Perceptible Voltages at Human and Animal Contact Points

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Presentation Summary

- Contact Voltage Complaint Sources
- Background on prior ‘industry’ research
- EPRI Strategic Roadmap and Gap Analysis
- EPRI Research Program Summary
- Significant Industry Needs
- Human and Animal Response to Current
- Establishing Levels of Concern
- Contact Voltage due to Faults vs NEV – Is there a way to tell the difference?
- Summary

Useful references are included on the final slide

Contact Voltage Complaint Sources
EPRI PQ Hotline Calls 1994-2009

- Pipelines in transmission right of ways – **shock and spark** concerns
- Animal **contact area** concerns related to health and productivity impacts
- Residential outdoor water faucet **shocking concerns**
- **Distribution Harmonic** frequency **contact voltages** on gas lines
- **Tingling sensation** felt at a boat dock when dangling feet in water
- Questions about the impacts of power line carrier signals and other transient generating devices at animal **contact locations**
- **Tingling sensations** when exiting swimming pools
- Power circuit **harmonic resonance** conditions creating elevated NEV levels
- Different opinions on measurement equipment specifications, **measurement protocols,** measurement durations and **load resistors**
- **Shocking sensation** felt when **contacting** a residential metal door frame
- Same level of voltage causing **shock complaints** at one swimming pool, but not at a similar pool served by the same power source
- Urban contact voltage situations where **no repairable problem found**

Observations Related to the Hotline Questions

- The **"source" or "cause"** of the concern is not always the same
  - **Intentionally** grounded neutral conductors creating neutral to earth voltages (NEV)
  - **Unintentionally** induced voltages from current flowing in power conductors (magnetic coupling)
  - Faulted power conductors **unintentionally** energizing other objects
  - Faulty customer wiring **unintentionally** using Kirchoff's Current Law (KCL) to return to currents their source
  - **Intentional and unintentional** bonding issues at human and animal contact locations
  - **Intentional** current return paths creating voltage drop at a contact location

More Observations Related to the Hotline Questions

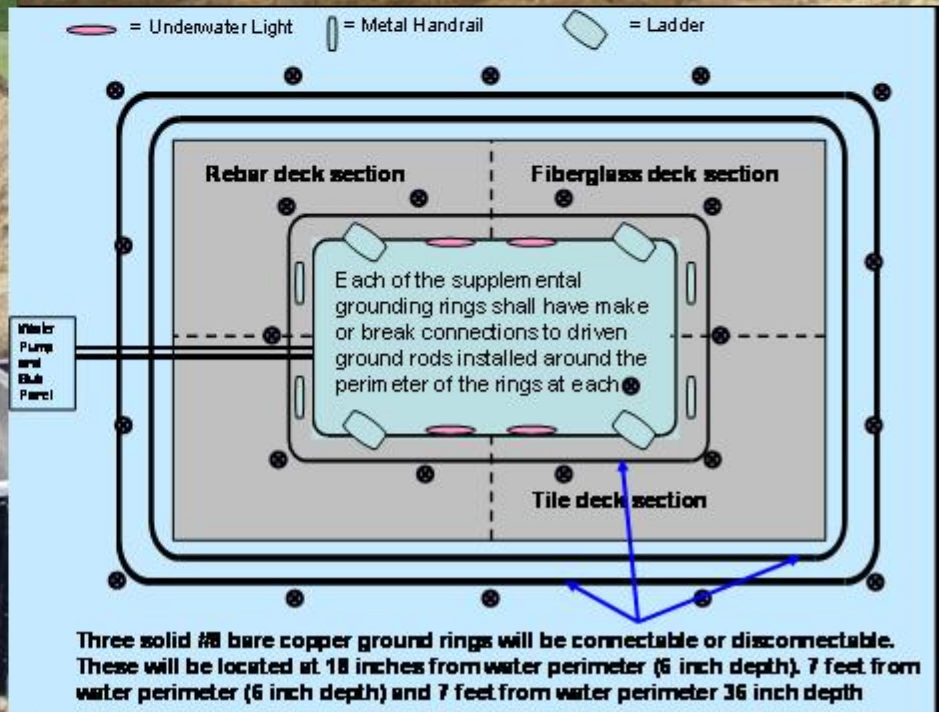
- The complaint is the same but the concern is not!
  - The **complaint** is almost always **contact** related:
    a) A human or animal simultaneously **contacting** two points (at different voltage potential) and creating the path for current to flow between those two points
    b) A measurement taken that could result in a potential **contact** complaint
  - The **concern** is either:
    a) A **nuisance concern** from a shocking or tingling sensation where current flows are relatively small and typically result in changes in behavioral patterns or in sensitivity to the sensation (can be dealt with over weeks or months)
    b) A human and animal **safety concern** where current flows may exceed published levels of concern (need to be remediated as soon as the source can be identified and acceptable mitigation options defined)

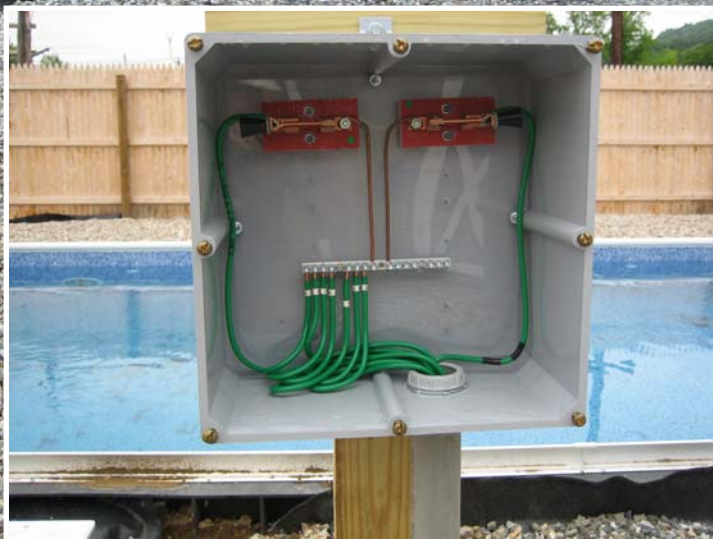
EPRI Stray Voltage (Contact Voltage) Research Roadmap – Program 128

