding and collapsing electric and magnetic fields surround nearly all of these current carrying conductors. Physical laws dictate that these time varying fields will cause electrical current to be present in all nearby conductive loops (i.e., induced current), and can result in the presence of a voltage on all nearby conductive surfaces (i.e., induced voltage). Because most electrical systems are physically connected to earth for reasons of safety, some amount of electrical current is also present in:

a) The conductive pathways that exist between the electrical system and the earth (e.g., grounding conductors, water lines).
b) Many of the parallel conductive pathways connected to the electrical system and/or the earth (e.g., phone and TV cable messengers and shields).
c) The earth itself.

Wherever electric current flows, voltage exists. As a result, humans and their domesticated animals are often exposed to these manmade voltages. These exposures occur when contact is made between any two conductive surfaces that have a difference of electric potential between them (e.g., metal water faucet and earth). We are generally not aware of these ubiquitous voltage exposures. They are generally imperceptible and far below levels known to cause harm.

This guide will discuss the presence of publicly and privately accessible voltages that can result in conducted current exposures. It will limit discussion to exposures directly related to operation of customer and utility electrical systems.

3.2 Differences between stray voltage and contact voltage

The term "stray voltage" has been historically used to describe the voltages that exist at animal accessible locations in the vicinity of confined livestock. In recent years, however, the term stray voltage has also been used to describe the presence of voltage from a wide variety of sources including unintentionally energized objects in the public right-of-way (e.g., energized lamp posts and hand-hole covers).

This guide is intended for those who have a desire, or a need, for a more complete understanding of the topic. It will provide a comprehensive, understandable, fact-based presentation of:

a) The causes of publicly and privately accessible voltage.

b) Levels of voltage that may be of concern.

c) Remedial actions that can or should be taken.

To better understand the issue of publicly accessible voltage exposures it is important to note that some amount of measurable voltage will always be present between conductive surfaces that are near operating electrical systems. This is true regardless of whether the system is operated by an individual property owner (i.e., electric customer) or an electric utility. It is also true regardless of the type of electrical system, its operating voltage, or how it is grounded. Under normal operating conditions, with a code compliant electrical system, publicly accessible voltages are usually imperceptible to both people and their animals. Special circumstances (e.g., confined livestock) or special exposure conditions (e.g., barefoot in an outdoor shower) can however result in perceptible exposures even when the electrical systems, utility and customer, are operating as intended. As defined in this guide this type of accessible voltage is termed "stray voltage".

Publically accessible voltages that are the result of an existing fault condition (i.e., a short-circuit or an unintended open-circuit), are referred to in this guide as "contact voltage". Understanding the difference between publicly accessible voltage exposures related to normal system operation (i.e., stray voltage), and potentially harmful exposures related to contact voltage is important to an understanding of this topic. To aid in this understanding, stray and contact voltage are defined and discussed separately in Clause 5 and Clause 6, respectively.

The organization of this document treats stray and contact voltage scenarios separately and distinctly. When a publicly accessible elevated voltage is found, it is either stray voltage, contact voltage, or both. A thorough understanding of all material contained in this guide will help the investigator choose appropriate techniques and procedures to safely and accurately identify the type of voltage present and its source(s).

Some jurisdictions have implemented local rules concerning stray and contact voltage. The investigator should be aware of these rules and make certain the instrumentation and methodology used in the investigation achieves the minimum requirement of the local rule.

3.3 The difficulty of stating a level of harm in terms of voltage

One of the difficulties of stray and contact voltage exposure assessment becomes apparent when you try to answer the question, "What level of voltage is harmful?" The voltage that we may make contact with at a publicly accessible location should not, in and of itself, be harmful. The voltage is merely the force that pushes the electric current through our conductive bodies. We feel and react to the current flow once it has reached a perceptible level. In general, once perception has been reached, increasing amounts of conducted current have increasingly negative consequences for both people and animals.

The amount of current that will flow through the person or animal (i.e., the amount of current in the exposure circuit) is dependent not only on the stray or contact voltage present at the point of contact (i.e., the exposure voltage), but on all elements of the exposure circuit (e.g., source impedance, contact impedance, and body impedance). In addition, the level of perception varies from one species to the next and even among individuals within a species. Because the impedances of the exposure circuit are different at every exposure location and can vary with time, the amount of voltage required to create a perceptible current exposure may also be different at each exposure location and for each exposure.

Because contact voltage is fault related and can easily go from an imperceptible level to a dangerous level in a short period of time, a determination of the voltage source should be made. When the voltage present is determined to be due to a system defect (i.e., contact voltage), the existing or potential hazard should be isolated from the public and/or mitigated as soon as practical.

The science behind human and animal exposure to electricity is well established. It has been ongoing for more than a hundred years. What we now know about human and animal exposure to conducted current, including levels of perception and levels of harm, is discussed in detail in Clause 4 of this guide. How to make meaningful exposure and diagnostic measurements, how to interpret findings, and how to mitigate stray and contact voltage sources are topics discussed in Clause 5 and Clause 6.

3.4 Safety

The annexes of this guide discuss procedures and methods for field investigations to locate and, if necessary, mitigate stray and contact voltages. Since many of these investigations will involve electrical systems with existing faults, strict adherence to current electrical industry working methods and safety procedures is paramount. Lethal voltages may be present on normally safe surfaces and equipment. Only qualified personnel with adequate personal protective equipment (PPE) should investigate locations with abnormal voltages. Possible contact voltages present can be considered and planned for so that the correct PPE is available on-site.

4. Human and animal electrical sensitivity

In this clause, results from previous research on human and animal electrical sensitivity to 50/60 Hz ac current and voltage are reviewed. Current flow through the human or animal body can cause a number of effects ranging from a slight tingling sensation at low current to muscle contraction at high current. These effects are only experienced if the current exceeds a perception threshold so that sensory neurons (producing sensations) and muscle neurons (producing muscle contractions) are activated (Reinemann [B39] [2]). The level of current flowing through the human or animal depends on the voltage applied and the impedance of the current path through the body. For stray voltage exposure scenarios where a long-term or repeated low voltage exposure may be of concern, an understanding of the body impedance of humans and animals is necessary for determining whether or not a perceptible exposure exists. In comparison, for fault related contact voltage scenarios knowing a person or animal's body impedance is not necessary because the objective is to identify and then mitigate the electrical fault that is the source of the contact voltage.

4.1 Impedance of the human body

Research shows that the shock severity is proportional to current flow through the body rather than the voltage imposed on the body when the shock occurs. As a result, threshold values are generally depicted in terms of current and not in terms of voltage.

IEEE Std 80-2013 [B27] gives recommended values for body impedance, which are based on research conducted by Dalziel, 1946 [B5], Dalziel, 1972 [B7], Dalziel and Lee, 1969 [B8], Geddes and Baker [B17], Geiges [B18], Kiselev [B30], and Osypka [B37]. According to these studies, the internal body impedance is approximately 300 Ω and the total body impedance, including the impedance of the skin, ranges from 500-Ω to 3000 Ω. For example, Dalziel and Massogilia [B10] determined experimentally that the hand-to-hand body impedance for saltwater wet conditions is 2330 Ω and the hand-to-feet body impedance for saltwater wet conditions is 1130 Ω. Based on Dalziel's and Massogilia's research, IEEE Std 80-2013 uses 1000 Ω for

[2] The numbers in brackets correspond to those of the bibliography in Annex G.

hand-to-hand and hand-to-feet body impedances, which is stated to be a conservatively low value that neglects hand and foot contact impedances and the impedance of gloves/shoes. Dalziel states that often a comparably low impedance of 500 Ω is used as a conservative value for the body impedance between major extremities to estimate shock currents during industrial accidents, but does not mention the research this impedance value is based on.

It should be noted that due to the physiological variability in humans, however, it is difficult to establish a firm value for the body resistance to alternating current, particularly at higher exposure voltage levels. As mentioned above, 1000 Ω is a widely accepted resistance value in the United States. Initially, this resistance value became an acceptable standard due to its recommendation by IEEE Std 80-2013 for substation ground grid designs where typical exposure voltage levels are expected to be much higher. As the need in other areas of electrical exposure evolved, the 1000 Ω value started being accepted for those areas also.

4.2 Current thresholds for humans

Many studies use current thresholds based on the research of Charles Dalziel. The current thresholds listed in Table 1 were published by Dalziel in 1956 [B10] and are widely used in the industry today for quantifying shock hazards. Dalziel based the non-lethal thresholds on shock experiments conducted on humans. Let-go thresholds are determined from experiments with 134 male and 28 female adults (Dalziel, 1968 [B9]). Perception thresholds are determined from experiments with 167 adult men (Dalziel, 1972 [B5]) and Thompson's experiments on 40 adult men and women (Thompson [B43]). The lethal thresholds (ventricular fibrillation possible/certain) are based on experiments conducted on sheep, calves, pigs, and dogs, whose chest dimensions, body weights, heart weights, and heart rates are comparable to humans. None of Dalziel's experiments were conducted on children. Instead, it was assumed that the thresholds for children are half of the thresholds for an adult male.

Dalziel and Lee [B8] derived the so-called "electrocution equation" from electrocution data documented by Lee [B31]. The electrocutions occurred in England and Wales during the years 1962–1963. Of the electrocutions, 166 occurred on voltages less than 250 V (50 Hz), 30% of the victims were female, and 26% were persons under 20 years of age. This equation specifies the current threshold I_{fib} at which ventricular fibrillation can occur. The actual average weight of the electrocution victims was estimated to be less than 70 kg, but, for conservatism, Dalziel and Lee chose to use this equation for adults of 50 kg of weight. The empirically derived electrocution equation is given below and is applicable for shock durations ranging from 8.3 ms to 5 s.

$$I_{fib} = \frac{0.116 \text{ to } 0.185 \text{ A}}{\sqrt{t}} \tag{1}$$

where

t is 8.3 ms to 5 s
I_{fib} is the current threshold in amperes at which ventricular fibrillation is possible
t is the shock duration in seconds

IEEE Std 80-2013 adopts this equation with a value of 0.157 in the numerator and for adults with 70 kg body weight. Dalziel and Lee extrapolated the data, which was only obtained from adults, to derive the following electrocution equation that is applicable to children.

$$I_{fib,\text{ children}} = \frac{0.052 \text{ to } 0.069 \text{ A}}{\sqrt{t}} \tag{2}$$

where

t is 8.3 ms to 5 s

Table 1—Effects of 60 Hz electric current on the human body

Effect	Current threshold for men (mA, rms)	Current threshold for women (mA, rms)
Perception threshold (slight tingling)	1.1	0.7
Painful shock	9.0	6.0
Let-go threshold	16.0	10.5
Painful and severe shock, muscle contract, breathing difficult	23.0	15.0
Ventricular fibrillation possible, short exposure (0.03 s)	1000	1000
Ventricular fibrillation possible, long exposure (3 s)	100	100
Certain death from ventricular fibrillation, short exposure (0.03 s)	2750	2750
Certain death from ventricular fibrillation, long exposure (3 s)	275	275

Relying on the research of Dalziel and others, Whitaker of Underwriters' Laboratories (UL) established a maximum uninterrupted 60 Hz ac current of 5 mA as the safe let-go current for a two-year-old child. He did this by extrapolating the ventricular fibrillation data of an animal having a body and heart weight proportional to that of a two-year-old child (Hammam and Baishiki [B23]). This value is still used by UL as the maximum continuous safe current for the general population.

4.3 Animal electrical sensitivity

The following sub-clauses document previous research on the electrical sensitivity of animals.

4.3.1 Dairy cows

Table 2 documents the electrical sensitivities of dairy cows (ASAE EP473.2 2001 [B3]).

Table 2—Electrical sensitivities of dairy cows

Effect	Cattle group	Current threshold	Voltage threshold	Comment
Mild behavioral modification	Most sensitive cows	2 mA	1–2 V	Documented for dairy cows. Similar levels for beef cattle expected.
	50% of all cows	5 mA	2.5–5 V	
	Least sensitive cows	8 mA	4–8 V	
Short term avoidance behavior (may result in depression of milk production)	Most sensitive cows	3 mA	1.5–3 V	Depression of milk production only expected if the water source with high electrical potential is the only water source.
	50% of all cows	7.5 mA	3.8–7.5 V	
	Least sensitive cows	12 mA	6–12 V	

The voltage threshold levels are based on contact resistance of 500 Ω at poorly drained, wet locations surrounding watering devices and on contact resistance of 1000 Ω in well designed, constructed, and managed facilities. While these levels have been well documented for dairy cows, they may also apply to beef cattle (Reinemann [B39]).

4.3.2 Swine

Table 3 documents the electrical sensitivities of swine (Godcharles, Matte, and Marineau [B19], Gustafson, 1986 [B21], Kennedy [B29], Reinemann [B39], Robert, Matte, and Martineau, 1996 [B41], Robert, Matte, and Bertin-Mahieux, 1992 [B42]). Research suggests that swine adapt to voltage exposure in a similar way as cattle (Matte et al. [B32] and Reinenmann [B39]).

Table 3—Electrical sensitivities of swine

Effect	Current threshold	Voltage threshold	Comment
Drinking behavior changes	3 mA	5 V	Continuous exposure to 5 V with intermittent exposure to 8 V produced behavioral changes, but did not change water intake.
Short term reduction in water intake	4 mA	8 V	Exposure up to 8 V did not impair welfare, reproductive performance, or health of sows and suckling pigs.

4.3.3 Sheep

Ewes avoided electrified feed bowls when exposure levels exceeded 5.5 V. Lambs showed the same behavior if exposure levels exceeded 5 V. Research suggests that current sensitivity for sheep is lower and body resistance is higher compared to cows (Duvaux-Ponter, Roussel, and Deschamps, 2005 [B12] and Duvaux-Ponter, et al., 2006 [B13]).

4.3.4 Poultry

Exposures to voltages as high as 18 V had no effect on the production and behavior of hens. This is likely due to the very high electrical resistance of poultry (between 350 kΩ and 544 kΩ) (Reinemann [B39]).

5. Contact voltage

Contact voltage is a voltage resulting from electrical faults which may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or animals. Contact voltage can exist at levels that may be hazardous.

5.1 Background

Contact voltages can arise from two distinct types of faults on electrical systems; phase conductor faults and neutral conductor faults. Contact voltage often results from damaged insulation on phase conductors or damaged or faulted neutral conductors. Improperly connected customer or utility equipment can also cause contact voltage. Since contact voltage often involves phase conductors, it should be treated carefully because a low voltage level can rise to full line voltage as the impedance of the conductive fault pathway changes.

Contact voltage is not a traditional step and touch potential problem. Step and touch potentials are usually discussed in terms of the accessible voltages present during a short duration electrical system fault event. The risk of contact voltage is not just from the momentary voltage associated with a short duration fault, but rather the presence of an electrical fault in customer or utility wiring that has not cleared (i.e., the protection device, if present, has not operated). As such, the fault can result in a long term publicly accessible voltage that may, under specific exposure conditions, reach harmful levels. Based on utility experience, in the majority of cases the voltage measured at the time of investigation is in excess of 5 V, but many cases are reported below 5 V (New York State Public Service Commission [B35]). Multiple voltage measurements recorded at different times of day or on different days often yield different results due to the variations in the fault conditions such as changes in temperature, fault impedances, and moisture levels in the soil.

In bodies of water contact voltage cases often result from un-cleared faults in vessel wiring or dock electrical systems. Voltage values near metal objects proximate to the source of the fault may be near line voltage, while the conductivity of the water may result in low voltages at nearby grounded objects.

When considering contact voltage it is important to understand voltage levels sourced by a fault and appearing on an accessible surface are rarely constant. For example a measurement of as little as 1 V_{ac} at one point in time could rise to full line voltage as environmental conditions change or as the insulation continues to degrade. While this complicates the detection and mitigation process, effective contact voltage detection (CVD) and mitigation can be accomplished with proper understanding and techniques.

5.2 Identification of contact voltage

When voltage is found on a surface or structure, it is important to determine whether or not it is contact voltage. Specifically, the characterization and troubleshooting process can be aided, and the investigation can be performed more safely, by first determining if the source of the voltage is a fault in either a nearby phase conductor or a neutral conductor. In addition to measuring voltage magnitude during the test process, a measurement of total harmonic distortion (THD) may be beneficial.

Determining whether or not the exposure voltage is contact voltage is often possible by measuring the THD of the voltage waveform. In cases where the THD is low, the voltage could be sourced by either a fault on the phase conductor or a fault on a neutral that is connected to a linear load or a load with harmonic suppression. If it is, the voltage is likely contact voltage. In cases where there is a higher level of harmonic distortion the voltage is likely being sourced from the neutral (or return side of the circuit) and is therefore stray voltage. It can be noted that harmonic measurements alone do not provide adequate information to differentiate between stray voltage and contact voltage. The final determination of stray voltage requires confirmation that no defects are present in the system, and thus the voltage is the result of a "normally operating electric system."

5.2.1 Contact voltages from line-side sources

To distinguish between contact voltage caused by phase conductor faults and faults in the neutral conductor, the harmonic content of the measured voltage can be utilized to suggest the source. The power quality standard IEEE Std 519-2014, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems, recommends that utilities deliver voltages that are ≤ 1 kV with < 5% THD. Since the earth, metallic objects, and other conductive surfaces of concern behave like resistive (linear) loads, voltage resulting from phase conductor faults has the same THD as the source (phase) voltage. A contact voltage caused by a phase conductor fault will almost always have a relatively low harmonic 60 Hz sinusoidal waveform, just like the voltage of its phase conductor source.

The important concept here is that the harmonic content of the source and the harmonic content of an inadvertently energized object will have exactly the same THD percentages, but may not have exactly the same voltage levels. The reason for the voltage difference between the source and the inadvertently energized object stems from the fact that the voltage measured on the energized object is a function of the series resistance of the connection between the phase conductor and the energized surface. This series resistance is typically referred to as the fault impedance, see Equation (3). Figure 1 shows a simplified version of the measurement schematic.

$$V_{object} = \frac{V_{source}\left(Z_{earth}\right)}{\left(Z_{fault} + Z_{earth}\right)} \tag{3}$$

where:

V_{object} is the voltage measure on the energized surface
V_{source} is the source voltage (typically 120 V in the US)
Z_{fault} is the impedance between the source conductor and the energized object

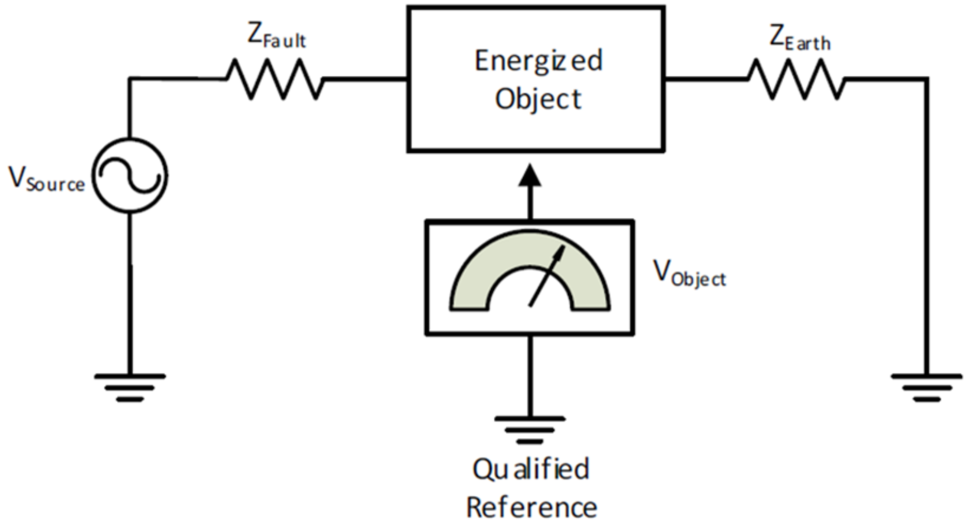


Figure 1—Phase conductor contact voltage source

Z_{earth} is the impedance of the earth return path

The previous equation suggests that the voltage level on the conductive surface may change as fault impedance (i.e., the series resistance components) changes due to environmental factors such as moisture, humidity, soil, or concrete resistivity. Since contact voltage is often the result of damaged insulation, the voltage can vary from low levels (less than a few volts) to full line voltage levels.

Figure 2 depicts a typical contact voltage waveform resulting from damaged insulation on a phase conductor. Figure 3 is a histogram representation from the waveform example shown in Figure 2.

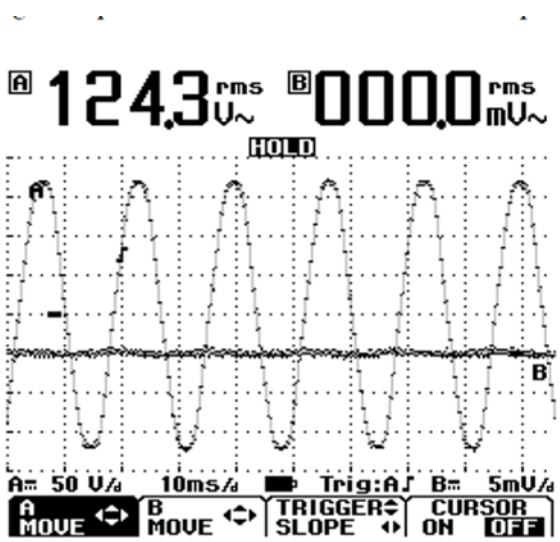


Figure 2—Contact voltage waveform resulting from damaged insulation on a phase conductor

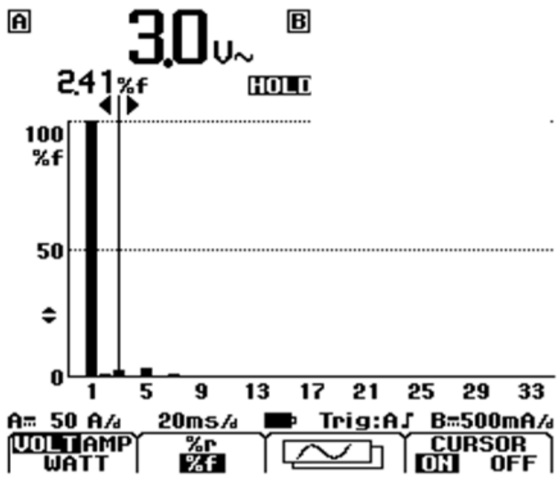


Figure 3—Contact voltage histogram resulting from damaged insulation on a phase conductor

Contact voltage from phase conductor sources will almost always show the fundamental frequency (i.e., 50/60 Hz) sinusoidal waveform with low distortion. It has been found that contact voltages from phase conductor sources have a THD typically less than 5% and rarely exceeding 10% by contact measurement with probes. These contact voltages result from a variety of conditions including; deterioration of conductors, faulted equipment, aged equipment, exposure to the elements, and various secondary wiring related issues. These fault related voltages should not exist on normally operating electric facilities and need to be mitigated to help prevent harm to the public and maintain system reliability. Some contact voltages associated with neutral conductor faults may also exhibit less than 10% THD. This can occur when the load is predominately a linear load.

5.2.2 Contact voltages from neutral conductor sources

The higher level of harmonics in faults associated with neutral conductors is a result of the characteristic of the current on the neutral conductor. Static power converters utilize power semiconductor devices for power conversion. These devices constitute the largest category of nonlinear loads connected to the electric power system. Static power converters are used in a variety of applications including: computers, television sets, compact fluorescent lighting, motor speed controllers, pump flow controllers, and other electronic equipment. Unless equipped with harmonic suppression devices, static power converters often draw non-linear currents and return them onto the neutral. If the load is purely linear then the resultant voltage will have a harmonic content that matches the harmonic content of the power system.

Contact voltages caused by neutral conductor sources are a simple extension of Ohm's Law where the return currents from the loads create a voltage drop as they pass through the impedance of the return path, see Equation (4).

$$V = Z\sqrt{(I_{h1}{}^2 + I_{h2}{}^2 + I_{h3}{}^2 + \ldots I_{hn}{}^2)} \tag{4}$$

where

V is the voltage
Z is the impedance of the conductive path
I_{h1} is the current at fundamental frequency
I_{h2} is the current at second harmonic frequency

I_{h3} is the current at third harmonic frequency
I_{hn} is the current at n^{th} harmonic frequency

If return-path impedance is high (e.g., a high impedance neutral connection), the voltage drop can be large. Because the voltage drop is directly proportional to the total current (fundamental and the harmonics), we can expect the resulting contact voltage will have the same harmonic components. The THD is dependent on the amount of non-linear load on the circuit of interest. It follows from this discussion that when the measured voltage on an inadvertently energized object has a high harmonic content it is almost always going to be caused by system return current on a neutral return path. There are always exceptions such as when a circuit has only motor or heater load, but the majority of the circuits feeding residential, commercial, or industrial facilities have neutral return current with at least a 10% or greater harmonic current content.

Figure 4 depicts an example of a contact voltage waveform from a neutral conductor source. Figure 5 is a histogram representation from the example shown in Figure 4.

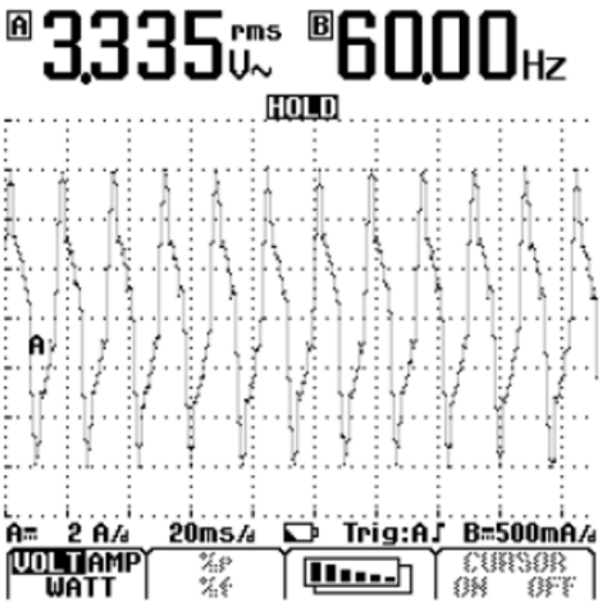


Figure 4—Contact voltage waveform from a neutral conductor source

In cases where the THD of the measured voltage is greater than 10%, it is often not clear whether the source of the voltage is normal return current or a faulted neutral conductor (open or nearly open neutral). In these cases, investigators can examine the circuit to determine whether the voltage is the result of normal power system operations or defective equipment. If the voltage is the result of normally operating equipment, the voltage would be considered a stray voltage (see Clause 6). Harmonic level measurements alone cannot determine the voltage source, a visual inspection is needed to determine if the source is stray or contact voltage. If the cause is defective equipment, it would be classified as contact voltage and the area should be safeguarded until repairs can be made.

5.3 Causes of contact voltage

A fault can occur where the electric system breaks down from mechanical, thermal, chemical, or electrical stress. The fault (i.e., a shorted-phase conductor or an open neutral conductor) can be a high-impedance fault

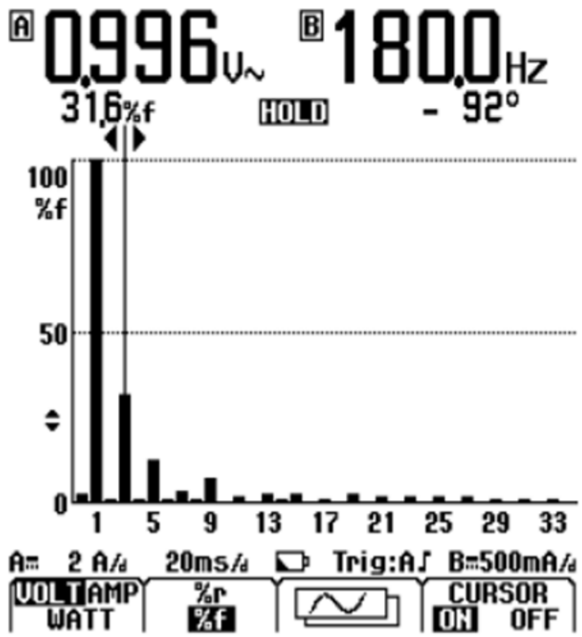


Figure 5—Contact voltage harmonics histogram from a neutral conductor source

which can go unnoticed by the customer or utility responsible for maintaining the asset until reported by a member of the public or identified through some kind of testing process. Experience has shown that any conductive structure in the vicinity of an electrical fault may become energized and pose a hazard to the public. The high impedance faults that cause contact voltage can be attributed to one or more of a list of causes, including, but not limited to:

a) *Environment:* Environmental factors (e.g., moisture, freeze thaw cycles, corrosive atmosphere, vibration, and lightning) can cause electrical insulation to fail on cables, connectors and other energized system components. Corrosion can also reduce the mechanical strength of conductors, conduits, supports, cable jackets, and mechanical connections, all of which can initiate damage to insulation and compromise neutral return paths.

b) *Design:* Issues related to system design can lead to insulation failure and result in an electrical fault. Damaged wires can occur due to improper rating, insufficient protection (both physical and electrical), inadequate mechanical support, improper weatherproofing, and other design related issues.

c) *Installation:* Incorrect installation can result in an electrical system fault that may become a hazard to the public. Specific examples include insulation damage from pinched wires, improper installation of hand taped insulation, accidently reversing polarity, failure to properly tighten connections, and insufficient mechanical protection of energized conductors. On an operating electrical system, customer or utility, all components should be installed in accordance with the manufacturer's instructions, and appropriate codes (NEC, NESC, etc.). Such components are tested and qualified by the manufacturer based on the assumption that they will be installed in accordance with the instructions provided. If they are not, the product cannot be expected to perform as intended.

d) *Accidents:* Accidental damage to an operating electrical system can occur in a variety of ways (e.g., vehicular accidents, dig-ins, and fires). The damage may result in an immediate or future electrical fault condition resulting in conductive surfaces near the fault becoming energized.

e) *Animal damage:* Animals such as insects, birds, squirrels, mice, gophers, moles, rabbits, and raccoons have been known to damage insulation and connections.

f) *Vandalism/theft:* Vandals can damage or remove access covers, resulting in exposed wires and the introduction of debris into electrical structures or streetlight bases. Thieves can create hazards that prevent the proper operation of protective devices by removing neutral and ground conductors. Unauthorized connections to supply circuits may be made using unapproved components or work practices prone to failure.

g) *Life-cycle events:* Workers may pierce or remove insulation to test for voltage on an underground supply cable. If not properly re-insulated, this can leave a path for current leakage to cable supports, duct work, and other normally non-energized surfaces.

h) *Temporary connections:* Temporary power connected for emergency restoration or seasonal lighting can create electrical hazards. This can occur if not properly installed or adequately safeguarded from the elements and from unauthorized access.

5.4 Contact voltage detection (CVD)

Identifying a need to repair a defect or fault begins with detection of voltage on a surface or structure not intentionally energized. The discovery process comes about through some form of detection.

