IEEE Standard 1695

An Introduction for the Technical Professional

IDAHO POWER

IEEE

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Our Service Area

IDAHO POWER

Customers: 620,000+

Line miles
Distribution: 29,384
Transmission: 4,832

Peak system load
3,751MW

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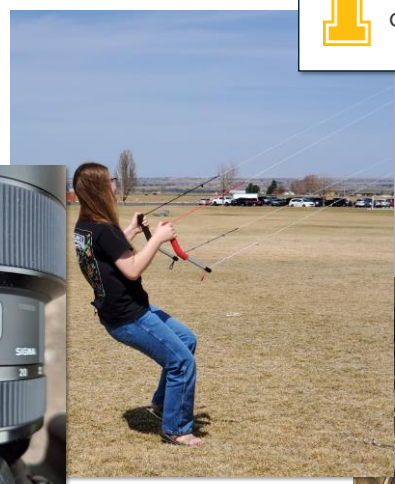
About me…



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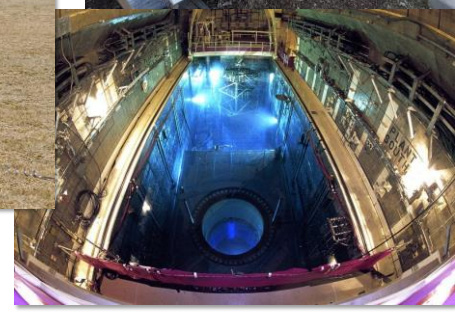

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Presentation Overview

- Objective:
  - To introduce IEEE Standard 1695-2024, describe some improvements from the 2016 edition, and highlight some key parts of the standard.
- Outline:
  - The standard creation process
  - The scope and purpose of IEEE Std 1695-2024
  - What is in the standard?
  - Why you should use IEEE Std 1695-2024
  - Some important definitions
  - Characterizing exposure voltages
  - An example application of IEEE Std 1695-2024

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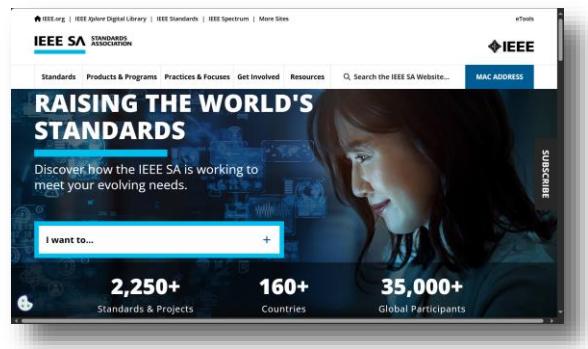
Creating IEEE Standards

- The IEEE is a standard development organization like the NFPA, IEC, and others.
- IEEE standards use an ANSI-approved consensus development process.
- The IEEE Standards Association (IEEE-SA) facilitates and manages the process.
  - IEEE-SA provides online collaboration tools, technical editing, publishing, and other services.
- Anyone can join the IEEE-SA, submit comments for revision, and participate in balloting.