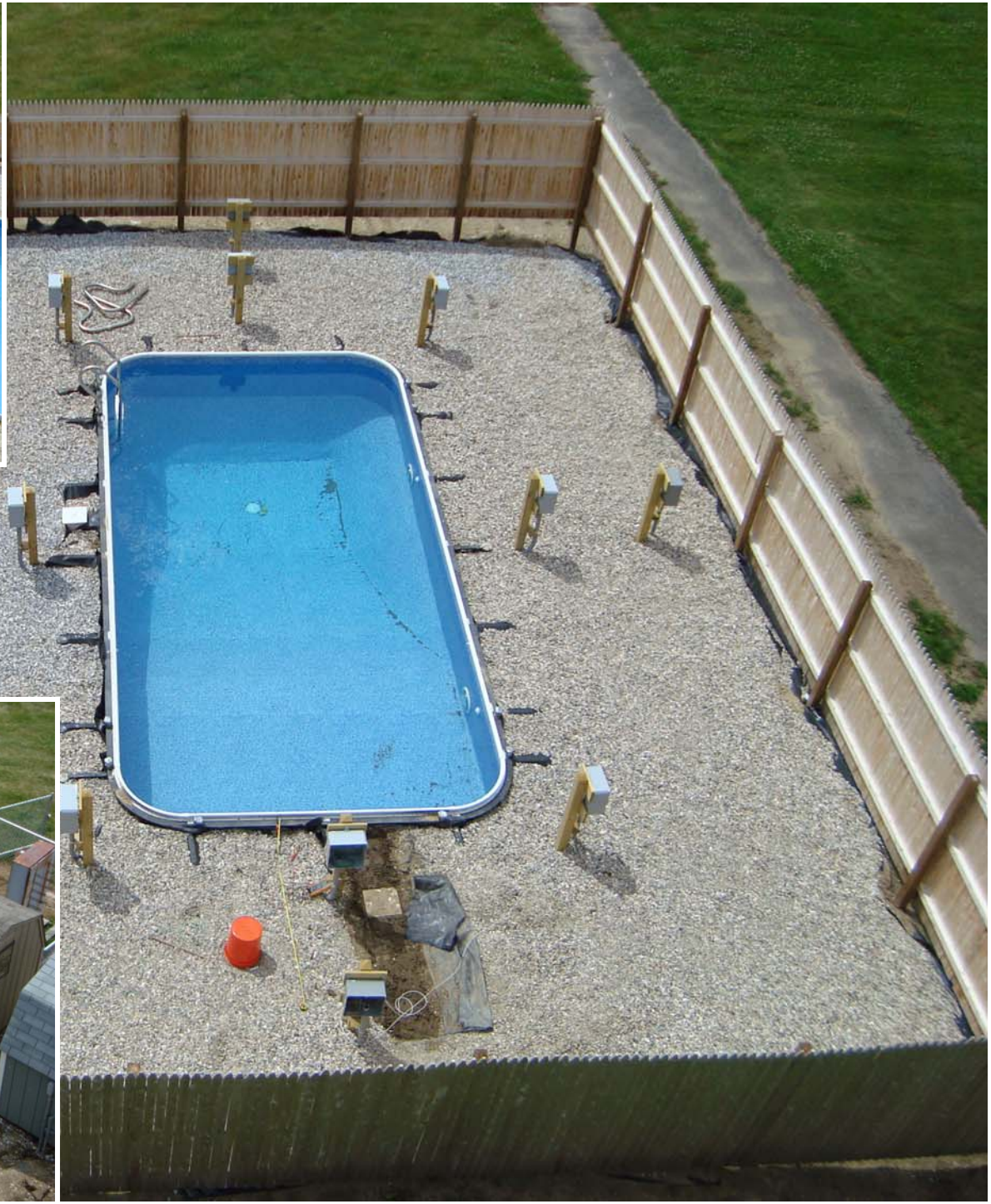
- The prioritized research plan identified five areas of opportunity where supplemental or new research was needed:
  1. Test and measurement protocols
  2. Modeling and simulation guidelines
  3. Test equipment and mitigation methods
  4. Technology transfer - Informational website
  5. Regulatory guidance (NEV and energized object identification and level of concern discussion)
- EPRI has conducted work in all of these areas between 2004 and 2009

Swimming Pool Testing to Be Conducted at the EPRI Lenox, MA Outdoor Test Facility

To support the project objectives, we have constructed a controllable test area at the Lenox, MA facility
Can vary: Distribution Configurations, Neutral impedances, grounding configurations, NEV sources....



