Stray and Contact Voltage Overview

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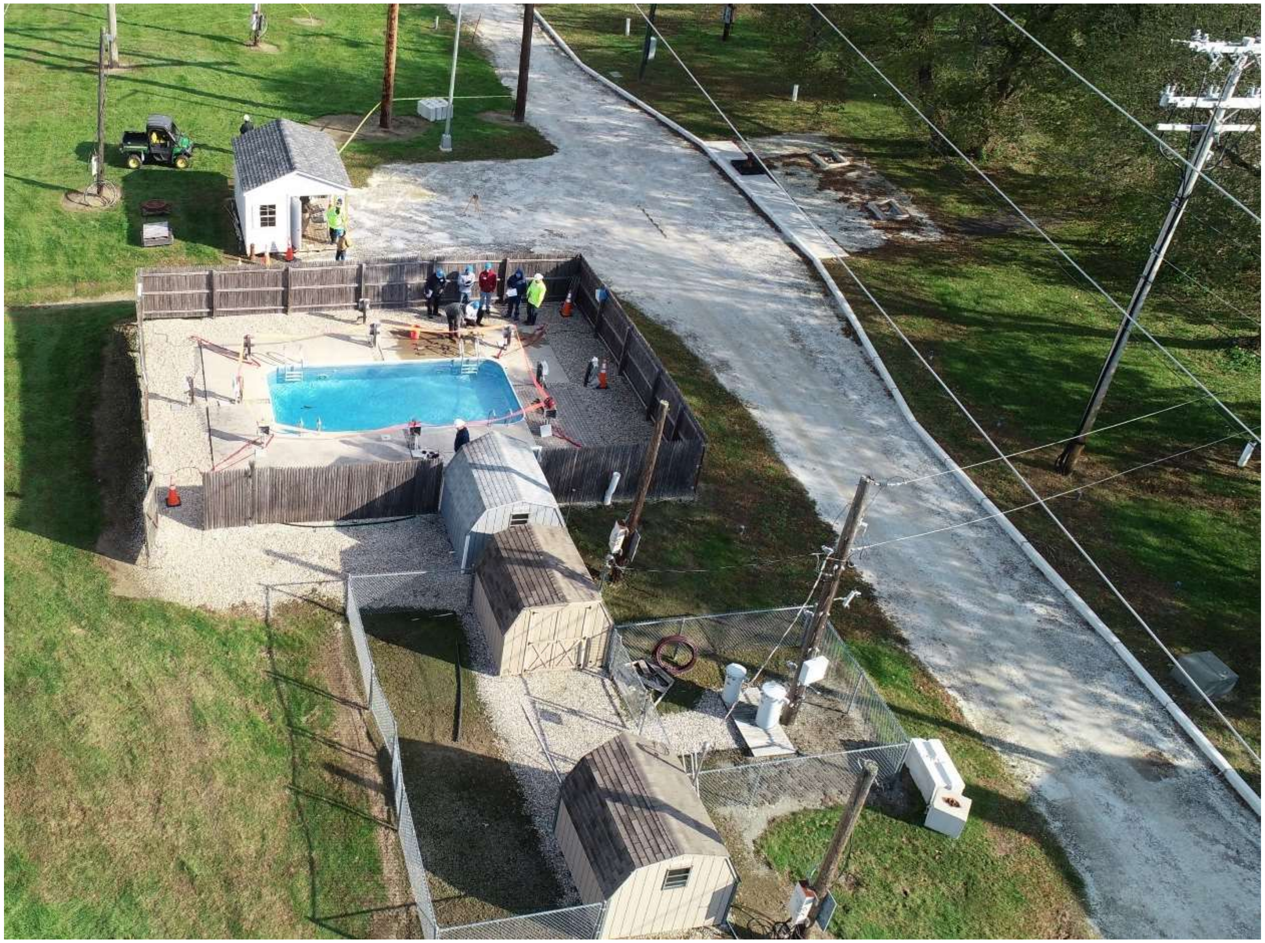
Discussion Topics

1. Terminology
2. Causes of Stray and Contact Voltage
3. Examples Utilities Deal With
4. Some Human and Animal Impact Perspectives
5. Mitigation Strategies
6. Investigation Procedures
7. Diagnostics
8. Distribution Side Use Cases

EPRI Research and Testing Facilities - Lenox, MA

- Consistent and replicable stray and contact voltage scenario evaluation and training capabilities

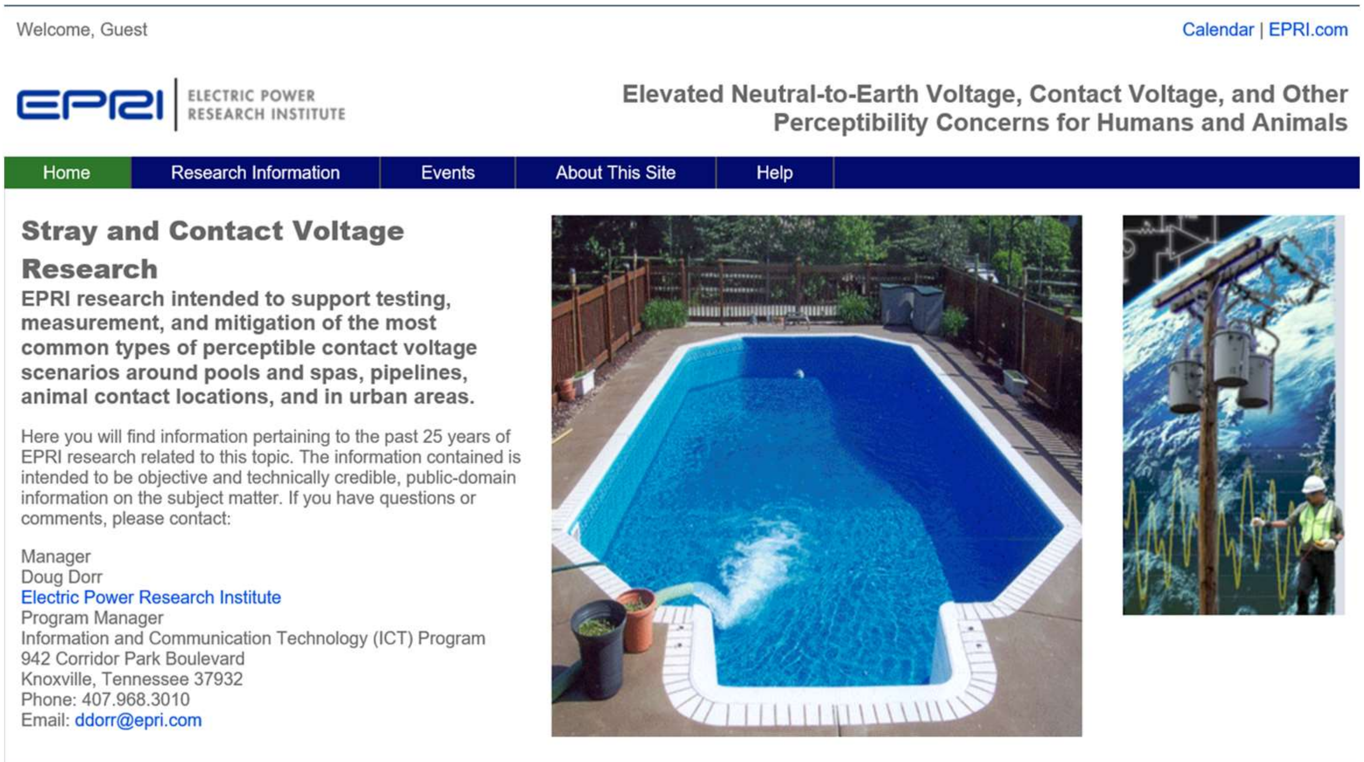


- EPRI Mission: Advancing ***safe***, ***reliable***, ***affordable*** and ***environmentally responsible*** electricity for society through global collaboration, thought leadership and science & technology innovation