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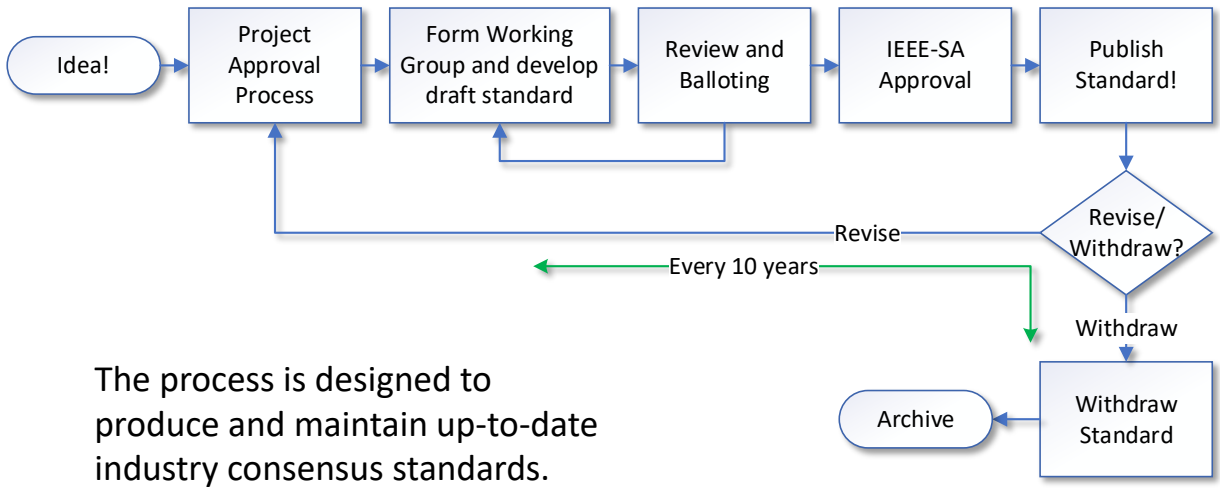
Creating IEEE Standards



The process is designed to produce and maintain up-to-date industry consensus standards.

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IEEE Std 1695-2024 Scope and Purpose

- *"IEEE Guide for Understanding, Diagnosing, and Mitigating Stray and Contact Voltage"*
  - Scope:
    - Voltages at accessible locations resulting from the delivery and use of electricity. The guide includes definitions, sources, testing techniques, and mitigation strategies.
  - Purpose:
    - Provide a public, industry-wide guide or standard
    - Provide information regarding potential risks
    - Provide guidance for investigators and others
    - Dispel misinformation
    - Enhance public safety

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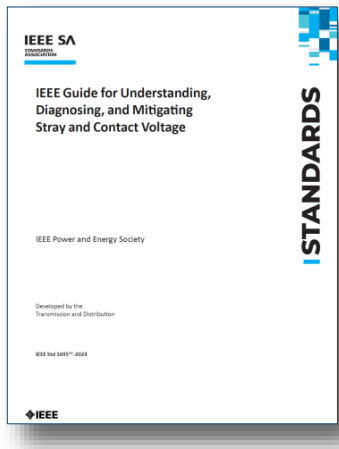
Got questions?
IEEE Std 1695 has answers

What tools do I need?

How do I tell if this is "stray" or "contact" voltage, or both? What's the difference?

Where can I get an organized, step-by-step process to investigate this situation?

Where can I find human and animal sensitivity information for my safety presentation?



It's in here.

I've never investigated shocks at a marina before. What do I need to know?

What's a shunt resistor for, and do I need more than one size?

How can we set up a Contact Voltage Detection (CVD) program?

How do I help this electrician understand that this voltage is normal, even with the load off?

I can't drive a "remote rod" through the sidewalk. What should I do?

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An overview of changes from 2016 to 2024

- Expanded definitions and explanations, including more information on:
  - Electromagnetically coupled currents and voltages
  - Equipotential planes
  - Characterizing sources based on waveforms and harmonic content
- Reorganized for improved clarity and usability
  - All instructions, flowcharts, educational information, and other guidance are in the main clauses
  - Case studies, forms, and the bibliography are in annexes
  - Consistent use of terms "Exposure voltage," "Contact Voltage," and "Stray Voltage."
- Added case studies (new to this edition) – including:
  - Contact voltage – a shocking shower and an underground fault
  - Stray voltage – on and off of livestock facilities

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IEEE Std 1695-2024 covers…

- Safety for investigators
- Causes of accessible voltages
- Investigation equipment
- Identifying stray and contact voltage
- Human and animal electrical sensitivity
- Contact and stray voltage mitigation
- Developing Contact Voltage Detection (CVD) programs