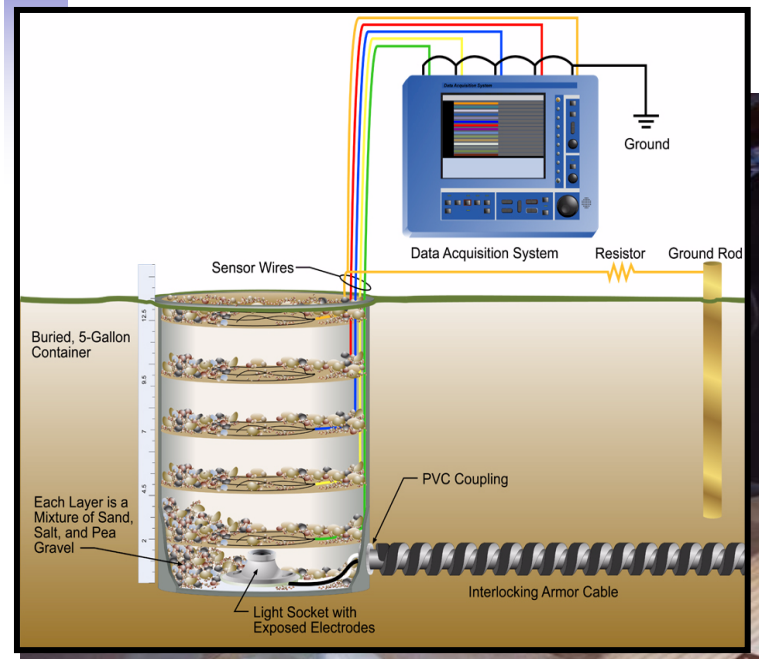


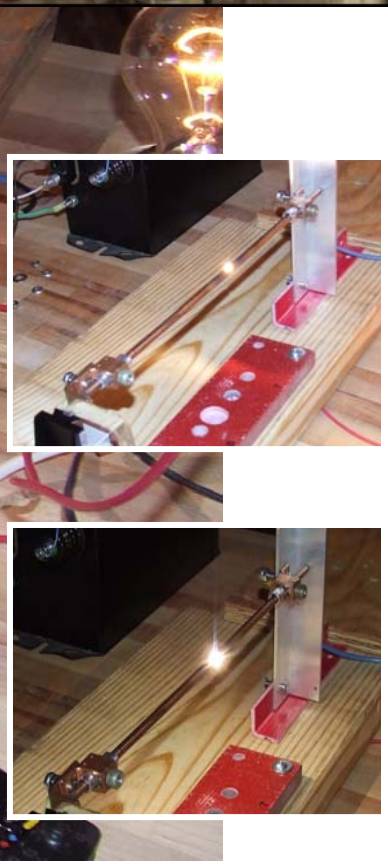


Significant Industry Needs

- **Better diagnostic tools to identify and repair contact voltage situations before they become a shock complaint**
- Industry group education and training
- Standardized measurement protocols (such as the IEEE P1695 working group's effort)
- Training on diagnostic tools that can distinguish between Voltage sources (source path) and current sources (return path)
- Better understanding of the wealth of literature, the biophysiological data and the electrical parameters that impact body current

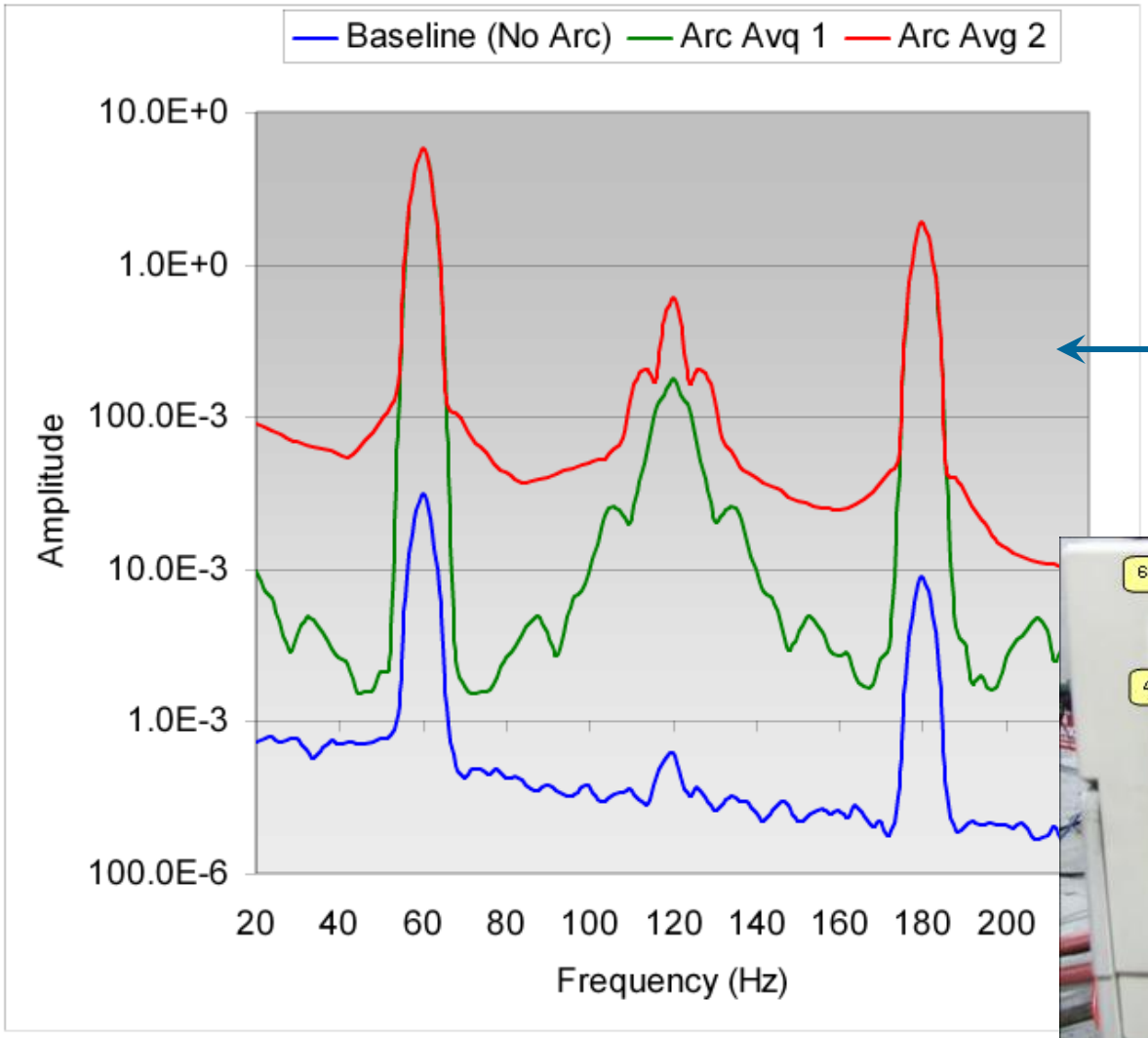
Arcing Sources Testing





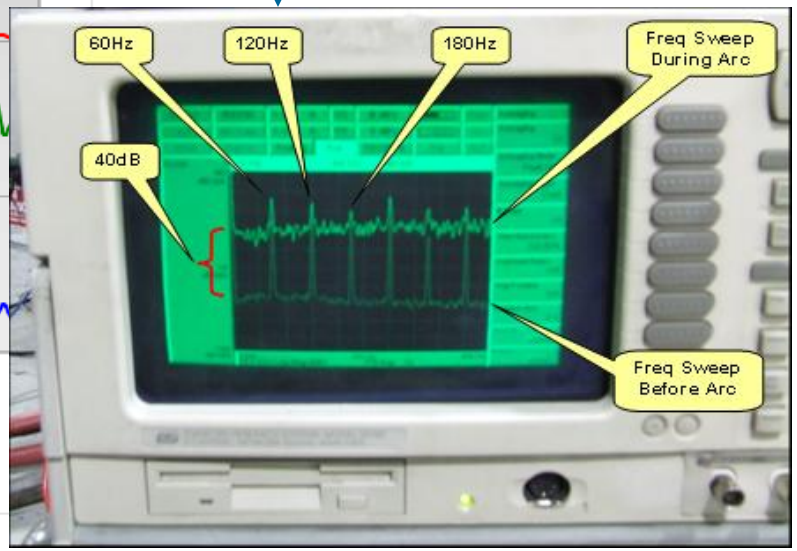
- Based on UL Arc Fault Breaker Test
- Stabilized Arc which allows for simplified measurements
- Waveform analysis provides clues for detection

If Arcing can be Detected Early, the Event Can be Mitigated Before it Becomes a Shock Concern



- Increase in signal level as voltage rises to surface
- Increase in wide band noise during recording of arcing

Compare FFT of arcing characteristics to the bench test.