2000-2020 Stray/Contact Voltage Research and Website

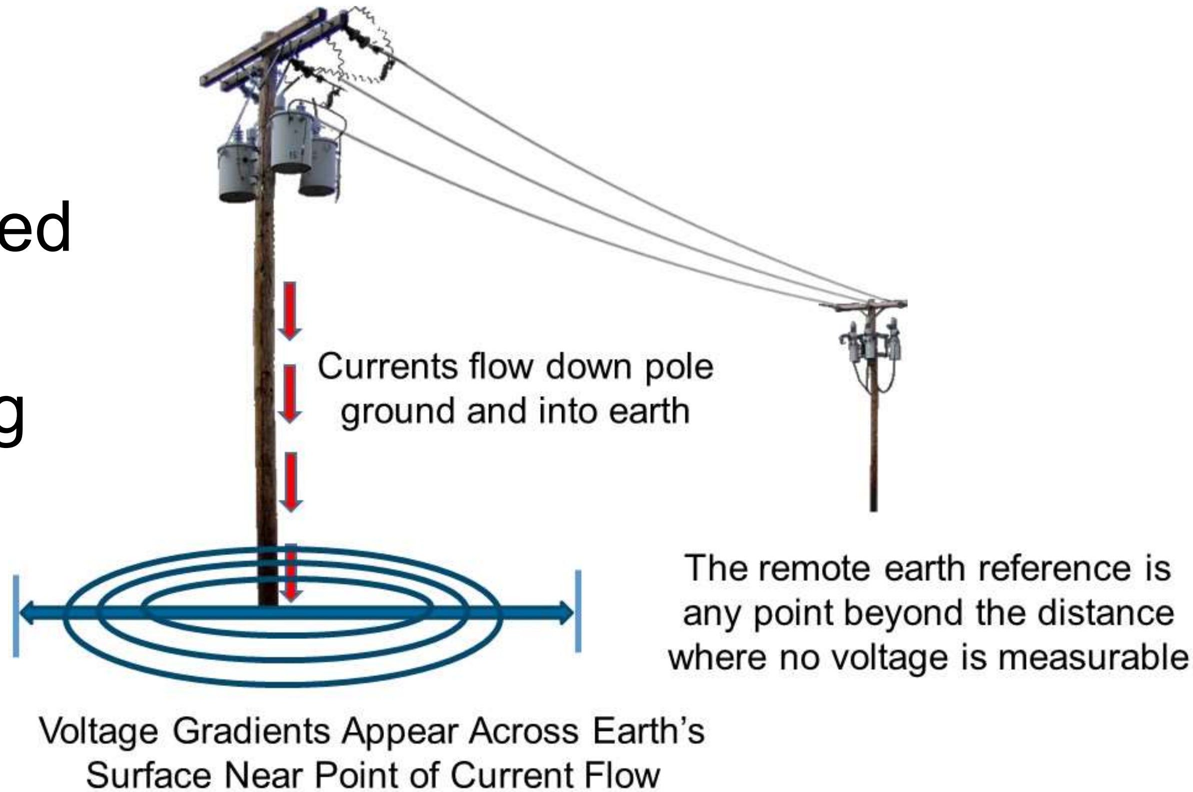
1. Test/measurement protocols
2. Modeling/simulation guidelines
3. Test equipment/ mitigation methods
4. Technology transfer - Informational website
5. Regulatory guidance/ Standards Input

http://strayvoltage.epri.com



Terminology and Definitions from IEEE 1695-2016

1. Stray Voltage
2. Contact Voltage
3. Inadvertently energized objects and surfaces
4. Equipotential Bonding
5. Remote Earth
6. Grounding



Technical Background for Energized Objects Cont'd

- Neutral-to-remote-earth voltage **(NEV)**
  - Currents flow through neutral conductor - resistance of conductor causes voltage drop (measurable as NEV or Stray Voltage)
- Power conductor insulation breakdown **(Faults)**
  - Objects and surfaces can get energized directly from faulted power conductor
- Degraded neutral return path (is it NEV or Fault?)
  - Return currents create larger voltage drops and promote current flow on unintended pathways

Technical Background for Inadvertently Energized Objects

- Energized power lines and other objects generate an "**Electric Field**" or "**E Field**" that varies with voltage level
- If current also flowing, power line/object can also generate a "**Magnetic Field**" - varies with amount of current flow
- Power lines typically emit electric and magnetic fields (voltage is present and currents are flowing)
- Inadvertently energized objects and surfaces **always** emit an Electric Field

L.O. 10

Contact VS Stray Voltage – Differences?

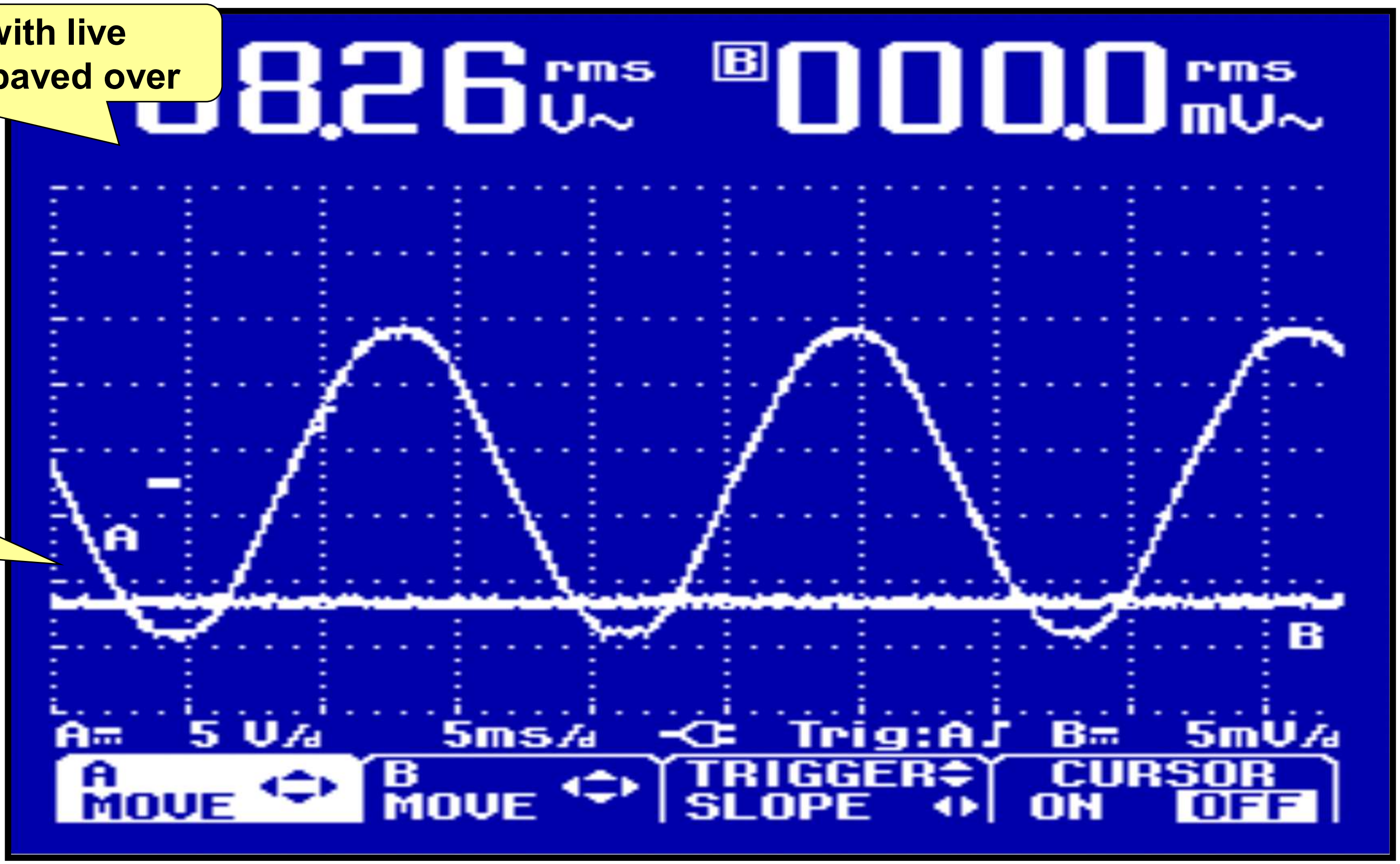
- Four Basic Voltage Sources:
  - Faults that don't self clear (service box covers, light poles, moisture paths)
  - Voltage Drop on Current Carrying Conductors – NEV
  - Magnetic Induction from current flow (metallic pipelines, rails)
  - Electric Induction (above ground pipelines, metal light poles)
- 90% of the time the source is distinguishable via wave shape analysis and phase angle analysis