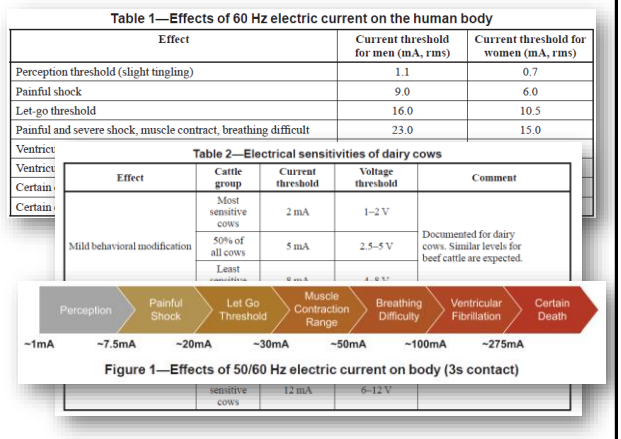

Table 1—Effects of 60 Hz electric current on the human body

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

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 are expected.
	50% of all cows	5 mA	2.5–5 V	
	Least sensitive cows	12 mA	6–12 V	

Figure 1—Effects of 50/60 Hz electric current on body (3s contact)

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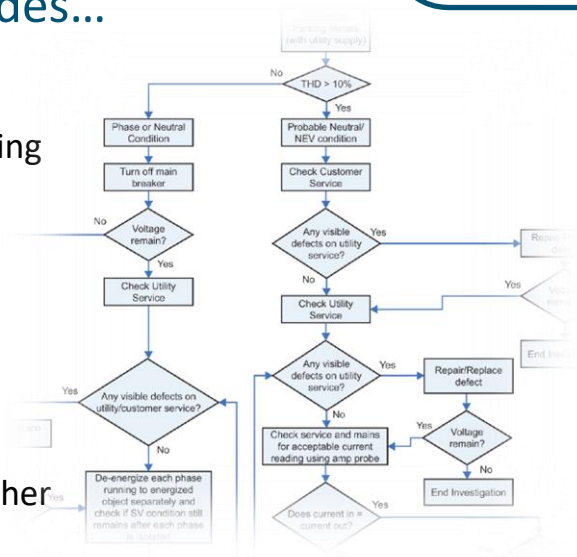
IEEE Std 1695-2024 also includes…

- Specific guidance and protocols for:
  - Accessible voltage at light poles, parking meters, manhole covers, etc.
  - Confined livestock
  - Swimming pools
  - Marinas and boat docks
- Stray voltage investigation forms
- Bibliography
  - Vetted sources of information for further study.



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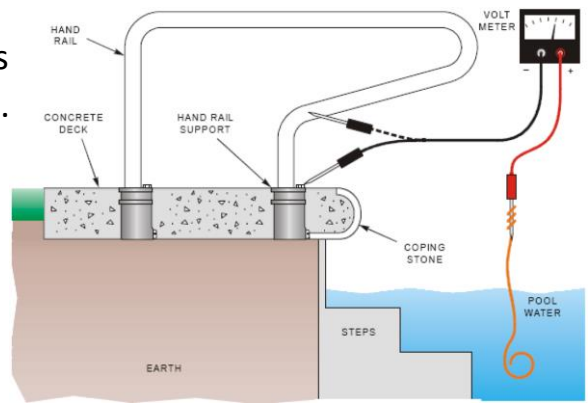
Why you should use IEEE Std 1695-2024

- To expand your skills
  - The standard is a "guide," providing flowcharts and recommended protocols for various possible exposure situations.
  - Dairy investigators can learn to apply familiar tools and techniques to investigate exposure voltages in other locations.



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Why you should use IEEE Std 1695-2024

- To increase your understanding
  - The standard explains what to do, and **why**.
  - The standard can be a self-directed course and "how-to" manual on stray and contact voltage.
  - Numerous photos and diagrams help explain how stray and contact voltages are produced and how to investigate these exposure voltages.