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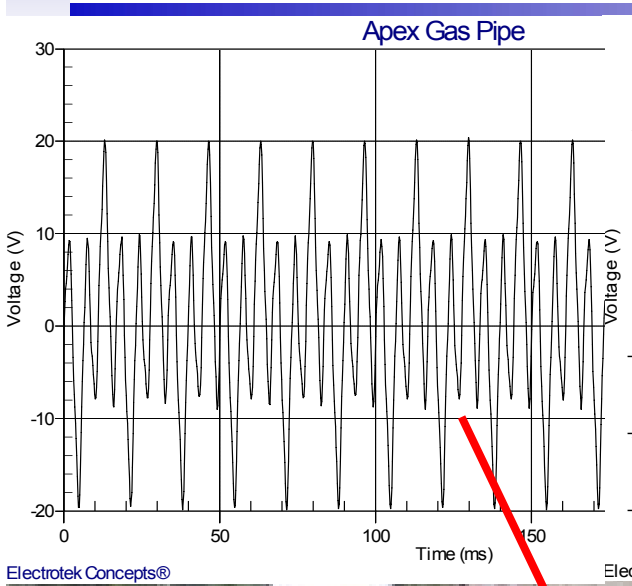
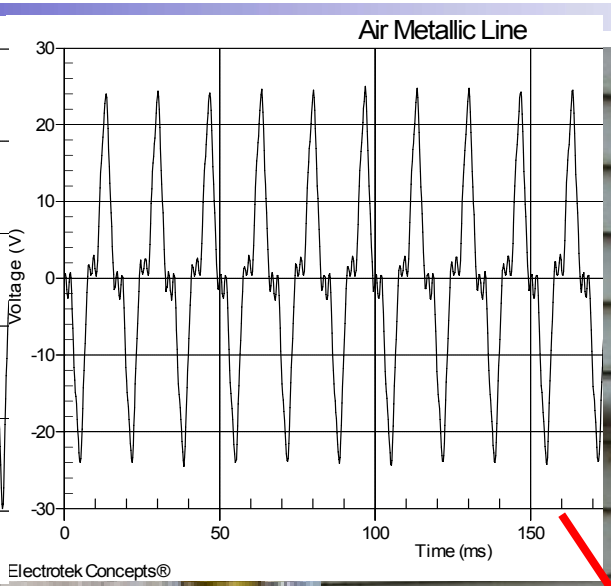
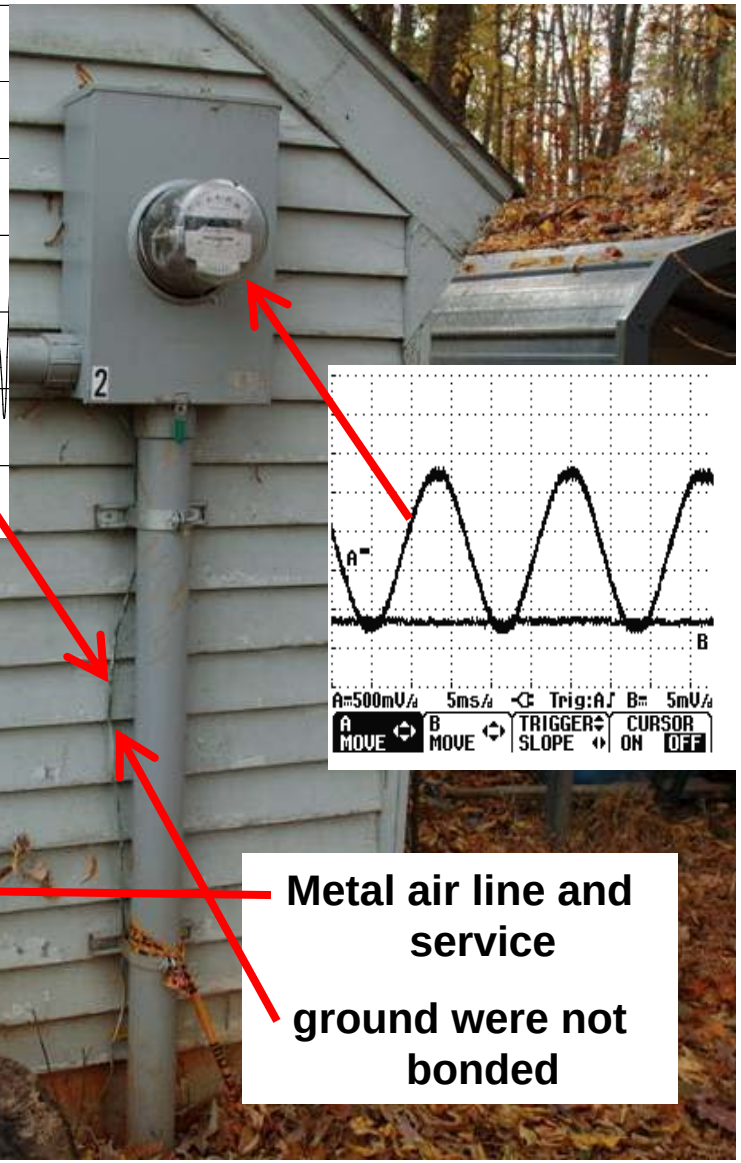
Contact Voltage – Faults vs Induced vs Neutral to Earth… Is there a way to tell the Difference?



