IEEE PES TR130 Protection Methods to Reduce Wildfire Risk from Transmission and Distribution Lines

ERCOT System Protection WG - Fall Meeting

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Introduction

Wildfire Ignition Risk: A Growing Concern

Wildfires are becoming more frequent and severe.

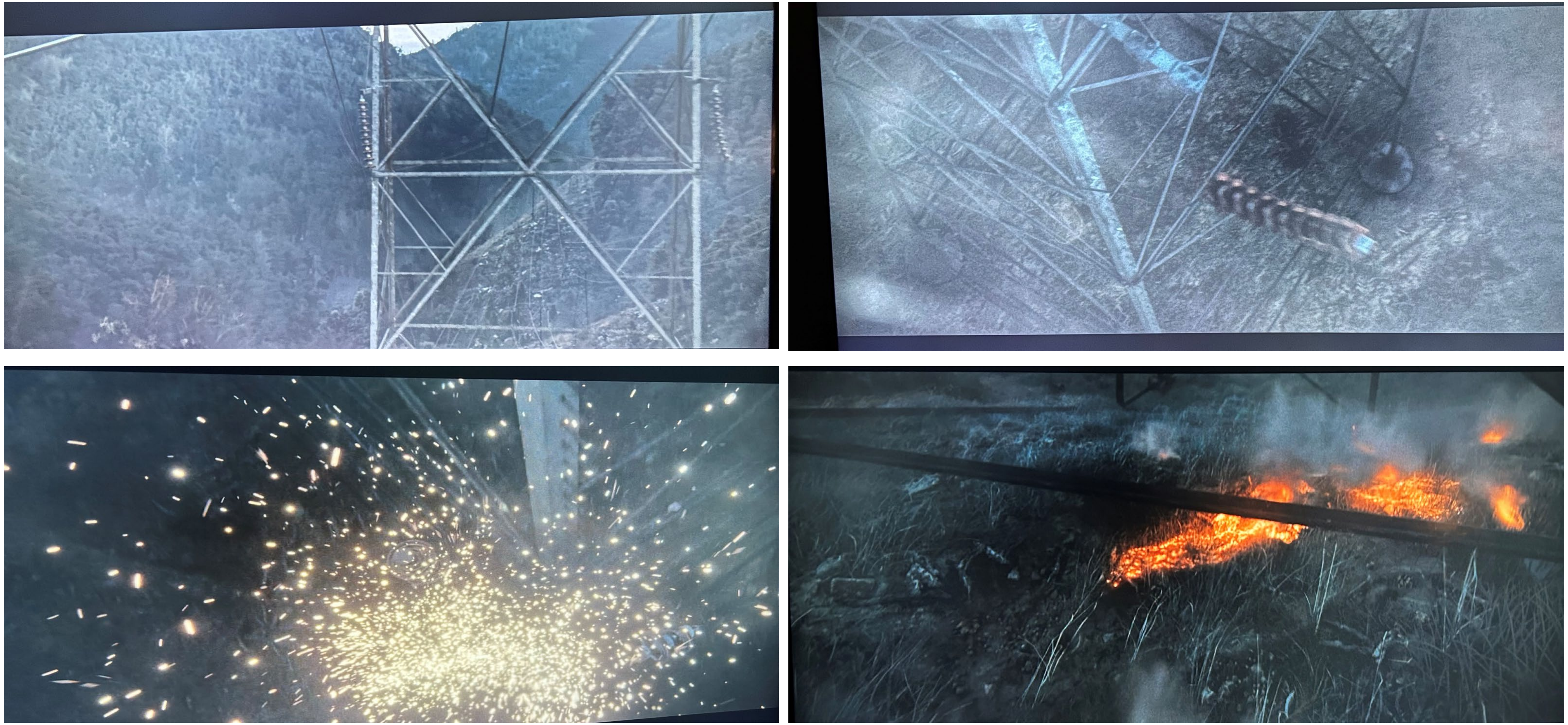
The electrical system is not the largest cause of wildfires but fires that ignite from powerlines are destructive, fueled by increasingly extreme weather.

Over the last decade, some of these *megafires* have destroyed over **400,000** hectares of land, **10,000** homes, and have impacted thousands of lives.

The U.S. Interagency Fire Center defines a **megafire** as a wildfire that burns more than 40,500 hectares (100,000 acres) of land.

Introduction

Paradise Fire, November 2018 (dramatization)



Source: The Lost Bus – Apple TV

Introduction

Eaton Canyon Fire, January 2025

Residents of a home abutting Eaton Canyon who were among the first people to report the fire to authorities told *Pasadena Now* that the fire began in proximity to electrical transmission towers above the canyon.

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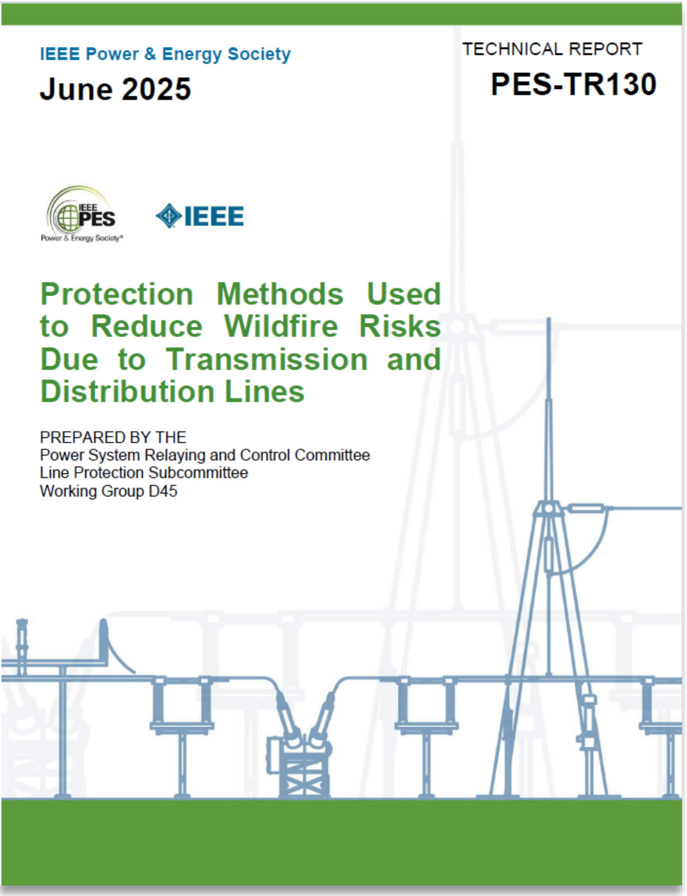
Overview