Contact voltage can be detected in four ways: a) Direct detection—a managed program of testing specific assets or geographical areas for contact voltage, b) Incidental detection—discovery of energized structures during routine maintenance work or through abnormalities noticed during visual inspections, c) Publicly reported shock—a member of the public or a pet receives and reports an electrical shock, and d) Public report of concern—reports from the public who have not been shocked, but have noticed a cause for concern. All public reports should be investigated.

a) *Direct detection:* An electrical system asset owner or an electric utility may periodically test for contact voltage. The goal of such a program is to locate un-cleared electrical faults by detecting voltage on nearby conductive surfaces within reach of the public. Once detected a series of tests can be performed to determine whether the voltage is related to a fault condition and/or whether a potential hazard exists. Test results can also be used to make informed decisions about repairs, if they are necessary. In a managed direct detection program it is advisable to use the most sensitive means available to detect energized surfaces. Using the most sensitive means available will help identify the potentially hazardous locations. Once identified, a more rigorous diagnostic process can be used to rule out conditions which do not come from a fault and therefore are not likely to become hazardous. A sensitive detection process can accomplish the goals of proactively finding faults, minimizing the number of contact voltage incidents, and improving the safety and reliability of the system. Insensitive detection processes may allow possible hazards to be filtered out before any diagnostics can be performed.

b) *Incidental detection:* Detection of contact voltage can also occur during regularly scheduled repair and maintenance work. The addition of pre and post-work tests for contact voltage can enhance the incidental detection process, and improve both public and worker safety.

c) *Public report of shock:* Reports of shock should be investigated as soon as practical. First responders investigating a reported shock site should assume a fault condition exists and treat surfaces as energized until proven otherwise. Structures determined to be energized as a result of an existing fault should be barricaded until the fault (customer or utility owned) can be de-energized and repaired.

d) *Public report of concern:* These are reports from the public by those who have not been shocked, but have noticed a cause for concern. Some examples include missing streetlight access covers, broken equipment, and code violations. These deficiencies might result in a voltage finding in the area or lead to one in the future.

5.4.1 Equipment for detecting contact voltage

This section describes existing test equipment that may be useful for detecting inadvertently energized objects and surfaces. There are a number of methods and hardware options available for this task. The two most commonly used methods are mobile detection and handheld detection.

There is no single technology or test method that works for all scenarios; therefore, it is important to understand the capabilities and limitations of the equipment being used and the test being performed. The investigator can conduct individual field trials and review test reports and manufacturers specifications to ensure that the selected devices perform as required for the objectives of the given test program and as expected in the given application.

5.4.1.1 Mobile electric field detection

Mobile electric field detection relies on a capacitive sensor which measures the ambient electric field and detects small changes in the field as the sensor passes by energized objects and surfaces. An example of such a system is shown in Figure 6. A mobile electric field detection vehicle can scan an area quickly providing a positive indication of objects or surfaces that are energized at the time of testing. A mobile detection vehicle can simultaneously detect the presence of voltage on all surfaces within range of the sensor. These surfaces include, but are not limited to: streetlights, manholes, fences, hand-hole covers, roadways, and sidewalks. Since mobile electric field detection identifies all energized objects and surfaces within the range of the detector rather than specific assets, it is the most inclusive detection method currently available.

Mobile electric field detection systems work well for underground distribution and some mixed overhead/underground systems. However, electric field levels from overhead medium and high voltage lines (distribution and transmission) typically mask contact voltage signals in their immediate proximity. Therefore mobile detection is not generally suitable in areas under or very near these overhead conductors.

5.4.1.2 Handheld detection

There are three types of handheld detectors currently in use for detecting inadvertently energized objects and surfaces. These include:

a) Probe-based (test lead) voltmeters

b) Physical contact based handheld capacitive or “pen” testers (as shown in Figure 7)

c) Non-contact based electric field strength indicators

For surveys of contact voltage in areas influenced by overhead primary distribution and transmission lines, one or more of the direct contact handheld measurement devices may be considered.

5.4.1.2.1 Probe-based voltmeters

Probe-based voltmeters and their uses are additionally described elsewhere in this document (5.5, 6.5, Annex C, and Annex D). These meters provide not only an accurate indication of an energized object, but they can additionally discern the precise voltage level on the object with decimal place accuracy. Getting a positive indication and obtaining the voltage parameters with a single measurement is convenient, but the trade-offs in efficiencies are the amount of time it takes to test individual assets and the need to identify a qualified reference (See 5.5.1.3).

5.4.1.2.2 Physical contact pen testers

Contact based pen testers are capacitively coupled detectors that provide visible or audio indication the object under test is energized at a voltage above the detector’s specified voltage threshold. The pen testers operate assuming the user is capacitively coupled to the earth and at zero potential, and therefore do not require a test

Figure 6—Example of a mobile detection system

Figure 7—CVD using a pen tester

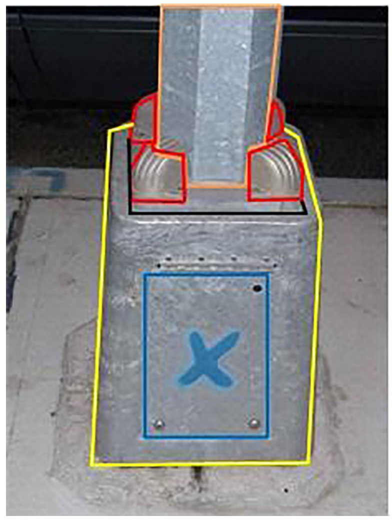


Figure 8—Physical contact is not electrical contact. Test each part of a lamp separately (e.g., pole, base, access door, bolt covers, mounting flange)

lead connected to a qualified reference in order to make the measurement. Physical contact pen testers may provide erroneous results when the user is unknowingly standing on energized earth and the pen tester is no longer provided with a ground reference at or near zero potential. Independent laboratory tests have documented the most commonly used pen testers can detect voltage as small as 5 V in the laboratory environment.

Pen testers are often used for asset list-based test programs. Typically these test programs target a specific list of assets such as traffic signals, street lights and other targeted metal apparatuses. The asset list-based detection process works well for inventory items, but is not intended to test for underground faults, which may energize sidewalks or other surfaces that do not appear on an asset list. Handheld pen testers are far more practical for testing a large number of assets than a traditional voltmeter because pass/fail criteria is indicated by a light, an audible alarm or both. These devices are not as sensitive as the voltmeter and may not identify a potential hazard that is energized below the minimum voltage threshold of the device.

Variations from user to user can affect the reliability of detection with a pen tester. Therefore standard practices are to be encouraged to ensure repeatable measurements are obtained:

a) Keep all body parts as far away from the object being tested as possible. Since the tester's body is the "ground reference" for the test, wearing thick gloves or boots may prevent a voltage indication from occurring.

b) Make solid metal-to-metal contact with each surface tested. Paint can insulate energized surfaces from detection with a contact device.

c) Test all metal parts of an object separately. Metal surfaces in physical contact are not necessarily in electrical contact, especially if painted or corroded (see Figure 8).

d) The investigator should follow all written test procedures and manufactures instructions (e.g., hold the detector at arms' length).

e) Verify if gloved hands are recommended by the manufacturer, some detectors require bare hand use. Grip these detectors firmly with a full hand.

f) The investigator should conduct multiple measurements from alternate locations to reduce the chance of standing on energized ground.

g) Verify the detector to a known reference often as battery performance may change due to environmental conditions (cold weather) and the batteries age.

5.4.1.2.3 Non-contact electric-field detectors (see also 5.5.1.5)

Handheld electric-field detectors are also capacitively coupled sensors that measure electric fields. They are similar to mobile electric-field detectors, without a mobile platform and with less sophisticated computer-based processing. These handheld detectors can be used to locate a specific energized object or surface following a positive indication from a mobile scan, or when investigating an incidental detection (e.g., an ESR from the public). They may also be used in areas where a mobile platform is difficult to deploy (e.g., foot traffic only areas), and can be useful when identifying a qualified reference (see 5.5.1.5).

The sensitivity of handheld electric-field detectors can vary greatly based on their intended application. For example, some handheld electric-field detectors are designed for measuring human exposures to electric fields. In these devices the field strengths may be several orders of magnitude larger than those associated with contact voltages. Care is needed in selecting a detector that has the requisite sensitivity. Some of these testers may also have directional sensitivity to help the investigator find and validate the energized object among multiple objects that may be energized. As a result of the high sensitivity needed to detect small amounts of contact voltage, handheld electric-field detectors are also subject to false readings that may be caused by a variety of electrical noise sources. Similar to mobile electric-field detectors, handheld detectors may be affected by electric fields from nearby overhead distribution and transmission lines (Consolidated Edison Co. of NY, Inc. [B40]).

5.5 Verification and measurement of contact voltage

5.5.1 Contact voltage measurement equipment

5.5.1.1 True rms digital voltmeter (DVM)

A true rms digital voltmeter (DVM) can be used as a means of quantifying the voltage once it has been detected. Voltage measurements require several steps, often including the use of a shunt resistor (see 5.5.1.4). Measurement of voltage on objects should commence anytime a detection by any of the previously described methods occurs. The meter can be outfitted with test leads which are long enough to access the object under investigation and qualified reference points.

5.5.1.2 True rms ammeter

A true rms ammeter or clamp-on ammeter can be used to determine the presence of ground faults by quantifying the net current in a circuit. DVMs with a built-in clamp-on ammeter are available and provide the user with the same functionality as using a separate current clamp. Care can be taken to ensure the proper measurement range of the meter is selected to provide accurate current measurement.

5.5.1.3 Qualified reference

Accurate measurements of contact voltage levels require the use of a qualified reference. A qualified reference is a measurement reference location that has been verified to be at zero potential relative to remote earth and have a low impedance connection to the earth. A qualified reference is selected from available nearby candidates that include fire hydrants, fence and sign posts, and other conductive metal objects in intimate contact with earth. A temporary ground rod may be used, but the investigator should ensure that it is of adequate length to provide a low impedance pathway to the earth. A confirmation process, detailed in Annex A, describes the process for qualifying a candidate reference for use in the contact voltage measurement process. All voltage measurements should be made via the qualified reference.

5.5.1.4 Shunt resistor

After measuring voltage on an energized structure or surface with a high impedance voltmeter, it is often helpful to perform measurements with the addition of a shunt resistor to the measurement circuit. Measurements with a properly sized shunt resistor can help eliminate false readings. The application of proper measurement procedures will result in more accurate measurements that are repeatable from user to user. This reduces confusion at all levels of the process and aids the investigator in discerning the difference between hazardous energizations that are caused by faults and energizations that are caused by other sources

Measureable voltage can be present on ungrounded, isolated metal objects due to the influence of nearby high voltage sources such as power lines, lighting ballasts, or unshielded power cords. This phenomenon is known as capacitive coupling, although other terms have been used to describe it, including "phantom voltage." In these cases, the object under test has a measurable voltage present, but no physical connection to a current source exists. Elimination of capacitively coupled voltages is the primary purpose of a shunt resistor when making contact voltage measurements.

An example of a shunt resistor is shown in Figure 9. The momentary push button allows the resistor to be inserted into the circuit without the need to reposition the test probes. By maintaining constant contact with the probes the introduction of additional measurement error into the circuit can be avoided. The push button also allows the investigator performing the test to compare the open circuit and shunt voltages quickly to determine if the voltage at the selected reference point has a low impedance source.

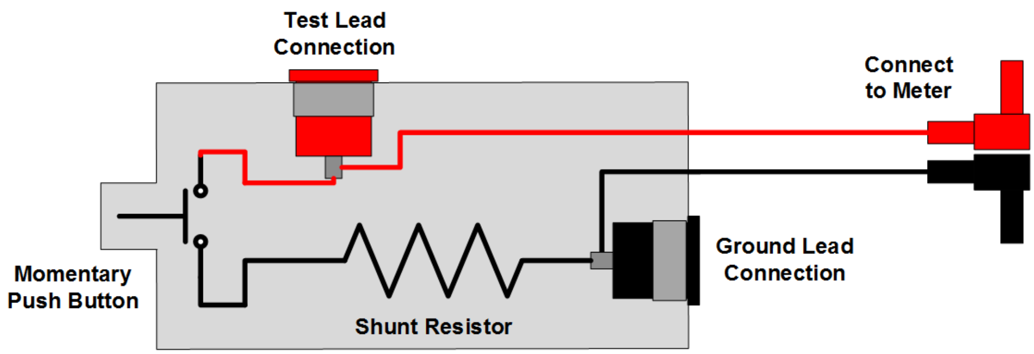


Figure 9—Push button shunt resistor schematic

When a high input impedance voltmeter is used to make contact voltage measurements from an energized surface to a qualified reference, placing a small known load, or shunt resistor, in parallel with the input of the voltmeter is an effective methodology to eliminate capacitively coupled voltages. If current flows from the object under test through the shunt resistor to earth, the voltage collapses to nearly zero, eliminating false positive voltages due to capacitive coupling. The voltage on objects energized by an actual low impedance current source will not collapse to zero, but may be reduced from the un-shunted open circuit voltage value (V_{OC}) according to Ohm's Law [see Equation (5)].

$$V_{SHUNT} \approx V_{OC}\left(\frac{Z_{SHUNT}}{Z_{SOURCE}+Z_{SHUNT}}\right) \tag{5}$$

where

V_{SHUNT}	is the voltage measured with the shunt resistor in parallel with voltmeter
V_{OC}	is the voltage measured without the shunt resistor
Z_{SHUNT}	is the impedance of the shunt resistor
Z_{SOURCE}	is the source Impedance

V_{SHUNT} collapses to nearly zero in cases where voltage is sourced via capacitive coupling, as $Z_{SOURCE} \gg Z_{SHUNT}$. This equation assumes zero contact impedance and ground impedance. The schematic shown in Figure 10 captures the circuit elements in the measurement circuit. Analysis of this circuit allows selection of an appropriate value of shunt resistance for the task at hand.

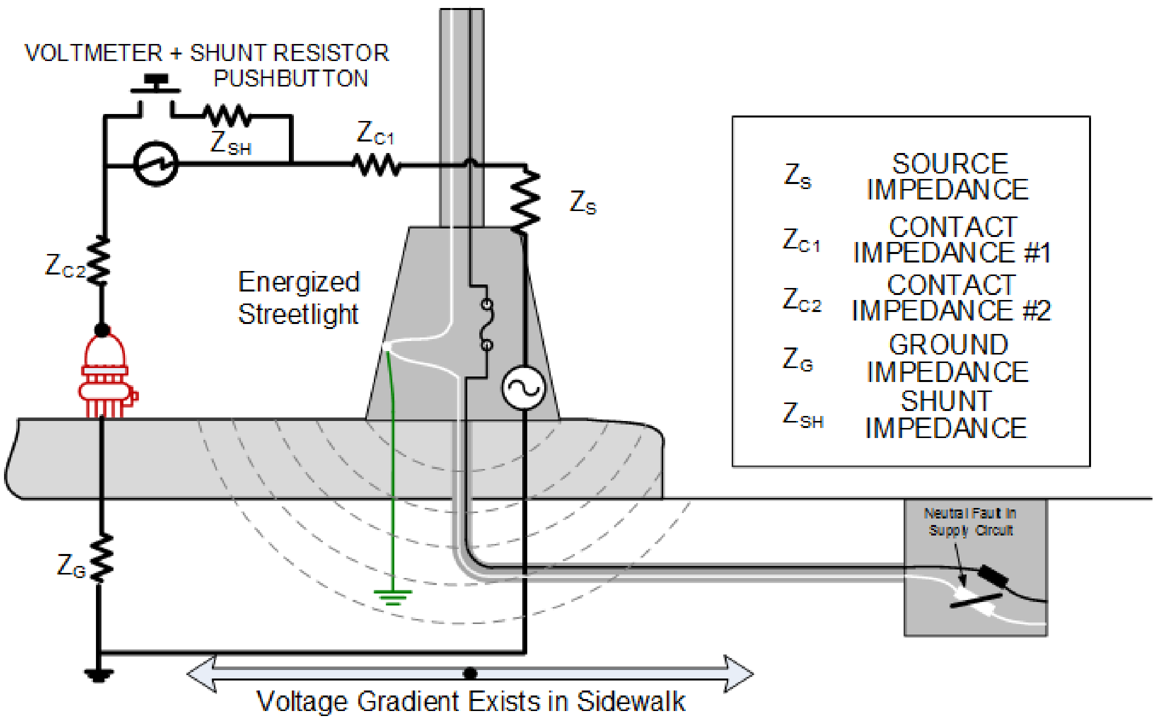


Figure 10—Measurement circuit including various circuit impedances

Errors due to contact and ground impedance can complicate the troubleshooting process. By observing and minimizing the change in voltage that occurs when a shunt resistor is introduced into the circuit, the investigator can minimize contact and ground impedances and get accurate readings that are repeatable from person to person. This positive feedback activity calls for a shunt resistor that can be quickly engaged and disengaged, without disconnecting or moving the test leads. It also calls for a shunt with resistance low enough to collapse the voltage from a capacitively coupled source, but high enough to minimize measurement error.

Historically, in farm investigations of stray voltage, a shunt resistance of 500 Ω was chosen as it represents a conservative estimate of a cow's body and contact resistance in real world conditions (Patel [B38]). By using this value for field measurements, it is possible to assess the amount of current that could flow through a cow making contact with the energized surface being investigated.

Contact voltage measurements bring their own unique set of measurement requirements. The measurements are performed to guide the investigator to a fault or defect so it can be repaired. The shunt resistor value selection is not guided by human or animal impedances as the measurement is not intended to be a measurement of exposure. Selection of a shunt resistor value for contact voltage measurements is guided by the need for accurate repeatable measurements. Shunt resistor values of 500 Ω, 3000 Ω, and 10000 Ω have been used in contact voltage investigations, but a higher resistance shunt is more likely to result in accurate and repeatable measurements.

Measurement error is a function of the impedances in the measurement circuit (see Equation (6), Equation (7) and Equation (8)). Ideally, the variability in measurements as a result of typical error values in the field is less than 10%. Table 4 shows shunt voltage variability for a 20 Ω source impedance, low total (ground and contact) impedances (50 Ω), and a more realistic value (250 Ω), using 500 Ω, 3000 Ω, and 10000 Ω shunt resistors. It is easy to see how a lower value of shunt impedance results in large measurement variability which can cause confusion and miscommunication between multiple diagnostic or repair crews that may make connection to different qualified references. The equations below show that the measurement error of the shunt voltage is a function of the ground and contact impedances in the measurement circuit.

$$\varepsilon = \frac{Z_{SHUNT} + Z_{SOURCE}}{Z_{SHUNT} + Z_{SOURCE} + Z_{CONTACT} + Z_{GROUND}} \tag{6}$$

where:

ε is the measurement accuracy
Z_{SHUNT} is the impedance of the shunt resistor
Z_{SOURCE} is the source impedance
$Z_{CONTACT}$ is the contact impedance
Z_{GROUND} is the ground impedance

$$V_{SHUNT} = V_{OC} \times \left(\frac{Z_{SHUNT}}{Z_{SOURCE} + Z_{SHUNT}} \right) \times \varepsilon \tag{7}$$

where:

V_{SHUNT} is the voltage measured with the shunt resistor in parallel with the voltmeter
V_{OC} is the voltage measured without the shunt resistor
Z_{SHUNT} is the impedance of the shunt resistor
Z_{SOURCE} is the source impedance
ε is the measurement accuracy

$$Measurement\ Error(\%) = (1 - \varepsilon) \times 100 \tag{8}$$

From Table 4, we see that error in measurements utilizing a 500-Ω shunt is only low when ground and contact impedances are very low. When typical values of ground and contact impedance are considered, measurement error increases rapidly. The importance of measurement accuracy and appropriately large shunt resistances was noted as early as 1984 (Gustafson, 1984 [B22]).

Table 4—Examples of measurement error for various shunt resistor values

	Ideal measurement conditions		Typical measurement conditions		
Z_{SHUNT} (Ω)	**500**	**3000**	**500**	**3000**	**10000**
Z_S (Ω)	20	20	20	20	20
Z_G+Z_C (Ω)	50	50	250	250	250
V_{SHUNT}	$0.88 \times V_{OC}$	$0.98 \times V_{OC}$	$0.65 \times V_{OC}$	$0.92 \times V_{OC}$	$0.98 \times V_{OC}$
Error (%)	9%	2%	32%	8%	2%
ε	0.91	0.98	0.68	0.92	0.98

The importance of shunt resistor value selection is illustrated in this example. Using lower shunt resistor values, for example 500 Ω, will result in higher measurement errors. As illustrated in the table even under ideal conditions a 500-Ω shunt resistor will yield a measurement error of 9%, and that error increases to over 30% in typical conditions. The investigator should carefully consider the measurement conditions when selecting a shunt resistor.

Figure 11 provides an example of how low value shunt resistors can impact the measurement process when high contact impedances are present. In this example a sidewalk is energized due to failed insulation on a service conductor located beneath the sidewalk and the investigator is using a pointed test probe to make measurements. The pointed test probe is a high resistance connection to the sidewalk. When a 500-Ω shunt resistor is placed in parallel with the multi-meter the resultant measured voltage is 0.95 V. This is below the mitigation threshold set by a number of utilities and regulatory authorities and the investigator would likely take no action to mitigate the existing fault. When a higher resistance shunt is used, the measured voltage rises above the mitigation threshold and the potential hazard would likely be identified and addressed. Using a high impedance voltmeter in this example, either without the use of a shunt resistor or with the use of a higher value shunt resistor can help the investigator recognize the presence of the fault so that appropriate action can be taken.

Example: Sidewalk Measurement	
Voltage (V)	Shunt Value (Ω)
0.95	500
5.4	3,000
16.0	10,000
97.6	None

Figure 11—Sidewalk energized by underground fault

5.5.1.5 Handheld electric-field detectors

During a contact voltage investigation a handheld electric field detector as shown in Figure 12 and Figure 13 helps an investigator to determine that candidate references are not energized, thereby completing the first step for ensuring a qualified reference. They often have displays that give a relative indication of field strength. Any voltage on a surface gives rise to an electric field. If the electric field is at or near zero, the voltage is also at or near zero. The detector should be capable or indicating electric field strengths that are indicative of an energized object. Handheld voltmeters are capable of indicating the presence of voltage to some reference location, but they are not suitable for validating a qualified reference.

Figure 12—Using a handheld electric field detector to check for the presence of electricity on a candidate reference

Handheld electric field meters are also valuable for detecting contact voltage on a nearby surface or structure. They can be more sensitive than pen type testers but their application as a primary detection tool in an asset list based testing program is subject to limitations imposed by the use of the asset list itself.

5.5.2 Investigation protocol

Once a voltage is detected, it can be verified and measured. The measurement scenario is unconventional compared with typical forms of electrical measurement. Voltages may be variable and far below line voltage. Suitable qualified reference points may not be close by. Significant contact and ground impedances may be present. Active faults should also be assumed, which could place nearby objects or the earth itself at an elevated voltage as shown below.

Figure 14 illustrates a measurement scenario where the neutral conductor of the supply circuit is open or highly resistive. Most of the return current for the street light flows through the earth via the driven ground and the street light standard mounting bolts. In doing so it creates a voltage gradient in the sidewalk. See Annex A and Annex B for a complete description of how to make a contact voltage measurement and how to perform a contact voltage investigation.

Figure 13—The use of a handheld electric field detector to locate energized objects

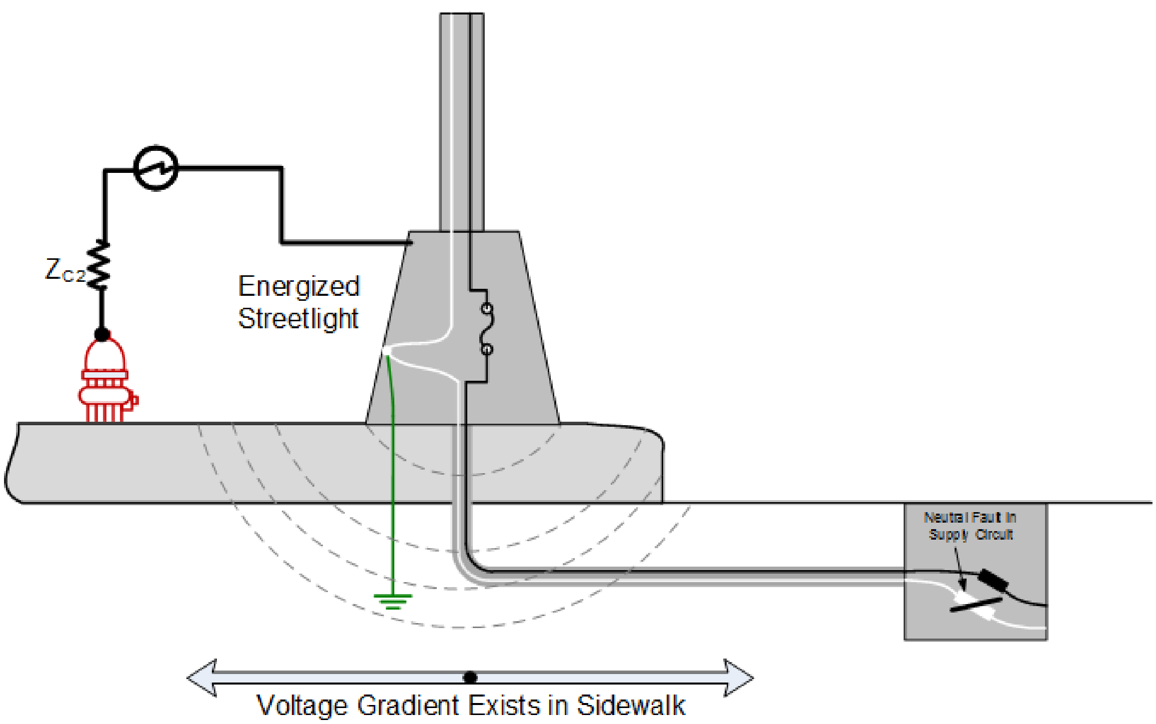


Figure 14—Measurement scenario with highly resistive/open neutral conductor

5.6 Developing a CVD program

Contact voltage is potentially present anywhere there is an operating electrical system. As the electrical system is exposed to external stresses such as heating, mechanical forces and age the possibility of an electrical fault that results in an accessible energized surface increases.

Due to the variable nature of a high-impedance-phase conductor fault or a failing system neutral, a hazardous voltage can be present and can remain on a conductive surface that is otherwise properly grounded and bonded. The protective device may not operate to remove the contact voltage hazard if the fault current is below the protective device trip threshold.

The emergence of contact voltage hazards is hard to predict. The most effective way to find them is to test on a regular basis. When establishing the scope and frequency of a CVD program the risk factors for contact voltage should be considered (see 5.6.3).

5.6.1 CVD program design

Not all standard industry practices for controlling hazards in the workplace apply to the issue of contact voltage and its implications concerning public safety. Workplace hazards are generally controlled by:

a) Hazard elimination or substitution
b) Engineering controls
c) Administrative controls
d) Personal protective equipment (PPE)

Utility and asset owners may consider a CVD and mitigation program to gather the data needed to target hazard elimination efforts or to measure their effectiveness. Hazard elimination can occur only after the specific electric fault has been detected. New engineering controls such as design changes or the application of guards or coatings can prevent future hazards from occurring or minimize the risk of exposure. Existing codes deal with wiring issues that can result in contact voltage conditions, but may not specifically address contact voltage, its origination or elimination. CVD targets specific hazards for repair, yielding an immediate safety benefit and actionable data for maintaining safer electrical facilities in the future.

A CVD program such as the one illustrated below in Figure 15 creates traceable, actionable data to guide repairs and upgrades and improve system safety. Detecting voltages on normally non-energized objects provides a set of locations where electrical faults may exist. The measurement and verification steps of a CVD program filter those findings down to exclude false detections and precisely quantify the voltage present at the time of the measurement. Harmonic analysis further separates the voltage findings into two categories: voltage created by possible phase conductor faults and voltage from either faulty neutrals or normal neutral return current. Further troubleshooting helps to separate the potentially hazardous system faults from the cases of stray voltage that occur on a normally operating system. System repairs finally remove the hazardous and potentially hazardous faults. Post-test analysis of this process gives the asset owner new information about what kinds of equipment, cable, connections and locations are most often associated with contact voltage. The process yields both system improvement and new knowledge about the state of the electrical system. Each subsequent cycle of the process enhances the depth and accuracy of that knowledge and informs future decisions.

5.6.2 CVD program options

Some utilities and asset owners in the United States are required to test their electrical assets multiple times per year, while others test voluntarily. Strategies to repair or prevent contact voltage are also diverse. Table 5 presents a number of mitigation strategies that could be used to mitigate or prevent contact voltage. Typically, a utility or asset owner will employ a combination of these strategies in concert to enhance safety and reliability based on the specific risk factors present.

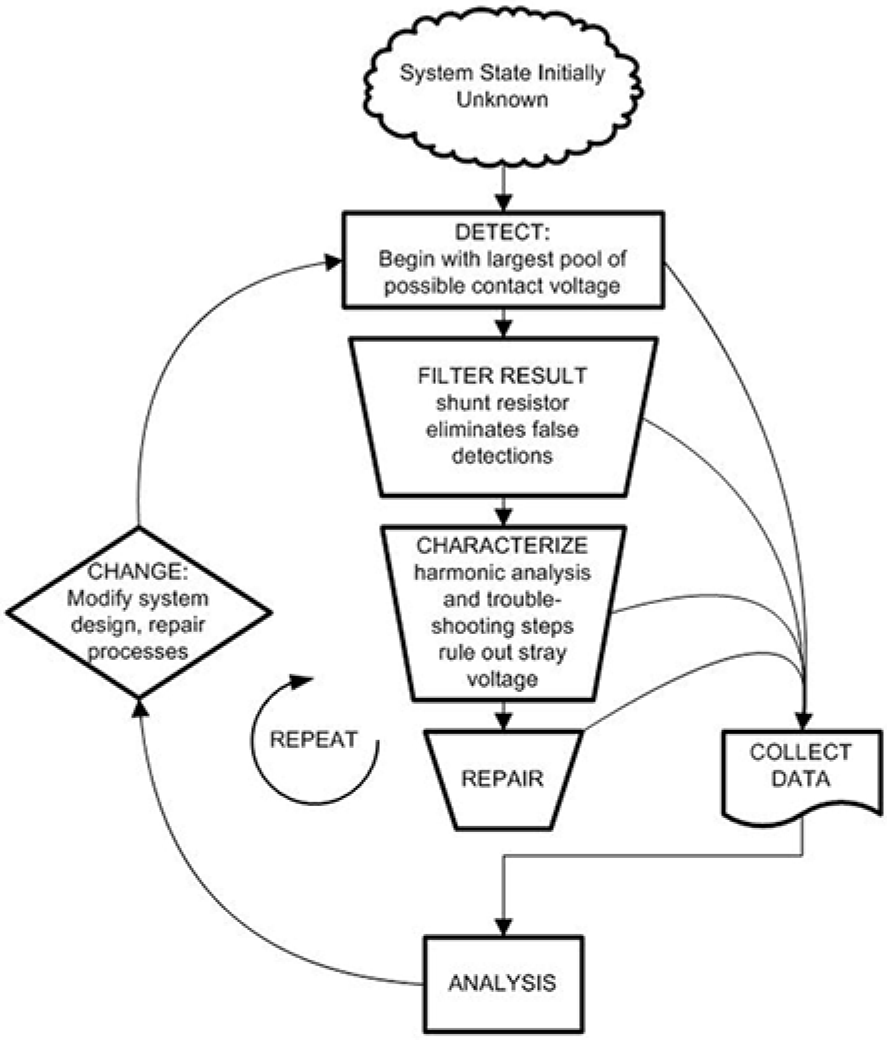


Figure 15—CVD process for identifying and mitigating existing contact voltage and gaining knowledge about the possibility of future incidents of contact voltage

Table 5—Summary of contact voltage mitigation strategies

No.	Life-cycle phase	Strategy	Notes
1	Systems design	Prevention	Specify equipment, protective devices, insulation, bonding conductors and system design with CV hazards in mind.
2	Equipment manufacturing	Prevention	Manage purchasing process to ensure suppliers conform to applicable standards (UL, ISO, etc.)
3	Installation	Prevention	Avoid creating hazards during cable pulls and splicing processes through training, supervision and the use of proper tools and materials.
4	Commissioning	Detection	Test and inspect new assets. This is the best opportunity to detect and correct wiring errors and hazards from insulation that is defective or damaged during installation.