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Why you should use IEEE Std 1695-2024

- To boost confidence and credibility
  - IEEE standards are respected consensus standards.
  - IEEE standards are available to energy providers, regulators, electricians, and others.
  - The protocols in IEEE Std 1695-2024 are designed to produce "*accurate readings that are repeatable from person to person.*"
  - Note: IEEE Std 1695's protocol for confined livestock facilities agrees with the Wisconsin Phase II protocol.

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Terms and definitions

- Accessible or Exposure Voltage
  - An elevated voltage between two conductive surfaces that may be simultaneously contacted by members of the public or animals.
- Stray Voltage
  - An exposure voltage resulting from the normal delivery or use of electricity (current in the neutral-grounding system). Stray voltage is not related to electrical faults.
- Contact Voltage
  - An exposure voltage resulting from electrical faults (a short-circuit or an unintended open circuit). Contact voltage can exist at levels that may be hazardous.

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Stray voltage versus contact voltage

- Stray Voltage
  - Nothing is broken.
  - If the stray voltage level is below some established threshold, it may not require mitigation.
- Contact Voltage
  - A *partial* failure in a conductor's insulation or continuity could progress to a *total* failure.
  - Finding and repairing the fault is required to resolve the contact voltage issue.

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More definitions

- Qualified reference
  - *A measurement reference point verified to be at zero potential relative to remote earth and have a low impedance pathway to the earth.*
  - i.e., A reference rod for urban situations.
  - The standard includes a process for qualifying a reference point.

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Characterizing exposure voltage

1. Open-Circuit Voltage: V_{oc}
2. Source Resistance: V_{sh}, R_{shunt}
   - Low R_{shunt} values (500-1,000Ω) for comparison to exposure thresholds.
   - 10,000Ω to help distinguish between capacitively coupled sources (a type of stray voltage) and conducted sources.
3. Voltage total harmonic distortion (THD), harmonic spectrum, and/or frequency

$$R_{source} = \frac{V_{oc} - V_{sh}}{V_{oc}} \cdot R_{shunt}$$

These exposure voltage characteristics guide the investigation and help us distinguish between stray and contact voltage.

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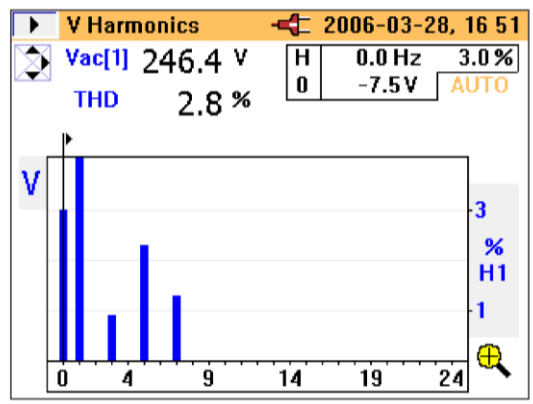
Characterizing exposure voltage: Harmonic analysis – a valuable diagnostic tool

- The earth, metal objects, and conductive surfaces are mostly resistive.
- **A conducted exposure voltage will have the same THD and harmonic content as its source.**
- Phase conductor sources:
  - THD is typically below 5%, and rarely over 10%.
  - Largest voltage component will be the system fundamental frequency.



THD = 2.8% for this line-to-line service voltage measurement.
(Screenshot from Fluke 345)

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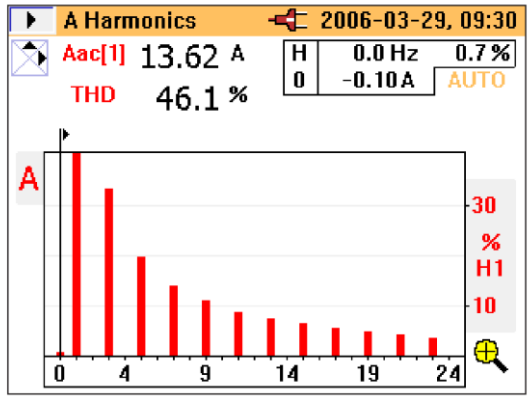
Characterizing exposure voltage: Harmonic analysis – a valuable diagnostic tool

- Neutral-grounding system sources:
  - Neutral current and the voltage drop it creates may have a high THD.
  - Largest voltage component may be 3rd harmonic (180Hz), especially in well-balanced three-phase systems.
  - IF your meter can't measure the harmonic spectrum or THD - Push the Hz button.