Faults That Don't Self Clear

PVC tape on split-bolt splice improperly applied

Excavated handwell with live conductors had been paved over

Degraded split-bolt tape insulation



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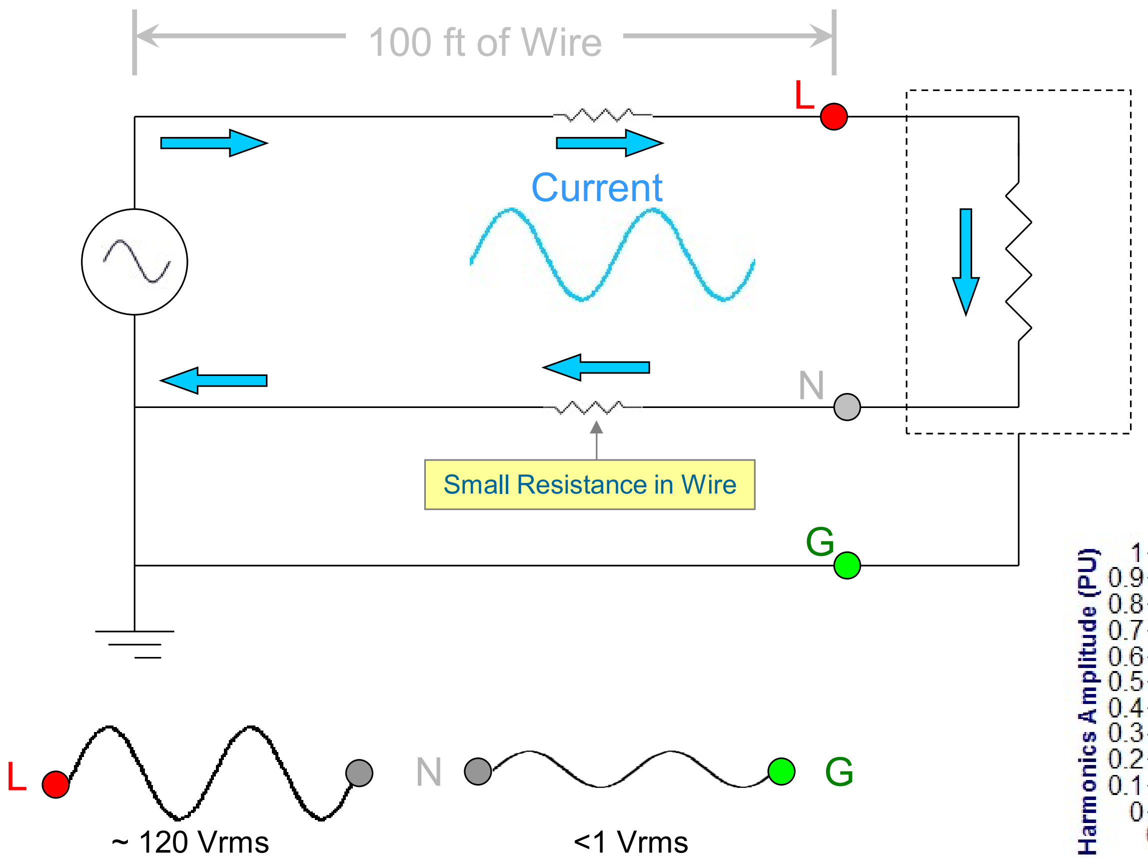
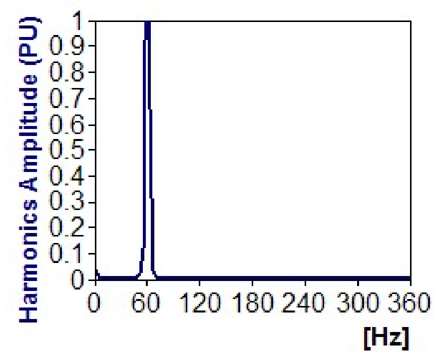
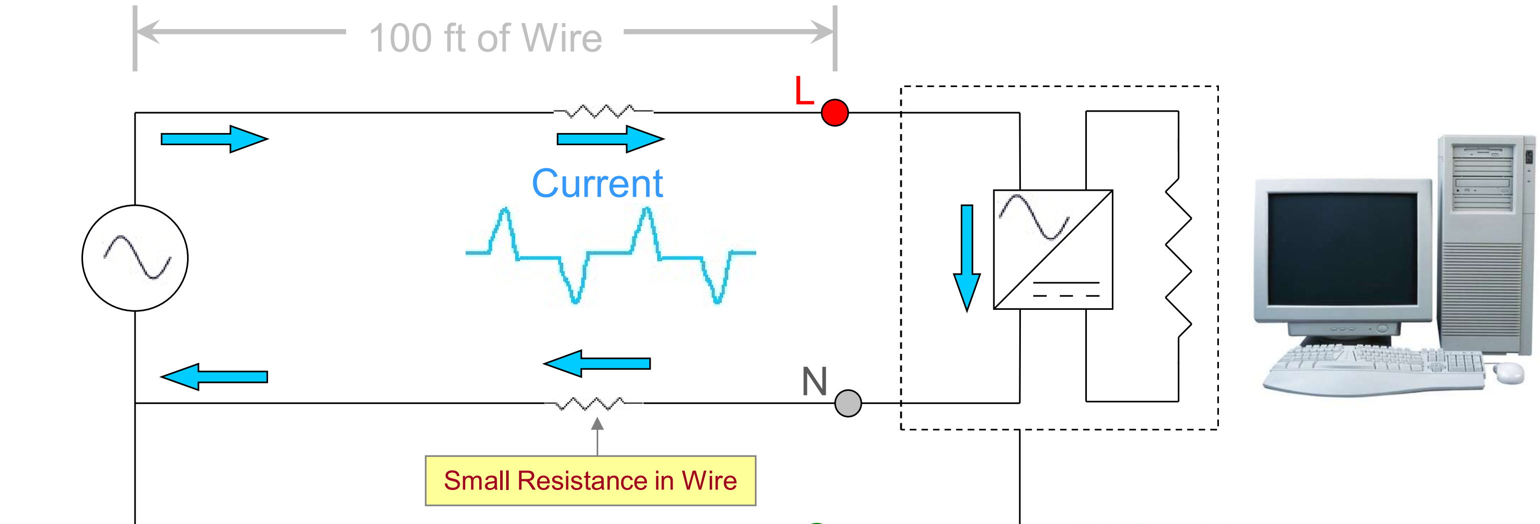
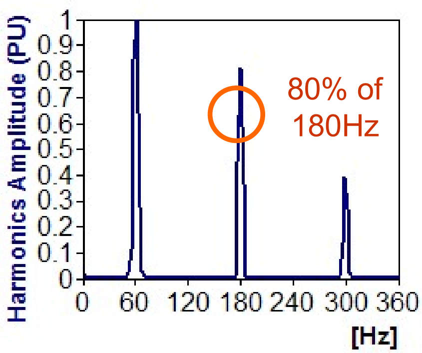
Neutral Voltage (Light Bulb Load)



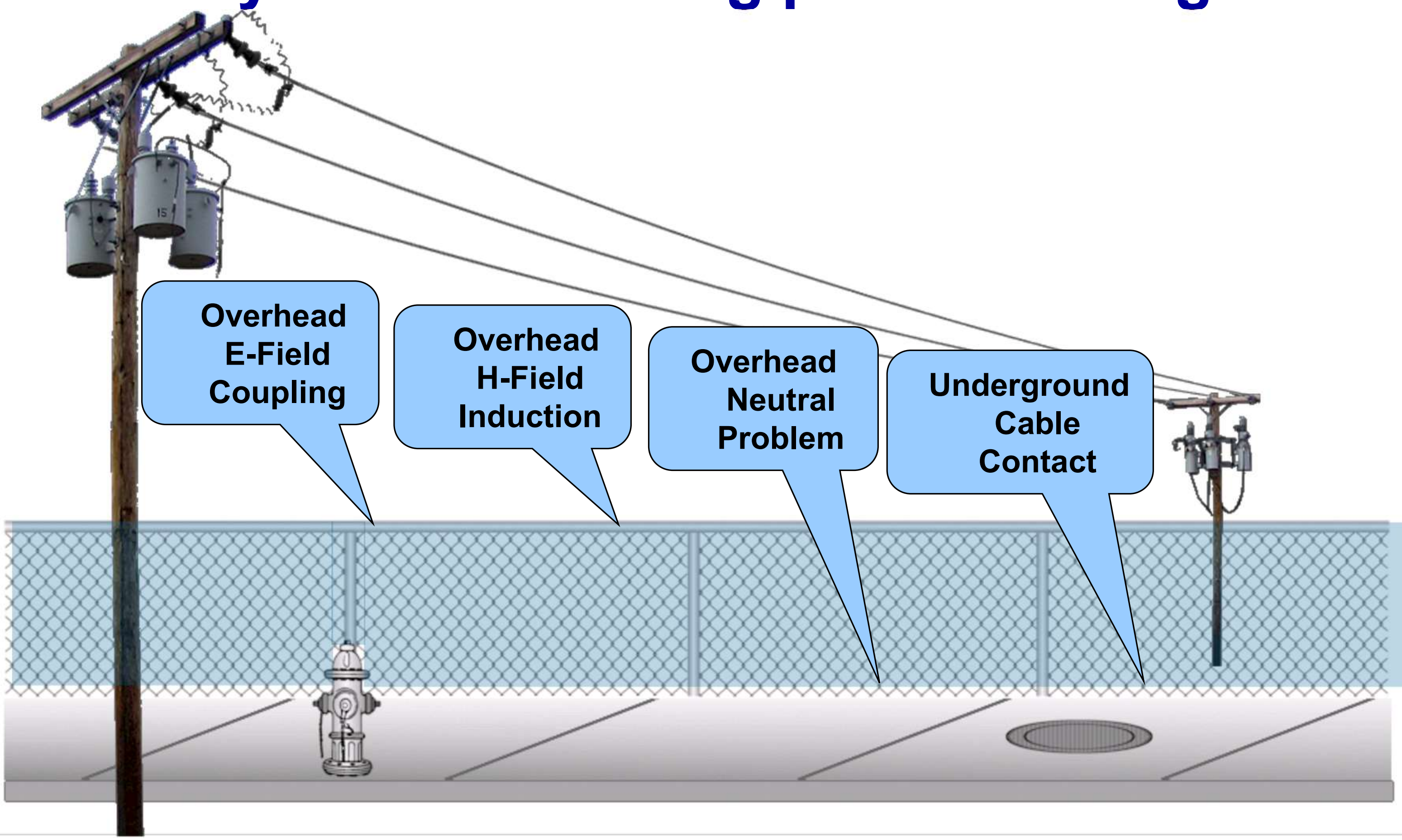


Neutral Voltage (Computer Load)