Table continues

Table 5—Summary of contact voltage mitigation strategies *(continued)*

No.	Life-cycle phase	Strategy	Notes
5	Operation and maintenance	Prevention Detection Corrective Action	Operating equipment at or below its rating can prolong service life and reduce the probability of faults. Routine pre/post work testing by properly trained workers can detect contact voltage.
6	Ongoing	Detection Corrective Action Analysis	A CVD program covering areas of high risk or specific assets, such as underground infrastructure and streetlights, focuses resources on the specific areas where contact voltage is present and is most likely to occur in the future.
7	Ongoing	Education	Conduct public awareness campaign. Coordinate with public/media relations personnel for bulletins, announcements, or electronic media to improve electrical safety knowledge.
8	Replacement	Analysis Prevention Corrective Action	Schedule replacement of deteriorated infrastructure before problems occur. May include cables, streetlight structures or power distribution panels and wiring.

5.6.3 Risk factors for contact voltage

A few of the key risk factors for contact voltage are as follows:

a) Streetlights and other loads supplied from underground infrastructure are more likely to have buried or concealed faults than overhead systems, where conductors are mostly visible and out of reach of the public.

b) High pedestrian/pet traffic increases the possibility of exposure to hazards, if they are present.

c) Conductive raceways/equipment provides more paths to transfer voltage to objects or surfaces in the public right of way not intended to be energized.

d) Deterioration/lack of maintenance, environmental conditions, high vehicular traffic, vandalism, and rodents may make some areas more prone to wear or damage that may lead to the presence of contact voltage.

NOTE—Incidence of reported shock is not the sole consideration when evaluating risk for the purpose of developing a CVD program. Many cases are reported to non-utility responders such as police/fire or not reported at all due to a lack of electrical safety awareness among the general public.[3]

Asset owners whose electrical systems or service areas encompass all or most of the risk factors may consider more frequent or comprehensive testing options, whereas those systems or areas which are at lower risk (i.e., overhead infrastructure), low or zero pedestrian exposure, newer infrastructure with non-metallic ductwork and sensitive GFCI protection, etc., may opt to perform less testing. Options for test intervals are as follows:

a) Test new installations upon commissioning

b) One-time audit of existing infrastructure

c) Test only areas of high exposure or high risk

d) Spot checks during trouble-calls

e) Routine tests at re-lamp intervals

f) Testing before and after maintenance work is performed

[3]Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

g) Regular testing independent of other maintenance cycles
h) Performing multiple-asset, wide area mobile patrols
i) Asset specific manual testing
j) Any combination of the above

An initial CVD effort provides a baseline of the number and type of contact voltage conditions that exist. A second test allows the asset owner to evaluate the success of repair efforts and estimate the rate of infrastructure failure that occurs over time.

Based on the data gathered from the CVD program, other mitigation strategies can be incorporated into maintenance and design procedure either system-wide or on a targeted basis.

5.6.4 CVD program management

Where it has been determined that a formal, comprehensive CVD program should be implemented, the following program elements may be incorporated:

a) A management team or committee
b) A policy or mission statement
c) A risk management assessment of assets
d) Written test procedures (for CVD)
e) Pre-determined acceptance standards (pass/fail criteria)
f) Test record and data collection forms
g) A testing schedule (frequency, areas etc.)
h) A test and repair protocol (who does what)
i) An incident reporting form and protocol
j) Tool and test instrument specifications
k) Test instrument calibration and inspection records
l) Procedures for barricading hazardous areas (if CV is found)
m) PPE requirements
n) A CV oriented review of engineering practices
o) Updates to existing asset inspection checklists
p) Changes to existing electrical work safety practices
q) Staffing requirements
r) A budget
s) A public reporting template
t) Communications literature for areas of risk (e.g., schools, stadiums, and other public venues)
u) Maps of highest risk areas based on annual or incidental pedestrian density

5.6.4.1 Testing personnel

Persons trained in performing CVD may assist in troubleshooting but should report incidents immediately and defer repair work to qualified persons.

This practice should apply whether the work is performed by the asset owners' staff, by the street lighting maintenance contractor or by a specialist brought in for the specific purpose of CVD.

Metal equipment housings or access covers can be checked both before regular maintenance work is performed (for worker safety) and after work is performed (for public safety). This helps protect against the possibility of worker induced faults.

5.6.4.2 Repair criteria for CVDs

A detected voltage may or may not be a hazard and repair decisions are not obvious from a voltage measurement alone. The more detailed measurement and validation steps outlined in this guide allow discrimination between contact voltage from a faulted phase conductor and a compromised neutral conductor, and also between the contact voltage created by a compromised neutral conductor and stray voltage. Using these distinctions, an investigator can more accurately describe a voltage as either contact voltage or stray voltage and then assess whether a hazard exists or could exist at the location under investigation.

5.6.5 Design improvement guideline

A comprehensive review of the system design can identify risk areas which can be reduced or eliminated. Prevention at the design level is a way to reduce the possibility of future contact voltages over the long term. Such a review can include:

a) Grounding and bonding practices
b) Conductor clearances and burial depths
c) Guarding and mechanical protection
d) Conductor insulation grades
e) Connection and splicing methods, especially hand-taping and the use of non-submersible equipment in outdoor environments
f) Component specifications (non-conductive enclosures, light poles, luminaires, etc.)
g) Protective devices (fuses, breakers, GFCI's etc.)

5.6.6 Conclusion

Contact voltage hazard mitigation is best accomplished by means of a balanced approach, which includes system design, quality control, inspection, testing, risk analysis, life-cycle analysis, and infrastructure replacement. Three conclusions can be made:

a) Electrical systems can exhibit contact voltage and test protocols are available to identify and mitigate contact voltage hazards.
b) Any CVD program can be scaled and tailored to the needs of the community it serves. Various technologies and detection strategies may be employed and the asset manager should understand the limitations and risks of each approach.
c) Contact voltage conditions found should be remedied in a timely fashion and proper records maintained.

6. Stray voltage

Stray voltage is a voltage resulting from the normal delivery or use of electricity which may be present between two conductive surfaces that can be simultaneously contacted by members of the general public or their animals. Stray voltage is not related to electrical faults.

6.1 Background

Stray voltages are often identified as part of a routine testing program (e.g., a CVD program as described in 5.6), during routine electrical work or by calls of concern from the general public. Because stray voltage readings are often less than 10 V, locations of concern are usually where exposure scenarios are unique such as swimming pools, outdoor showers, confined livestock facilities and marinas and boat docks. The electrical nature of each of these exposure scenarios requires the implementation of distinct investigation and mitigation processes.

6.2 Causes of stray voltage

Although small voltages from a variety of sources can often be measured at publicly and privately accessible locations (e.g., dc voltage from naturally occurring galvanic cells and radio frequency voltage from nearby radio transmitters), this document discusses only voltage from power frequency sources related to the delivery and use of electricity. Sources of stray voltage include normal system return current and electromagnetically coupled currents and voltages.

6.2.1 Normal return current

Stray voltage can occur in the vicinity of any operating electrical system whether referenced to earth or not. It is more likely to occur on a grounded electrical system, especially a multi-grounded system consisting of a neutral conductor with multiple intentional and un-intentional connections to earth (Figure 16). As return current passes through the impedance between the neutral conductor (and all conductive objects connected to the neutral conductor) and the earth a neutral-to-earth voltage (NEV) is developed (Figure 17). Elevated NEV can be caused by the flow of normal neutral return current through the electrical circuit's return-path impedance, or it can be the result of fault current flow through the return-path impedance. When the NEV is caused by normal neutral return current, that portion of the NEV that can be measured between surfaces that can be simultaneously contacted by people or their animals is stray voltage. Generally speaking, as the amount of normal neutral return current increases or the return-path impedance increases, the level of stray voltage also increases.

6.2.1.1 Factors that increase return current

On a radial single-phase electrical system return current increases when the amount of load served increases. As the system becomes more complicated (e.g., polyphase, with power factor correction, with multiple bridging points), return current may increase for other reasons. On three-phase electrical systems load unbalance results in return current. The greater the unbalance, the larger the return current. Non-linear loads such as switch mode power supplies used in mobile phone chargers and computer power supplies generate a multitude of harmonics in the power system, some of which are the 3rd harmonic. On three-phase systems triplen harmonics (especially the 3rd harmonic) are of particular concern because they add arithmetically in the neutral conductor and can significantly increase the amount of neutral return current (Dorr, Martino, and Hanebuth [B11]).

Figure 18 shows a typical switch mode regulated power supply and associated load current. Notice current is only drawn as the capacitor charges, creating a very non-linear load current.

Figure 19 shows a balanced three-phase system with only fundamental (60 Hz) current and demonstrates how balanced load currents cancel.

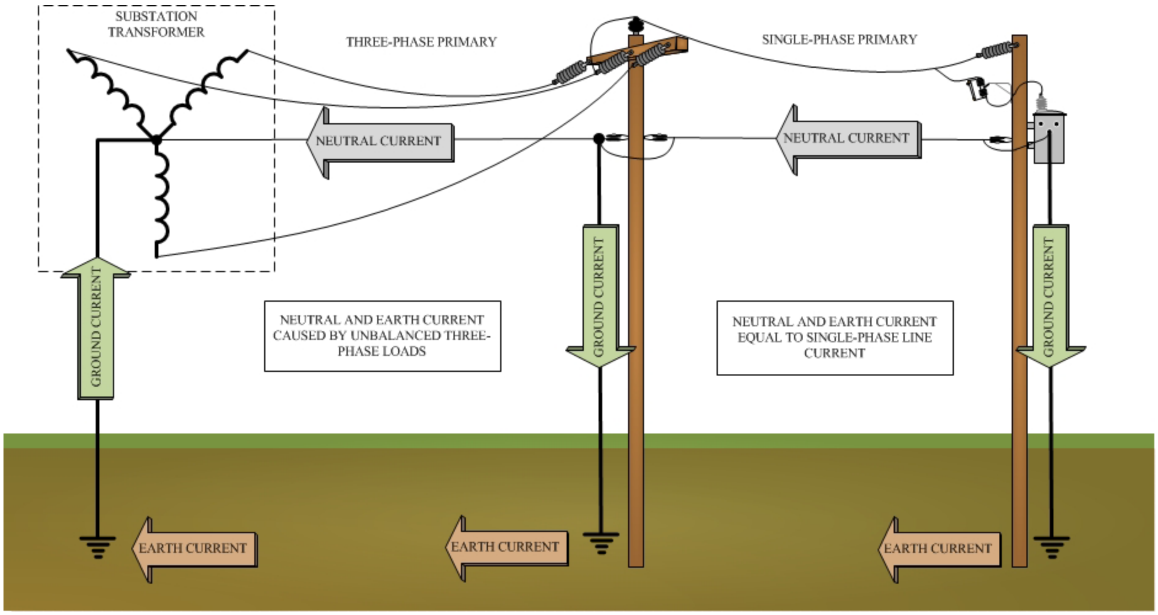


Figure 16—Normal neutral, ground and earth current paths in a multi-grounded Wye distribution system

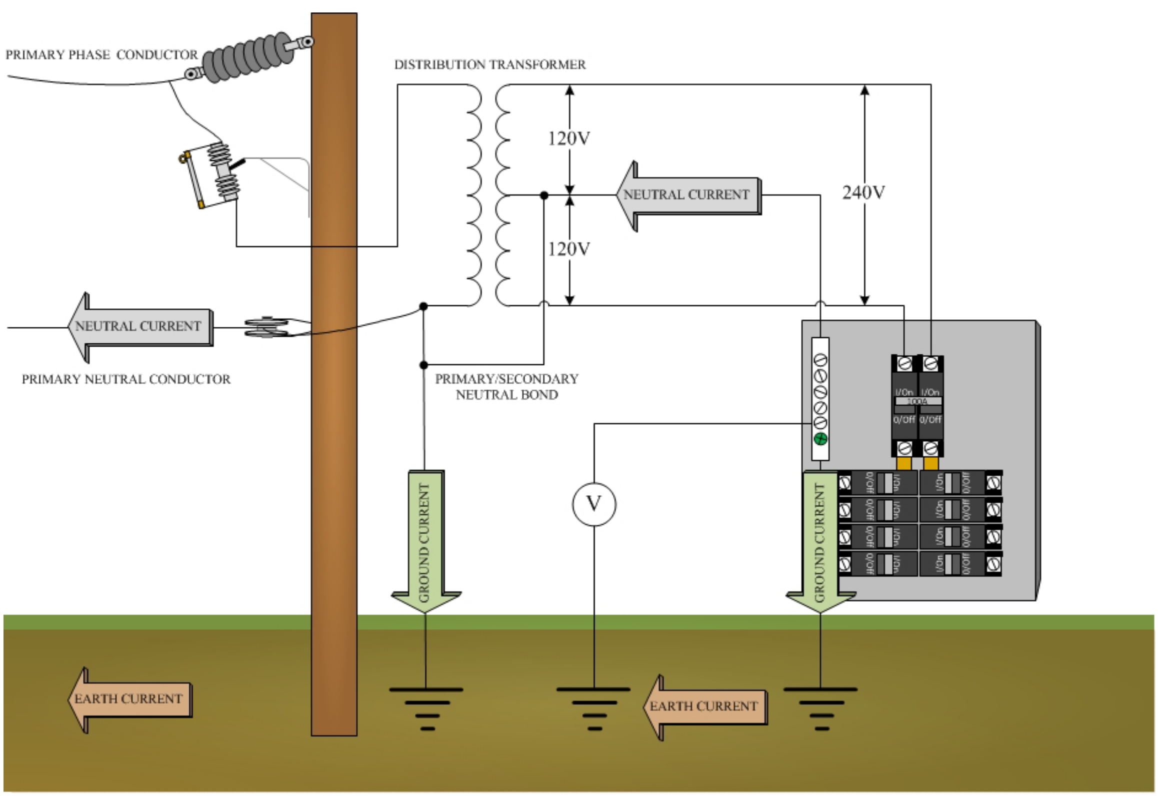


Figure 17—Typical residence with secondary neutral bonded to primary neutral and earth

Figure 20 shows a perfectly balanced three-phase system with fundamental and 3rd harmonic currents and demonstrates that these currents do not cancel. These non-linear loads create neutral current because of triplen harmonics.

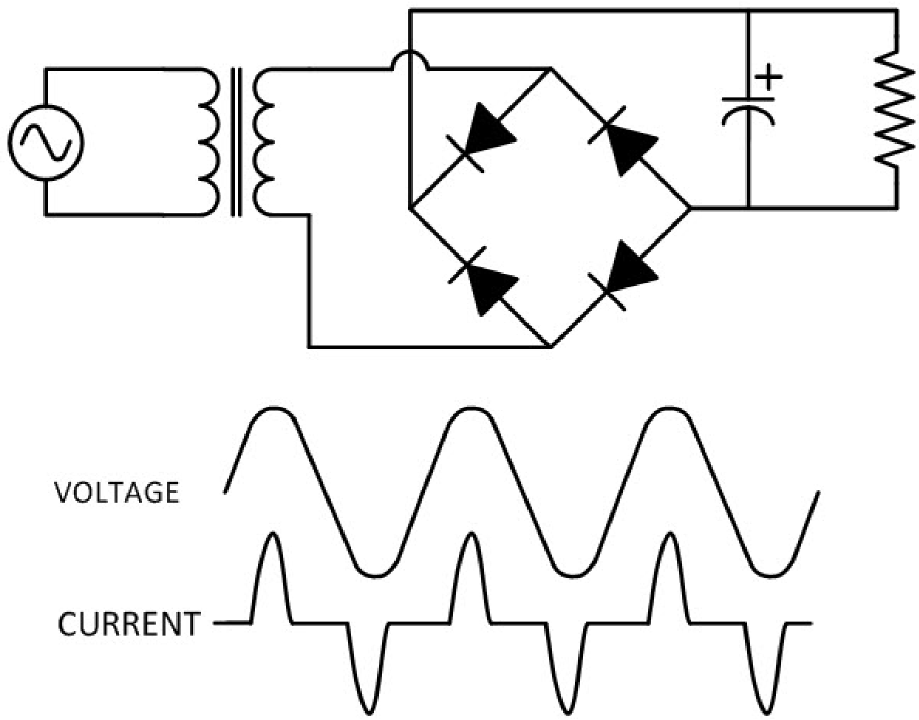


Figure 18—Single-phase power supply

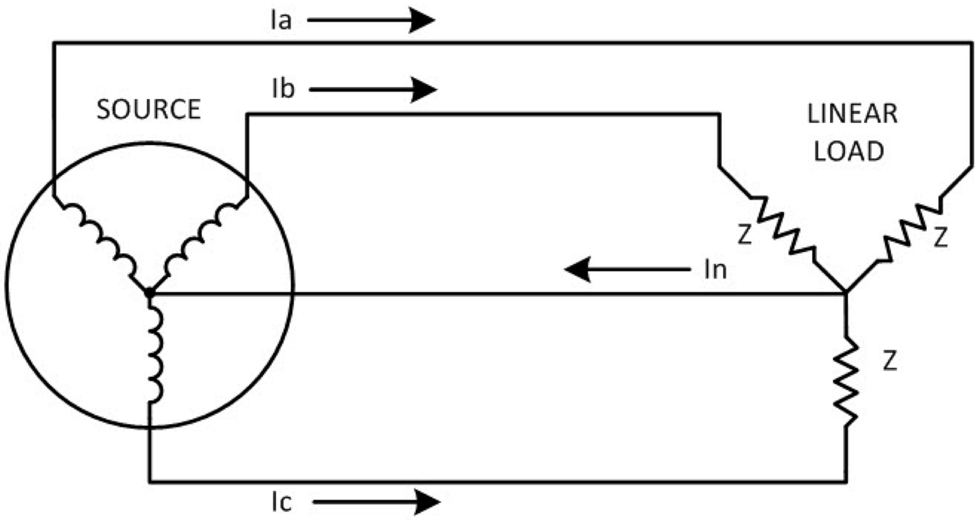
6.2.1.2 Factors that increase return-path impedance

Factors that may cause an increase in return-path impedance include poor soil condition (i.e., highly resistive soil, such as dry sand), loose or corroded grounded and grounding conductor connections, neutral conductor size and length, inadequate and/or ineffective bonding and insufficient system grounding.

6.2.2 Electromagnetically coupled currents and voltages

6.2.2.1 Inductive coupling (magnetic field)

Inductive coupling is the transfer of energy between a current-carrying conductor and all nearby conductive loops due to a time-varying magnetic field that is created by time-varying current in the energized conductor. A common example of inductive coupling capable of creating stray voltage can occur when a multi-grounded distribution circuit is underbuilt on a transmission structure. The magnetic fields associated with transmission system operation will induce a current in the conductive loops formed by the distribution system neutral, its connections to earth (e.g., ground rods) and the earth path between those connections. The amount of current that flows in each conductive loop and the amount of NEV created is dependent on numerous factors including the amount of current in the transmission-phase conductors, the distance between the transmission and distribution systems, the integrity of distribution neutral and ground lead connections, and soil resistivity. Increased levels of NEV due to inductive coupling can result in increased levels of stray voltage.



$$Ia = I\sin(\omega T)$$
$$Ib = I\sin(\omega T + 240^\circ)$$
$$Ic = I\sin(\omega T + 120^\circ)$$
$$In = Ia + Ib + Ic$$
$$In = I\sin(\omega T) + I\sin(\omega T + 240^\circ) + I\sin(\omega T + 120^\circ) = 0$$

Figure 19—Balanced linear load results in zero-neutral current

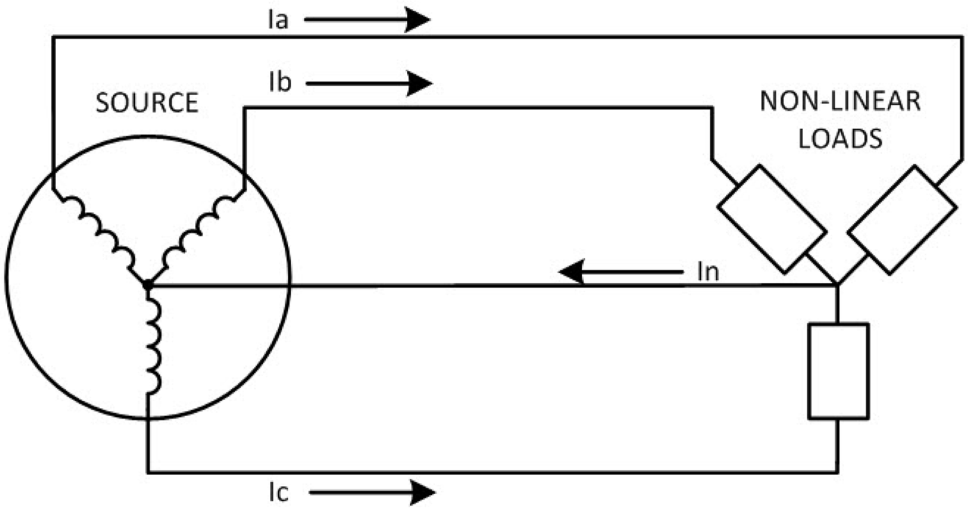
6.2.2.2 Capacitive coupling (electric field)

Capacitive coupling occurs when a time varying electric field exists between two adjacent conductors typically less than a wavelength apart. An example of capacitive coupling that can result in a stray voltage exposure may occur when a long metallic poorly grounded feed bunk is constructed near or beneath a high voltage transmission line. The magnitude of the capacitively coupled voltage on the feed bunk depends on the distance to the energized conductor, the electric-field strength (i.e., system voltage), the size and shape of the feed bunk and how well it is connected to earth. If the feed bunk is effectively grounded, the voltage on it is reduced to near zero potential with respect to earth. When near zero potential a person or animal standing on the earth and making contact with the feed bunk will not be exposed to perceptible current. If the feed bunk is poorly grounded or not grounded at all, a voltage can exist between it and the earth and a perceptible exposure is more likely to occur.

6.3 Detection of stray voltage

As with contact voltage stray voltage can be detected in one of four ways:

a) Direct detection: a managed program of testing specific assets or geographical areas



$$
\begin{aligned}
&Ia = I\sin(\omega T) + I\sin(3\omega T)\\
&Ib = I\sin(\omega T + 240^\circ) + I\sin[3\times(\omega T + 240^\circ)]\\
&Ic = I\sin(\omega T + 120^\circ) + I\sin[3\times(\omega T + 120^\circ)]\\
&In = Ia + Ib + Ic\\
&In = I\sin(\omega T) + I\sin(3\omega T) + (\omega T + 240^\circ)\\
&\quad + I\sin[3\times(\omega T + 240^\circ) + I\sin(\omega T + 120^\circ) + I\sin[3\times(\omega T + 120^\circ)]]\\
&\quad = I\sin(3\omega T) + I\sin(3\omega T + 720^\circ) + I\sin(3\omega T + 360^\circ)\\
&In = 3\times I\sin(3\omega T)
\end{aligned}
$$

Figure 20—Balanced non-linear load elements

b) Incidental detection: discovery of unacceptable levels of stray voltage during routine maintenance work or through abnormalities noticed during visual inspections

c) Publicly reported exposure: a member of the public reports a perceptible exposure

d) Publicly reported concern.

6.4 Equipment for detecting stray voltage

In situations where stray voltage is detected through either direct or incidental detection [see a) and b) in 6.3] the equipment for detecting stray voltage is often identical to the equipment for detecting contact voltages (see 5.5.1). Alternately, when an investigation is triggered by a public report of exposure or an expression of concern [see items c) and d) in 6.3], the investigator can move directly to the verification and measurement process described below in 6.5.

6.5 Verification and measurement of stray voltage

In addition to the DVMs, ground leads, shunt resistor, and power quality meters documented in 5.5 of this guide, the following devices are often used during a stray voltage investigation:

a) Clamp-on ammeter
b) Recording voltmeter or ammeter
c) Oscilloscope
d) Ground-resistance tester
e) Insulation tester.

Some of these instruments and their applications are discussed in detail in this section. When making measurements, instrument characteristics and monitoring points should be given significant consideration. Because harmonics of the fundamental frequency (i.e., 50 Hz or 60 Hz) are present at many stray voltage locations true rms reading meters can be used to improve measurement accuracy. If the instrument is to be operated over extended periods, it should be able to withstand the harsh environment of the facility being investigated or physical protection should be provided. The instruments used for this application can also be protected from electrical extremes, such as faults or lightning.

6.5.1 Stray voltage measuring instruments

Usually, voltage is measured with an analog volt-ohm meter (VOM), a digital multimeter (DMM), a recorder, or an oscilloscope. For use in stray voltage investigations, a voltmeter should meet three basic requirements:

a) It should be able to separate ac and dc voltages
b) It should have minimum voltage resolution of 0.1 V
c) It should have an impedance of at least 5000 Ω/V.

If the meter reads on the ac scale when connected to a flashlight battery, it does not separate ac and dc voltage. A capacitor of at least 5 microfarads with a voltage rating of 50 V may be placed in series with one of the meter leads to block the dc voltage. A voltmeter with input impedance of less than 5000 Ω/V may unduly load the measurement circuit causing the instrument to read the open circuit voltages (V_{OC}) lower than the actual values. When routing measurement leads greater than 7.5 m (25 ft) care should be taken to avoid areas where there is significant RFI or other noise sources, such as radio transmission towers or large adjustable-speed drives.

6.5.1.1 Recording meters

A recording voltmeter should have the same characteristics as the indicating meter discussed above. Because this type of meter is generally used for long duration measurements that include capturing momentary events, a fast response time (< 0.14 ms) for transients is suggested. (Note: this value was chosen to match a 128 sample per cycle resolution common for recording meters.) In addition, it is desirable that a recording meter be able to record multiple voltages simultaneously. Multiple-channel recorders are available in both analog and digital types. Analog recorders have a specific voltage range while digital recorders are often auto ranging. Recording voltmeters can gather voltage information for several days or weeks. This long duration assessment capability is especially important when problem voltages are suspected but are not found at the time of voltage measurements with indicating meters. Recording voltmeters can also be used to record test results for a variety of tests (e.g., equipment signature test).

6.5.1.2 Oscilloscopes

A portable oscilloscope can be used to display actual waveforms including fast rising peaks. The oscilloscope allows the simultaneous measurement of both ac and dc components of a waveform. It will reveal whether a dc source is pure dc or has been rectified from ac. It will also indicate whether an ac source is only 50/60 Hz or has other harmonic frequency components. Sometimes, such information can provide valuable clues as to where to look for stray voltage sources. The multichannel oscilloscope can also measure the phase angle between the current and the voltage. The oscilloscope can be battery operated such that it can be operated in differential mode (two inputs balanced to ground). Some line voltage operated oscilloscopes have one terminal permanently connected to the equipment grounding conductor which makes it difficult to properly measure the voltage between two animal contact points.

6.5.2 Additional stray voltage test equipment

6.5.2.1 Clamp-on ammeters

In stray voltage investigations, it may be necessary to make several current measurements. These measurements commonly include primary and secondary neutral current, load current, net current, and fault or leakage currents. The current in motors, lights, or other equipment can be measured to determine whether the equipment is operating properly. The current in the equipment grounding conductor can be measured to check for fault or leakage currents. Neutral current measurements can be made to assess neutral voltage drop and to determine whether or not the electric loads are properly balanced. For many current measurements, clamp-on-type ammeters or recording ammeters are used.

There are many types of clamp-on ammeters that are available in the market. Some digital clamp-on ammeters or DMM accessory clamp-on probes have auto ranging from 1A to their maximum current range value and are easily and accurately read. They may also have a locking function to measure peak amperes from rapidly changing loads such as motor starting current. The accuracy of many clamp-on ammeters is degraded when measuring currents below 1 A and these are not considered reliable. Detection of currents less than 1 A in grounding conductors can be of significant value in locating sources of stray voltage. Special ac clamp-on ammeters are available, which have ranges from 1 mA to 20 A full scale. These ammeters can be used for quick measurements of low currents.

6.5.2.2 Clamp-on ground-resistance tester

A clamp-on ground-resistance tester can be very useful and improve the efficiency of a stray voltage investigation. Ground rod resistance can be quickly assessed because the clamp-on resistance tester measures the resistance without the use of auxiliary ground rods. Because these devices also measure the current on the ground lead, an assessment of NEV can also be accomplished. This can be extremely helpful when searching for discontinuities (e.g., a high-resistance connection) in multi-grounded neutral conductors.

6.5.2.3 Shunt resistor

When making an assessment of exposure an exact representation of the complex human and/or animal body path impedance is not possible. Nor is it possible to exactly replicate the impedance of the contact the person or animal is making with an energized surface. A shunt resistor representing a conservative estimate of the average path impedance is used instead. Refer to 5.5.1 for a detailed discussion on the proper use of shunt resistors and how they may impact measurement accuracy. When making a determination of exposure a shunt resistor can be selected to represent the resistance of both the typical human or animal body and its contact with the energized surfaces. For example, the resistance used to represent a swimmer immersed in water and experiencing a tingling sensation near the pool light would likely be different than that of a cow touching both water bowl and barn floor. For humans the studies discussed in Clause 4 indicate a typical resistance value of

1000 Ω can be selected as a conservative value for most exposure scenarios, while a smaller resistance of 300 Ω can be used to represent the resistive path between the hand and foot under water-wet conditions. For dairy cattle the studies (Reinemann [B39]) indicate the use of a 500-Ω resistor conservatively represents both the cow's contact resistance and the resistance of the path from hoofs to mouth.

As discussed in 5.5.1.4 a shunt resistance device can be constructed using a selector switch and various resistance values with a momentary switch to perform the closed-circuit test. Wattage ratings of resistors should be no less than 50 W to handle a wide range of circumstances without limiting the measurement sample period.