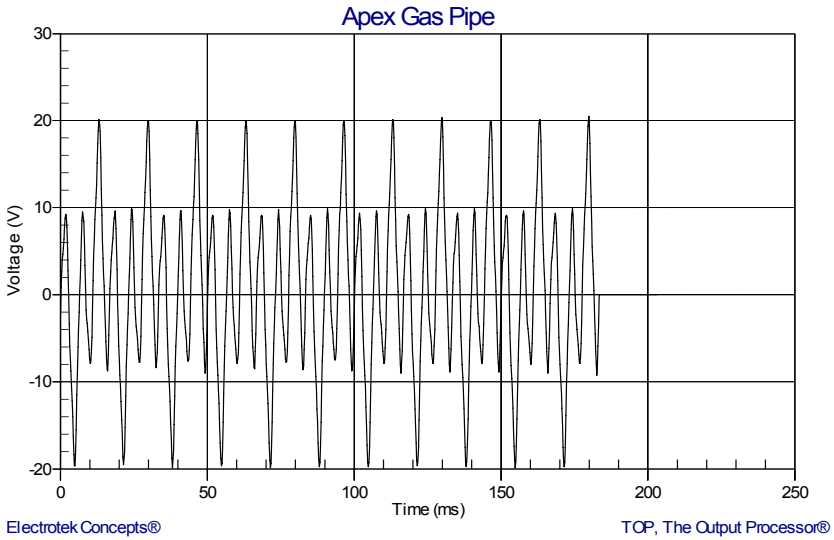


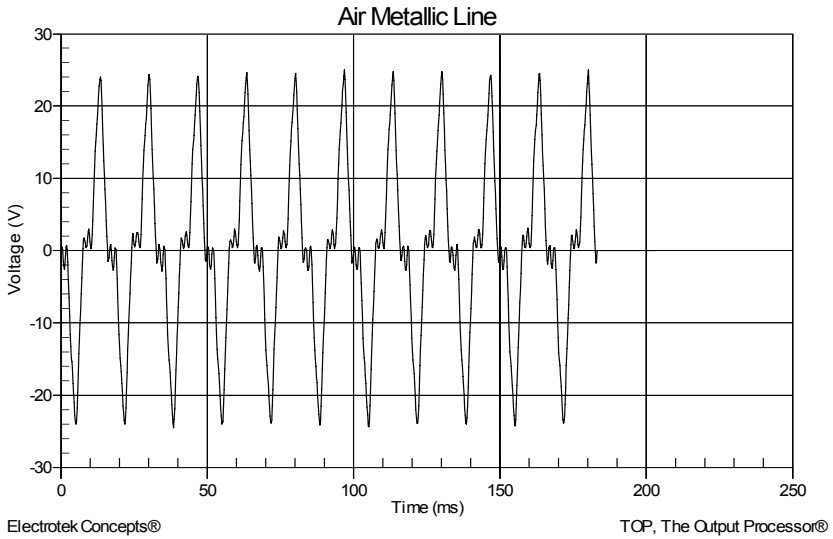


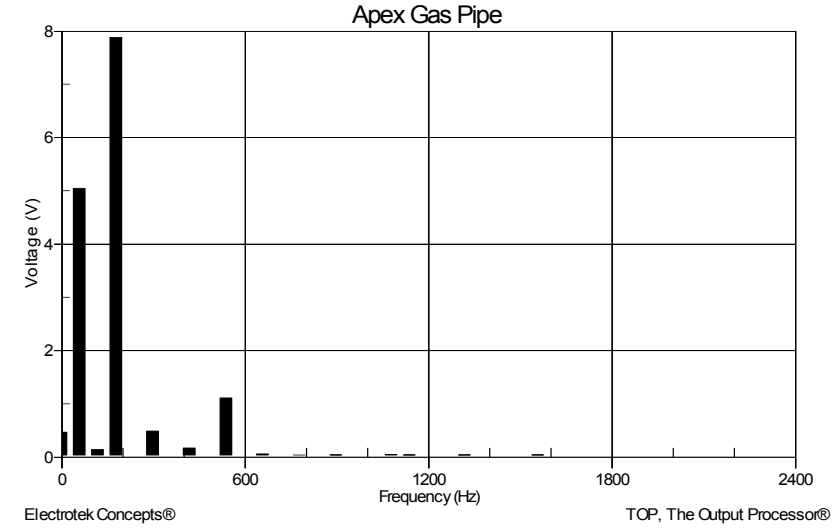
Metal air line and service

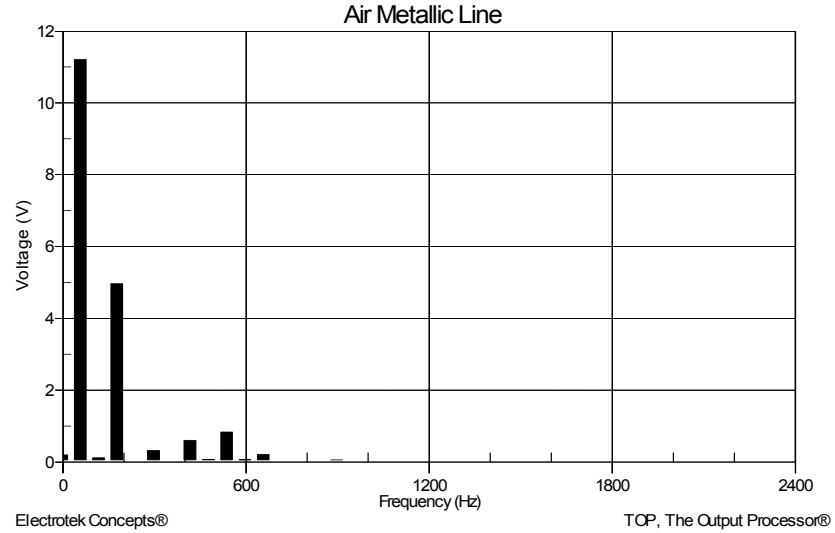
ground were not bonded

Measured RMS Voltages were Virtually Identical at Gas and Air Pipelines but Waveforms Were Not!