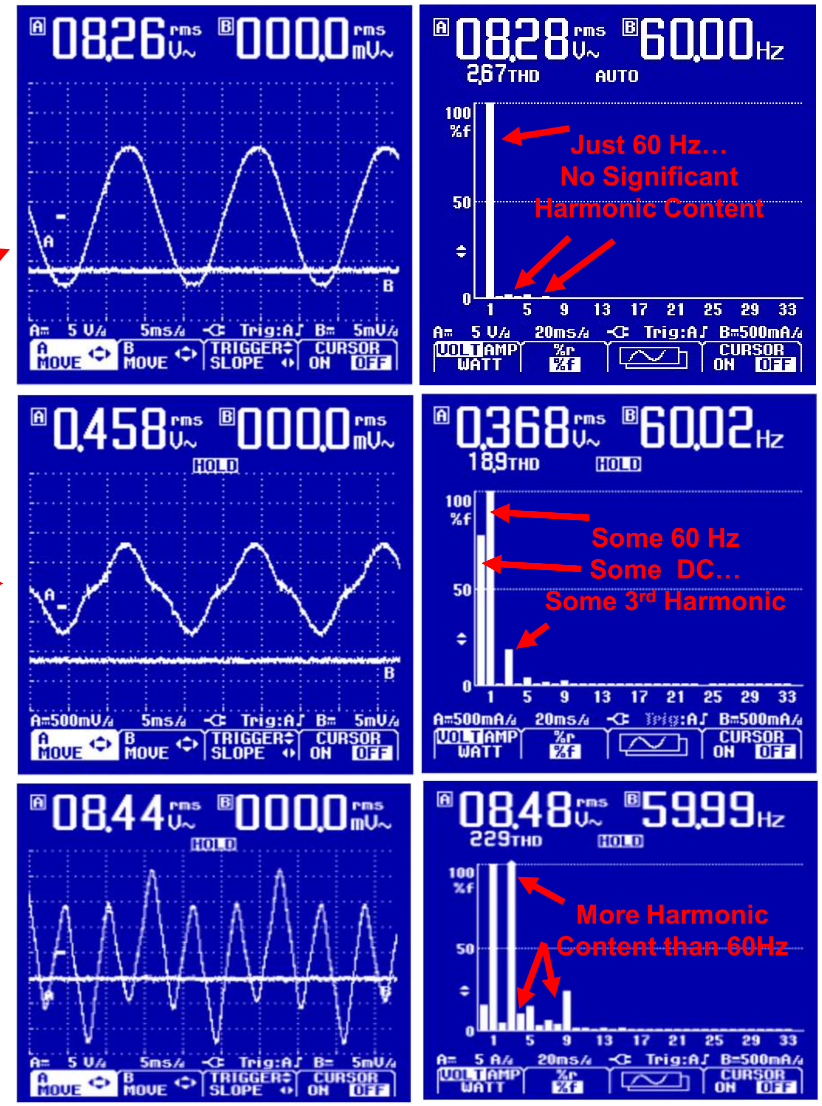


Example: The fence can be energized at least 5 ways! Harmonic analysis and trending provides insight



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)



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Investigation Procedures – No single go to resource! EPRI Pubs, State PUC Pubs, IEEE 1695-2016, CEATI Pubs

- **IEEE 1695-2016 Guide to Understanding Diagnosing and Mitigating Stray and Contact Voltage**

- Clause 3 – General Discussion
  - Provides a detailed explanation of why a voltage chart is not included
- Clause 4 – Human and Animal Electrical Sensitivity
  - Human body impedance and current thresholds
  - Animal behavior impact
- Clause 5 – Contact Voltage
  - Outlines the differences between stray and contact voltage measurement protocol
  - Detection and measurement methods
  - Contact voltage detection (CVD) programs
- Clause 6 – Stray Voltage
  - Causes of stray voltage (NEV, inductive and capacitive coupling)
  - Detection and measurement methods
  - Mitigating stray voltage

- Annex A – Contact Voltage Measurement Protocol
  - Qualified references and measurement surfaces
  - Characterization of voltage sources
- Annex B – Contact Voltage Investigation Protocol
  - General mitigation procedures
  - Asset specific procedures
  - Data collection
- Annex C – Stray Voltage Investigation for Confined Livestock
  - Data collection
  - Analysis of collected data
  - General considerations
- Annex D – Swimming Pool Investigations
  - Voltage source diagnosis
  - Construction methods and NEC requirements
  - Measurement point selection
  - Analysis of collected data
- Annex E – Marina and Boat Dock Investigations
  - Voltage source diagnosis
  - Codes and standards
  - Measurement point selection
  - Analysis of collected data

Diagnostics

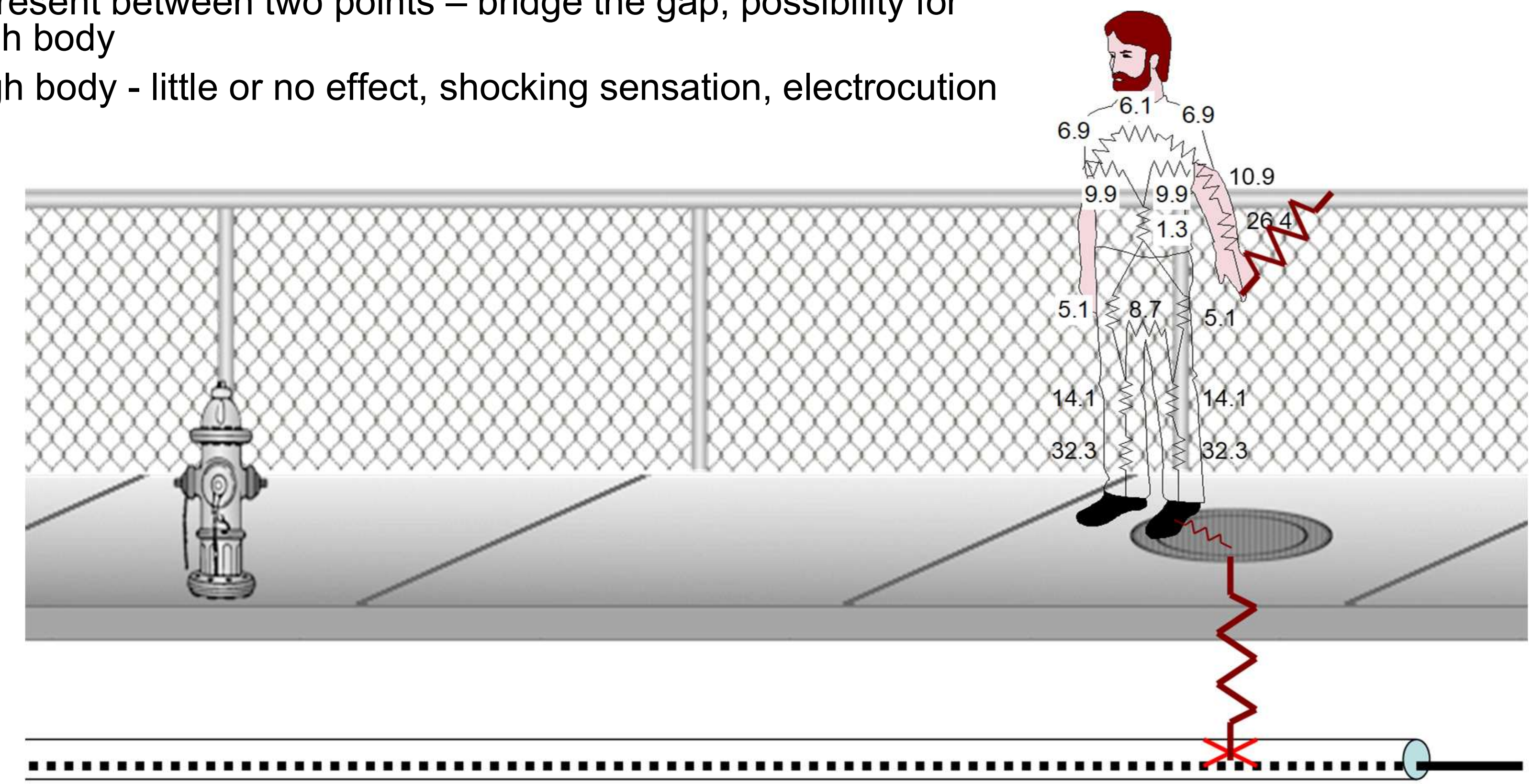
- Validate the voltage source strength **(Voc vs V20K)**
- Record the voltage at the complaint location **(both Voc and Vr)**
- Assess the source type with waveform analytics
- Understand the voltage change at the point of common coupling vs the complaint location
- Get a voltage trend over time - or at least a minimum and a maximum load difference
- Based on the prior bullets, customize the test plan according to IEEE, EPRI and CEATI resource documents
- Each test should have a rationale and an expected result if that source or pathway is to be considered or ruled out