6.5.2.4 Measurement electrodes

Because the accuracy of the measurements can be negatively impacted by the contact area of the electrode selected, particularly in the case of water, consideration should be given to the material it is made of, its size, and shape. If testing for stray voltage in the area of a swimming pool, a copper or copper-coated plate or sheet with a surface area of 58 cm^2 (9 in^2) can be used when making measurements to the pool water. The electrode can be placed into the water and can be attached to a non-conductive handle to allow for measurements at various depths and distances to replicate a swimmer's location. If making a measurement to a concrete surface, whether at a pool or in a barn, a copper sheet with a surface area of 113 cm^2 (18 in^2) can be used as the measurement electrode. When necessary, the thickness of the sheet should allow it to conform to curved surfaces such as pool coping. A weight can be placed on the electrode and the concrete surface can be wetted with a solution of saltwater to ensure sufficient contact area and a low-resistance contact. When making measurements to earth, copper plated rods of approximately 0.6 m to 1.2 m (i.e., 2 ft to 4 ft) in length can be used to make low-resistance contact with the soil. Before placing rods into the earth, check local dig safe requirements to ensure care in avoiding underground conduits or direct buried cables.

6.5.2.5 Load box

Adding a resistive load to the utility transformer with the building or facility load turned off allows a determination of the primary neutral contribution to the stray voltage measured. Load boxes can include space heaters attached in parallel or purpose-built resistive load banks. Commercially available 240-V heaters are commonly available up to 25 kW, and smaller units can be banked together. Leads can be constructed to allow connection by qualified utility personnel at the secondary bushings of overhead transformers. A typical wiring diagram of a resistive load box is shown in Figure 21. Figure 22 shows a photograph of a three-stage 30-kW load box in use.

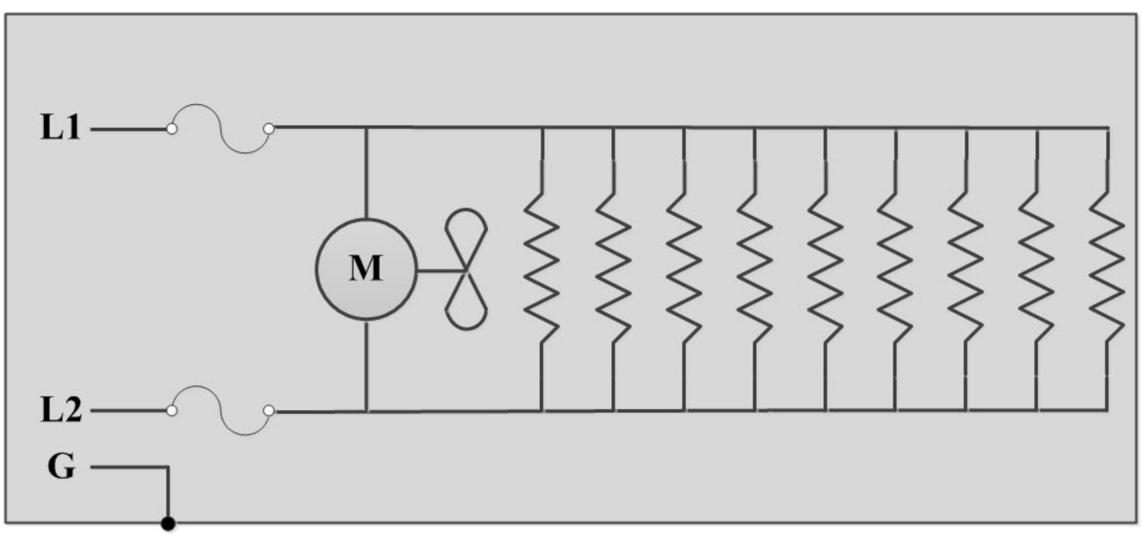


Figure 21—Simplified diagram of a resistive load box

Figure 22—Three 10-kW load boxes demonstrating leads that allow units to be banked together

6.5.3 Stray voltage investigation protocol

Field measurement is an integral part of any stray voltage related investigation (e.g., confined livestock, campground shower, and swimming pool). Both the equipment and procedures should match the measurement objective of identifying problematic levels of stray voltage and detecting its source or sources. If carefully selected and used, standard electrical instruments are adequate for most types of measurements required for stray voltage investigations. However, more sophisticated instruments may be required for detailed investigations requiring short and/or long duration measurements. In this respect, both the equipment and the procedure should also match the electrical expertise of the investigator.

As shown by experience, voltage is the easiest and most convenient electrical quantity to measure in a stray voltage investigation. It is also the most reliable first indicator of a possible stray voltage problem. Typically, a stray voltage investigation includes two types of voltage measurements: a) point-to-point and b) point-to-reference ground. Understanding the difference is essential to quantifying the severity of the problem and, if necessary, determining the most appropriate remedy:

a) *Point-to-Point Measurement:* The point-to-point method measures voltage between two points that can be simultaneously contacted by a person or animal. It is a measurement of possible exposure and provides important information concerning the ability of the voltage to do harm. Normally this measurement is made between a metal structure, such as a stanchion or a faucet, and the concrete floor or soil. On a dairy farm, these measurements of exposure may include water bowl to floor, parlor steel to floor, and heated waterer to floor. In the case of a residential exposure the points of contact may be from the outside water faucet to the nearby soil. The shower knob or showerhead and the concrete floor are often the contact points used in a campground investigation. When investigating stray voltages at swimming pools, voltages between pool water and the concrete deck and between pool water and the handrails are typically measured. At a boat dock for example, the contact may be made between water and the metallic structure of a boatlift.

b) *Point-to-Reference Rod Measurement:* A point-to-reference rod voltage measurement is essentially a measurement of NEV. This is a diagnostic measurement that may help identify stray voltage sources and mitigation strategies. It is not a measurement of exposure. To make a point-to-reference rod voltage measurement a high impedance multimeter is connected between the contact point under investigation and a reference rod or a qualified reference.

To assess the severity of any stray voltage exposure, two point-to-point voltage measurements are necessary. These voltage measurements include measurement of the open circuit voltage (V_{OC}), and measurement of the closed circuit voltage (V_{CC}). Of these two measurements, the measurement of open circuit voltage is quick and easy and is invariably performed first. This measurement is obtained simply by connecting a high-impedance DVM between the two contact points. It is the closed-circuit voltage measurement which demands the most attention. This is because the closed-circuit voltage is used to estimate the amount of exposure current and the equivalent source resistance between the contacted points. It is important that these measurements be relatively accurate so that if necessary, the severity of the exposure can be ascertained. The closed-circuit voltage measurement is obtained by connecting a suitable shunt resistor between the contact points and measuring the voltage across that resistor.

An important objective of any stray voltage investigation protocol is to determine at which locations people or animals may be exposed to stray voltage (i.e., where their bodies inadvertently become part of the neutral/ground electrical circuit). At these locations the nature of the stray voltage needs to be determined such as its magnitude and whether it is a steady value, periodic, or intermittent. If unacceptable levels of stray voltage are present, the stray voltage sources can also be located. Specific conditions that result in elevated levels of stray voltage can be identified by tests that isolate those conditions. An investigation to determine the source or sources of stray voltage needs to be an organized step-by-step procedure with the investigator understanding the purpose of each test. Measurements made during a stray voltage investigation need to be for a specific purpose. It is important not to perform testing simply to collect data or for which the investigator does not understand the purpose of the tests. Tests that involve accessing utility owned equipment should be performed with the knowledge and cooperation of utility personnel.

The following identifies step-by-step procedures that can be used to assess levels of stray voltage present and their sources for various common stray voltage scenarios. Use of these procedures will help ensure a thorough analysis has been performed and provide consistency during testing, documentation, and mitigation.

6.5.3.1 Confined livestock

Attached, as Annex C, is a guideline that may be used when testing for stray voltage on farms with confined livestock. Although test procedures are discussed in terms of stray voltage, it is important to note that contact voltage from farm and/or utility sources may also be present. Because contact voltage can reach lethal levels, stray voltage investigators are encouraged to proceed with caution and perform a contact voltage investigation prior to an in-depth analysis of stray voltage (see Clause 5).

Although written specific to dairy cows, the confined livestock investigation guideline can be used for assessing stray voltage in any type of animal confinement facility with minor modification. It contains test recommendations for both farm and utility electrical systems.

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

6.5.3.2 Swimming pools

Electrical safety is important in the swimming pool/aquatic environment because of the unique exposure conditions available. Surfaces are wet and swimmers wear little clothing and no footwear, providing low contact impedance. An electrically safe environment in and around swimming pools requires that significant differences of electric potential a person can be exposed to be identified and eliminated under all system conditions. To that end, existing electrical codes require equipotential bonding in swimming pools to create an area where there is no significant voltage difference between objects that can be touched simultaneously thus helping to ensure there is no perceptible body current. These objects include concrete decking, ladders, handrails, light fixtures, pool pumps, and even the pool water. An equipotential system is created by intentionally connecting all of these objects using connection methods that conform to the electrical code.

If the investigation was triggered by a public report of shock, a determination of whether the shock was the result of a contact voltage exposure can be made prior to an in depth analysis of stray voltage. The investigation protocol covered in Annex B can be used as a starting point in making this determination.

Refer to Annex D for additional detailed information on this subject and a guideline that may be used when performing stray voltage investigations at swimming pools.

6.5.3.3 Marinas and boat docks

Many of the investigation steps and procedures involved in swimming pool analysis can be used in the investigation for stray voltage at marinas and boat docks. The complexity of the wiring systems in these environments can vary greatly from a single branch circuit supplying a boat lift to complete distribution systems designed to supply numerous large vessels. As in any investigation the integrity of the wiring system can first be verified to ensure that degradation and installation deficiencies are not contributing to stray and/or contact voltage levels.

If the investigation was triggered by a public report of a shock, a determination of whether the shock was the result of a contact voltage exposure can be made prior to an in depth analysis of stray voltage. The contact voltage investigation protocol covered in Annex B can be used as a starting point in making this determination.

Refer to Annex E for additional detailed information on this subject and a guideline that may be used when performing stray voltage investigations at marinas and boat docks.

6.6 Mitigating stray voltage

6.6.1 General

The sources of stray voltage are primarily normal return current and induced current that flows through the impedance of the grounded and grounding conductors of a power system. The amount of return current is determined in part by the amount of energized load, system balance, and system voltage. The power system can be operated at primary or secondary voltage and can be either utility or privately owned. In general, as the amount of current on these conductors increases so do stray voltage levels. Stray voltage sources can therefore be mitigated in two fundamental ways:

a) Reduce the amount of return and induced current that flows on the neutral and grounding conductors of the power system.

b) Reduce the impedance of the neutral/ground return path.

6.6.2 Distribution system

The following is intended to serve as a guide for the minimization of stray voltage when constructing or modifying primary and secondary distribution facilities. It is general in nature. Decisions regarding system construction or modification intended to minimize stray voltage levels should be technically and economically justified, and should necessarily give site specific factors appropriate consideration.

6.6.2.1 System voltage

For the same amount of system load a higher system voltage will result in a smaller amount of return current. All other things being equal, the reduced neutral/ground current in turn reduces the level of stray voltage along the entire feeder. Although increasing primary system voltage is a very effective method of reducing stray voltage, it is a significant system modification and may not always be technically feasible or cost-effective.

6.6.2.2 Number of phases

The amount of current on the neutral and grounding conductors of a primary distribution system and the stray voltage that may result can often be reduced through the operation of balanced three-phase primary distribution circuits. If necessary, and where there is appropriate technical and economic justification, existing single and two-phase feeder taps can be rebuilt to full three-phase in order to reduce stray voltage levels.

6.6.2.3 Phase balancing

The amount of current on the neutral and grounding conductors of a primary distribution system and the stray voltage that may result can often be reduced by making certain the connected load is reasonably balanced along the length of the feeder. Existing connected load can often be reconnected in an attempt to improve balance and reduce the amount of neutral return current and resultant stray voltage. Phase balancing is not effective in reducing the amount of triplen harmonic current flowing in the neutral conductor for reasons specified in 6.2.1 In addition, the amount of neutral current resulting from phase imbalance can change hourly, daily, and seasonally due to phase loading variations. It is therefore recommended that remediation made through phase balancing be verified during other times, such as peak loading, when differences between phases can be most prevalent.

6.6.2.4 Neutral conductor resistance

The level of stray voltage at any specific location on the distribution system is dependent on a number of factors, one of which is primary and secondary neutral conductor resistance. Neutral conductor resistance is determined by the size and type of neutral conductor and the number and quality of neutral splices. On a multi-grounded electrical system the earth is a parallel conductive pathway and some amount of return current will flow to earth as it finds its way back to its source. As neutral conductor resistance increases more return current can flow to earth thereby increasing stray voltage levels. Increasing neutral conductor size and/or making certain all neutral conductor connections are intact and properly made can lower return-path resistance and may help decrease stray voltage levels. Where the primary distribution system is direct burial and the neutral cannot be visually inspected, the stray voltage investigator can perform a load box test (see Annex C) to assess the concentric neutral integrity and determine the concentric neutral's ability to contribute to stray voltage levels. If load box testing reveals a need, additional cable testing can be performed to identify specific locations of concentric neutral discontinuity, and assess the need for cable replacement. Load box analysis of a concentric neutrals ability to contribute to stray voltage levels is a widely accepted and effective method of assessment for both bare and jacketed cable.

6.6.2.5 Neutral-to-earth resistance

Neutral-to-earth resistance is determined by the number and quality of earth connections. Reducing neutral-to-earth resistance often also reduces stray voltage levels. Stacking of ground rods to achieve greater depth (lower resistance), multiple (parallel) rod installation, and installation of additional low-resistance (i.e., less than 25 Ω if reasonably attainable) ground rods at intervals less than required by code can sometimes be utilized to reduce neutral-to-earth resistance. Burial of a counterpoise conductor can also be used to minimize neutral-to-earth resistance. In addition to the resistance of the ground rods and their connections to earth, the grounding wires and any electrical connectors on the grounding wires can also have resistance. If necessary, connector resistance can be checked and older high resistance connectors can be replaced with newer low-resistance compression connectors.

6.6.2.6 Transformer connections

On multi-phase systems the type of transformer connection used can result in an increase of grounded and grounding conductor current. This increase can lead to larger stray voltage levels. Open delta transformations and transformations utilizing a grounded phase conductor are commonly cited examples. Where technically feasible and appropriate, alternative transformations that generate less grounded and grounding conductor current can be used to reduce stray voltage levels.

6.6.2.7 Transformer location (service length)

The resistance of the secondary neutral conductor increases as a service drop's length increases. To minimize this resistance and reduce stray voltage levels transformers can be located (or relocated) in a manner that minimizes service conductor length. This may require the extension of primary facilities into private property. The location chosen should not result in a service so short that it increases available short-circuit current levels above the fault duty rating of existing equipment and/or available new equipment. The location can also be kept far enough from buildings to comply with code required clearances, and can be kept far enough from the service equipment and its grounding system to allow for neutral isolation, should that become necessary.

6.6.2.8 Primary/secondary neutral separation

Separation of primary and secondary neutrals (isolation) opens the low impedance connection between the primary and secondary neutrals and effectively removes the primary neutral contribution to stray voltage. Because this change also removes the service drop’s line-side low-resistance connection to earth that is provided by distribution system grounding, it often also reduces the secondary neutral contribution to stray voltage levels. Unfortunately, neutral separation also removes grounding from the utility primary distribution system and the customer service. Care should be taken to ensure that both systems are adequately grounded when their interconnection is severed. The effect of neutral isolation on a distribution system depends on the number of services that are isolated relative to the total number of services and other grounds on the feeder.

Electrical codes allow for neutral separation and a variety of neutral separation devices are in use. Prior to installing an isolator, the investigator should ensure the device used, and the method of installation, meet applicable codes and satisfy the requirements of the local regulatory authority. Available devices include low voltage surge arresters, saturable core reactors and electronic switches.

6.6.3 Privately-owned secondary electrical facilities and premise wiring

The quality of service and premises wiring systems often has the largest single influence on stray voltage levels. Wiring codes are designed to protect the safety of both humans and animals from electrocution, but they can also reduce stray voltage levels by helping to ensure the grounded and grounding conductors are properly sized for the load. Making good electrical connections and making sure that these good electrical connections are maintained by the proper choice of wiring materials for wet and corrosive locations can reduce the resistance of the grounded neutral system and thereby reduce stray voltage levels. Proper wiring techniques also include safe and effective equipment grounding, adequately sized conductors and equipment, and the required isolation of the grounded conductors from grounding conductors beyond the service entrance equipment for the building. In addition to compliance with electrical codes and proper maintenance of the electrical system, stray voltage levels can be reduced in the following ways:

a) Improve Grounding: Installing additional ground rods and providing a solid metallic bond from the load end of the service neutral to a metal well casing are common methods of improving grounding.

b) Proper Load Balance: Balancing 120-V loads and converting 120-V equipment to 240-V equipment can reduce the amount of neutral current and therefore stray voltage levels.

c) Equipotential Bonding (Animal Confinement): Stray voltage levels can also be reduced by electrically bonding the two surfaces between which the stray voltage exists. If the impedance between the two surfaces is low, the voltage will also be low. Equipotential planes that electrically connect all accessible metallic structures in an animal confinement facility are required by code because they effectively reduce stray voltage levels and help prevent shock during fault conditions ASAE EP473.2 2001 [B3].

d) Equipotential Bonding (Swimming Pool and Hot Tubs): As described in 6.5.3.2 equipotential bonding is required in swimming pools and hot tubs. However, equalizing the potentials of conducting non-metallic surfaces, such as concrete or brick paver decks around swimming pools, nearby objects, and the swimming pool water is more challenging if the deck is not constructed with internal metallic bonding, such as structural reinforcing steel. Equipotential bonding of the deck, other objects near the swimming pool and the water is required to help minimize the potential difference sufficiently so that shock hazards can be eliminated. As described in Article 680.26(B)(2) in the National Electric Code (NEC) [B36], bonding to the perimeter surface around swimming pools may be provided via a grounding grid, which is a buried mesh constructed of metal, that is connected to the swimming pool deck and other conducting objects in the pool area.

e) Equipotential Bonding (Outdoor or Basement Shower): Bonding the faucet to the drain can often help reduce stray voltage levels at an outdoor or basement shower where metallic pipe is used.

f) Give consideration to a central location for service entrance equipment: This will allow for shorter, lower impedance, service conductors which may help to minimize voltage drop contribution to stray voltage levels.

g) Properly Size Feeders: Feeders that are too lengthy, are undersized, have numerous splices, or have deteriorated insulation can unnecessarily increase return-path impedance and negatively affect stray voltage levels.

h) Intersystem Bonding and Isolation: Power system return current flowing on other utility infrastructure such as phone lines, water lines and gas lines can be transported to premise wiring by interconnection with the facility's neutral/ground system. These grounding connections can also form a parallel path across isolation devices rendering them ineffective. If necessary these infrastructure connections from other utilities can also be isolated. The serving utility is responsible for performing the mitigation to their respective system(s) to ensure compliance with applicable codes and regulations.

i) Secondary Isolation: The National Electric Code allows for the installation of isolation transformers in many circumstances. The National Electric Energy Testing, Research and Application Center (NEETRAC) worked with utility members in 2012 to evaluate the performance of an isolation transformer to create a new separately derived source that is ground isolated to supply residential boat dock loads as a means of stray voltage mitigation. The secondary side equipment grounding terminal is bonded to dock equipment, but this grounding termination has no reference to the distribution system neutral, thus mitigating stray voltage originating from the distribution system (NEETRAC, 2013 [B33]). This method of isolation has also been used in animal confinement facilities. Unlike primary to secondary neutral separation it comes with a few drawbacks for the facility owner. These include less effective protection on the load side of the transformer from lightning and system faults; and an increase in maintenance and expense for the facility owner. There is also a safety concern regarding the voltage that may develop across the transformer in the event of a fault.

j) Active Suppression: There are a number of active suppression devices that have been developed to be installed on premise wiring to reduce stray voltage levels. These technologies usually actively cancel stray voltage by the application of a 'negative' voltage. These devices can be expensive to install and have not enjoyed a large market penetration. This is likely because identifying and addressing stray voltage sources through other methods is almost always a less expensive and safer way to reduce stray voltage levels. These special devices also require additional testing and maintenance to ensure they remain operational and effective.

k) Use separate neutral and ground conductors to all sub-panels: Configure single- or multi-phase electrical systems with separate neutral and equipment grounding conductors from the service entrance equipment (e.g., single-phase, 4-wire service). Ensure all equipment and subpanels are properly grounded; that all neutral conductors are isolated from ground conductors at all equipment and within sub-panels; and that the electrical system neutral and ground conductors are bonded only at the service entrance equipment (e.g., yard pole or meter location). Figure 23 shows earth current return paths on a single-phase, 3-wire electrical system eliminated by conversion to a single-phase, 4-wire system.

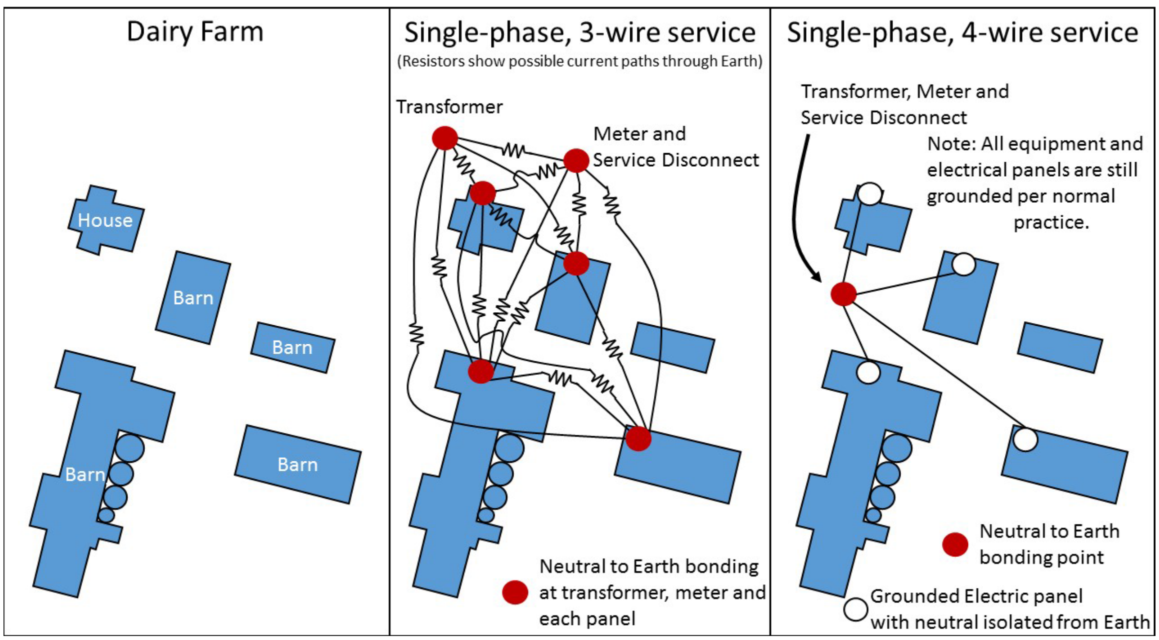


Figure 23—Elimination of multiple earth current return paths with a 4-wire electrical system

Annex A

(normative)

Contact voltage measurement protocol

This annex may be used when performing contact voltage investigations. The guideline, with minor modifications dependent on the individual exposure scenario (e.g., pools and outdoor showers), can be used for contact voltage testing at most publicly and privately accessible locations. Although test procedures are discussed in terms of contact voltage, it is important to note that stray voltage from customer and utility sources may also be present.

Electrically, contact voltage exposure scenarios vary widely in wiring complexity and faulted-circuit characteristics. The individual responsible for the investigation should be allowed to make an on-site determination of the actual investigative procedure to be used after giving proper consideration to employer and/or regulatory requirements. The investigator's analysis of the verbal, visual, and recorded data should remain the most important factor in deciding upon the direction and detail of any investigation. The investigator should exercise judgment in determining how much time should be spent, the amount of data that need be collected, and the action that can be taken. At locations where a detailed investigation is determined to be necessary, adherence with the following guidelines can, in most cases, provide information to help make informed decisions regarding contact voltage sources and appropriate mitigation measures.

During the measurement phase of the investigation the investigator can accomplish the following tasks:

a) Identify suitable qualified reference
b) Prepare measurement surfaces
c) Eliminate false positive detections due to capacitive coupling
d) Accurately measure the voltage
e) Characterize the voltage source

A.1 Establish a qualified reference

A qualified reference is one that is not energized and has low impedance to earth. Since the reference is being used for measurement, any voltage potential on the reference will introduce measurement error. Steps can be taken to verify the selected reference is not energized. The impedance of the selected reference will have an effect on measurement as detailed in 5.5 of this document. Steps can be taken to assess the impact of the chosen reference on measurement accuracy. Candidate references available at street level include but are not limited to fire hydrants, fence or sign posts driven into earth, grounded street furniture, and temporary ground rods placed for the purpose of testing.

Often standard length test leads are too short to simultaneously contact both the qualified reference and the object under test. In urban environments a long reference lead, at least 15m (50ft), is recommended for reaching qualified reference points. Strong spring clamps ensure solid contact throughout the process without having to move or adjust the connections.

General "Do's and Don'ts" for selecting a qualified reference include the following:

a) Do carry long test leads (Figure A.1), 15m (50ft) minimum, to easily reach a qualified reference in the immediate area. Test leads with strong spring clamps are advisable.

b) Do verify the continuity of reference leads using a multimeter before beginning an investigation.

c) Do spend extra time making a clean, bare metal contact for your measurement.

d) Do verify that the candidate references are not energized.

e) Don’t drive ground rods without following any applicable dig safe procedures to avoid disturbing underground infrastructure.

f) Don’t use references (i.e., ground rods, anchor bolts, etc.) inside or directly adjacent to the object under test. If the object is energized the ground rod may also be energized.

g) Don’t connect to an auxiliary part of a candidate reference, such as an operating handle or knob. The main body is more likely to have better electrical connectivity to earth.

Figure A.1—Long test lead

A.2 Verify candidate references are not energized

If a suitable handheld electric field meter is not available, candidate references can be qualified by making voltage measurements from the surface under test to multiple candidate reference locations. The voltage reading should be the same among them if all reference locations are at or near zero potential. If they differ, one or more references could be at elevated potential. The larger voltage measured is usually the correct one, though it is always appropriate to corroborate recorded values with more measurements rather than assuming a value on the basis of only one measurement.

A.3 Prepare measurement surfaces

Reducing contact impedance to a practical minimum is important, but often difficult to achieve in the field. Even bare metal surfaces like manhole covers have a resistive patina which can be removed from the test site to ensure repeatable measurements. Scratching with test lead tips may not penetrate this layer. Metal surfaces at both the measurement point and reference are best prepared with a wire brush, sand paper, or file to remove corrosion and paint.

For non-metallic surfaces (e.g., concrete sidewalk and asphalt roadway), good electrical contact depends on sufficient surface area. Utility regulations in dairy states and the guide published in 2008 by NEETRAC suggest a copper plate with a weight applied to maximize electrode contact surface area (Patel [B38]). This works well in a wet, electrolytic environment like a muddy feedlot, but not on a hard textured dry surface like a sidewalk. Instead, for hard textured surfaces, wetting the contact area with a solution of salt water (approximately 3.5% salt content) and using a copper sheet with a surface area of 113 cm^2 (18 in^2) is recommended (ERPI, 2011 [B13]). The thickness of the sheet should allow it to conform to curved surfaces by placement of a weight to ensure sufficient contact area. Extra attention to making good contact may be especially important when following up on reports of electric shock which occurred in earlier, wetter conditions.

A.4 Eliminate false positives due to capacitive coupling

Field voltage measurements can be subject to false readings from capacitively coupled voltage sources and it is important to avoid this situation. Refer to 5.5.1.4 for detailed information on this subject.

A.5 Characterize the voltage source

A voltage measurement alone cannot identify the source of the voltage but harmonic analysis of the voltage can often reveal its source, guide repair efforts, and help determine the possible hazard level. Publicly and privately accessible ac voltages that are not electromagnetically coupled can be one of three types:

a) Phase (or supply) conductor fault - Faults in internal wiring, service cable, or third party owned conductors and equipment often result in elevated voltages at accessible locations. Because this elevated voltage is fault related it is contact voltage. Regardless of the initial voltage readings, these faults have the potential to rise to full line voltage as environmental conditions around the fault change.

b) Faulted neutral conductor – If the neutral conductor is compromised, normal return current is forced to flow through alternative parallel pathways including the grounding electrode. This can result in an increase in measureable voltage between the neutral conductor or an extension of the neutral conductor and remote earth. The increase in NEV will be proportional to the increased return-path impedance. This voltage is contact voltage because it is fault related.

c) Normal neutral return current – The flow of normal neutral return current can result in a measureable voltage between the neutral conductor or an extension of the neutral conductor and remote earth. This voltage is stray voltage because it is not fault related.

Phase and neutral conductor faults have the potential to deliver a hazardous shock under certain conditions. Harmonic analysis allows a determination of whether the measured accessible voltage is from a neutral related source or a phase conductor source. All electrical faults from phase sources have the potential to increase to full line voltage as the impedance of the fault path changes. These faults should always be considered hazards regardless of the initial voltage measurement.

NEV levels vary with load conditions and other factors. Increased electrical loads on neutral conductors often result in higher values of NEV. This voltage can only be considered non- hazardous when the system is inspected and confirmed to be operating within design specifications.

Harmonic analysis works by measuring the degree of voltage distortion present in a measured voltage due to non-linear loads. Instruments are available from several manufacturers to perform this analysis. Non-linear loads, including lighting ballasts, impose harmonic voltage distortion on voltages caused by normal neutral return current. Measurements of greater than 10% THD in a voltage waveform indicate the voltage was likely caused by neutral return current and not phase conductor fault current. The neutral return current could be the result of operating the electrical system normally or with a compromised neutral conductor. Observing the voltage with and without the normal loads connected may help to identify the source of the voltage. If the NEV rises significantly when a circuit's normal load is connected, a compromised neutral is the more likely cause.

Accessible voltages caused by phase or line conductor faults are much closer to a pure 60 Hz sine wave with less than 5% THD. When THD is between 5% and 10%, the source is less clear and should not be characterized from harmonic analysis alone. Further hands-on troubleshooting steps may be needed to identify the source. An example output from a harmonic analyzer is shown in Figure A.2.

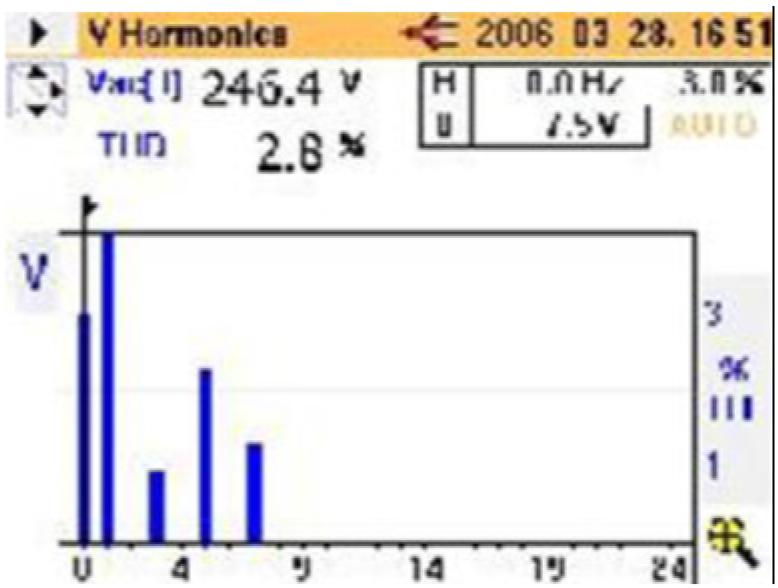


Figure A.2—Output screen showing 2.8% THD

Annex B

(normative)

Contact voltage investigation protocol

The investigative process begins with a report of elevated voltage. That report may have come from a crew conducting a periodic testing program, a crew that made a detection during routine work activities, or from a member of the public who reported a shock. The investigator's job is to determine the exact component on the power system that is causing the elevated voltage, whether it is stray or contact voltage, and if necessary, what corrective actions are needed to eliminate the voltage.