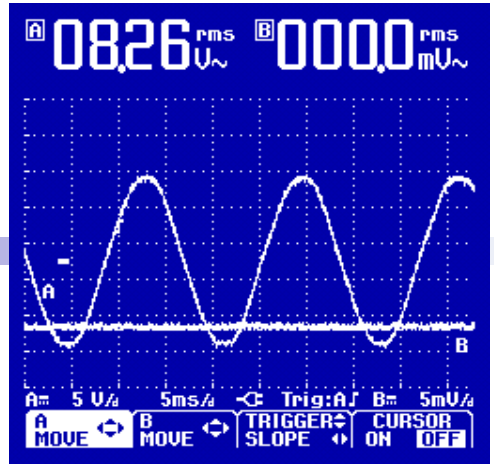


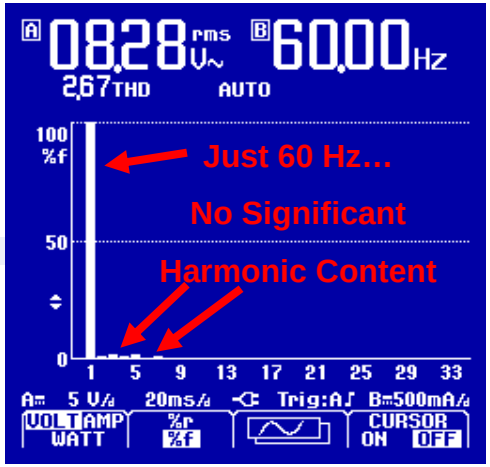


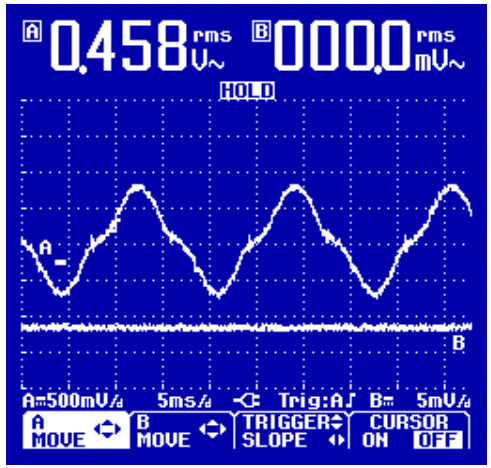


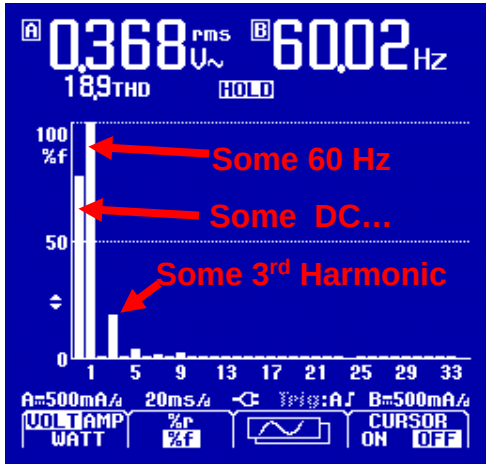
ScopeMeter Waveform Analysis Helps with Source Identification

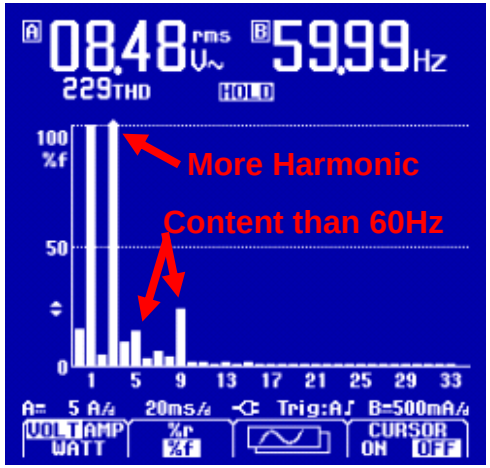
- 60 Hz Faulted Phase Conductor (Source path Issue)
- Higher Harmonic Content Neutral to Earth Voltage (return path issue)
- Voltage Snapshot Gas Pipeline to Remote Earth (high % return path issue)