THD = 46.1% for this neutral current.

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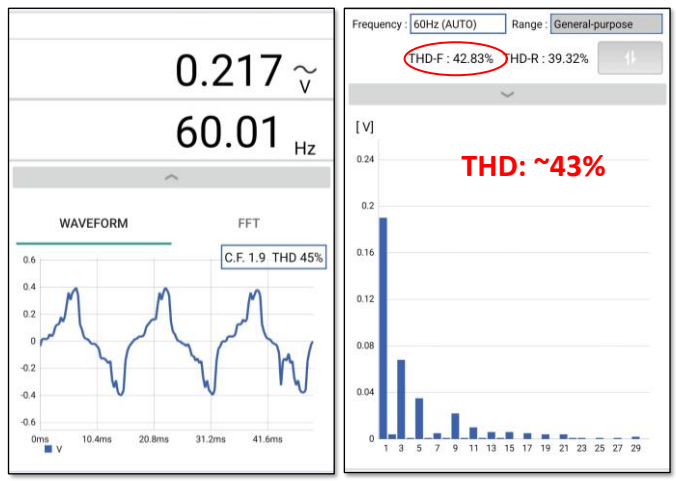
Tools for characterizing exposure voltage

- Pictures in IEEE Std 1695 are from a Fluke 345 handheld Power Quality Analyzer – discontinued by Fluke.
- Hioki DT4261 Digital Multimeter, with wireless module, ~$350 USD in February 2025.*
- Hioki phone app lets you view and save waveforms, harmonic spectrum, THD data, and photos.

*Not an endorsement.

Neutral-to-ground voltage waveform and spectrum



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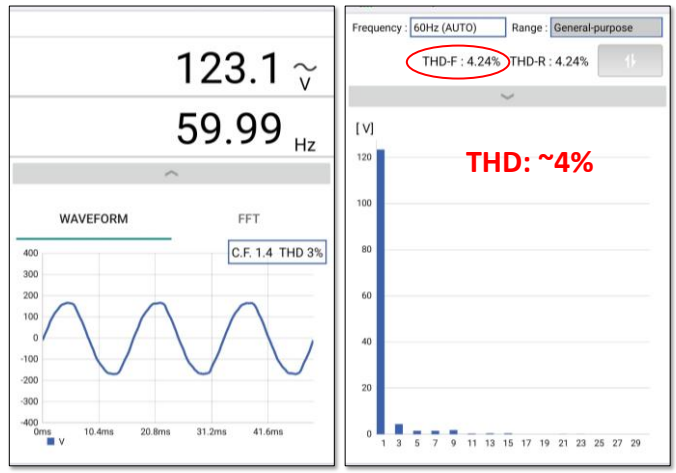
Tools for characterizing exposure voltage

- Characterizing the exposure voltage helps us identify the source.

Hioki DT4261 LoZ setting uses 1MΩ.

Line-to-ground voltage waveform and spectrum



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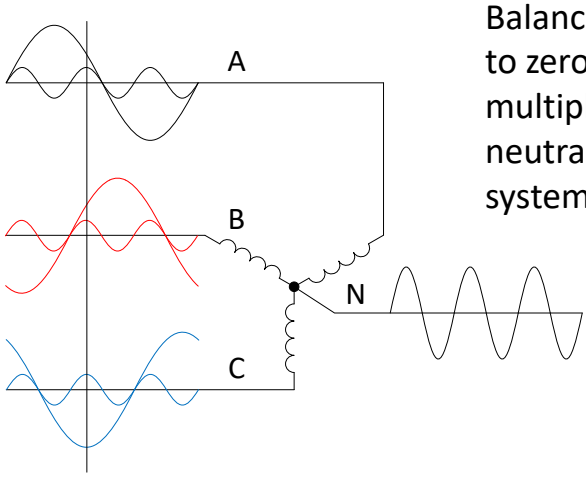
Characterizing exposure voltage:
Why the neutral current may be mostly 180Hz



Balanced fundamental (60Hz) currents sum to zero. Triplen harmonic currents (odd multiples of 3) are in-phase and add in the neutral in wye-connected distribution systems.