Without the aid of advanced diagnostic tools, such as an oscilloscope capable of analyzing THD, investigators may rely on basic information from a voltmeter and shunt resistor. Prior to the development of techniques that use harmonics, investigators would begin their investigation by disconnecting the most likely source of the voltage and re-measuring the voltage on the object. They would repeat this process until the voltage was eliminated.

With the introduction of harmonics analysis, the investigative process begins with a measurement that often helps to eliminate one possible source of the elevated voltage. For objects with greater than 10% THD investigators can look for defects associated with damaged or defective neutral and grounding conductors. For objects with less than 5% THD, investigators can focus on defects associated with phase conductors.

The voltage measurements and harmonic analysis together can help investigators categorize the source of elevated voltage.

Common causes of contact voltage are:

a) *Line-side (phase) sources:* Most line-side sources, which typically have a THD of less than 5% and rarely over 10%, are easily identified by isolating or de-energizing possible sources. On the underground system investigators have reported finding abandoned cables with improperly sealed ends, improperly insulated split bolt connectors, defective cable insulation and reversed phase and neutral conductors as the causes of these contact voltage cases. These conditions can exist in utility-owned infrastructure such as manholes, vaults and conduits, municipally-owned infrastructure such as streetlights, or customer-owned equipment. Line-side sources of contact voltage are dangerous because even if voltage is detected at a low level, the voltage has the potential to rise to full line voltage.

b) *Neutral (return) sources:* An uncompromised neutral conductor is a very low impedance path for return current. Open and/or high-impedance neutrals are considered electrical faults because normal return current and fault current are forced to take higher impedance parallel return paths. This can negatively impact protection schemes and create publicly accessible contact voltages. Because they are fault related these voltages may always be capable of rising to a level of harm. In addition to electric-shock reports (ESRs) and CVDs a defective neutral may result in customer voltage complaints and reports by cable TV and telecommunication crews of excessive current on their cable shields and messengers.

When troubleshooting cases where the THD is greater than 10% investigators can first inspect neutral connections and ensure that they are not loose or corroded and that the neutral is carrying the appropriate amount of current compared to the phase conductor.

Investigators should also be aware of the relationship between the current and voltage. Otherwise, they may accidently address the problem when they disconnect the service line, and note that the voltage has been eliminated and order a replacement of the service. The replacement would likely fix the problem because it replaces both the phase and neutral conductors. But it also results in the installation of new connections on both ends of the neutral line which may have been the cause of the elevated voltage. Thus, the elevated voltage could have been eliminated by simply remaking the connection and not replacing the entire service.

B.1 General mitigation procedure

General steps that can be applied to a variety of electrical installations are outlined as follows (other scenarios may require more steps to identify, locate, and mitigate the electrical fault causing the measurable contact voltage):

— For less than 5% harmonic distortion (Phase conductor source), the steps are as follows:
  - Inspect the area for obvious signs of physical damage that could compromise electrical safety.
  - Test the "hot" and neutral wires for reversed polarity and correct if necessary. This wiring error can result in energized surfaces.
  - Open any disconnecting means (e.g., fuse, meter, main switch). If the contact voltage condition subsides, the fault is downstream of the fuse, switch, etc. Check connections and accessible parts for damage and implement necessary repairs.
  - If the contact voltage condition remains with the fuse and any other sources disconnected, the fault may be in the feeder being investigated or the main service conductor. De-energize these possible sources to see if the contact voltage is eliminated. Locate and repair the fault.
  - Because the contact voltage being investigated may be the result of an electrical fault elsewhere, survey the area for additional sources of contact voltage. Check for voltage on all nearby conductive surfaces including the telecommunication and cable television facilities, service conduits, hand holes, sidewalks, or roadways. Things such as overhead cables from a nearby streetlight or underground building service cables running adjacent to or under the site can experience a phase conductor fault that energizes all nearby conductive objects. De-energize possible sources one at a time to see if they are the cause. When the fault is located implement necessary repairs.
  - Disconnect the service. If voltage remains, disconnect other supply conductors which are routed near the energized surface. This may be a faulty service to a nearby kiosk, building, etc. or a fault in the secondary feeder running past/under the site. Hot, dry patches of sidewalk or soil may be present, even in wet weather. This is an indication of an electrical fault and may be a hazardous condition. The area should be safeguarded until repairs can be made.

— For greater than 10% harmonic distortion (normal neutral return current or a neutral conductor fault), the steps are as follows:
  - If the voltage measured is less than 10V the source may be normal neutral return current (i.e., stray voltage). If the voltage is greater than 10V the source may be a compromised neutral conductor and the voltage may be the more hazardous contact voltage.
  - To confirm the voltage is stray voltage measure the voltage between the system neutral and a qualified reference. If normal return current the voltage will likely be measureable as a small voltage with high harmonic distortion even with no loads attached. The final classification of stray voltage requires an inspection of the equipment and cables in the area to ensure that all equipment is operating as designed. Stray voltage mitigation is covered in Clause 6 of this guide.
  - Open any disconnecting means (e.g., fuse, meter, main switch). If the measured voltage condition subsides there is likely a compromised neutral somewhere in the circuit supplying power to the load. Check for neutral conductor faults in the supply circuit by performing a load test with a load bank, typically 1000 W or more. Start at the feed structure and work back toward the supply transformer. If voltage drop is greater than 5%, check the neutral conductor and its connections, and repair or replace as necessary.

- If voltage is not eliminated it could be stray voltage. Or, it could be a neutral failure in another nearby building or device. There may be electrical complaints or malfunctions that help identify a degraded neutral. Check neighboring buildings or street furniture by de-energizing them one at a time.
- When the line (phase) current and neutral current are not equal there is “Net current”. A current transformer placed around the supply and neutral conductors of each service should measure near zero amps. If it does not, that service or a nearby service may have a compromised neutral conductor that can be located and repaired as necessary. When investigating these conditions it is also helpful to measure the line and neutral conductors separately. If more current is observed on the neutral conductor than on the line conductor then it is likely that current is flowing in on the neutral from some external source with a defective neutral.

NOTE—Between 5% and 10% THD the source is likely a phase conductor fault, but it could also be a neutral conductor fault or simply stray voltage. Perform all steps needed to make a determination and, if necessary, implement repairs.

Figure B.1 gives a block diagram of the CVD and measurement work flow.

B.2 Asset specific troubleshooting approaches

B.2.1 Objects that are directly fed by the electric system (customer and/or utility)

For energized objects that are normally supplied with electric power, such as illuminated bus stops, kiosks, etc., the first step in the troubleshooting process is to capture a voltage waveform and measure its THD to help determine the possible source. The general investigative strategy is shown in Figure B.2.

If the THD is greater than 10% the source of the elevated voltage is most likely associated with a neutral conductor, either on the customer side of the meter or on the utility side of the meter. If a neutral issue is suspected, current readings on the neutral and ground connections at the meter and at the service entrance equipment may provide useful information. If there is more current on the customer side, then a high-impedance neutral conductor or neutral connection is likely.

Disconnecting the load at the main circuit breaker is a simple and effective way to determine whether line-side faults are the responsibility of the utility or the customer. But it is important to make sure that the elimination of the voltage is not due to the reduction in the load. If disconnecting the loads using a main breaker does not eliminate the voltage, then the elevated voltage is likely being caused by a defective service wire. Continue by disconnecting the service wire and re-testing for voltage. If the voltage is eliminated, the service should be replaced. If this does not eliminate the voltage then the source is not associated with the service and other sources should be considered. They may include other nearby mains and services, current circulating on other utility lines such as cable TV shields, signaling systems for rapid transit, etc.

B.2.2 Objects that are not normally supplied with electric power (customer and/or utility)

When voltage appears on objects such as sidewalks, roadways, and fences, harmonics measurements can help determine a starting point for the investigation. Investigators may also choose to use a voltmeter without a shunt resistor to determine where the highest voltage can be measured. They can then center their investigation on this location. Investigators should consider facilities that cross under the energized object. Isolation of these facilities is helpful in determining their relationship to the source of the voltage. General steps for making this determination are outlined in Figure B.3.

Often the most difficult cases to resolve are those with harmonic content greater than 10% THD. These cases generally involve high-impedance neutrals in service or feeder conductors. As a result of the high-impedance

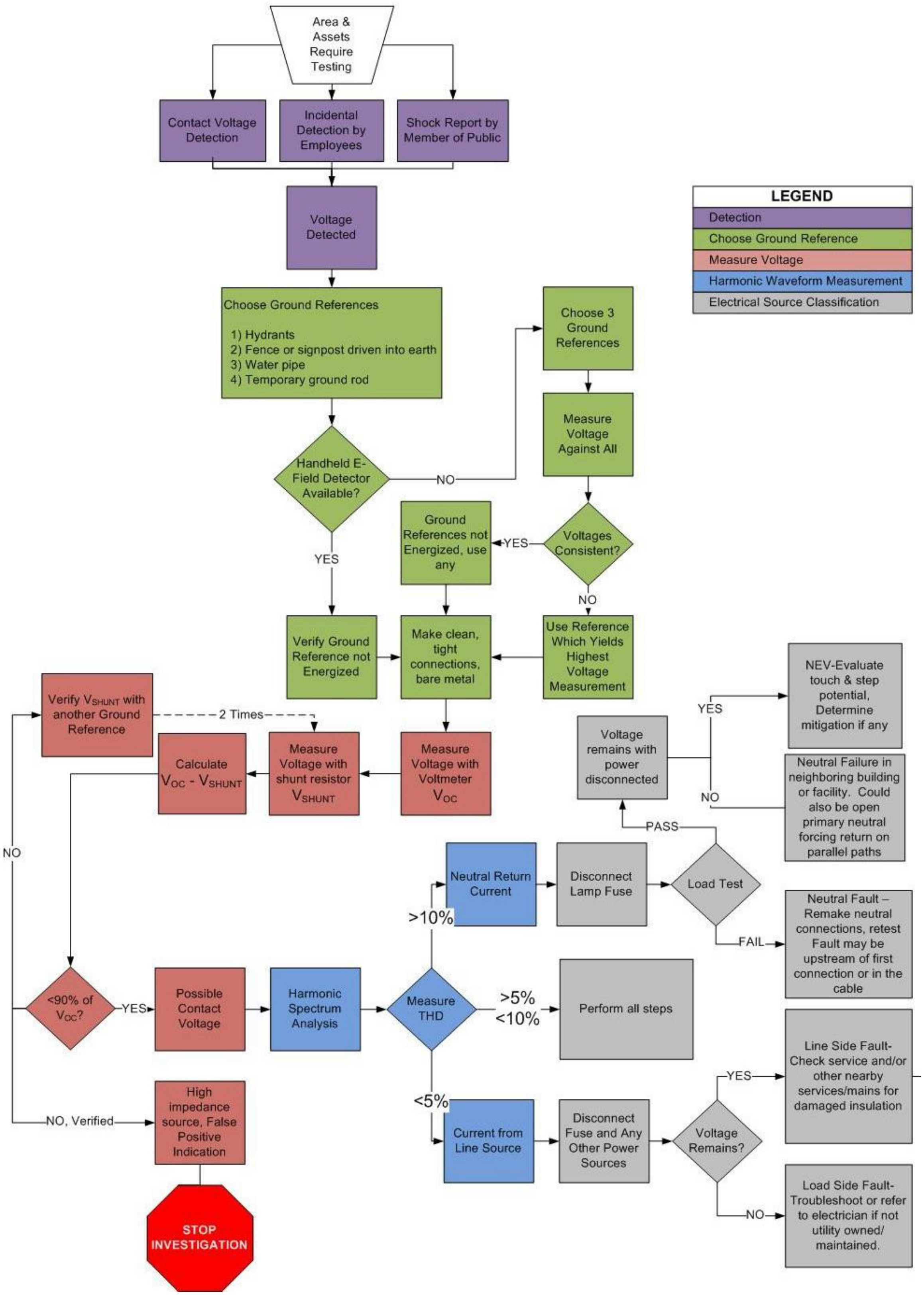


Figure B.1—CVD and measurement work flow

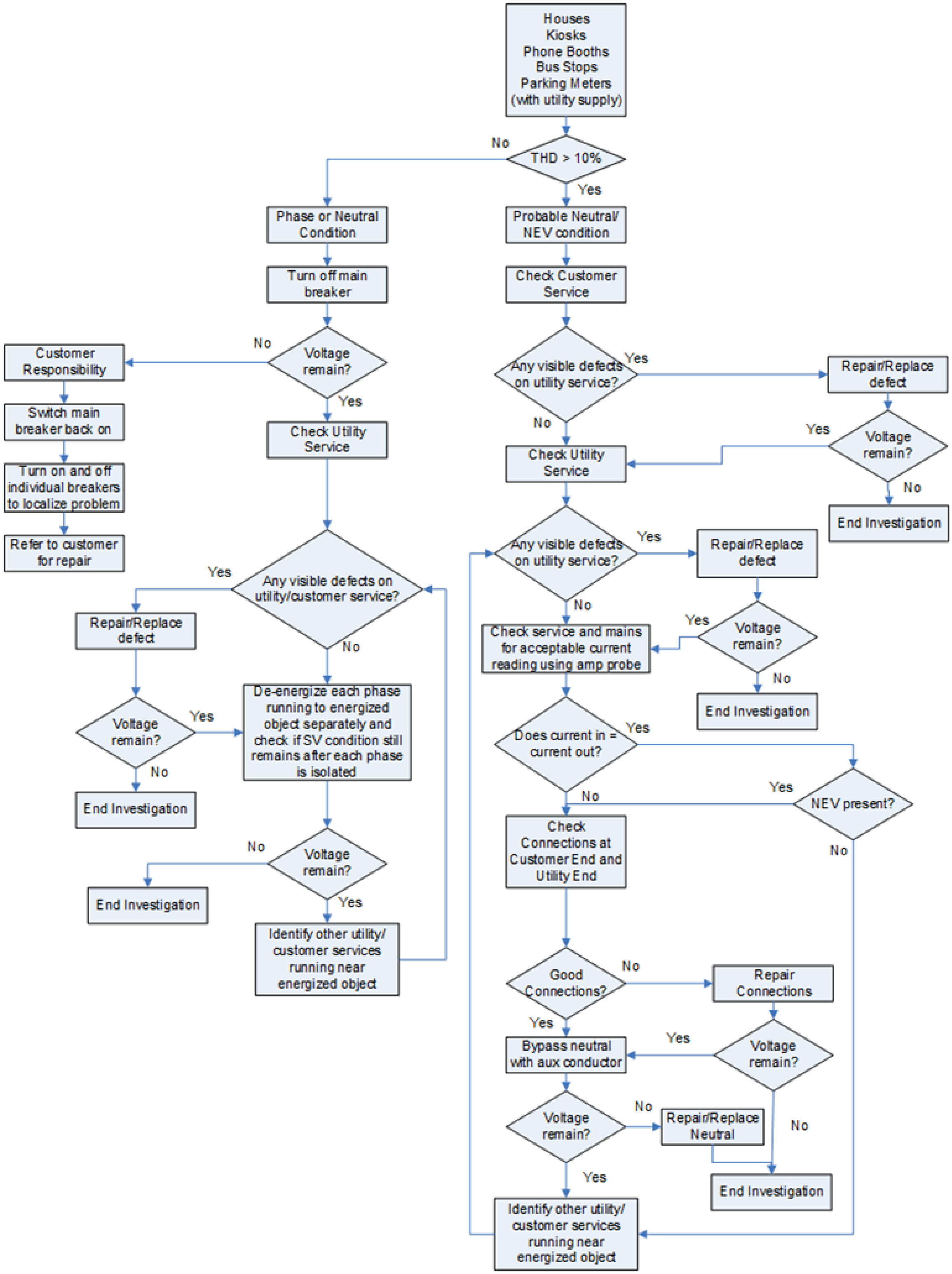


Figure B.2—Troubleshooting flow chart for objects that are directly fed by the electric system (customer and/or utility)

neutral conductor, a greater amount of return current flows through a variety of metallic and non-metallic objects including fences, sidewalks and cable television shields. In these instances it helps to search for points on the neutral system that are at the same potential as the energized object, or that have the same harmonic content as the energized object.

For example, if voltage on a cable TV shield measures 3 V to a qualified reference and zero volts to the service neutral inside of a nearby house, a logical next step would be to measure the current on the neutral at the house and the current flow at the point where the service connects to the system. If they are significantly different there may be high impedance in the service neutral. If there is not a significant difference, the investigator would repeat this process until determining the cause of the elevated voltage.

B.2.3 Street and traffic lights

Investigations of elevated voltage on street and traffic lights are similar to investigations involving other objects that are directly fed by the utility. The slight difference is that often no circuit breaker is present at the interface between the light and the utility. The general investigative strategy is shown in Figure B.4.

When investigating cases where the THD is greater than 10%, the investigator should also consider that the voltage may not be a result of a high-impedance streetlight neutral. Instead, it may be the result of a high-impedance neutral somewhere else in the electric distribution system. Metallic street lighting standards are frequently connected to service neutrals. Because the standards are also grounded, either via driven grounds or through the mounting hardware, current from the system neutrals can flow to the streetlight ground. Investigators are often able to measure voltage as a result of this phenomenon. In this case the mitigation efforts revolve around identifying the high-impedance component in the electrical system and making the repairs, which may be some distance from the light.

B.2.4 Utility objects (manhole covers, vaults, down grounds, etc.)

These investigations are often quite straight-forward. In many instances, a defective cable, or other piece of equipment is found inside a utility structure or on a pole and the event is quickly mitigated. The general investigative strategy for these types of objects is provided in Figure B.5.

Using the voltage and harmonics measurements, investigators often find cable with defective insulation generating contact voltage with low harmonic distortion or high-impedance neutral connections generating contact voltage with high harmonic distortion. In cases where a detailed inspection does not reveal either of these types of defects, investigators should consider that other objects may be providing a conductive connection to the energized structure. Cases have been reported where the actual fault was in a structure more than 15 m (i.e., ~50 ft) away and the metallic conduit connecting the two structures acted as the conductive pathway.

Investigators may also consider electric cables in conduits that are in the ground near the cover, but not routed through the structure. Since the metallic cover is often the only object that is tested, it is possible that the ground surface around the structure has been energized from a nearby secondary cable fault. Isolation of these cables may eliminate the elevated voltage.

B.3 Considerations when previously reported voltage cannot be found

Sometimes investigators arriving at the location of a previously reported detection are unable to measure voltage at that location. Because of the nature of these events, it is possible that the condition has temporarily eliminated itself. Before recording the event as unsubstantiated, investigators can evaluate the effect of factors such as system load, reference grounds, time of day, weather, and other conditions that may be impacting the area.

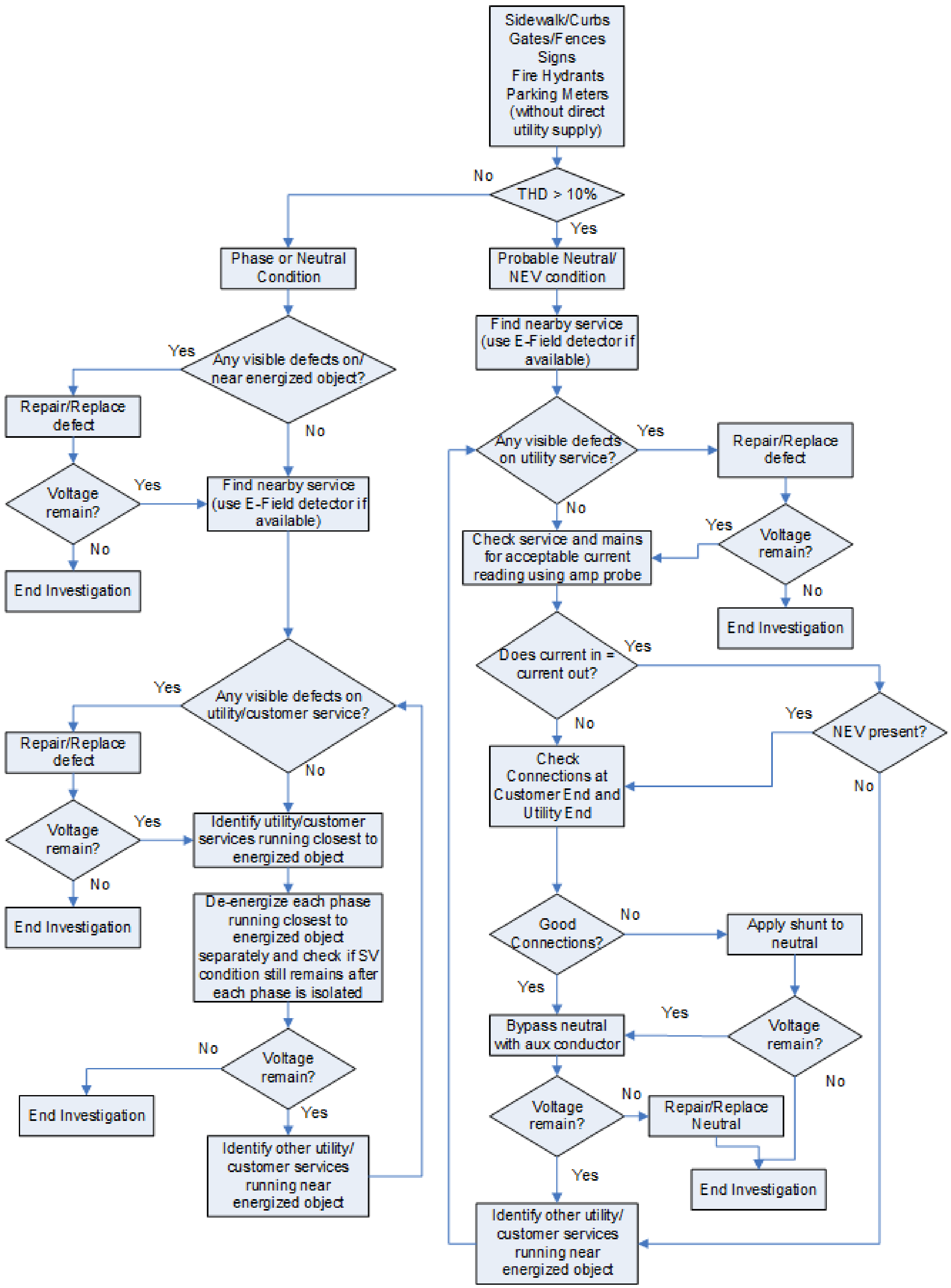


Figure B.3—Troubleshooting flow chart for objects which are not directly connected to the electric system (customer and/or utility)

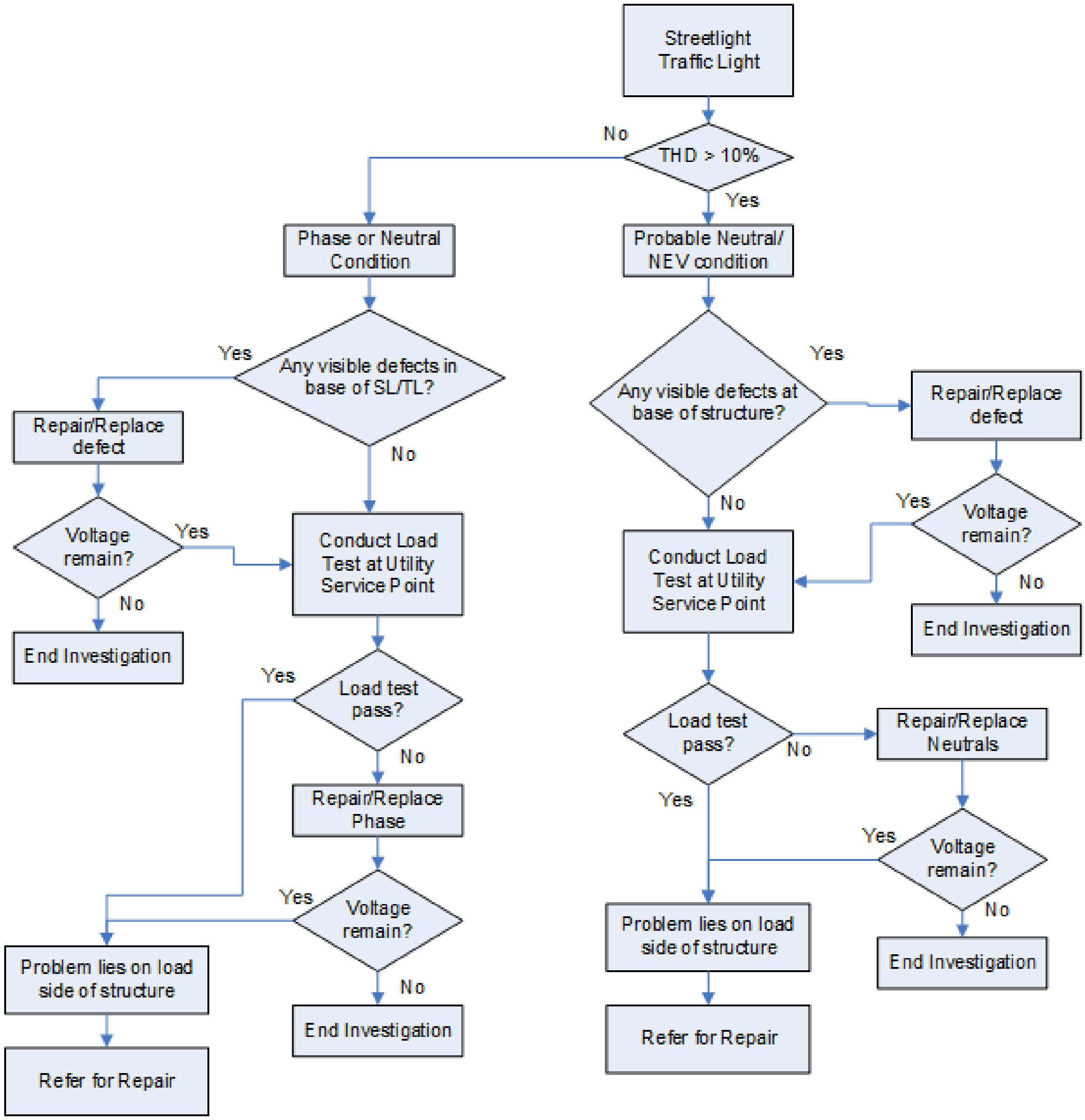


Figure B.4—Troubleshooting flow chart for street and traffic lights

B.3.1 Effects of different references

As discussed previously, using different references can cause significant differences in voltage measurement, since voltmeters measure the difference between the two inputs. When possible, investigators should use the same reference for the initial and subsequent voltage measurements. If investigators cannot use the same reference that was used for the initial reading and can't measure the previously reported voltage they should ensure that the new reference is not energized and consider repeating the measurement from other acceptable grounds before leaving the location.

B.3.2 Time of day

When investigators cannot measure previously reported voltage, they should consider the time of day when the initial reading was taken. For example if the initial reading was taken when it was dark, investigators can

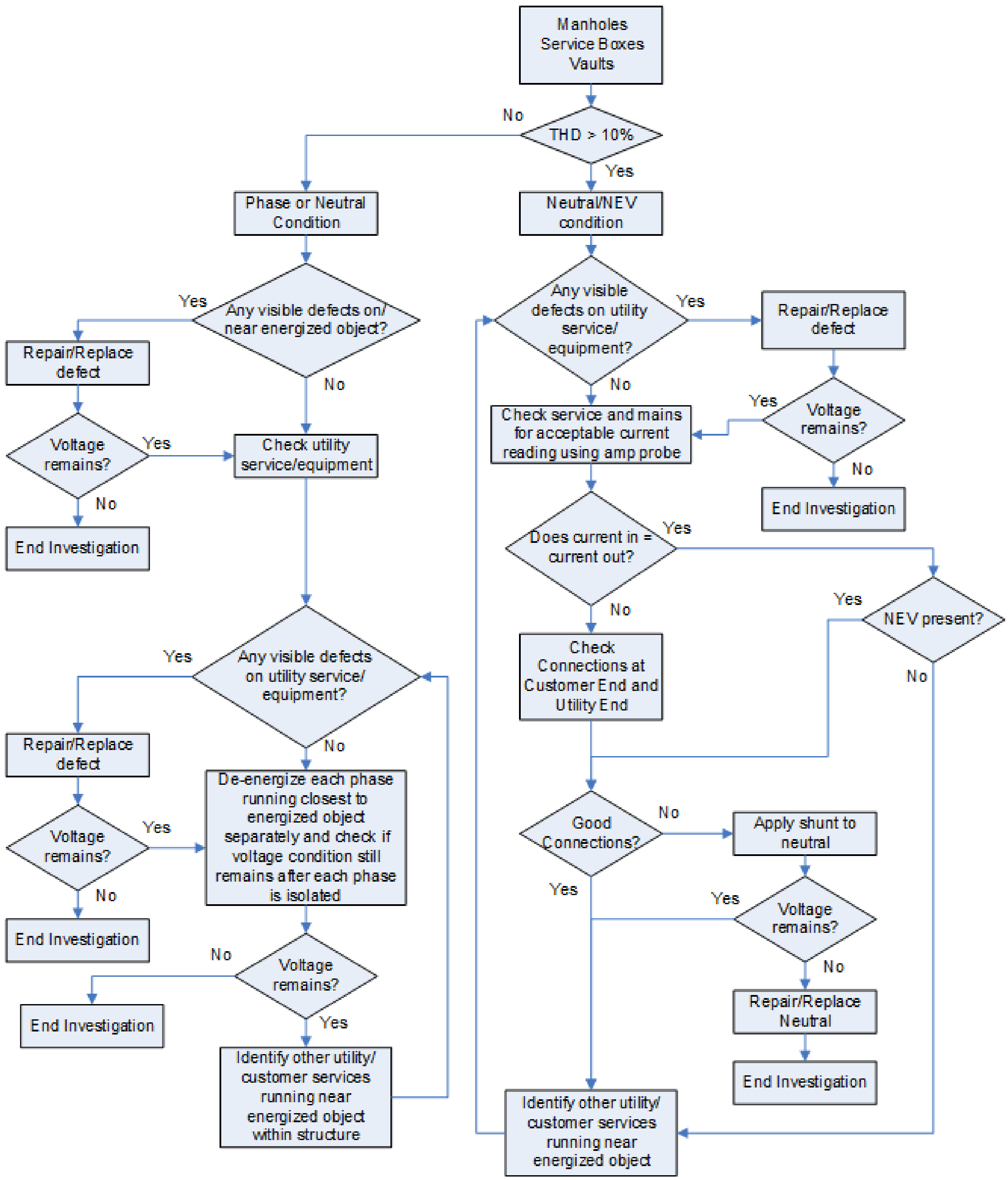


Figure B.5—Troubleshooting flow chart for utility objects

inspect the area for lights or other equipment operated by photocells or timers. Investigators can also consider the current load at the time of the initial and subsequent readings, as discussed below.