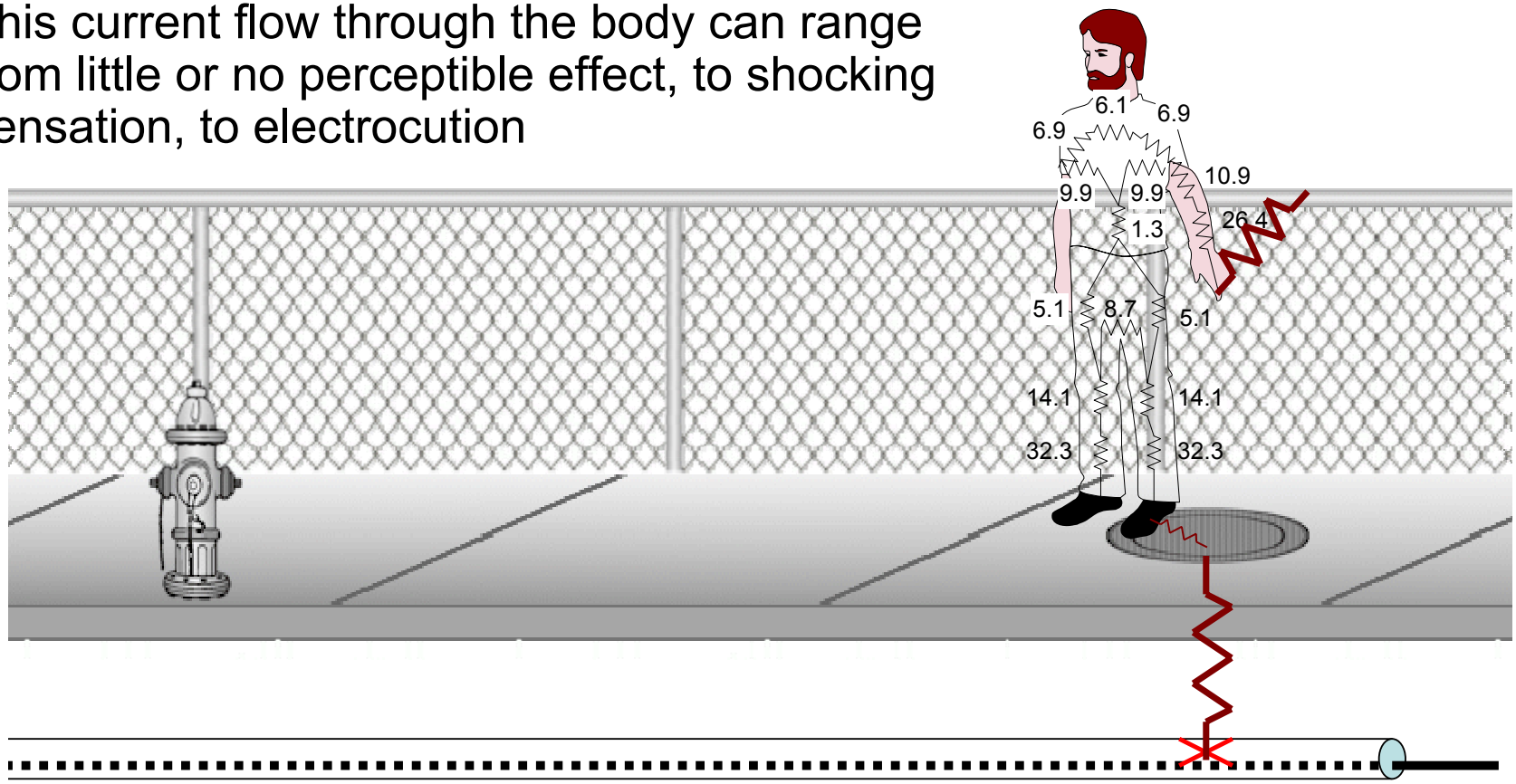


An IEEE PES Paper Intended to Support "Level of Concern" Discussion

- **Determining Voltage Levels of Concern for Human and Animal Response to AC Current**
- Doug Dorr, EPRI Paper Number: 09GM0484 – PES July 27th 2009
- **Abstract:** Whenever a voltage potential is present between two points - In close enough proximity - for a human or an animal to bridge the gap between them, there is the possibility for current to flow through the body. For the purposes of this paper, the contact scenarios of interest are limited to publicly or privately accessible locations such as swimming pools, hot tubs, pipe lines, street lights, electric service boxes and other areas where electric shock complaints are reported. This paper supplies a review of the literature on human and animal response to ac current along with a review of the standards and documents that presently have published values for voltage, current or resistance. These documents prove useful in understanding the establishment of published limits and levels of concern. A methodology is described whereby new levels of interest for contact scenarios may be developed using a systematic process that follows the basic methodology applied in establishment of prior limits.

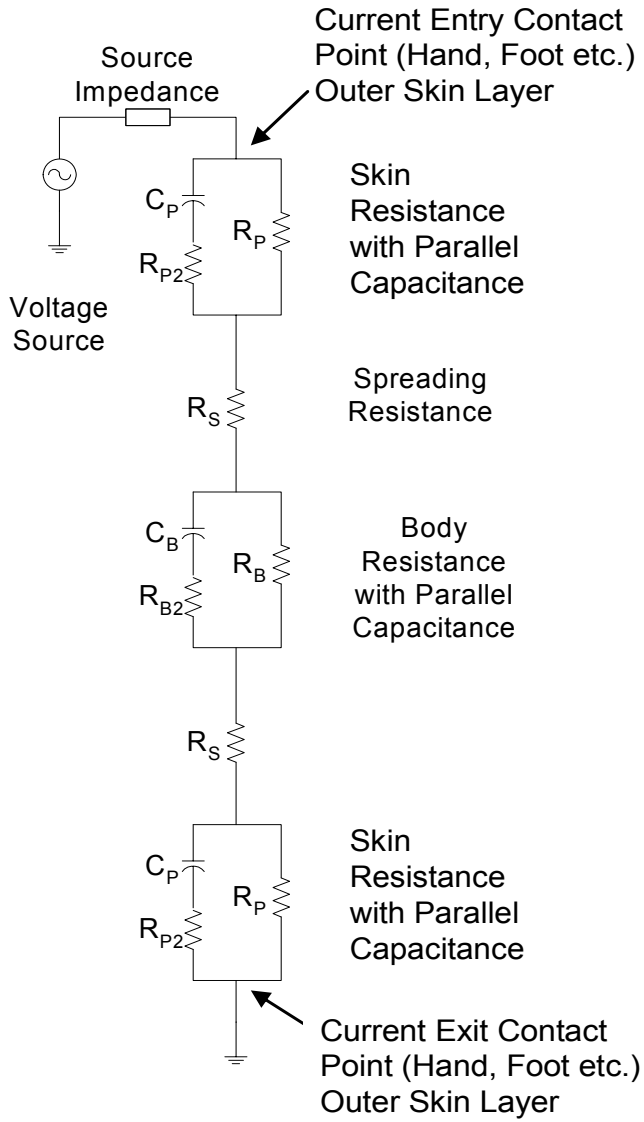
Parameters Controlling Body Current and Impacts on Humans and Animal

- Whenever a sufficient voltage potential is present between two points – In close enough proximity – for a human or an animal to bridge the gap between them, there is the possibility for a current path through the body
- This current flow through the body can range from little or no perceptible effect, to shocking sensation, to electrocution



Body Effect Dependencies

- The effect on a given body is dependent upon [6]:
  - the path impedance
  - the applied frequency
  - the current magnitude
  - the duration of the current flow



Questions that Must Be Answered in Order to Establish a Level of Concern

- Contact Impedance of the skin for humans, and hoofs or paws for animals tends to be at least 30 times greater than the internal tissue impedance, therefore the contact impedance and the environment (wet, salty sweat, or dry) becomes the dominant variable
- Human Body Impedance - For dry conditions, 1000 ohms is frequently cited as a conservative number for a bare foot to hand contact and values below 200 ohms might apply for a swimming pool or a hot tub
- Animal Impedance – The literature is not specific on impedance values other than for dairy cows (500 ohms is a value frequently used there), but the values cited for humans (200 to 1000 ohms) are conservative values for dogs and other animals as well
- Acceptable and Unacceptable 50/60 Hz contact voltage levels– Based on the 200 ohm wet value and the 1000 ohm dry value, the voltages can be calculated dependent upon the threshold of interest (perception, reaction, startle, fibrillation etc.)