Distribution Mitigation and Use Cases

- Mitigation Options (Diagnostic Results must be Well Understood):
  - Isolation
  - Neutral Remediation
    - Identify Problem Sections
    - Resized Neutral
    - Parallel Neutrals
    - Increasing Pole Ground Counts
    - Decreasing Substation Ground Mat Resistance

Body Paths, Body Resistance and Voltage Levels

- Body Paths and Body Resistance = two basics of voltage propagation and current flow
- Voltage potential present between two points – bridge the gap, possibility for current path through body
- Current flow through body - little or no effect, shocking sensation, electrocution



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Concern Categories from Reference Standards

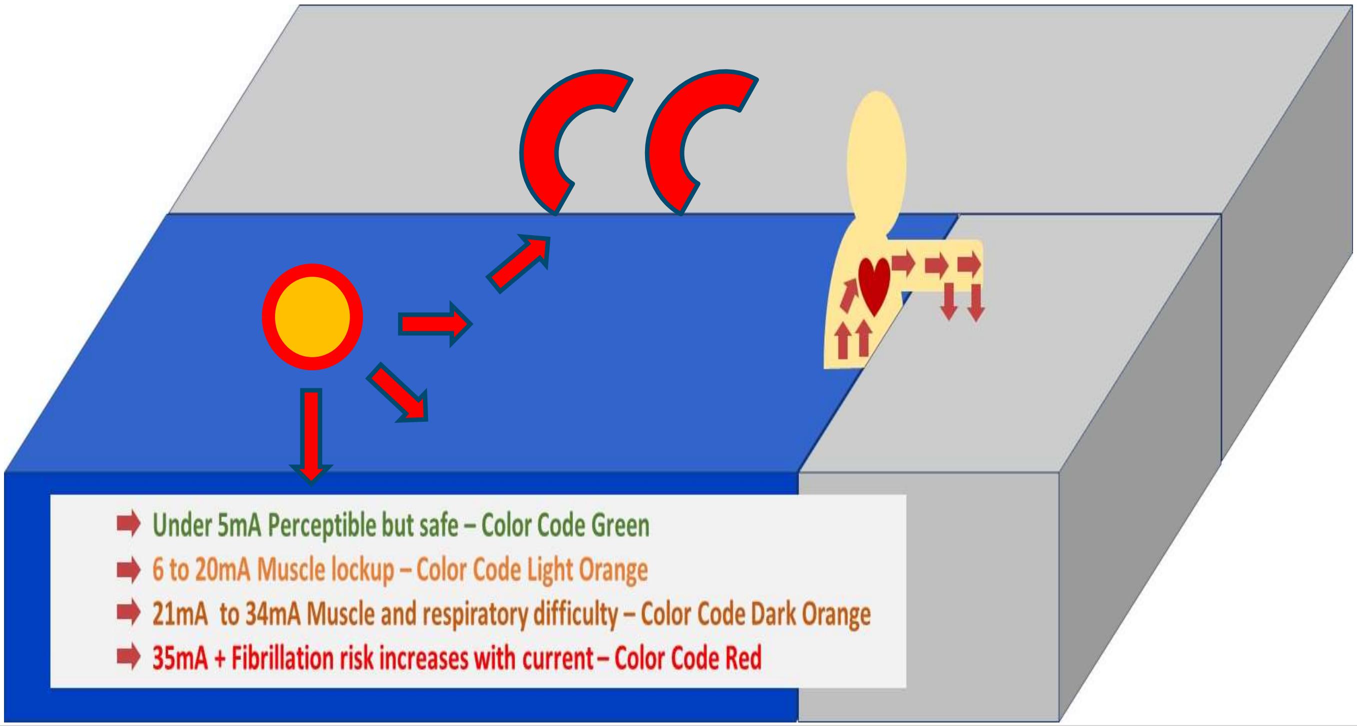
Reference Document	Published Level	Concern Category
UL-101 [4]	0.75 milliamps reaction current – 2,000-ohm human body Z	
UL-60950-1 [8]	42.4 Vac and 60 Vdc is the stated limit under dry conditions and human hand path	Shock Hazard
IEC 479-1 [9]	25 Vac clearly safe, 50 Vac marginally safe (during dependent). 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

Example Level of Concern Considerations

- **Aversion** – humans not wanting to enter pool or hot tub and livestock not wanting to drink water or enter a location
- **Injury** – level of concern referred to as “startle reaction,“ result is possible injury (such as: falling from ladder, or spilling pan of boiling water)
- **Fatality** – level of concern is “heart fibrillation” or “respiratory paralysis”

Example: How to Define Perceptible Current Path

- Identify source of voltage (in this case water is energized)
- Identify pathway through human body
- *Why important?* Pathway determines potential hazard level