B.3.3 Effects of system load

The voltage associated with high-impedance neutrals is a function of the current traveling through the high-impedance portion of the circuit. If the initial readings are taken when the load on the neutral is high and subsequent readings are taken when the load is low, the voltage will be proportionally lower or even zero. If the investigators suspect a high-impedance neutral and are unable to measure a previously recorded voltage, they should consider changes in load between the time of the initial reading and the subsequent investigation.

B.3.4 Effects of weather

Weather, particularly precipitation, can play a significant role in the voltage level. Precipitation can reduce the impedance of the conductive pathway to the surface, causing the voltage to increase. When that water evaporates or drains away, the impedance increases and the voltage may disappear. For this reason investigators should consider the weather conditions that existed during the initial detection. If they cannot detect the voltage, they can consider revisiting the location when the weather conditions are similar to those of the initial measurement.

B.4 Data collection

Each detection and subsequent mitigation offers insights into system performance, risk and repair practices. Collecting this data into a meaningful database can help to spot trends, improve processes and identify underperforming components. A standard collection of data across a number of organizations would enable a more broad and detailed analysis of the topic of contact voltage.

Some of the data fields that have proven useful that have been previously published include: Date, Location, Voltage and Harmonic Levels, Ground connection point, Shunt resistor value etc. Outlined below are data fields that have proven useful in documenting contact voltage conditions for present and possible future analysis:

a) Data fields useful for analysis collected during proactive contact voltage testing and investigations include the following:
   1) *Unique Identifier:* This field is used to uniquely identify the event, and may be a sequential number, work order number or trouble ticket number. If a sequential number is used it is often useful to add a field which refers to the trouble ticket or work order since they often contain useful information when analyzing results in the future.
   2) *Event Location:* This may include latitude and longitude or street address. Location information may be helpful in determining if local environmental conditions are impacting the performance of the cable or other components.
   3) *Detection Method:* The method of detection could include values such as Electric Shock Report, Asset Based Manual Testing, Routine Work, Pool Shock Report or Mobile Testing. This data is useful when evaluating the effectiveness of different programs, and identifying trends.
   4) *Duplicate Ticket:* When multiple items are detected at the same locations some utilities have chosen to generate a unique ticket for each item. For analysis purposes it is helpful to have the ability to measure both sources of elevated voltages and the number of objects that are impacted. This field allows for the differentiation between the parent job and the associated children. This is generally a true\false field to allow for easy sorting of sources and objects.
   5) *Lead Unique ID:* If the parent child relationship is established between sources and objects a field is required to relate the children to the parent job. This field contains the unique identifier of the parent job.
   6) *Confirmed:* The data in this field records as a true\false value if the investigators were able the measure a previously reported voltage.
   7) *Source Voltage:* The source voltage is the nominal line voltage of the source circuit. It typically contains values such as 120 kV/208 kV/460 kV/13 kV, etc. It should not be confused with the voltage that is measured at the location which is described below.

8) *Event Date and Original Time of Discovery:* This is a date\time field that captures the time of the original discovery. This data can be helpful when time of day factors are impacting measurements.

9) *Failure Location:* This field is different from the event location field. It captures data on the specific location of the failure, such as duct edge. This field can be used to help identify failure trends and better target mitigation efforts. For maximum data quality it is best if these locations are selected from a predefined list.

10) *Privately Accessible:* Many reports from the public are associated with shocks that are received in areas that are not accessible to the general public and are therefore not tested as a part of routine testing programs (New York State Public Service Commission [B35]). Understanding whether or not a location is publically accessible is important when assessing the impact of the testing programs. For ease of analysis this may be recorded as a True\False field.

11) *Asset Type Where Voltage was Detected:* This field captures data on the type of asset or structure where the voltage was detected, for example: sidewalk, manhole, streetlight, gate, etc. For maximum data quality it is best if these are selected from a predefined list.

12) *Fault Location: Utility or Non-Utility Electrical System:* Identifying and documenting the owner of the faulted electrical system can be helpful in optimizing programs and understanding where defects are occurring. Often these are recorded in large groups such as: Utility, Customer, and Municipality.

13) *Root Causes:* The root cause field should summarize the findings of the investigation. This data is useful in analyzing failure trends and in developing proactive programs. It may include items such as: reversed phase\neutral, loose neutral connection, damaged neutral conductor, damaged cable insulation, improperly installed equipment, etc. For maximum data quality, it is best if these are selected from a predefined list.

14) *Voltage Open Circuit:* This field captures a numeric record of the voltage measured without shunt resistor in the circuit.

15) *Voltage with Shunt Resistor:* This field captures a numeric record of the voltage measured with the shunt resistor in the circuit.

16) *Shunt Resistor Value:* This field is a numeric record of the shunt resistor value that was used for the Voltage with Shunt Resistor measurement. This is an important value when comparing data across utilities since different shunt resistor standards exist in different states.

17) *Harmonics:* A numeric recording of the percent THD is helpful in evaluating failure trends and helps to give context to voltage readings.

18) *Qualified Reference Used:* Record the details regarding the qualified reference used in voltage measurements. This may include object type (e.g., driven ground rod, fire hydrant, etc.) and the physical location of the object. This will allow repeatable follow up measurements in subsequent investigations.

19) *Weather:* This field captures a brief summary of the weather at the time of the original discovery. This data can be helpful when weather factors are suspected of impacting measurements. For maximum data quality it is best if these are selected from a predefined list.

b) Data fields for ESRs include the following:

1) Normally Energized: When analyzing electric shocks in the context of contact voltage it is important to be able to quickly eliminate shocks which were the result of contact with normally energized equipment. Including a True\False field in the database makes it is easy for an analyst to quickly eliminate reports of shocks where members of the public or employees contacted energized lines, or other energized equipment which is properly installed and functioning.

2) ESR Party Person\Animal: A categorization of the individuals shocked: public, employees or animals.

3) ESR Type: Data on the severity of the shock is helpful when assessing shock reports. Classifications, such as shock report, medical attention, injury, or fatality, give a sense of the relative impact of the event. It is often beyond the scope of the utility investigator to differentiate between medical attention and injury, although some regulators have chosen to require this differentiation.

4) ESR Party Count: This is a numeric field that captures the number of individuals that were reported shocked at a location, in some instances more than one individual may report a shock at a location, and this is particularly true when shocks involve domestic pets and their owners.

c) Data Fields for Asset Management: The largest asset pool in most underground distribution systems is the cable. Collection of relevant data is vital to understanding the health of the cable system and is a vital component to a successful asset management program. The cable related data fields identified below can be easily expanded to include other assets.

1) Cable Manufacturer: This is a text field populated from a list. This data can help to identify trends by specific manufacturers. Consideration can also be given to the insulation composition. Since many utilities purchase cable from one or two sources over several years, failure trends in a specific manufacturer's cable could be the result of the insulation composition and not a result of a manufacturing related problem.

2) Cable Manufacture Date (Year): Numeric field collected by the utility investigating the event. Often, the year of manufacture along with the manufacturer's name, is stamped periodically on the center strand of the cable.

3) Insulation Composition: This is a text field populated from a list. This data may be useful when attempting to develop targeted programs to replace cable. The most common types of insulation used on underground secondary cable include: Paper Insulated Lead Covered (PILC), Synthetic Butyl Rubber (SBR), Neoprene, Ethylene Propylene Rubber (EPR), and Cross Linked Polyethylene (XLPE).

Annex C

(normative)

Stray voltage investigation for confined livestock

C.1 Data collection

Annex F shows the Confined Livestock Stray Voltage Investigation Forms. The forms are provided as an example of what an electric utility might use to document general information about the farm and stray voltage test results. The investigator should decide upon and perform the test procedures that are important to a determination of stray voltage levels, stray voltage sources, and, if necessary, appropriate mitigative action. The forms also provide a location for documentation of observations and commentary.

C.2 Case history

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

C.3 Electrical system review

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

C.4 Record of measurements[5]

The record of measurements is as follows:

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

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

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

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

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

CAUTION

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

b) *Barn/Parlor Sketch:* Indicate north and document spot-check and recorder placement locations for the barn, parlor, and/or other measurement location in the Spot Checks section of the Confined Livestock Stray Voltage Investigation Forms.

c) *Cow Contact Measurements before Bonding Improvement:* In an as-found condition, the investigator can first document stray voltage measurements at several locations within the animal confinement area. Documenting measurements under these conditions can help provide an indication of internal structural and electrical bonding. An effort should be made to stabilize farm load while measurements are being made. A 120-V, 1.2-kW test load, such as a hair dryer may be used to help accomplish this. All measurements at cow contact locations should be made with and without a 500-Ω shunt, and can be recorded as indicated in the Spot Checks section of the Stray Voltage Investigation Forms.

These as-found measurements are also used to select a stray voltage recorder location (see C.4.h). The preference is to set up the cow contact channel of the recorder at the location where the stray voltage during the spot check is the highest. However, consideration can also be given to the farm operator's preferred location, the possibility of animal interference, etc. While not always possible, the investigator can attempt to find a location where he/she can connect one meter lead to a copper plate on the floor in the vicinity of the animals rear hooves and at least 45 cm (i.e.,18 in) away from other metallic objects. A jack post, insulated from the copper plate, or other means of applying pressure to the plate can then be utilized. The plate contact area should be scraped clean and kept wet throughout the period of testing by placing a paper towel saturated with a salt-water solution under the plate. This will help minimize contact resistance resulting in a worst case exposure scenario during the recording period. The other meter lead can be solidly connected to a metallic object that the cow could contact while standing on the plate contact area (e.g., water line, stanchion post, etc.). Milk lines, bulk tanks, metal conduit, and other objects that cannot come in contact with the cow should not be used for making stray voltage measurements.

d) *Cow Contact Source Resistance Measurements:* Source resistance can be determined by performing two stray voltage measurements. Making certain that the contact resistance of the meter connections is minimized; compare the voltage measured without a shunt resistor to the voltage measured with a 500-Ω shunt. If there is a significant (50%) reduction in voltage measured with the shunt, it may be an indication of inadequate structural/ electrical bonding or a high resistance floor contact. The investigator may need to choose another cow contact location or temporarily improve bonding before choosing this location to set the stray voltage recorder. If another location is chosen for the recorder, a source resistance assessment can be made at the new location.

e) *Establish Qualified Reference:* Determine an acceptable location and install a remote reference ground rod. If possible the ground rod should be installed in moist soil 30 m (i.e., ~100 ft) or more from the barn and any conductive underground structures such as water pipes, the well casing, building grounds, etc. Make primary neutral to remote reference and secondary neutral to remote reference voltage measurements with and without a 500-Ω shunt resistor. If there is a significant (50%) change in measured voltage an attempt should be made to reduce the ground resistance of the qualified ground before proceeding. However, too low of a ground resistance may be an indication that the rod is too close to underground facilities connected to the neutral/ground network.

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

f) *Degree of Bonding:* Operate a 120-V, 1.2-kW test load, such as a hair dryer, at an outlet near the animal confinement area. Where practical other farm load should be turned off at this time. Measure the following voltages at the setup location to determine the degree of bonding between the metal work in the area that the cow may contact and the electrical system; barn metal (usually water line) to the ground bar of the barn electrical panel serving that location, barn metal to qualified reference, and barn panel ground bar to qualified reference. (If the farm is three wired, the neutral and ground bars are the same, and the measurement can be to either. If the farm is four wired, measurements should be to the separate ground bar and NOT to the neutral bar.) Record these measurements as “pre-bond” measurements in the Spot Checks section of the Stray Voltage Investigation Forms. Because the possibility exists that intentional or inadvertent bonding to the electrical system may occur in the future, if necessary the investigator can attempt to temporarily improve this bonding before proceeding with the investigation. The “post-bond” measurements can also be recorded.

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

g) *Cow Contact Measurements after Bonding:* Create voltage on the secondary neutral by operating a 120-V, 1.2-kW test load, such as a hair dryer at or near the panel to which the barn metal bonding has been supplemented. Where practical, all other farm load can be turned off prior to making voltage measurements. Measure and record the voltage at the cow contact setup location in the Spot Checks section of the Confined Animal Stray Voltage Investigation Forms.

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

h) *Stray Voltage Recorder Connections:* If not done previously, at this point in the investigation a voltage recorder should be set up to assist in the collection of data. The following discussion assumes that the stray voltage recorders used are digital voltage recorders that have four channels and an internal shunt in the fourth, cow contact, channel.

   1) The principal voltage recording is to be made at the predetermined cow contact location. Prior to connecting the recorder the relative magnitude of the source resistance can be determined. This determination can be made, and the input of the recording channel with the internal shunt can be connected as described in c) above.

   2) A second recording channel can be installed to record secondary NEV between the single-phase secondary ground bar at the barn service entrance and the qualified reference previously established.

   3) A third recording channel can be installed to record voltage between the primary neutral (primary neutral ground lead at the utility transformer) and the qualified ground previously established. If required, the primary NEV level recorded during the period of maximum stray voltage can later be estimated or artificially recreated with all farm load off in order to determine maximum primary neutral contribution to stray voltage levels (see C.5).

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

5) Take adequate measures to ensure that leads are placed in a manner that minimizes the impact on farm operations.

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

i) *Equipment Signature:* Set the recorder for a 1 s or higher data recording or storage rate, and start recording the voltage at the monitored points. As much as possible, this test should be conducted with minimal other farm load operating and/or switching on and off. Identify and momentarily energize individual pieces of farm equipment while monitoring the voltmeter or recorder for abnormal readings. The investigator can include in this signature test numerous types of equipment from various farm locations. The equipment location, type of equipment and on/off times can be recorded in the Signature section of the Confined Animal Stray Voltage Investigation Forms. If a significant on farm problem is found (e.g., defective equipment or high resistance neutral) and it cannot be immediately repaired, the livestock farmer should be urged to temporarily disconnect the equipment. The investigator can document all abnormalities. Figure C.1 is a typical Signature Test recording.

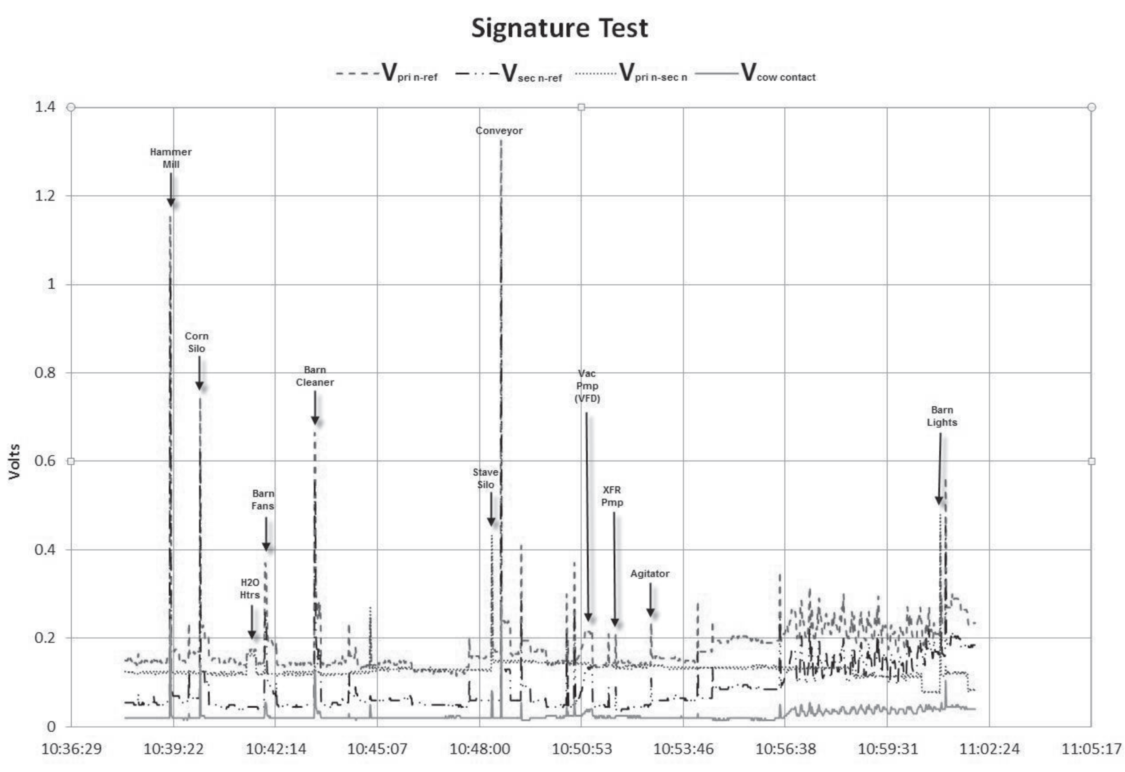


Figure C.1—Signature Test recording

j) *System Assessment (Load Box Test):* An assessment of the distribution system neutral and its ability to contribute to stray voltage levels can be made using 240-V single-phase farm loads and/or a single-phase 240-V load box (multi-stage load box preferred). The use of 240-V load (all 120-V loads off) results in primary neutral current flow and increases the contribution from primary neutral stray voltage sources with minimal impact from the secondary neutral and its potential stray voltage sources[6]

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

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

As rapidly as possible, energize the first stage of the 240-V load box to create 240-V load, and measure/record the same voltages and currents. These measurements can be repeated and documented in the Load Box Test section of the Confined Animal Stray Voltage Investigation Forms for each of the 240-V pieces of equipment or load box stages energized[7].

After all of the 240-V equipment or load box stages are operating, and while still energized, turn the farm on. In addition to the other current and voltage measurements made when only the load box was operating, record the amount of current in both (or all) of the energized service conductors and the secondary neutral conductor. Finally, the load boxes are turned off and the same voltages and currents can again be measured with the farm still on. Figure C.2 is a typical Load Box Test recording.

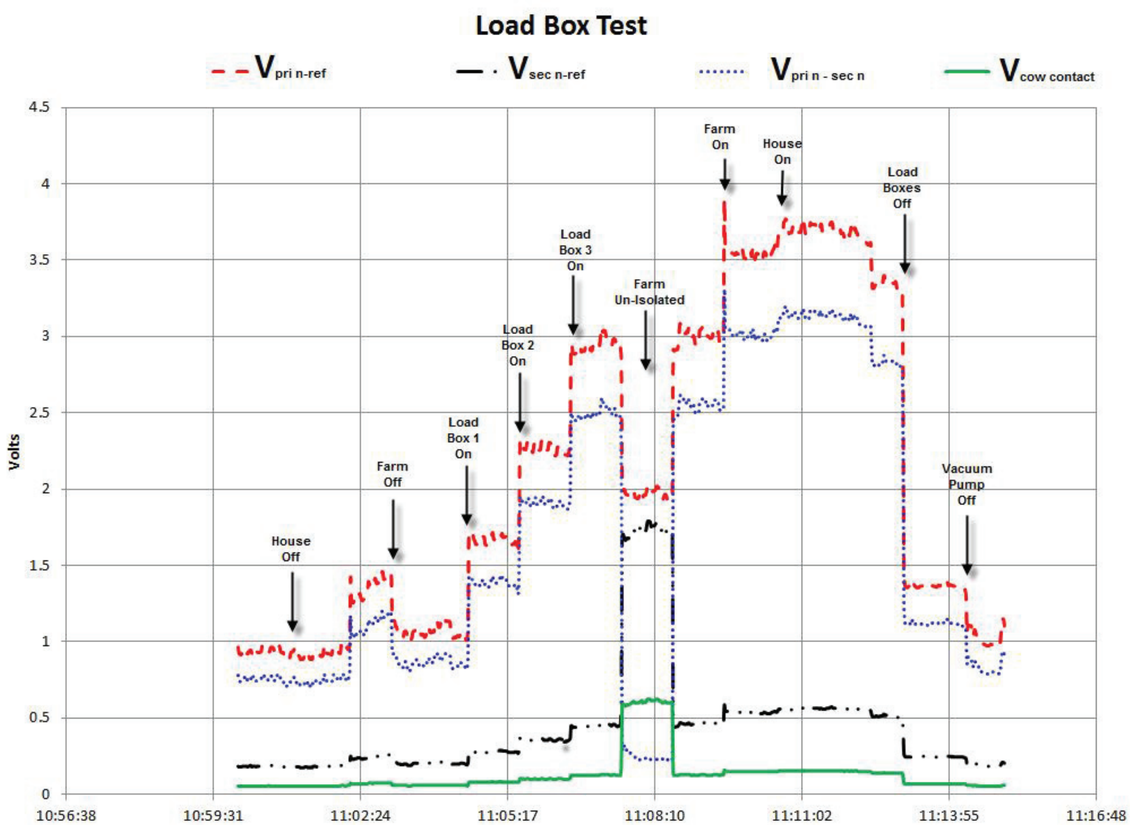


Figure C.2—Load Box Test recording

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

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

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

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

k) *Secondary Neutral Voltage Drop:* The purpose of this test is to determine the effect of secondary neutral voltage drop on stray voltage levels. A 120-V test load is operated at the load end of each of the on-farm feeders, and a measurement is made of the voltage drop on the secondary neutral conductor caused by that load. The farm wiring examined should include the service drop from the transformer to the farm's main distribution point, and then individually all of the farm feeders from that distribution point to the various farm buildings. This may include numerous segments of wire of varying size and material, connections, and segments that may extend past and through the various farm buildings.

Although the ideal would be to do this test with all farm loads off, it is acceptable to conduct the test with other loads operating and note the change, or step in voltage between when the load is turned on and when it is turned off[8]. A 1.2-kW or larger 120-V hairdryer with two heat settings is ideal for use as the test load. The preset stray voltage recorder may again be used to assist in capturing data. Care should be taken so that the additional loading does not trip circuit protection, depending on existing load levels.

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

The individual feeders of a properly wired "four wire" system have an equipment grounding conductor (fourth wire) that is separate from the neutral (grounded) conductor. Although 120-V load current will flow on the neutral, there should be little or no current on the equipment grounding conductor. Therefore, if a feeder is properly four wired, there will be little or no change in voltage drop between the building's ground bar and the main distribution point neutral when the test load is applied. If there

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

is an identifiable voltage drop change associated with the operation of the test load, a current is flowing on the equipment grounding conductor, the equipment grounding conductor and the neutral conductor are in parallel, and the system is NOT properly four wired.

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

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

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

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

m) *Primary Profile:* In the Primary Profile Test section of the Confined Animal Stray Voltage Investigation Forms record the pole ground current and pole ground resistance of several primary neutral grounds on either side of the location being investigated. The greater the physical distance over which this is accomplished, the better the chance of identifying neutral conductor abnormalities and uncleared secondary faults. Calculate, using Ohms Law, the pole ground voltage (primary NEV) at each pole. Use the comments section of the form to annotate the condition at each location such as whether the pole has equipment mounted on it, a primary or secondary riser, is close to a telephone pedestal, etc.

n) *24-Hour Recording:* Before leaving the farm, slow the sampling rate of the recorder(s) to ensure that there is sufficient storage capacity to record voltages for the remainder of time the recorder will be left to monitor voltage levels on the farm. Allow the recorder(s) to operate for at least 2 milking cycles or a 24-h period. Remove the recorder(s) and analyze collected data. If existing neutral separation devices had been bypassed for testing, restoring isolation and recording voltages for another 24-h period may provide additional useful information. When testing is complete an isolated farm should remain isolated until the data has been analyzed, discussed with the farm operator and a decision regarding future isolation status has been reached.

o) *Recorded Data:* After review of the recorded data, document dates and times, weather conditions, voltages at the time of maximum stray voltage, and any other relevant information in the End of Test Information section of the Confined Animal Stray Voltage Investigation Forms.

p) *System Resistance Analysis:* Using the data collected in j) "System Assessment," the farm and distribution system neutral-to-earth resistances can be calculated. This information may be important to a determination of appropriate mitigative action.

q) *Comments:* The "Comments" section of the "Confined Animal Stray Voltage Investigation Forms" can be used to document important findings and issues discussed with the livestock farm's owner/operator.

C.5 Analysis of collected data

C.5.1 Stray voltage level

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

Several states now require electric service providers to limit stray voltage contribution from utility facilities to 0.5 V. The following discussion concerning levels found and action recommended is based on this conservative requirement.

If the maximum recorded steady state voltage at the cow contact location did not exceed 0.5 V, the level of stray voltage resulting from the combination of both on and off farm sources is not sufficiently high to warrant mitigative action. If a neutral separation device is currently in place, the livestock farmer should be informed that the device is not necessary.

If the maximum recorded steady state voltage at the cow contact location was greater than 0.5 V, it may be necessary for the investigator to determine maximum off-farm contribution to stray voltage levels. Quantifying the off-farm contribution will provide information necessary for the eventual determination of the best technique(s) for reducing stray voltage levels.

C.5.2 Primary neutral contribution

Using the 24-h recording and data collected during the "System Assessment" tests (see j) above), an estimate of the maximum utility contribution to voltage at the cow contact location can now be made. This is possible because of the relative linearity between increasing levels of primary NEV and stray voltage when on-farm factors are eliminated. The maximum contribution to stray voltage levels (CC_{mv}) will be the ratio of primary NEV at the time of maximum recorded voltage at cow contact ($P_{nev@ccv\max}$), to primary NEV as created by the 240-V farm load and/or load box test (P_{nevlb}); times the voltage at cow contact as created by the load box test (CC_{vlb}).

$$CC_{mv} = \frac{P_{nev@ccv\max}}{P_{nevlb}} CC_{vlb} \tag{C.1}$$

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

a) Less than 0.5 V

1) *Neutrals Bonded:* If the maximum off-farm contribution to voltage at cow contact locations with neutrals tied is less than 0.5 V, and the primary and secondary neutrals have not been separated, collected data can be used in an attempt to further reduce stray voltage from on farm sources.

2) *Neutrals Isolated:* If the maximum off-farm contribution to voltage at cow contact locations with neutrals tied is less than 0.5 V, and a neutral separation device(s) is currently in place, the farm owner should be informed that the isolation device is not necessary and collected data can be used to help the farm owner further reduce stray voltage levels from on farm sources.

b) *Greater than 0.5 V:* If the maximum off-farm contribution to voltage at cow contact locations with neutrals tied is greater than 0.5 V, the investigator, working with utility personnel, should take whatever action is necessary to lower utility contribution to a level below 0.5 V. This should be done regardless of whether the primary and secondary neutrals are presently tied or separated. A determination regarding the best on and/or off-farm method(s) by which this is to be accomplished should be based on an analysis of previously collected data as well as any necessary additional testing. Following a reduction of off-farm stray voltage contribution to levels below 0.5 V, the investigator may offer to utilize collected data to help the farm owner further reduce stray voltage levels from on-farm sources.

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

C.6 General

In addition to the specifics of confined livestock investigation discussed above, adherence with the following general guidelines may provide valuable information, help resolve difficult situations and/or improve the investigative process.

a) Where a decision is made to install a neutral separation device, the investigator can assess its impact on neighboring non-isolated livestock farms located within several spans (~300 m) of the newly isolated farm.

b) If the farm owner has expressed a concern regarding personal shocks, the investigator can make measurements where necessary in an attempt to determine the source(s) of the voltage. Because personal shocks can be an indication of secondary wiring or equipment failure, the farm owner should be encouraged to contact a qualified electrician immediately. Voltage levels, specific measurement locations, and recommendations/action can be documented.

c) At the completion of the investigation the farm owner should be encouraged to monitor voltage at cow contact locations.

d) The investigator can visually inspect the electric fencer/trainer installations at all farms investigated to determine if the device(s) was installed in accordance with the manufacturer's recommendations. Where appropriate the fencer/trainer installation(s) should be corrected.

If the primary and secondary neutrals of a farm's electrical system are separated, the telephone and/or cable television companies serving the farm should be notified of the separation. Notification procedures vary between the various communication companies. Should the stray voltage investigation reveal that the telephone or cable television systems provide a parallel path for off-farm contribution, and, this path prohibits effective isolation from off-farm sources, the investigator can seek immediate assistance from the appropriate communication company.

Annex D

(normative)

Swimming pool investigations

D.1 Voltage-source diagnosis

When investigating a report of a perceptible exposure at a swimming pool it is important to determine whether the shock is due to a hazardous contact voltage source or to stray voltage. Stray voltage that may be present is typically a result of inadequate, improperly installed or degraded/compromised equipotential bonding. Abnormally high levels of NEV can result in small potentials even where proper equipotential bonding is present. These situations may require additional mitigation measures outside of the pool installation. Painful electric shocks can be due to faulty equipment or wiring problems. These contact voltage sources should be located and repaired immediately. If the faulted equipment belongs to a neighbor, the investigator may require the assistance of the electric utility and the cooperation of the neighbor.

Underwater lighting and pool pump motors installed in swimming pools are sources of electrical faults in pool areas. Faulted equipment typically results in a short circuit between the hot wire and ground/neutral. Failing electrical insulation may also result in faults. Insulation degrades over time due to exposure to environmental conditions. Exposure to environmental conditions may widen already existing small openings in cable insulations. It also may cause porcelain insulators used on overhead lines to crack, and can cause polymer insulators to become covered with contaminants. As a result, this insulation degradation may allow electrical tracking across the insulated path, creating high-impedance faults and thus a potential for a harmful contact voltage condition.

Harmonic analysis is covered in Clause 5. Performing a harmonic analysis may be an important step in determining the type and source of the measured voltage.

D.2 Construction methods

There are three basic swimming pool types that are commonly used today:

a) Above-ground pools

b) Portable pools

c) In-ground pools

Above-ground swimming pools are constructed on or above the ground and are capable of holding water to a maximum depth of 1.0 m (42 in.) (NFPA 70-2011 [B36]). Above-ground pools comprise two types: soft-sided pools and hard-sided pools. Soft-sided pools are constructed from rubber or latex. Hard-sided pools are constructed using metals and fiberglass, which makes them more durable and expensive (Johnson [B28]). Hard-sided pools often have an elevated wooden deck constructed around them. Above-ground pools are usually less expensive than in-ground pools and are typically easier to install. However, their lifetime is typically shorter than the lifetime of in-ground pools.

Portable swimming pools are small pools that can be taken to any location, filled/drained easily, and conveniently stored when not in use. They are typically made of inflatable plastic.