Neutral current may be primarily third harmonic (180Hz).

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Characterizing exposure voltage:

- Distinguishing between Stray and Contact voltage.
  - Voltage level alone is not enough.
  - Source resistance alone is not enough.
  - THD alone is not enough.
- Voltage measured with and without a shunt resistor, AND the THD or harmonic content of that voltage can help the investigator decide where to continue their investigation.
  - >10V AC-RMS and <5% THD? – more likely a line-conductor fault
  - <10V AC-RMS and >10% THD? – more likely a result of neutral voltage drop

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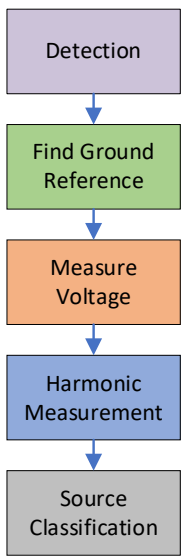
Example application of IEEE Std 1695



A utility worker, a CVD program, or the public detects an exposure voltage.

Set up to take repeatable voltage measurements.

Measure open-circuit and shunted voltage to distinguish between high and low-impedance sources.

Measure THD, spectrum, frequency, to help characterize the source as a line conductor or a neutral conductor.

Additional work to identify the source(s) by opening circuits, load testing, etc.

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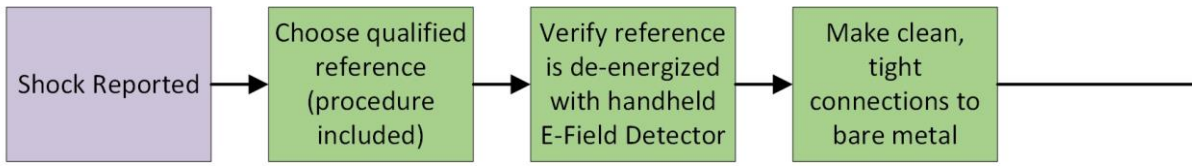
Example application of IEEE Std 1695-2024

- You're called about someone reportedly feeling a shock at a streetlight pole during the day. We'll follow one path through a flowchart included in IEEE Std 1695-2024.



Setting up to take voltage measurements and characterize the voltage.

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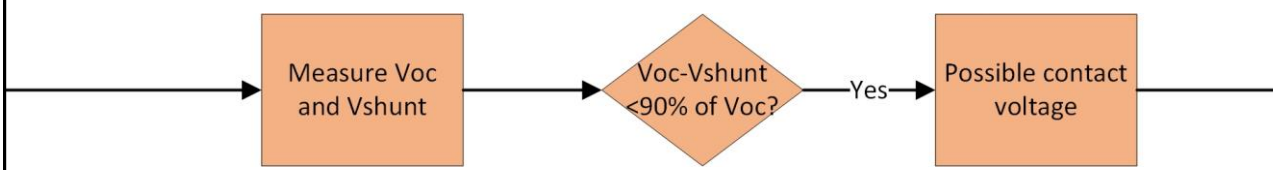
Example application of IEEE Std 1695-2024

- Taking voltage measurements.
- Source is low-impedance – not capacitive coupling and not a fault through a high impedance.