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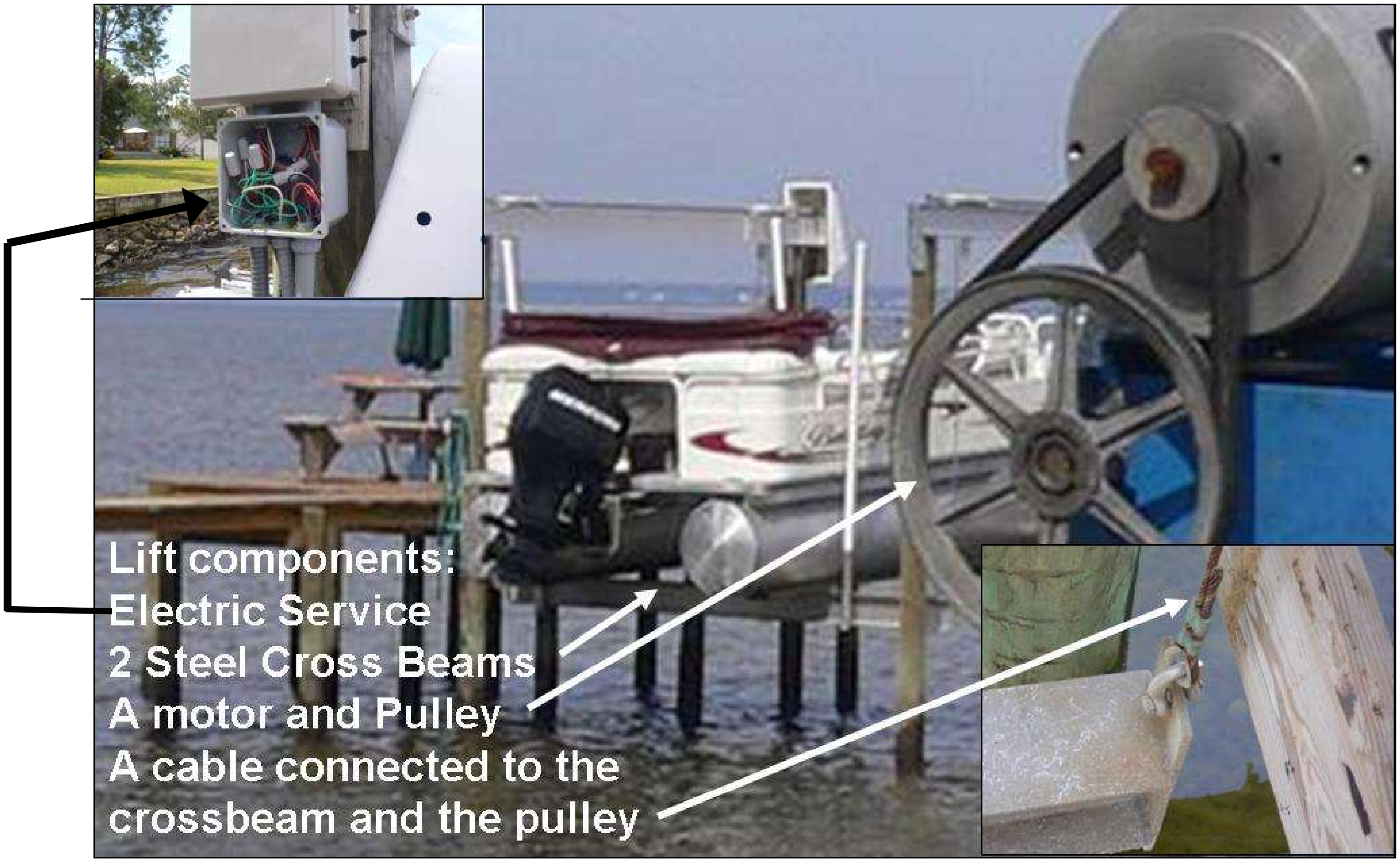
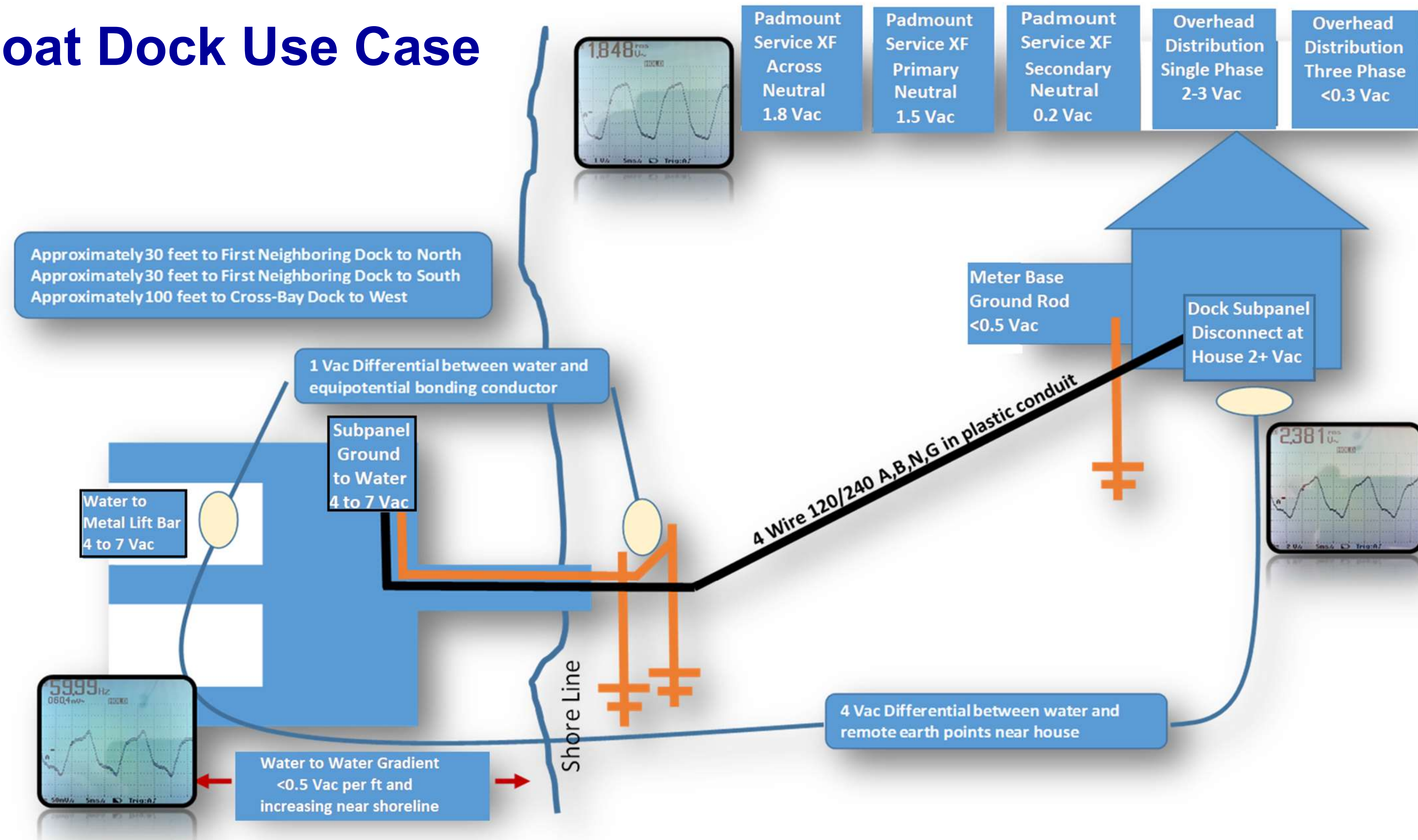
Boat Dock Use Case – With Degraded Concentric Neutral



Boat Dock Use Case

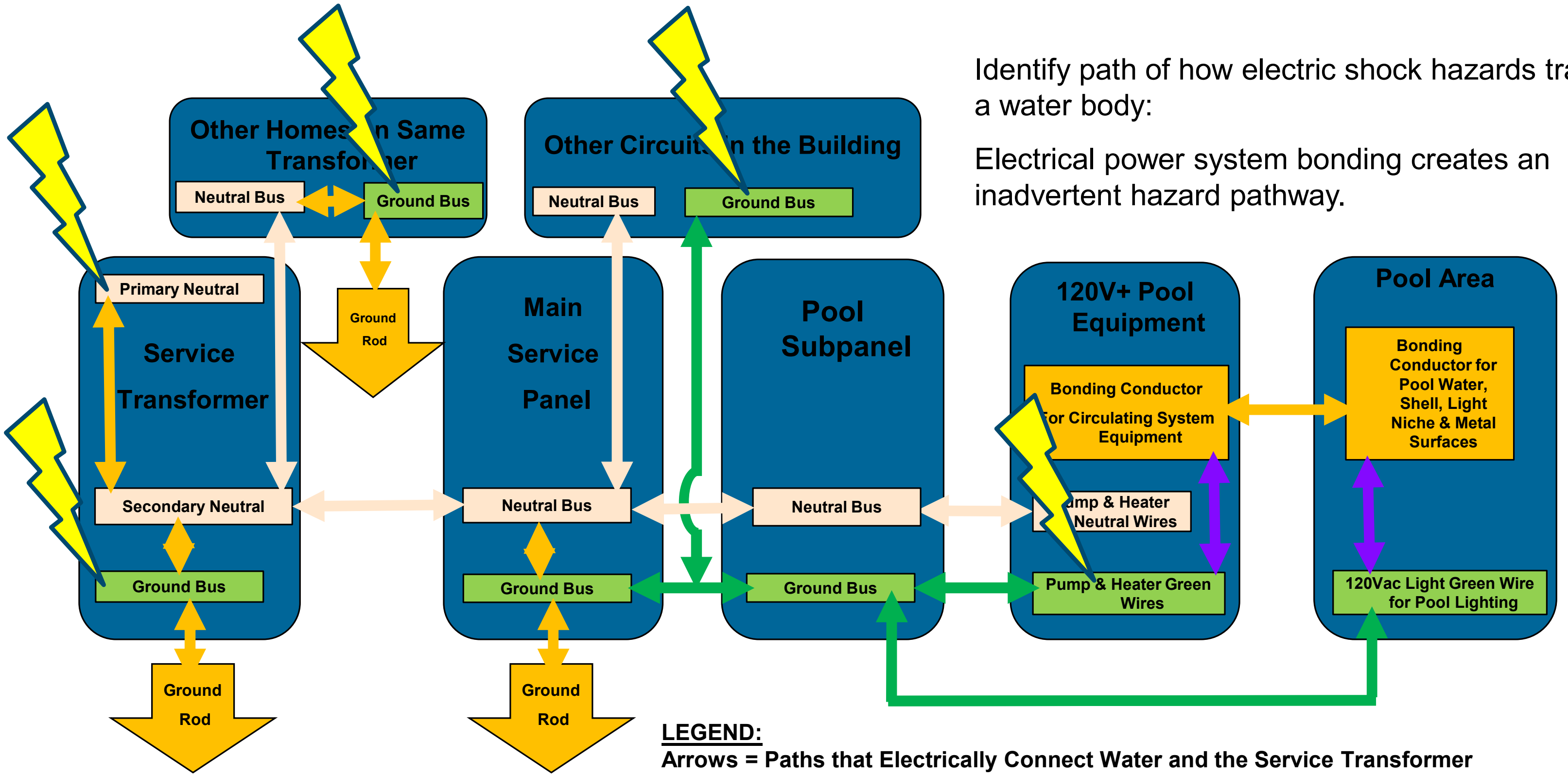


Case Study Findings

- Voltage on boat lift coming from three different sources:
  - Power system's neutral conductor
  - Other neighbor's boat docks
  - Home's electrical loads
- Unplugging boat lift motor reduces the voltage by 80%
- Customer Side Solution Options
  - **Low Voltage DC Retrofit Option**
  - **Motor Circuit Modifications**
  - **Double Insulated Isolation Transformers at the Dock Sub-panel**
- **Customer Fix Will Not Address the Root Cause**

Distribution Side Fault Example and Swimming Pools

How Electric Shock Hazards Travel to a Water Body



Identify path of how electric shock hazards travel to a water body:

Electrical power system bonding creates an inadvertent hazard pathway.