This annex focuses on construction methods for in-ground swimming pool structures. In-ground swimming pools are swimming pools that are constructed in the ground (or partially in the ground), and all pools installed inside of a building (NFPA 70-2014 [B36]). Some of the common shell types used when constructing in-ground pools are discussed as follows:

a) Poured concrete pools involve the pouring of concrete into wooden frames for its construction (Johnson [B28]). Poured concrete pneumatically applied or sprayed concrete or concrete block with painted or plastered coatings are considered conductive materials due to water permeability and porosity (Harris [B24] and Herzig [B25]). Rebar is reinforcing steel that is used for structural support of concrete swimming pool structures. It is installed in a grid pattern under the concrete pour. Some swimming pool structures employ 'bare' rebar, which acts as an equipotential grid but is subjected to rust and corrosion. Other swimming pool structures employ rebar that is encapsulated in a non-conductive compound, such as epoxy, to protect it from deterioration. This type of rebar is electrically insulated and does not function as an equipotential grid. Poured concrete pools are highly customizable giving the owners many options regarding the pool layouts. However, the installation of this pool type is difficult and time consuming.

b) Fiberglass pools are made from fiberglass-reinforced plastic which are molded into a basin shape (Harris [B24]). Fiberglass is an insulator and consequently cannot be used for establishing an equipotential system. Fiberglass pools have lower maintenance costs as compared to the vinyl type and are usually installed by professional swimming pool installers using pre-made shells (Johnson [B28]).

c) Vinyl-liner in-ground pools are the most commonly used type of in-ground pools. For this type of pool soil is dug out, a frame is constructed for the pool structure and sand is placed at the bottom. The walls constructed out of metal, wood or plastic are covered with a vinyl liner. The vinyl liner is a thin insulator, but the wall material may or may not be an insulator. These pools are relatively inexpensive compared to poured concrete and fiberglass pools. However, the vinyl lining needs to be replaced every few years (Johnson [B28]).

d) Gunite pools are installed by creating a steel reinforcing rod framework called 'rebar rods' (Johnson [B28]). This framework of steel rods is built within the space dug out for the pool. The framework is then sprayed with a heavy gunite coating which is a mixture of cement and sand mixed with water. The gunite coating is smoothed and left for a week, after which the plaster is added to give it a smooth finish. These pools last longer than other types.

e) Shotcrete pools are created from a variation of concrete and gunite. The main difference from concrete is that shotcrete is sprayed. The spray application is similar to gunite however it differs because the water is premixed with the cement and sand in the mixer prior to arriving at the jobsite. Shotcrete is sprayed on with a pressurized hose in order to form the walls and floor (Home Guide123 [B26]).

D.3 National Electrical Code (NEC) requirements

The investigator responding to the report of a shock occurring in and/or around a pool should be familiar with code requirements contained in the NEC. The following sub-clauses provide specific details that may be useful for determining where deficiencies in the construction and maintenance of a pool may be contributing to stray or contact voltage.

D.3.1 Equipotential bonding

The objective of an equipotential system is to create an area where there is no significant voltage difference between objects that can be touched simultaneously, thus helping to reduce the risk of hazardous body (i.e., exposure) current. Near a swimming pool these objects include concrete decking, ladders, handrails and light fixtures. An equipotential system is created by intentionally connecting all these objects together electrically, a practice that is known as 'equipotential bonding.' This can be done simply and effectively by electrically connecting these objects together via a metal wire that is attached to each object using connection methods that conform to code.

Equalizing the voltage potentials between conducting non-metallic surfaces such as concrete or brick paver decks and the swimming pool water is more challenging if the deck is not constructed with internal metallic bonding such as structural reinforcing steel. The outside of the non-metallic conductive pool deck is at earth potential, while the bonded objects in proximity to the pool and the water are at or near neutral potential. A potential difference between the neutral and the surrounding earth (i.e., NEV) will result in a voltage gradient that spans from the pool water to the outside part of the deck section. A person that bridges the gap between the "water potential" and the "deck potential" (i.e., a person in the swimming pool touching the deck or a person standing on the deck and touching the water) is in danger of receiving an electric shock if the NEV is large. Equipotential bonding of the deck, other objects near the swimming pool, and the water is required to help minimize the potential difference sufficiently so that shock hazards can be eliminated.

Article 680.26(B)(2) in the NEC NFPA 70-2014 [B34]requires bonding to the swimming pool deck if the swimming pool deck has a conductive surface, such as concrete or brick. NEC defines the perimeter surface as the surface that extends ~1 m (i.e., 3 ft) horizontally beyond the inside wall of the pool. The code requires that bonding to the perimeter surface shall be provided by either one of the following bonding methods:

a) *Structural reinforcing steel,* which shall be bonded together by steel tie wires or equivalent bonding means

b) *Alternate means*, which shall comply to the following requirements:

    1) At least one minimum 8.5 mm^2 (8 AWG) solid copper conductor shall be provided.

    2) The conductors shall follow the contour of the perimeter surface.

    3) Only listed splices shall be permitted.

    4) Installed at a minimum of 450 mm to 600 mm (18 in to 24 in) from the inside walls of the pool.

    5) The required conductor can be secured within or under the perimeter surface 100 mm to 150 mm (4 in to 6 in.) below the subgrade.

Two implementations of the alternate-means option are listed here:

— A single 8.5 mm^2 (8 AWG) solid copper conductor that follows the contour of the perimeter surface and is installed 450 mm to 600 mm (18 in to 24 in.) from the inside walls of the pool. This single-conductor implementation is the minimum-requirement alternate-means option.

— A copper conductor grid constructed of a minimum 8.5 mm^2 (8 AWG) bare solid copper conductors bonded together at each point of crossing that follows the contour of the perimeter and is installed from the pool wall out to a minimum of 450 mm (18 in.) from the pool wall. The copper grid also conforms to the requirements listed in the alternate-means option.

The only alternate-means option permitted in the 2005 version of the NEC code was a copper grid that extends a minimum of ~1 m (i.e., 3 ft) horizontally from the inside wall of the pool and that has a 30 cm × 30 cm (i.e., 12 in × 12 in) rectangular grid pattern, which complies to the copper-grid option described above. The 2008 and 2011 versions of the NEC include the single-conductor option as an economic alternative to the copper-grid option. There has been some controversy related to the effectiveness of the single-conductor option in reducing voltage gradients in swimming pool areas to safe levels. Notable studies on this subject, which are summarized and discussed in a report published by the Fire Protection Research Foundation (FPRF) [B16] were conducted previously by the Electric Power Research Institute (EPRI) and the National Electric Energy Test Research and Application Center (NEETRAC). In these studies the effectiveness of the "Single Conductor" option and the "Copper Grid" option were compared. Brief summaries of the experiments conducted and the findings of EPRI and NEETRAC are provided below:

— In 2008 EPRI constructed a swimming pool at their Lenox, MA test facility to evaluate the NEC "Copper Grid" and "Single Conductor" options, and also to assess other implementations of the "Alternate Means" option. The conclusion of their experiment based on different NEV and fault scenarios was that the "Copper Grid" option was more effective than the "Single Conductor" option and other options. For the "Copper Grid" option the accessible voltages stayed at less than 1.0 Volt for every condition, including high-current faults. Voltages never exceeded 0.1 Volt for the steady-state NEV tests. On the other hand, the voltages were in the order of tens of volts during fault conditions when only the "Single Conductor" option was employed (ERPI, 2010 [B14]).

— In 2008 NEETRAC conducted tests at a residential pool in Buford, Georgia to compare the equipotential bonding effectiveness of the "Copper Grid" option with the effectiveness of the "Single Conductor" option. Based on their experimental results they concluded that the "Copper Grid" option was more effective in mitigating the voltages than the "Single Conductor" option. The "Copper Grid" option reduced the water-deck voltage to values that were 70% to 93% lower than the voltages measured when the "Single Conductor" option was employed. Step voltages were reduced to values that were 57% to 97% lower than the voltages measured when the "Single Conductor" option was employed (NEETRAC, 2008 [B34] and Patel [B38]).

D.3.2 Ground-fault circuit interrupter (GFCI) requirements

The NEC began to incorporate ground-fault circuit interrupter (GFCI) protection requirements beginning in 1971, starting with all residential outdoor receptacles and those located within 4.5 m (15 ft) of the inside walls of indoor pools. Underwater lighting fixtures were not specifically required to have GFCI protection until 1975. It was not until 1999 that protection of 15A and 20 A, 120 V through 240 V, single-phase pool pump motors was included, but this did not apply to residential installations.

The 2002 NEC was expanded to include the requirement for residential pool pump motors, whether hard-wired or cord and plug connected. This requirement was removed in 2005 and again replaced in 2008. The investigator responding to the report of a shock should determine the location of the GFCI protection in the circuit(s) supplying equipment to determine whether the devices are operating as intended. It should be noted that ground faults within the wiring system supplying a GFCI protected outlet may not be cleared by the circuit protective device and may have contributed to the reported shock. (The Ground-Fault Circuit-Interrupter Protection Journey [B20])

D.4 Measurement point selection

The initial stage of a swimming pool investigation is to identify deficiencies or degradation of the bonding of pool equipment and surfaces, and to locate problems within the electrical supply to the pool equipment. Measurement points can be carefully selected to represent surfaces that a swimmer would normally come in contact with. For this reason measurements should be limited to the distance that a human can step or touch, with standards such as IEEE Std 80-2013 [B27] identifying the typical step distance as 1 m. Exceeding this distance may be necessary, for example, where a swimmer reports a perceptible exposure when lying on a towel with feet extended into the water and hands touching the decking. This distance could be greater than 2 m and it would be appropriate to perform measurements at 1 m and 2 m.

Measurements between the pool water and any surrounding objects or surfaces can be performed in both open circuit and closed circuit using a shunt resistance to the represent the swimmer in the closed-circuit measurement. Open-circuit measurements to the pool water can be performed using a short section of bare conductor connected to the voltage probe. To maintain accuracy and consistency closed-circuit measurements to the water should use a copper plate to provide sufficiently low contact resistance and to help ensure conduction of the current produced by the load resistor selected.

D.4.1 Pool water to metal hand rail(s)

Voltage measurements around the pool area can begin with a measurement between the pool water and any metal handrail(s) that are present. To obtain an open-circuit voltage measurement a length of bare wire can be placed in the pool water with the other probe in contact with the metal hand rail as illustrated in Figure D.1. Any non-conductive coatings should be removed without causing noticeable damage to the handrail. Closed-circuit voltage measurements can only be performed using a submerged copper plate to help ensure accurate measurements. The plate placed in the pool water can be made to float with a block of closed cell foam or simply held below the surface with a non-conductive pole.

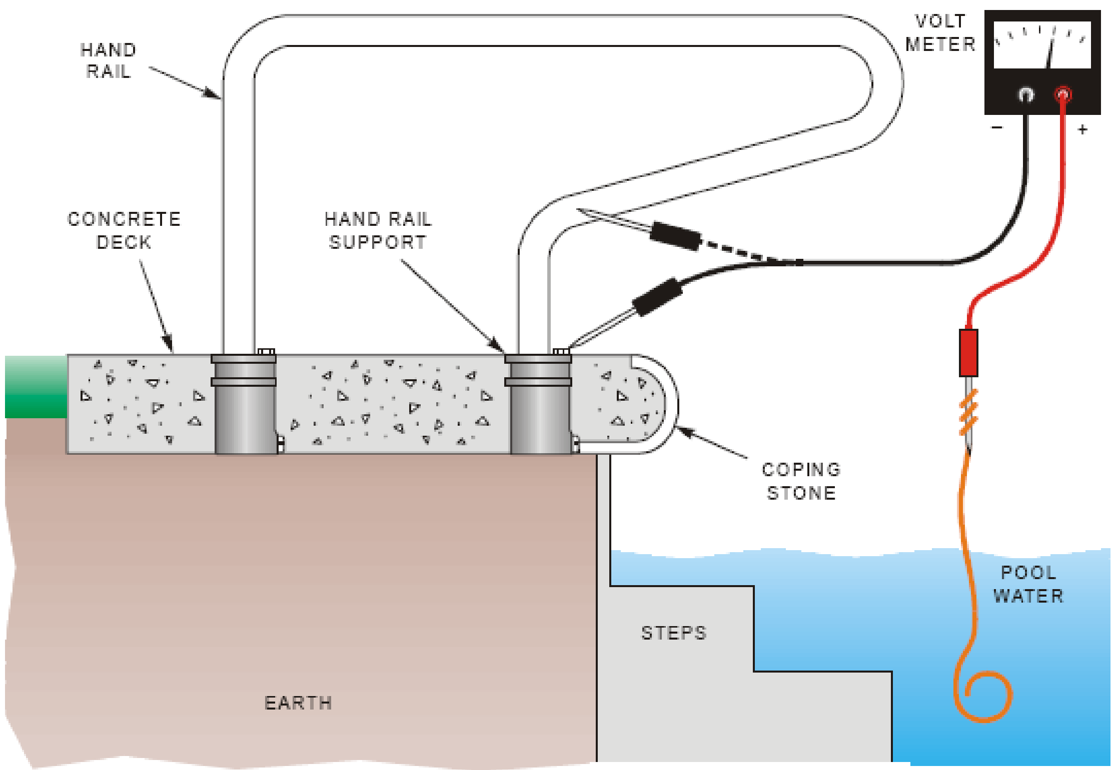


Figure D.1—Measuring voltage between pool water and metal hand rail(s)

D.4.2 Handrail(s) to concrete decking

Handrails that are mounted to the wall or steps within the pool can be measured against a plate on the decking surface at a distance of 1 m to represent a swimmer exiting the pool. Start by wetting the concrete decking surface at a distance of 1 m with salt water and place the measurement plate with sufficient weight to make adequate contact.

D.4.3 Pool water to concrete decking

Measurements between the water and the decking can be obtained from each side of the pool. Start by wetting the concrete decking surface at a distance of 1 m with salt water and place the measurement plate with sufficient weight to make adequate contact. The plate placed in the pool water can be made to float with a block of closed cell foam or simply held below the surface with a non-conductive pole. Measurements can be repeated with the plate on the concrete decking moved out to 2 m.

D.4.4 Pool water to coping stone

Pool coping stone is generally installed onto the walls of the pool prior to the concrete decking surface installation. There may be an expansion joint between the two surfaces. Start by wetting the coping stone with salt water and place the measurement plate with sufficient weight to make contact. A cooper sheet can be used to accommodate curved surfaces. The plate placed in the pool water can be made to float with a block of closed cell foam or simply held below the surface with a non-conductive pole.

D.4.5 Pool coping stone to concrete decking

After wetting both surfaces with salt water, the open and closed-circuit voltages can be measured between two plates or copper sheets placed on the concrete decking surface and the coping stone at distances of 1 m and 2 m.

D.4.6 Wet niche pool light to pool water

Wet niche pool lights may present a difference in potential between the metal housing of the light and the surrounding pool water when the equipotential ground grid is compromised, improperly installed or is conducting abnormal amounts of current (i.e., fault current). The plate placed in the pool water can be made to float with a block of closed cell foam or simply held below the surface with a non-conductive pole at varying distances from the pool light. The other voltage probe should make contact with the pool light housing or trim ring.

D.4.7 Equipotential bonding conductor current

Current flow between the supply-circuit equipment grounding conductor(s) and the equipotential bonding grid can occur at equipment such as pump motors, pool water heaters, and wet-niche lighting fixtures. Current measurements can be recorded at each location where a supply-circuit equipment grounding conductor is terminated. Measurements will need to be repeated with the pool equipment (motors, lights, heaters, etc.) in operation to determine if any ground faults are present.

D.5 Recording measurements

Measurements recorded for each possible exposure location can include the open-circuit voltage and the closed-circuit voltage at the user-selected resistance values. Clause 4 can be referenced when determining the appropriate resistance value. The time of day should be noted for each measurement to account for variations in the power system load. A standardized measurement form may assist in ensuring that all measurements are accurately recorded. The form can include an area for the investigator to provide a sketch of the pool and the measurement locations involved. Accurate documentation of any load switching or load box tests can be made and can include the location of the electrical source supplying the load.

The following is a list of testing that can be included in any investigation where stray voltage is suspected as the source:

a) *Meter Check:* Check the continuity of voltmeter leads and verify that the shunt resistor is connected across the meter input before making any closed-circuit stray voltage measurements. Doing so will help to ensure proper meter operation and accurate readings. This is accomplished by performing the following two steps:
    1) Set the meter to enable resistance measurements. Connect the spring-clips of the meter leads together and flex each lead just above the point of termination on the spring-clip. The meter readings should go to near zero and remain there without fluctuation.

2) Set the meter to the proper resistance scale. Hold the meter leads apart so the spring-clips are not touching each other and note the reading on the meter. The meter should indicate a resistance of approximately the value of the shunt resistor selected.

CAUTION

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

b) *Exposure Measurements:* The investigator can first document stray voltage measurements at several locations within the pool area. Documenting measurements under these conditions may provide an indication of existing internal structural and electrical bonding. An effort should be made to stabilize load while measurements are being made. A 120-V, 1.2-kW test load, such as a hair dryer, may be used to help accomplish this. All measurements at swimmer accessible locations should be made with and without a shunt resistor.

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

These measurements are used to select the stray voltage recorder set-up location. The preference is to set up the stray voltage channel of the recorder at the location where the stray voltage during the spot check is the highest. Conductive non-metallic contact areas should be clean and kept wet throughout the period of testing by placing a paper towel saturated with a salt-water solution under the plate. This will minimize contact resistance and helps to establish a worst case exposure scenario during the recording period.

c) *Source Resistance Measurements:* Source resistance can be determined by performing two stray voltage measurements. Making certain that the contact resistance of the meter connections is minimized; compare the voltage measured without a shunt resistor to the voltage measured with a 500-Ω shunt. If there is a significant (50%) reduction in voltage measured with the shunt, it may be an indication of inadequate structural/ electrical bonding or a high resistance deck contact. The investigator may need to choose another exposure location or temporarily improve bonding before choosing this location to set the stray voltage recorder. If another location is chosen for the recorder, a source resistance assessment can be made at the new location.

d) *Establish Qualified Reference:* Determine an acceptable location and install a remote reference ground rod. If possible the ground rod should be installed in moist soil 30 m (i.e., ~100 ft) or more from the pool and any conductive underground structures such as water pipes, well casings, building grounds, etc. Make primary neutral to remote reference and secondary neutral to remote reference voltage measurements with and without a 500-Ω shunt resistor. If there is a significant (50%) change in measured voltage an attempt can be made to reduce the ground resistance of the qualified reference before proceeding. However, too low of a ground resistance may be an indication that the rod is too close to underground facilities connected to the neutral/ground network.

The above procedure will help ensure that an adequate isolated reference ground has been established. The location of the qualified reference can be documented on the layout sketch for later reference.

e) *Stray Voltage Recorder Connections:* Care should be taken to avoid creating additional hazards when placing the monitoring device such as using cable protection troughs where cords and leads cross walk ways and GFCIs when powering equipment.

1) The principal voltage recording is to be made at the predetermined swimmer accessible location. The user selected shunt resistor is placed across the channel measuring the voltage between the exposure points using a connection method that will remain reliable during the entire monitoring period. Hose clamps can be used to make the connection to metal railings and copper plates placed onto the concrete decking can be kept wet by covering with a layer of plastic sheeting.

2) A second recording channel can be installed to record secondary NEV between the secondary ground bar at the service entrance and the qualified reference previously established.

3) A third recording channel can be installed to record voltage between the primary neutral (primary neutral ground lead at the utility transformer) and the qualified reference previously established. If required, the primary NEV level recorded during the period of maximum stray voltage measurement can later be estimated or artificially recreated with all facility load off in order to determine maximum primary neutral contribution to the stray voltage measured in the pool.

4) The fourth recording channel can be set up to monitor the difference in voltage between the connection at the transformer (i.e., primary neutral connection) and the connection in the service entrance panel (i.e., the secondary ground bar connection). This will provide an indication of voltage drop in the main service neutral conductor.

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

f) *Equipment Signature:* Set the recorder for a 1 s or higher data recording or storage rate, and start recording the voltage at the monitored points. As much as possible, this test should be conducted with minimal other building load operating and/or switching on and off. Identify and momentarily energize individual loads (pumps, lights, etc.) while monitoring the voltmeter or recorder for abnormal readings. The equipment location, type of equipment and on/off times can be recorded by the investigator. If a significant facility wiring problem is found (e. g., defective equipment or high resistance neutral) and it cannot be immediately repaired, the facility owner should be urged to temporarily disconnect the equipment. The investigator can document all abnormalities.

g) *System Assessment (Load Box Test):* An assessment of the distribution system neutral and its ability to contribute to stray voltage levels can be made using 240-V single-phase loads and/or a single-phase 240-V load box (multi-stage load box preferred). The use of 240-V load (all 120-V loads off) results in primary neutral current flow and increases the contribution from primary neutral stray voltage sources with minimal impact from the secondary neutral and its potential stray voltage sources[9].

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

As rapidly as possible, energize the first stage of the 240-V load box to create 240-V load, and measure/record the same voltages and currents. These measurements can be repeated and documented in a “Load Box Test” section of an investigation form for each of the 240-V pieces of equipment or load box stages energized[10].

[9]When performing this test on a 240 V three phase three wire service, use single phase 240 V equipment (or the load box) connected between the ungrounded phases.
[10]Artificial system loading should not exceed the equipment rating if the load is applied through building switches and equipment. (An analysis of circuitry and equipment, and/or a method of monitoring current at critical locations may be required).

After all of the 240-V equipment or load box stages are operating, and while still energized, turn the service on. In addition to the other current and voltage measurements made when only the load box was operating, record the amount of current in both (or all) of the energized service conductors and the secondary neutral conductor. Finally, the load boxes are turned off and the same voltages and currents can again be measured with the service on.

At those locations where primary NEV levels appear to be abnormal, distribution system repair or modification, and/or isolation may be necessary prior to additional testing. For most three-phase transformer connections, three-phase loads will not generate current in the primary neutral and are not suitable for use in conducting a load box test. Where a pool is served solely from a three-phase service, other measures may have to be used to generate current on the primary neutral, such as applying the load at a neighboring transformer. Load box testing cannot be adequately performed at all locations.

h) *Secondary Neutral Voltage Drop:* The purpose of this test is to determine the effect of secondary neutral voltage drop on stray voltage levels. A 120-V test load is operated at the load end of the service and each feeder, and a measurement is made of the voltage drop on the secondary neutral conductor caused by that load. In the case of a housing complex or resort setting the facility wiring examined should include the service from the transformer to the facility's main electrical service, and then individually all of the feeders from that distribution point to the various buildings. This may include numerous segments of wire of varying size and material, connections, and segments that may extend past and through the various buildings.

Although the ideal would be to do this test with all building loads off, it is acceptable to conduct the test with other loads operating and note the change, or step in voltage between when the load is turned on and when it is turned off[11]. A 1.2-kW or larger load bank, such as a 120-V hairdryer with two heat settings, is ideal for use as the test load. The preset stray voltage recorder may again be used to assist in capturing data.

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

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

Calculate the approximate anticipated voltage drop using the resistance values for that wire size and material. If there is an indication that secondary neutral or B-phase voltage drop may be a concern (higher than anticipated readings coupled with lengthy and/or small conductors, numerous split bolt

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

connectors, etc.), the investigator may perform additional tests and/or make recommendations to the building owner regarding necessary secondary system modifications.

i) *Primary Profile:* In a “Primary Profile Test” section of an investigation form record the ground current and ground resistance of several primary neutral grounds on either side of the location being investigated. The greater the physical distance over which this is accomplished, the better the chance of identifying neutral conductor abnormalities and un-cleared secondary faults. Calculate, using Ohm’s Law, the primary NEV at each location. In a comments section of an investigation form annotate the condition at each location such as the type of equipment present and the proximity of telephone and cable pedestals.

j) *24-Hour Recording:* Before leaving the pool location, if possible slow the sampling rate of the recorder(s) to ensure that there is sufficient storage capacity to record voltages for the remainder of time the recorder will be left to monitor voltage levels. The pool owner can be provided a log sheet to record the operation of lighting and other premises loads to be used later during the analysis of the collected data. Allow the recorder(s) to operate for at least a 24-h period.

D.6 Analysis of collected data

The data can be carefully analyzed to identify trends such as operation of pool equipment or outdoor lighting that may point to ground faults not identified while on site. An event log filled out by the pool owner identifying operation of these loads is essential for this analysis. Trends may also closely follow the profile of the area loading, indicating a possible contribution from a primary neutral source. The utility may need to perform additional tests to determine the integrity of the primary neutral and its ability to contribute to stray voltage at the pool.

In some cases monitoring of the neutral current at multiple points along the feeder may be necessary to aid in determining whether load unbalances are contributing to increased neutral current. Monitoring of the voltage at the pool should be performed simultaneously with the primary system monitoring whenever possible to help to correlate the data collected.

The effect of each change/repair to either the customer or utility electrical system can be documented with additional monitoring to help ensure effective resolution of the concern. Considerations can be made to changing load conditions throughout the year and, when necessary, follow-up measurements can be performed when system loading levels will be similar to those present when the exposure was first reported.

Resolution of the stray voltage concern does not necessarily require that the existing utility voltage contribution be lowered. Stray voltage levels may be reduced by premises wiring changes such as grounding improvements or the installation of additional equipotential bonding. In many cases a combination of utility and premises wiring improvements may be required. Mitigation methods are covered in 6.6 of this guide.

Annex E

(normative)

Marina and boat dock investigations

E.1 Voltage source diagnosis

When investigating reports of perceptible exposures at a marina or boat dock it is important to determine whether the shock is due to a hazardous contact voltage source or to stray voltage. Stray voltage sources typically are going to be detected by swimmers as a result of lengthy or undersized neutral conductors; and inadequate, improperly installed or degraded/compromised equipment grounding and bonding. Abnormally high levels of NEV can result in small potentials even where proper bonding is present. These situations may require additional mitigation measures outside of the marina or boat dock installation. Painful electric shocks can be due to faulty equipment or wiring problems. These contact voltage sources should be located and repaired immediately. If the faulted equipment belongs to a neighbor, the investigator may require the assistance of the electric utility and the cooperation of the neighbor.

Commonly faulted equipment at marinas and boat docks include the vessels, the boat lift equipment and all wiring. Incorrect wiring and/or electrical faults within vessels can lead to metal components such as the motor, propeller and hull being energized at line potential. Faults within loads such as boat lifts may not be readily apparent until the lift is operated and may require the investigator to install a recording voltmeter to capture the voltage at the shock location over an extended period.

Harmonic analysis of the voltage measured is covered in Clause 5 and is an essential step in determining the source of voltages measured.

E.2 Codes and standards

NEC Article 555 covers the installation of wiring and equipment in marinas, boat docks and similar locations that are located at places other than single-family dwellings. NEC requirements for ground fault protection of personnel are limited in Article 555 to only 15-A and 20-A, single-phase, 125-V receptacles for general use. Shore power cords are not required to have GFCI protection, but should be grounded in accordance with Article 555.15. The main overcurrent protective device feeding a marina is required by the NEC to have ground fault protection; however, the maximum setting requirement is 100 mA and is not intended to provide protection for personnel.

At single-family dwellings the applicable provisions of chapters 1 through 4 would apply, in particular those dealing with outdoor, wet locations. At single-family dwellings a dock with a boat lift is required to have GFCI protection under the requirements of article 210.8(C), but this requirement is limited to 15-A or 20-A branch circuits rated at 250 V or less.

The NEC does not cover the installation of wiring systems within vessels; the United States Code of Federal Regulations (CFR) is applicable to these installations. Title 33, CFR Part 183 Subpart I [B1] covers electrical systems, however, the subject of grounding is limited to the installation of dc wiring for starter circuits. The American Boat and Yacht Council (ABYC) has published standard E-11 [B2] covering the installation of ac and dc electrical systems on boats, which provides more detailed guidelines .

E.3 Measurement point selection

The initial stage of the investigation is to identify deficiencies or degradation of the dock wiring and equipment, as well as problems within the electrical systems of energized vessels. Measurement points can be carefully selected to represent surfaces that a swimmer or boater would normally come in contact with. For these reasons measurements should be limited to the distance that a human can step or touch, with standards such as IEEE Std 80-2013 identifying the typical step distance as 1 m. Exceeding this distance may be necessary, for example, where a swimmer reports a perceptible exposure when lying on a towel with feet extended into the water and hands touching the conductive dock surface. This distance could be greater than 2 m and it would be appropriate to perform measurements at 1 m and 2 m.

Measurements between the water and any surrounding objects or surfaces can be performed in both open circuit and closed circuit using resistance to represent the person being exposed. Open circuit testing to the water can be performed using a short section of bare conductor connected to the voltage probe. Closed circuit measurements should use a copper plate to provide sufficiently low resistance to help ensure conduction of the current produced by the representative load resistor selected.

E.3.1 Water to metal dock or vessel components

Voltage measurements around marinas and boat docks can begin with a measurement between the water and any metal dock or vessel components that are present. To obtain an open-circuit voltage measurement a length of bare wire can be placed in the water, with the other probe in contact with the metal object. Any non-conductive coatings should be removed without causing noticeable damage to the component. Closed-circuit voltage measurements should only be performed using a submerged copper plate to help ensure accurate measurements. The plate placed in the water can be made to float with a block of closed cell foam or simply held below the surface with a non-conductive pole.

E.3.2 Swimmer voltage gradients

Voltage gradients surrounding vessels and dock structures that swimmers may be exposed to can be located using a non-metallic pole with voltage probes separated at a distance of approximately 60 cm (2 ft). The surface area of the test probes should be at least 58 cm^2 (9 sq in) to help ensure consistent readings, and the probes can be made of commonly available copper tubing. Measurements can be performed at the stern of vessels with wood or fiberglass hulls and all areas surrounding metal boat hulls and energized boat lifts. Indications of voltage gradients surrounding a vessel should be rechecked following disconnection of the shore power cable.

E.3.3 Shore power leakage testing

Each shore power cord can be measured using a clamp-type ammeter to determine the presence of leakage current from vessel wiring and equipment. Where leakage current is detected the investigator may be required to determine if the current is from sources other than the vessel being served. This can be accomplished by turning off the supply circuit breaker. Current flow that remains with all sources of power removed from the vessel may be from a nearby vessel or dock. Additional investigation may be required.

E.4 Recording measurements

Measurements recorded for each measurement point can include the open-circuit voltage and the closed-circuit voltage at the user-selected resistance values. Clause 3 can be referenced when determining the appropriate resistance value. The time of day can be noted for each measurement to account for variations in the power system load. A standardized measurement form may assist in ensuring that all measurements are accurately recorded. The form can include an area for the investigator to provide a sketch of the marina/dock and the locations involved. Accurate documentation of any load switching or load box tests can be made and can include the location of the electrical source supplying the load.

The following is a list of testing that may be included in any investigation where stray voltage is suspected as the source:

a) *Meter Check:* Check the continuity of voltmeter leads and verify that the shunt resistor is connected across the meter input before making any closed-circuit stray voltage measurements. Doing so will help to ensure proper meter operation and accurate readings. This is accomplished by performing the following two steps.

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

    2) Set the meter to the proper resistance scale. Hold the meter leads apart so the spring-clips are not touching each other and note the reading on the meter. The meter should indicate a resistance of approximately the value of the shunt resistor selected.

CAUTION

The shunt resistor should only be used when making voltage measurements at accessible locations and when evaluating source and ground rod resistance. It should not be used to make line voltage measurements.

b) *Exposure Measurements:* The investigator can first document stray voltage measurements at several locations within the marina/dock area. Documenting measurements under these conditions may provide an indication of existing internal structural and electrical bonding. An effort should be made to stabilize load while measurements are being made. A 120-V, 1.2-kW test load, such as a hair dryer may be used to help accomplish this. All measurements at swimmer accessible locations should be made with and without a shunt resistor.