Reference sources for these values: 2,3,4,5,6,7,9,15

Three Reactions to Body Current that are Useful for Level of Concern or Limit Setting

- ***Aversion*** **–** Examples include animals avoiding a metal grate, animals not wanting to drink water, and humans not wanting to enter a pool or hot tub
- ***Injury*** **–** The actual level of concern here is referred to as “startle reaction,“ where the result is a possible injury (such as falling from a ladder or spilling a pan of boiling water)
- ***Fatalities*** **–** The level of concern here is “heart fibrillation” or “respiratory paralysis”

Existing Publications with Voltage or Current Levels 15 Vac 'Wet' to 60 Vac Dry

Reference Document	Published Level	Concern Category
UL-101 [4]	0.75 milliamps reaction current - 2,000-ohm human body Z.	Reaction Current
UL-60950-1 [8]	42.4 Vac and 60 Vdc is the stated limit under dry conditions and human hand path.	Shock Hazard
IEC 479-1 [9]	25 Vac clearly safe, 50 Vac marginally safe (duration dependent). 1000 ohm body impedance cited	Shock Hazard
OSHA Rule" (29 CFR Part 1910) [10]	Circuits operating above 50 Vac or 50 Vdc.	Shock Hazard
NFPA 70E [11]	30 Vrms or 60 Vdc. 500-ohm wet human body resistance.	Shock Hazard
IEEE Yellow Book – Std. 902-1998 [5]	Currents as low as (10) milliamps and voltages above 50 V can cause fibrillation. 500-ohm minimum body resistance for wet conditions or cuts. 100-500 ohms for immersion (Table 7-2)	Heart Fibrillation
NACE [12]	15 volts.	Shock Hazard
NESC [13]	51 volts.	Shock Hazard
NEC® [14]	Circuits operating above 50 Vac or dc or 15 V for wet areas.	Shock Hazard
IEEE Std 80 [2]	60 Vac for 4 sec. 1000 ohm human body impedance	Shock Hazard

Comparing Criteria Among the Standards and Publications

- Factors of Safety – *Not the Same*
- Wet vs Dry Objectives – *Not the Same*
- Safety Objectives – *Not the Same*
- Conclusions:

1. Unless the scenario is identical - Rely on the biophysical data and the condition of interest - and not other published values from existing standards!
2. Insure that limit objectives are clearly articulated to avoid future misapplication of potential IEEE 1695 information
3. Documentation in the standards appendices is invaluable in understanding true levels of concern as opposed to levels of concern with built in factors of safety

Boiling the Criteria Down to a Systematic Process to Develop Levels Of Concern

- The literature provides a large and diverse selection of both voltage and current limits already
- What we can derive from the historical limits and the rationale behind those limits is that a scientific methodology does apply to the establishment of the established limits
- 13 steps define the methodology as follows:
  - 1. State the application scenario where the limit will be proposed (street-level metallic objects, pools, and spas, and so on)
  - 2. Refer to existing standards (such as Table 1) to find any “similar reference scenario” to ensure that an appropriate limit cannot be pulled directly from existing material
  - 3. If nothing in the existing standards is applicable, define the level of concern objective (aversion, injury, fatality)
  - 4. Define the species where the limit will apply (humans, dogs, or other species)

Boiling the Criteria Down to a Systematic Process to Develop Levels Of Concern

- 5. Define the contact mode(s) - hand-to-hand, foot-to-hand etc…
- 6. Based on the application scenario (from 1) where the limit will be proposed, define a worst case voltage expectation
- 7. Estimate a minimum body impedance value based on the contact mode(s) and the worst case voltage expectation
- 8. Consider how wet or dry conditions might warrant either raising or lowering the body impedance value
- 9. Estimate a complete circuit current path impedance value
- 10. Define the current threshold(s) based on the objective and taking into consideration the contact scenario(s) as well as the full current path impedance value.
- 11. Where practical, reduce the current threshold to a single worst case and articulate/document any factors of safety that have been considered
- 12. Calculate the voltage limit(s) that apply to the contact scenario and the species based on the current threshold and the impedance value(s).
- 13. Define the appropriate measurement protocol for the limit(s)

Final Comments and Recommendations

- This process is an adaptation of the basic process used to establish the limits found in existing standards
- The possible areas where future levels or limits may be useful include:
  - Wet contact locations (swimming pools, hot tubs, and so on)
  - Non-wet area residential contact locations
  - Above-ground pedestrian-level contact locations (light poles, bus shelters, and so on – with applicable mainly to humans)
  - Street-level contact locations (manhole covers, grates, service boxes, and so on – with applicability to pets and to humans)

References

- [1] D. Dorr, C. Perry, M. McGranaghan, Standardized Measurements for Elevated NEV Concerns, IEEE T&D 2006, Stray Voltage Panel Session. IEEE, T&D 2006.
- [2] ANSI/IEEE Standard 80-2000, IEEE Guide for Safety in AC Substation Grounding.
- [3] D. J. Reinemann, Review of Literature on the Effect of the Electrical Environment on Farm Animals, Updated December 2005, University of Wisconsin.
- [4] Leakage Current for Appliances, UL 101, Fifth Edition, April 29, 2002.
- [5] IEEE Std. 902-1998, IEEE Guide for Maintenance, Operation, and Safety of Industrial and Commercial Power Systems.
- [6] J. P. Reilly, Applied Bioelectricity: From Electrical Stimulation to Electropathology, Springer-Verlag, New York, 1998.
- 7] Power System and Railroad Electromagnetic Compatibility Handbook: Revised First Edition. EPRI, Palo Alto, CA, Oncor Energy Delivery Services, Dallas, TX, The National Grid TranscoCompany, Warwick, UK, Association of American Railroads (AAR), NW, Washington DC and American Railway Engineering and Maintenance-of-Way

References

- [8] UL 60950-1 Information Technology Equipment – Safety – Part 1: General Requirements.
- [9] IEC 60479-1, Third Edition, *Effects of Current on Human Beings and Livestock, Part 1: General Aspects,* 1994.
- [10] CFR 29, Part 1910, Occupational Safety and Health Standards (OSHA).
- [11] NFPA 70E-2004, Standard for Electrical Safety Requirements for Employee Workplaces.
- [12] Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems, National Academe of Corrosion Engineers (NACE), Standard RP0177-95, Item No. 21021, March 1995.
- [13] Accredited Standards Committee C2-2002, National Electrical Safety Code (NESC).
- [14] NFPA 70-2005, National Electrical Code® (NEC®).
- [15] P. Sutherland, D. Dorr, K. Gomatom, “Human Current Sensitivities and Resistance Values in the Presence of Electrically Energized Objects,” IEEE Industrial and Commercial Power Systems Technical Conference, pp. 159–167, 2005 IEEE, ISBN 0-7803-9021-0.