LEGEND:
Arrows = Paths that Electrically Connect Water and the Service Transformer

Green and Bronze Arrows = Hard Wired Connections

Blue Arrows = Equipment Bonds Embedded in the Product

L.O. 6

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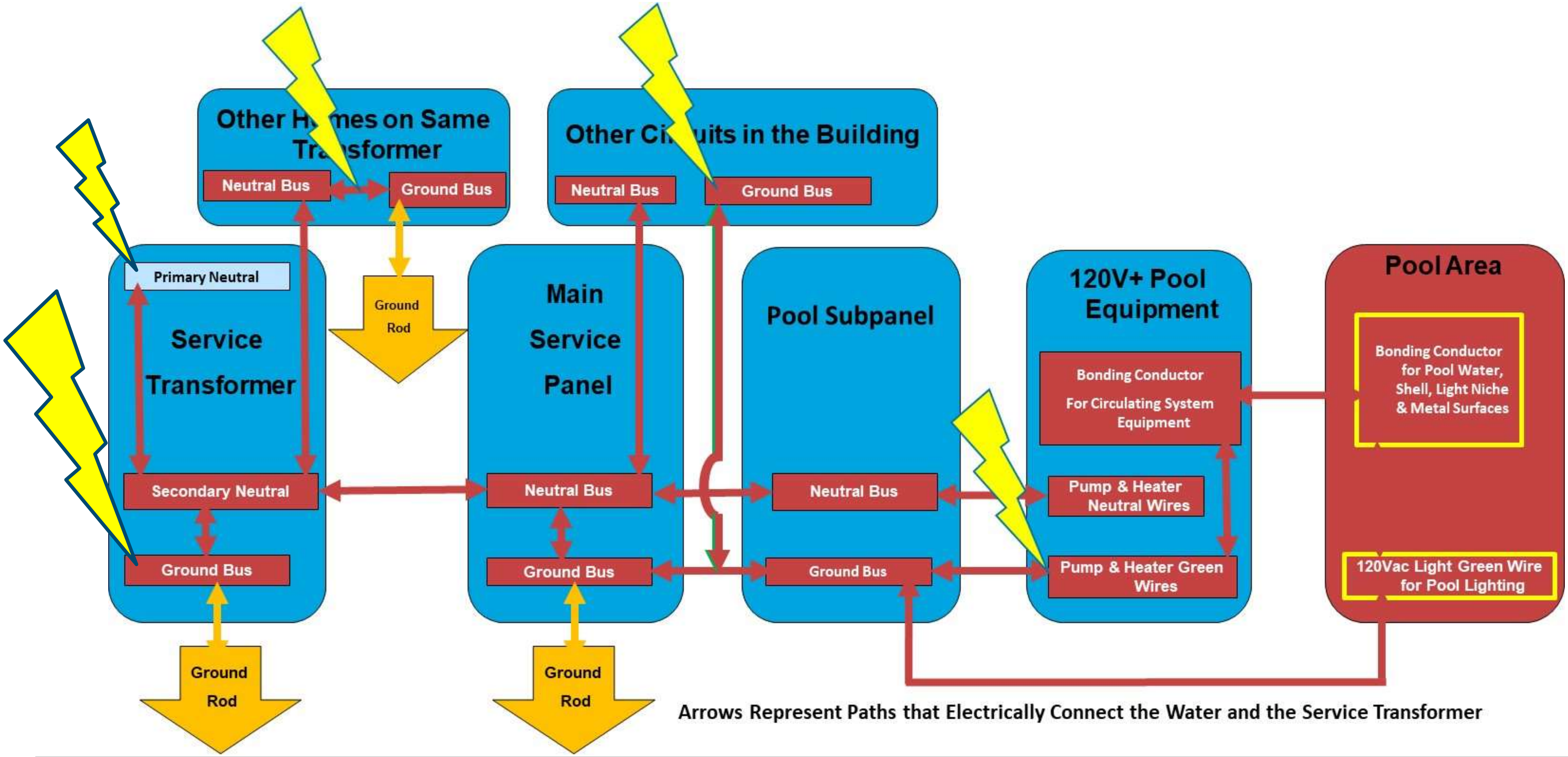
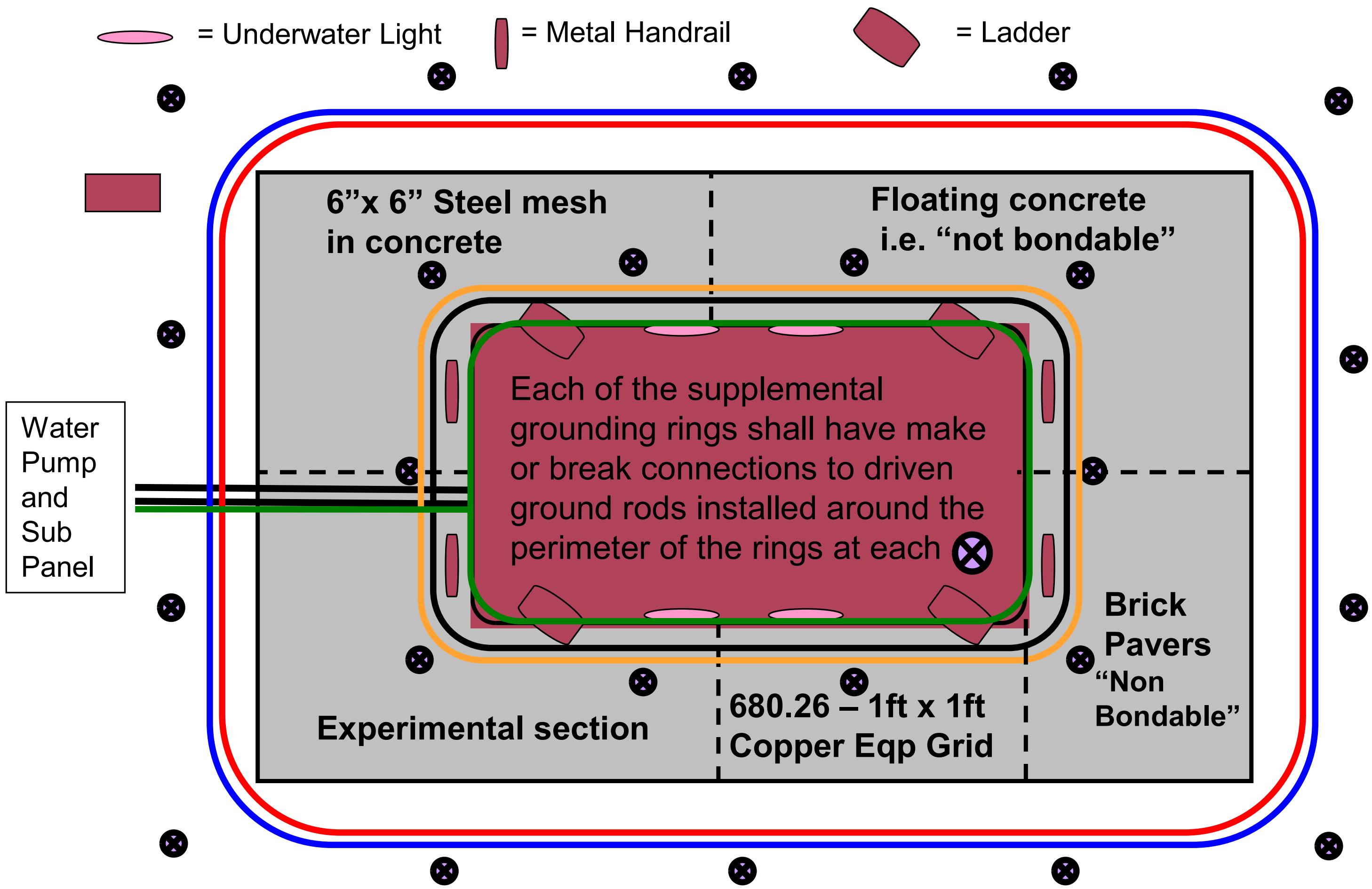
How Electric Shock Hazards Travel to a Water Body