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

   These measurements are used to select the stray voltage recorder set-up location. The preference is to set up the contact channel of the recorder at the location where the stray voltage during the spot check is the highest. Conductive non-metallic contact areas should be clean and kept wet throughout the period of testing by placing a paper towel saturated with a salt-water solution under the plate. This will minimize contact resistance and helps to establish a worst case exposure scenario during the recording period.

c) *Source Resistance Measurements:* Source resistance can be determined by performing two stray voltage measurements. Making certain that the contact resistance of the meter connections is minimized; compare the voltage measured without a shunt resistor to the voltage measured with a 500-Ω meter shunt. If there is a significant (50%) reduction in voltage measured with the shunt, it may be an indication of inadequate structural/ electrical bonding or a high resistance dock contact. The investigator may need to choose another location or temporarily improve bonding before choosing this location to set the stray voltage recorder. If another location is chosen for the recorder, a source resistance assessment can be made at the new location.

d) *Establish Qualified Reference:* Determine an acceptable location and install a remote reference ground rod. If possible the ground rod should be installed in moist soil 30 m (i.e., ~100 ft) or more from the dock or boatlift and any conductive underground structures such as water pipes, well casings, building grounds, etc. Make primary neutral to remote reference and secondary neutral to remote reference voltage measurements with and without a 500-**Ω** shunt resistor. If there is a significant (50%) change in measured voltage an attempt can be made to reduce the ground resistance of the qualified reference before proceeding. However, too low of a ground resistance may be an indication that the rod is too close to underground facilities connected to the neutral/ground network.

   The above procedure will help ensure that an adequate isolated reference ground has been established. The location of the qualified reference can be documented on the layout sketch for later reference.

e) *Stray Voltage Recorder Connections:* Care should be taken to avoid creating additional hazards when placing the monitoring device such as using cable protection troughs where cords and leads cross walk ways and ground fault-circuit interrupters when powering equipment.

   1) The principal voltage recording is to be made at the predetermined swimmer accessible location. The user selected shunt resistor is placed across the channel measuring the voltage between the exposure points using a connection method that will remain reliable during the entire monitoring period. Hose clamps can be used to connect meter leads to metal railings and copper plates can be placed onto the dock surface and held down with a weight. Where concrete decking is encountered the plate and deck can be kept wet by covering with a layer of plastic sheeting.

   2) A second recording channel can be installed to record secondary NEV between the secondary ground bar at the service entrance and the qualified reference previously established.

   3) A third recording channel can be installed to record voltage between the primary neutral (primary neutral ground lead at the utility transformer) and the qualified reference previously established. If required, the primary NEV level recorded during the period of maximum stray voltage can later be estimated or artificially recreated with all load off in order to determine maximum primary neutral contribution to swimmer accessible stray voltage.

   4) The fourth recording channel can be set up to monitor the difference in voltage between the connection at the transformer (i.e., primary neutral connection) and the connection in the service entrance panel (i.e., the secondary ground bar connection). This will provide an indication of voltage drop in the main service neutral conductor.

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

f) *Equipment Signature:* Set the recorder for a 1 s or higher data recording or storage rate, and start recording the voltage at the monitored points. As much as possible, this test should be conducted with minimal other electrical load operating and/or switching on and off. Identify and momentarily energize individual loads (boat lifts, lights, etc.) while monitoring the voltmeter or recorder for abnormal readings. The equipment location, type of equipment and on/off times can be recorded by the investigator. If a significant facility equipment or wiring problem is found (e.g., defective equipment or high resistance neutral) and it cannot be immediately repaired, the facility owner should be urged to temporarily disconnect the equipment. The investigator can document all abnormalities.

g) *System Assessment (Load Box Test):* An assessment of the distribution system neutral and its ability to contribute to stray voltage levels can be made using 240-V single-phase loads and/or a single-phase 240-V load box (multi-stage load box preferred). The use of 240-V load (all 120-V loads off) results in primary neutral current flow and increases the contribution from primary neutral stray voltage sources with minimal impact from the secondary neutral and its potential stray voltage sources[12].

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

Starting with all load turned off (120 V and 240 V, single phase and three phase), measure and record the current in the primary neutral conductor (both directions if necessary), the net secondary neutral current on the service(s) from the transformer (the current measured simultaneously on the line and neutral conductors as a bundle), and the primary neutral ground lead current at the transformer. Additionally, using the previously established remote reference, measure and record primary NEV, secondary NEV, the voltage difference between the transformer ground and the service entrance panel ground/neutral bar (the "secondary neutral"), and the stray voltage at the swimmer accessible location. (These voltages may be monitored by the electronic recorder.) The resistance of the grounds at the pole can also be measured at this time.

As rapidly as possible, energize the first stage of the 240-V load box to create 240-V load, and measure/record the same voltages and currents. These measurements can be repeated and documented in a "Load Box Test" section of an investigation form for each of the 240-V pieces of equipment or load box stages energized[13].

After all of the 240-V equipment or load box stages are operating, and while still energized, turn the service on. In addition to the other current and voltage measurements made when only the load box was operating, record the amount of current in both (or all) of the energized service conductors and the secondary neutral conductor. Finally, the load boxes are turned off and the same voltages and currents can again be measured with the service on.

At those locations where primary NEV levels appear to be abnormal, distribution system repair or modification, and/or isolation may be necessary prior to additional testing. For most three-phase transformer connections, three-phase loads will not generate current in the primary neutral and are not suitable for use in conducting a load box test. Where a marina or boat dock is served solely from a three-phase service, other measures may have to be used to generate current on the primary neutral, such as applying the load at a neighboring transformer. Load box testing cannot be adequately performed at all locations.

h) *Secondary Neutral Voltage Drop:* The purpose of this test is to determine the effect of secondary neutral voltage drop on stray voltage levels. A 120-V test load is operated at the load end of the service and each feeder, and a measurement is made of the voltage drop on the secondary neutral conductor caused by that load. In the case of a marina the facility wiring examined should include the service drop from the transformer to the facility's main electrical service equipment, and then individually all of the feeders from that distribution point to the various docks/vessels. This may include numerous segments of wire of varying size and material, connections, and segments that may extend past and through the various docking facilities.

Although the ideal would be to do this test with all marina loads off, it is acceptable to conduct the test with other loads operating and note the change, or step in voltage between when the load is turned on and when it is turned off[14]. A 1.2-kW or larger load bank, such as 120-V hairdryer with two heat settings, is ideal for use as the test load. The preset stray voltage recorder may again be used to assist in capturing data.

To conduct the test, the test load should be energized at the dock being served by the service drop under consideration. Record in a "Voltage Drop" section of an investigation form the test load current magnitude and the change in voltage drop between the equipment ground bar (for a three wire service this may be the neutral bar) at the individual dock panel and the ground at the central distribution point. Simultaneous to measuring the change in voltage drop, measurement should be made of the change in ground bar to earth voltage at the test dock and NEV at the source end (e.g., the main distribution point

[13]Artificial system loading should not exceed the equipment rating if the load is applied through building switches and equipment. (An analysis of circuitry and equipment, and/or a method of monitoring current at critical locations may be required).

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

to the qualified reference, and from the “dock under test” panel ground bar to the qualified reference). Additionally, the change in the voltage at the swimmer accessible location (i.e., stray voltage), and the voltage change at all other measurement points monitored by the voltage recorder can be documented along with the time of each test. These voltage measurements may be taken from the preset recorder or a separate voltmeter(s) may be used.

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

Calculate the approximate anticipated voltage drop using the resistance values for that wire size and material. If there is an indication that secondary neutral or B-phase voltage drop may be a concern (higher than anticipated readings coupled with lengthy and/or small conductors, numerous split bolt connectors, etc.), the investigator may perform additional tests and/or make recommendations to the facility owner regarding necessary secondary system modifications.

i) *Primary Profile:* In a “Primary Profile Test” section of an investigation form record the ground current and ground resistance of each of several primary neutral grounds distributed on either side of the location being investigated. The greater the physical distance over which this is accomplished, the better the chance of identifying neutral conductor abnormalities and un-cleared secondary faults. Calculate, using Ohm’s Law, the primary NEV at each ground location. In a comments section of an investigation form annotate the condition at each location such as the type of equipment present and the proximity of telephone and cable pedestals.

j) *24-Hour Recording:* Before leaving the marina/dock location, slow the sampling rate of the recorder(s) to ensure that there is sufficient storage capacity to record voltages for the remainder of time the recorder will be left to monitor voltage levels. The facility owner can be provided a log sheet to record the operation of lighting and other electrical loads to be used later during the analysis of the collected data. Allow the recorder(s) to operate for at least a 24-h period

E.5 Analysis of collected data

The recorded data can be carefully analyzed to identify trends such as operation of boat lift equipment or outdoor lighting that may point to ground faults that may not have been identified while on site. An event log filled out by the facility owner identifying operation of these loads is essential for this analysis. Trends may also closely follow the profile of the area loading, indicating a possible contribution from a primary neutral source. The utility may need to perform additional tests to determine the integrity of the primary neutral and its ability to contribute to stray voltage at the marina or dock being investigated.

In some cases monitoring of the neutral current at multiple points along the feeder may be necessary to aid in determining whether load unbalances are contributing to increased neutral current. Monitoring of the voltage at the marina/dock should be performed simultaneously with the primary system monitoring whenever possible to help to correlate the data collected.

The effect of each change/repair to either the customer or utility electrical system can be documented with additional monitoring to help ensure effective resolution of the concern. Considerations can be made to changing load conditions throughout the year and, wherever possible, follow-up measurements can be performed when system loading levels will be similar to those present when the problems were first experienced.

Resolution of the stray voltage concern does not necessarily require that the existing utility voltage contribution be lowered. Voltage at swimmer accessible locations may be reduced by premises wiring changes such as grounding improvements or the installation of additional bonding. In many cases a combination of utility and premises wiring improvements may be required. Mitigation methods are covered in 6.6 of this guide.

Annex F

(informative)

Confined livestock stray voltage investigation forms

CONFINED LIVESTOCK INVESTIGATION

Identification

The investigator need only perform tests and record results sufficient to resolve the stray voltage concern. As a result, various portions of this report may intentionally be left blank.

Date of Investigation: ______________________ Region: ______________

Farm Name: ______________________ Township: ______________

Customer Name(s): ____

Farm Address: ______________________ County: ______________

Mailing Address: ______________ City & State ______________ ZIP: ________

Phone #: ______________ Phone # (Alt.): ______________

Phone Co.: ______________ Cable Co.: ______________

Electrical Contractor: ______________ Electrician's Name: ______________

NATURE OF INVESTIGATION

☐ Advisory Investigation or isolator re-evaluation only. Customer not currently experiencing production or herd health problems.

☐ Response to customer concern that stray voltage may currently be affecting production and/or herd health.

☐ Other ____

Lead Investigator: ______________________

Others: ______________________

Service Center: ______________________

Report Prepared By: ______________________

Figure F.1—Identification

CONFINED LIVESTOCK INVESTIGATION

Case History

Cows Milking: ________ R.H.A.________ S.C.C. ________ DHI OTHER NONE (CIRCLE ONE)

Reason customer requests testing: ____________________

What effects on the herd does customer believe this has? ____________________

When was condition first observed and by whom? ____________________

What was done about it? ____________________

Were any other changes made around the time first observed? ____________________

Other concerns: ____________________

	Y/N	Describe:
Any electrical difficulties?	_____	____________________
Any lightning damage?	_____	____________________
Do all animals react?	_____	____________________
Do animals avoid any areas?	_____	____________________
Does weather have an effect?	_____	____________________
Did farmer, electrician or others take any measurement?	_____	____________________

Common well (y/n)? _____

Well to tank	_____Metal	_____Plastic
Tank to house	_____Metal	_____Plastic
Tank to barn	_____Metal	_____Plastic

NOTES:

____

____

Figure F.2—Case history

CONFINED LIVESTOCK INVESTIGATION

Electric System

	XFMR #1	XFMR #2	XFMR #3	Total KVA
OH or UG	________	________	________	
XFMR KVA	________	________	________	________
Phase Configuration	________	________	________	
Equipment ID#	________	________	________	
Isolator (y/n)?	________	________	________	

End of line (y/n)? ________________

Feeder number ________________

Substation name ________________

Line distance to substation from which supplied ________________

Size and type of phase conductor on feeder serving the farm (at the tap) ________________

Size and type of neutral conductor on feeder serving the farm (at the tap) ________________

Phase configuration (at the tap) ________________

Primary voltage ________________

ON FARM CONDITIONS (AS FOUND)	**Y/N**
Cows milked in stanchion or tie-stalls?	____
Pipeline milking system?	____
Electronic pulsation?	____
Equipotential plane?	____
Four-wire system?	____
Active suppression device (EGS)?	____
Isolation transformer?	____
Fencer/Trainer OK?	____

Transmission System Conditions (As Found)	**Y/N**
Transmission Line within 1 mile of Farm	____
Transmission Line in Same Corridor with Distribution	____
Transmission Line Voltage	____

NOTES:

____

____

____

____

Figure F.3—Electric system

CONFINED LIVESTOCK INVESTIGATION

Tailgate

Job Description: ☐ **Load Box Test**

☐ **Other** ______________________________

☐ **The scope of the work to be performed**

☐ **Hazards that may be encountered**

☐ **Safe practices for doing the work and the responsibilities of those involved**

☐ **Special precautions** ______________________________

☐ **Energy source controls** ______________________________

Personal Protective Equipment

☐ Hard Hat	☐ Face Shield	☐ Respirator
☐ Safety Glasses	☐ Gloves / Sleeves	☐ Foot Protection
☐ Hearing Protection	☐ Clothing (FRC)	
☐ Goggles		
☐ Other		

Comments / Concerns: ______________________________

____

Troubleshooter: ______________________________

Crew Members: ______________________________

____

____

____

____

Figure F.4—Tailgate

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

Spot Checks

METER CHECK: ____________ **SHUNT RESISTOR** ____________ **LEADS OK?**

BARN/PARLOR SKETCH

VOLTAGE (Volts unless otherwise noted)

FROM	TO		#1	#2	#3	#4	#5	#6	#7	#8
A		w								
Waterline to floor		w/o								
B		w								
Stall metal to floor		w/o								
C		w								
Milkline to floor		w/o								
Stall Number (ex. 10 East)										

SETUP AT MEASUREMENT LOCATION **NOTES:** ____________

_________ (1-8) _________ (A-C) ____________

☐ Setup location at customer's request

PRE-TEST SOURCE RESISTANCE

	W Res.	W/O Res.	
Primary Neutral to Reference Voltage	______	______	______ Calc'd Res.
Secondary Neutral to Reference Voltage	______	______	______ Calc'd Res.
Cow Contact Voltage	______	______	______ Source Res.

BONDING

	WATERLINE TO SEC NEU.	WATERLINE TO REF. ROD	SEC NEU. REF. ROD		
Pre-Bond	______	______	______	Bonding Required (y/n)?	______
	______	______	______		
Post-Bond	______	______	______	Bonded For Test (y/n)?	______
	______	______	______		

Post-Bonded Vcc AC ____________ w ____________ w/o **Source resistance** ______

Post-Bonded Vcc DC ____________ w ____________ w/o

Figure F.5—Spot checks

CONFINED LIVESTOCK INVESTIGATION

Sketch

Indicate location of all stock waterers, feed bunks, panels, fencers, trainers, wells, the location of the driven reference rod, the length and sizes of service drops and the panel to which you are bonded.

Figure F.6—Sketch

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

Voltage Drop Test

LOCATION				
TIME	LOAD ON:	LOAD OFF:	LOAD ON:	LOAD OFF:
LOAD		Thru Zero?		Thru Zero?
PRI-REF				
SEC-REF				
PRI-SEC				
VCC				
SRC-REF				
LOAD-REF				
SRC-LOAD				

Δ Vcc_______________ Meas'd Vdrop ____________ Δ Vcc_______________ Meas'd Vdrop ____________

LOCATION				
TIME	LOAD ON:	LOAD OFF:	LOAD ON:	LOAD OFF:
LOAD		Thru Zero?		Thru Zero?
PRI-REF				
SEC-REF				
PRI-SEC				
VCC				
SRC-REF				
LOAD-REF				
SRC-LOAD				

Δ Vcc_______________ Meas'd Vdrop ____________ Δ Vcc_______________ Meas'd Vdrop ____________

LOCATION				
TIME	LOAD ON:	LOAD OFF:	LOAD ON:	LOAD OFF:
LOAD		Thru Zero?		Thru Zero?
PRI-REF				
SEC-REF				
PRI-SEC				
VCC				
SRC-REF				
LOAD-REF				
SRC-LOAD				

Δ Vcc_______________ Meas'd Vdrop ____________ Δ Vcc_______________ Meas'd Vdrop ____________

NOTES: ____

Figure F.7—Voltage drop test

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

Signature Test

	LOCATION	TYPE OF LOAD	TIME ON	TIME OFF	REV?
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

NOTES: ____

____

____

Figure F.8—Signature test

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

Load Box Test

Load #1 ________________ **Off @** ________________ **On @** ________________ **Shooter:**
Load #2 ________________ **Off @** ________________ **On @** ________________
Load #3 ________________ **Off @** ________________ **On @** ________________ ________________

	SERVICES OFF	LOAD BOX 1 ON	LOAD BOX 1+2 ON	LOAD BOX 1+2+3 ON	SERVICES ON LB'S ON	LB'S OFF
TIMES -->	(NOTE TIME ABOVE)				(NOTE TIME ABOVE)	
Pri Crnt (up)						
Pri Crnt (dn)						
Pri Neu (up)						
Pri Neu (dn)						
Sec Neu Net 1						
Sec Neu Net 2						
Sec Neu Net 3						
Load Box						
Pri Gnd Crnt						
Sec Gnd Crnt						
Pri Gnd Res						
Sec Gnd Res						
Sec Neu 1						
Phase 1						
Phase 2						
Sec Neu 2						
Phase 1						
Phase 2						
Sec Neu 3						
Phase 1						
Phase 2						
Vp-ref						
Vs-ref						
Vp-s						
Vcc						

ISOLATOR JUMPERED OUT @ ________________ **ISOLATOR ACTIVATED @** ________________

Figure F.9—Load box test

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

Waterer & Bunk Feeder Test

Draw a simple sketch of the farm, indicating the locations of the waterers and bunk feeder(s), numbering each location.

Measurements taken during which test: ☐ Sig ☐ Load Box ☐ Vdrop ☐ 24Hr

$V_{PANEL\text{-}REF}$ ___________
(Prior to testing)

$V_{PANEL\text{-}REF}$ ___________
(After to testing)

LOC. #	VOLTAGE with	VOLTAGE w/o	TIME	LOC. #	VOLTAGE with	VOLTAGE w/o	TIME
1				11			
2				12			
3				13			
4				14			
5				15			
6				16			
7				17			
8				18			
9				19			
10				20			

Figure F.10—Waterer & bunk feeder test

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

Primary Profile Test

	POLE #	POLE GND CURRENT (A)	POLE GND RESISTANCE	POLE GND VOLTAGE (V)	COMMENTS
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

________ *Number of grounds within the first mile toward the substation*

NOTES: ______________________________

____

____

Figure F.11—Primary profile test

Farm isolated for this portion of the testing? _____(Y/N)

CONFINED LIVESTOCK INVESTIGATION

End Of Test Info

POST-TEST SOURCE RESISTANCE

___________ **SHUNT RESISTOR**

	VOLTAGE W Res.	*VOLTAGE* W/O Res.		
Primary Neutral to Reference Voltage	________	________	________	**Calc'd Res.**
Secondary Neutral to Reference Voltage	________	________	________	**Calc'd Res.**
Cow Contact Voltage	________	________	________	**Source Res.**

Date Recorder Installed: ____________________ **Date Recorder Removed:** ____________________

Weather Conditions For Overnight Testing: ____
(wind, rain, lightning, etc)

Recorder Type ____________________________________ **Recorder Serial #** ______________

Max Cow Contact Info:
(At time of max. Vcc)

Vcc max ____________

Vp-ref ____________

Vs-ref ____________

Date ____________

Time ____________

SVM Recorder Channel Setup Information

CH1 ____________________ **to** ____________________

CH2 ____________________ **to** ____________________

CH3 ____________________ **to** ____________________

CH4 ____________________ **to** ____________________

Figure F.12—End of test info

CONFINED LIVESTOCK INVESTIGATION

Coments

NOTES:

Figure F.13—Comments

Annex G

(informative)

Bibliography

Bibliographical references are resources that provide additional or helpful material but do not need to be understood or used to implement this standard. Reference to these resources is made for informational use only.

[B1] 33 CFR Part 183, Subpart I—Electrical Systems.[15]

[B2] ABYC E-11, AC & DC Electrical Systems on Boats.[16]

[B3] ASAE EP473, 2 2001 (R2011), "Equipotential Plane in Livestock Containment Areas," American Society of Agricultural and Biological Engineers Standard.

[B4] Consumer Product Safety Commission, "Don't Swim with Shocks—CPSC, American Red Cross Warn of Electrocutions in Swimming Pools, Hot Tubs, and Spas, May 2003[17]

[B5] Dalziel, C., "Dangerous electrical currents," Transactions of the American Institute of Electrical Engineers, vol. 65, no. 12, pp. 1123–1124, 1946. [Available at: and], http://dx.doi.org/10.1109/T-AIEE.1946.6464964[18,19]

[B6] Dalziel, C., "Effect of electric shock on man," IRE Transactions on Medical Electronics, vol. PGME-5, pp. 44–62, July 1956. Available at:, http://dx.doi.org/10.1109/IRET-ME.1956.5008573

[B7] Dalziel, C., "Electric shock hazard," IEEE Spectrum, vol. 9, no. 2, pp. 41–50, February 1972. Available at:, http://dx.doi.org/10.1109/MSPEC.1972.5218692

[B8] Dalziel, C. and W. Lee, "Lethal electric currents," IEEE Spectrum, vol. 6, no. 2, pp. 44–50, Feb. 1969, pp. 44–50, http://dx.doi.org/10.1109/MSPEC.1969.5213962.

[B9] Dalziel, C. and W. Lee, "Reevaluation of lethal electric currents," *IEEE Transactions on Industry and General Applications*, vol. IGA-4, no. 5, pp. 467–476, September/October 1968, http://dx.doi.org/10.1109/TIGA.1968.4180929.

[B10] Dalziel, C. and F. Masogilia, "Let-go currents and voltages," Transactions of the American Institute of Electrical Engineers, Part II: Applications and Industry, vol. 75, no. 2, pp. 49–56, 1956.

[B11] Dorr, D., S. Martino, and S. Hanebuth, "Using harmonic measurements to aid in source determination during elevated voltage investigations," in IEEE/PES General Meeting, Vancouver, Canada, 2013, http://dx.doi.org/10.1109/PESMG.2013.6672136.

[B12] Duvaux-Ponter, C., S. Roussel, and F. Deschamps, "Determination of a stray voltage threshold leading to aversion in sheep," in Proceedings of the 39th Annual Conference of the ISAE, Sagamihara, Japan, 2005.

[15]CFR standards are available at: http://www.ecfr.gov/cgi-bin/text-idx?c=ecfr&tpl=/ecfrbrowse/Title33/33cfr183_main_02.tpl
[16]ABYC standards are available at: http://abycinc.org/?page=StandardsIndex
[17]Available at: http://www.cpsc.gov/en/Newsroom/News-Releases/2003/Dont-Swim-With-Shocks---CPSC-American-Red-Cross-Warn-of-Electrocutions-in-Swimming-Pools-Hot-Tubs-and-Spas/
[18]The IEEE standards or products referred to in this clause are trademarks of The Institute of Electrical and Electronics Engineers, Inc.
[19]IEEE publications are available from The Institute of Electrical and Electronics Engineers, 445 Hoes Lane, Piscataway, NJ 08854, USA (http://standards.ieee.org/).

[B13] Duvaux-Ponter, C., S. Roussel, M. Ennifar, F. Fortin, and T. Louyot, “It is possible to define the aversiveness threshold of stray voltage when animals are allowed to avoid it,” in Proceedings of the 40th International Congress of the ISAE, Bristol, UK, 2006.

[B14] EPRI, “Guidebook for Evaluating Elevated Neutral-to Earth and Contact Voltage in Distribution Systems, Part 1: Swimming Pools, Water Bodies, and other Wet Areas,” Dec. 2010.[20]

[B15] EPRI, “Stray and Contact Voltage Advancements in Measurement and Diagnostics,” Dec. 2011.

[B16] Fire Protection Research Foundation (FPRF), “Evaluation of ‘Alternate Equipotential Bonding Means’ to Reduce Voltage Gradients In Pool Areas,” October 2011 (revised December 2011).[21]

[B17] Geddes, L. and L. Baker, “Response of passage of electric current through the body,” Journal of the Association for the Advancement of Medical Instrumentation, February, pp. 13–18, 1971.

[B18] Geiges, K., “Electric shock hazard analysis,” Transactions of the American Institute of Electrical Engineers, vol. 75, no. 3, pp. 1329–1331, 1956.

[B19] Godcharles, L., S. Robert, J. Matte, J. Bertin-Mahieux, and G. Marineau, “Transient stray voltage: Is it detrimental to growth performance health status and welfare of market pigs?” Veterinary Research Communications, vol. 17, no. 1, pp. 41–53, 1993. Available at:http://dx.doi.org/10.1007/BF01839179[22]

[B20] The Ground-Fault Circuit-Interrupter Protection Journey—Applying the Code, National Fire Protection Association, 2014.[23]

[B21] Gustafson, R., R. Appleman, and T. Brennan, “Electrical Current Sensitivity of Growing/Finishing Swine for Drinking,” Transactions of the ASAE. American Society of Agricultural Engineers, vol. 29, no. 2, pp. 592–596, 1986. Available at:http://dx.doi.org/10.13031/2013.30195[24]

[B22] Gustafson, R., “Instrumentation for Stray Voltage” Proceedings of the National Stray Voltage Symposium, Syracuse, NY Oct 10–12, 1984.

[B23] Hammam, M. and R. Baishiki, “A range of body impedance values for low voltage, low source impedance systems of 60 Hz,” IEEE Transactions on Power Apparatus and Systems, vol. PAS-102, no. 5, pp. 1097–1105, May 1983. Available at:, http://dx.doi.org/10.1109/TPAS.1983.318050

[B24] Harris, T., “How Swimming Pools Work,” Website Article: http://home.howstuffworks.com/swimming-pool1.htm.

[B25] Herzig, B., “The Danger of Voltage Gradients in the Aquatics Environment,” IAEI Magazine, Nov.–Dec. 2002. Available at: http://iaeimagazine.org/magazine/2002/11/16/the-danger-of-voltage-gradients-in-the-aquatics-environment/.

[B26] ASA Pool & Recreational Shotcrete Committee, “Position Statement #2, Definitions of Key Shotcrete Terminology,” Shotcrete, vol. 15, no. 3, p. 29, Summer 2012.

[B27] IEEE Std 80-2013, IEEE Guide for Safety in AC Substation Grounding.

[20]EPRI publications are available at : http://www.epri.com/
[21]Fire Protection Research Foundation and NFPA publications are available at: http://www.nfpa.org/
[22]Spirnger publications are available at: http://link.springer.com/
[23]This NFPA article is available at: http://www.necconnect.org/resources/gfcis/
[24]ASABE publications are available at: http://elibrary.asabe.org/

[B28] Johnson, P., "Types of Swimming Pools." Available at: http://www.buzzle.com/articles/types-of-swimming-pools.html.

[B29] Kennedy, M., "A behavioral and physiological study of the response of inexperienced gilts to electric fencing.," in Proceedings of the 29th International Congress of the ISAE, Exeter, UK, 1995.

[B30] Kiselev, "Research into electric shock," Electrical Review, vol. 31, December 1965.

[B31] Lee, W., "Deaths from electric shock in 1962 and 1963," British Medical Journal, vol. 2, pp. 616–619, September 1965. Available at:http://dx.doi.org/10.1136/bmj.2.5462.616[25]

[B32] Matte, J., S. Robert, L. Godcharles, J. Bertin-Mahieux, and G. Marineau, "Factors affecting the electrical impedance of growing-finishing pigs," Canadian Agricultural Engineering, vol. 34, no. 2, pp. 189–194, 1992.[26]

[B33] NEETRAC, "Boat Dock Exposure Voltage Mitigation," IEEE PES Joint Technical Committee Meeting, Memphis, TN, January 13–17, 2013.

[B34] NEETRAC, "Evaluation of Ground Ring vs. Equipotential Mat at a Swimming Pool in Buford, Georgia," Project Number 08-132, Buford, GA, Nov. 2008. Available at: http://www.cmiwebsite.com/NEETRAC_08132_CMI_POOL_RP1.pdf.

[B35] New York State Public Service Commission, Electric Safety Standards, Annual Reports, Available at: http://www3.dps.ny.gov/W/PSCWeb.nsf/All/400E5FF8A07FEFC185257687006F38C8?OpenDocument.

[B36] NFPA 70-2014 National Electrical Code (NEC), 2014.

[B37] Osypka, P., Quantitative investigation of current strength and routing in AC electrocution accident involving human beings and animals, in *Technische Hochschule Braunschweig.* Brunswick, Germany, 1966.

[B38] Patel, S., "Exposure Voltages—Concerns, Analysis, and Mitigation," NEETRAC Project Number 04-159, Dec. 2008.

[B39] Reinemann, D., "Literature Review and Synthesis of Research Findings on the Impact of Stray Voltage on Farm Operations," March 31, 2008.

[B40] Report Filed Pursuant to 1/05/05 Order, Case 04-M-0159, Consolidated Edison Co. of NY, Inc., New York, NY, January 17, 2006. Available at: http://www3.dps.ny.gov.

[B41] Robert, S., J. Matte, and G.-P. Martineau, "Sensitivity of reproducing sows and suckling pigs to stray voltage," American Journal of Veterinary Research, vol. 57, no. 8, pp. 1245–1249, 1996. Available at: [27]

[B42] Robert, S., J. Matte, J. Bertin-Mahieux, and G.-P. Martineau, "Stray Voltage: Its influence on swine production during the fattening period," Canadian Journal of Animal Science, vol. 72, no. 3, pp. 467–475, 1992. Available at: http://dx.doi.org/10.4141/cjas92-059[28]

[B43] Thompson, G., "Shock threshold fixes appliance insulation resistance," Electrical World (Brisbane), vol. 101, pp. 793–795, June 1933.

[25]British Medical Journal publications are available at: http://www.bmj.com
[26]Canadian Society for Bioengineering publications are available at: http://csbe-scgab.ca/
[27]American Veterinary Medical Association publications are available at: http://avmajournals.avma.org/
[28]Canadian Sciece Publishing publications are available at: http://www.nrcresearchpress.com/

[B44] USDA, Effects of Electrical Voltage/Current on Farm Animals: How To Detect and Remedy Problems, Agriculture Hand-Book No. 696 ed., 1991.

Consensus

WE BUILD IT.

Connect with us on:

Facebook: https://www.facebook.com/ieeesa

Twitter: @ieeesa

LinkedIn: http://www.linkedin.com/groups/IEEESA-Official-IEEE-Standards-Association-1791118

IEEE-SA Standards Insight blog: http://standardsinsight.com

YouTube: IEEE-SA Channel

IEEE
standards.ieee.org
Phone: +1 732 981 0060 Fax: +1 732 562 1571