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Example application of IEEE Std 1695-2024

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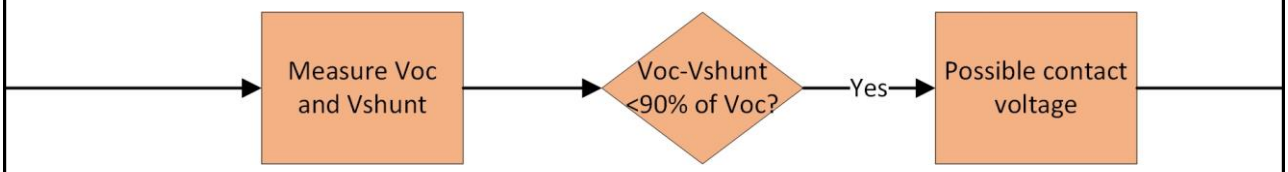

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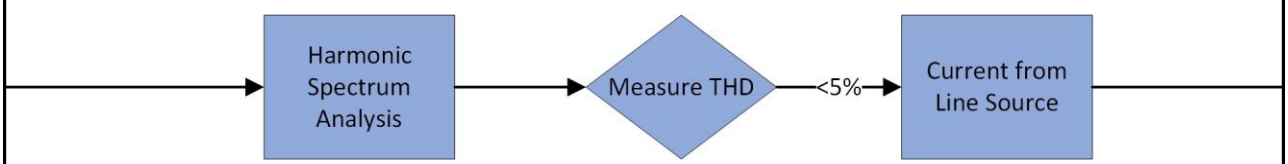
Example application of IEEE Std 1695-2024

- Check voltage THD, frequency, spectrum.
- Low THD, 60Hz source – suggests a line conductor fault.



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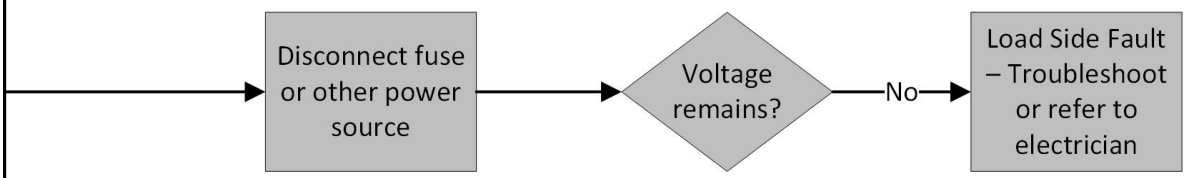
Example application of IEEE Std 1695-2024

- Isolate fault by disconnecting fuse.
- Fault is in the light pole wiring.
- Pole is left safe (fuse removed).



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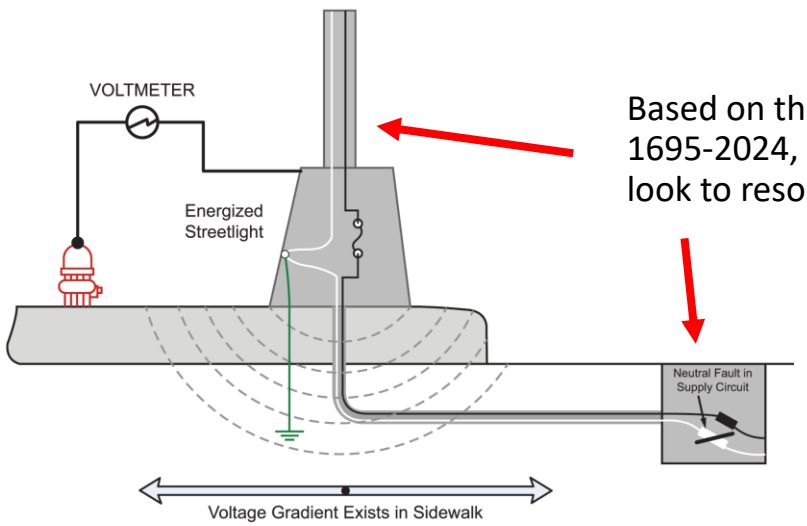
Example application of IEEE Std 1695-2024



Based on the protocol in IEEE Std 1695-2024, we know where to look to resolve this issue.

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Questions?

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