Arrows Represent Paths that Electrically Connect the Water and the Service Transformer

Mitigation Options (Lenox test pool):

- Test Rings - connected or disconnected to main bonding ring (Green 30 ohms)
- Blue – 8' from water – 30" soil depth (17 ohms)
- Black – 18" from water – 6" soil depth (29 ohms)
- Red – 8' from water – 6" soil depth (18 ohms)
- Yellow – 18" from water – encased in deck (28 ohms)
- Different surfaces can be evaluated as well



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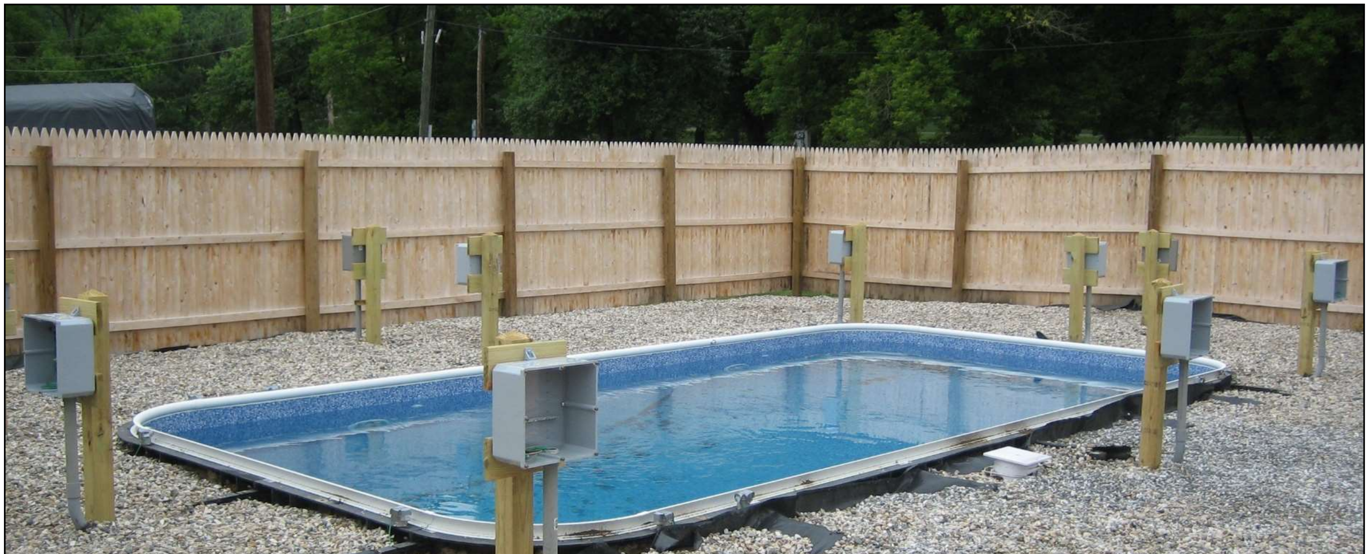
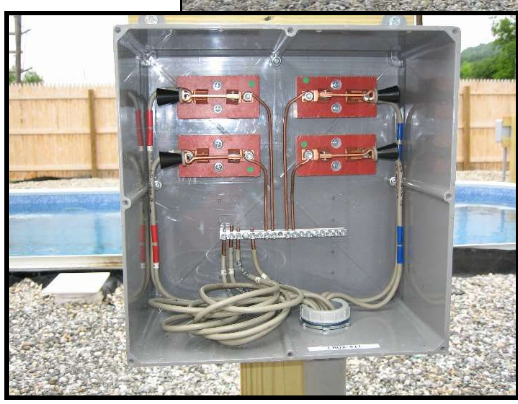
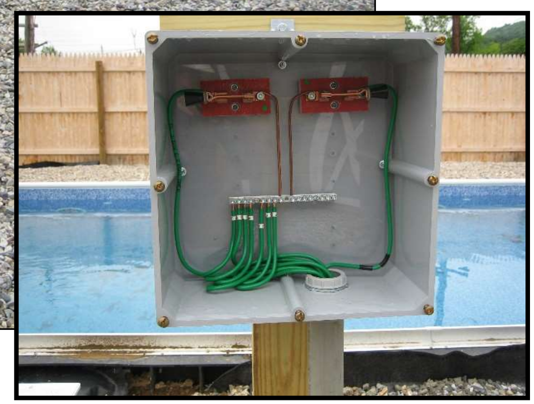
Equipotential Bonding for Swimming Pools and Spas Testing







Physical Installation of Deck Surfaces

Key Takeaways from the EPRI Pool Tests

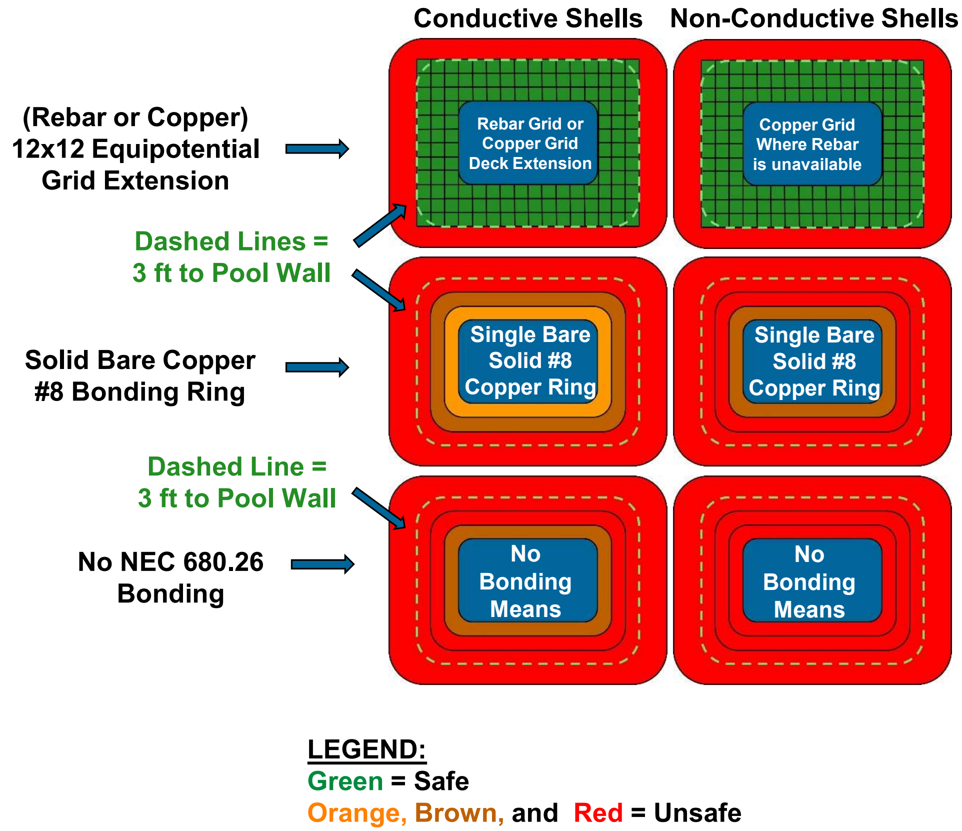
- Uncleared faults - 120/240 Vac residential service, 208Y/120 Vac or 240/120 Vac or 480Y/277 Vac commercial services *can all create unsafe voltage differences* between water and all inadequately bonded conductive surfaces
- In-ground pools - voltage difference between water and pool deck during fault conditions, - equipotential bonding necessary
- NEC Article 680 “alternate means” specifying single bare copper wire in or beneath pool deck does **not** adequately bond (deck or earth) to water and therefore no equipotential surface and no (safe zone) achievable on deck during faults
- Voltage potentials created during uncleared ground faults cannot be remediated with ground fault circuit interrupters (GFCIs). GFCI only protects equipment downstream of its own current sensor
- Promote an electrically safe zone on deck surface
  - properly installed and bonded equipotential grid
  - rebar, copper or other approved materials necessary within or underneath the decking area
  - Grid should extend out (3’ or more) from inner pool wall and should be constructed to form 1’ x 1’ or smaller squares

Conductive VS Non-Conductive Pool Construction During Fault Conditions

1. Conductive – poured Concrete decking, the preferred method - extend rebar grid out to three feet out from perimeter walls in human accessible areas

2. Conductive - walking surfaces are pavers or other non-poured walking surfaces copper in walking areas is a more resistant approach

3. Non conductive - the copper grid in or beneath walking areas is preferred method for achieving near equipotential between water and human accessible areas



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