IEEE PES PSRC Working Group D45:
Prepare a technical report to the Line Protection Subcommittee to “document protection methods used to reduce wildfire risks due to transmission and distribution lines.”

Chair: Jonathan Sykes
Vice Chair: Scott Hayes
Published: June 5, 2025
Team: Utilities, Consultants, Academia, and Manufacturers

IEEE PES PSRC Working Group D45

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Status:

- Multi-Year Effort
- Approved by IEEE PES.
- Published: Protection Methods Used to Reduce Wildfire Risks Due to Transmission and Distribution Lines | IEEE Resource Center

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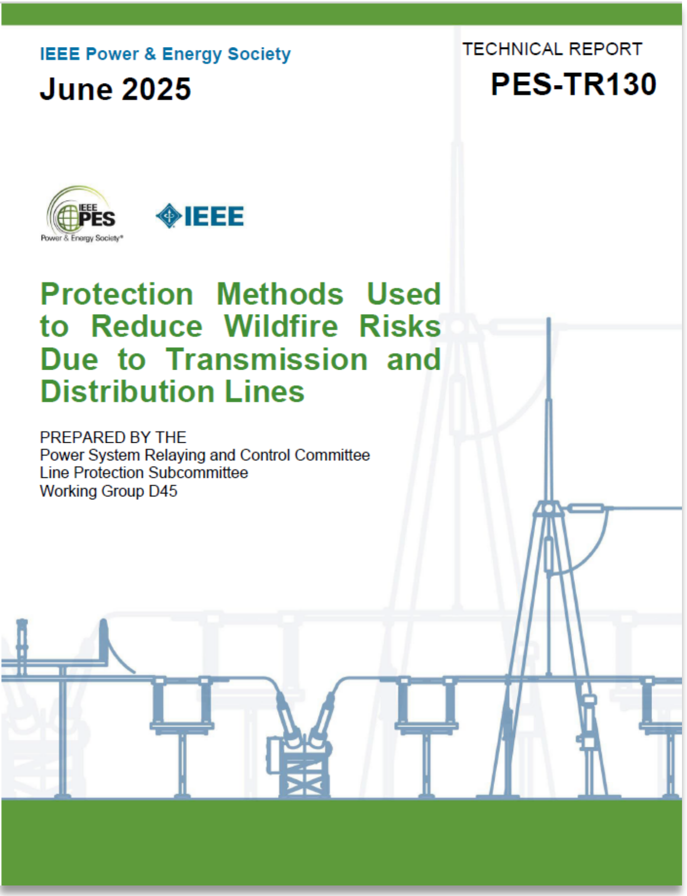
Table of Contents (Abbreviated)


IEEE Power & Energy Society
June 2025

TECHNICAL REPORT
PES-TR130

Protection Methods Used to Reduce Wildfire Risks Due to Transmission and Distribution Lines

PREPARED BY THE
Power System Relaying and Control Committee
Line Protection Subcommittee
Working Group D45

7 Technical Chapters

- Fault Behavior and Ignition Risks
- Fault Responsive Relay Applications
- High Impedance Fault Detection
- Neutral Grounding Practices
- Compensated Neutral Schemes
- Incipient Fault Detection
- Impact of Fuses on Fire Risk

Fault Behavior and Ignition Risk

Ignition Risk Increases with Fault Energy

- **Fault energy is a function of the magnitude of fault current and the duration of the fault.**
- There are too many variables to determine the exact risk (fault conditions, fuel, climate).
- The electrical grid extends thousands of miles throughout the forest and has millions of arc possibilities.
- **The longer the fault or arc lasts, the more heat energy is present and the greater risk of a wildfire.**

Fault Behavior and Ignition Risk

Types of Ignition Events

Wildfires from electric equipment primarily happen when ignitions occur due to a fault on a powerline.

These faults fall into two categories:

1. Direct contact faults
2. Wire down faults
3. Overhead arcing faults

Instantaneous Faults: Immediate Risk

Direct Contact Faults
Energized equipment makes direct contact with combustible fuel

Wire Down Faults
Electrical current flows from conductors onto combustible fuel

Public Safety Power Shutoff (PSPS)

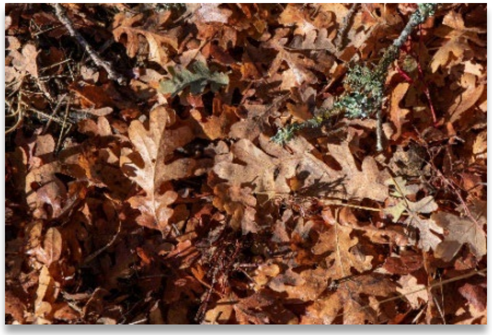
Risk and Reliability

- The deliberate de-energizing of electrical lines when the conditions exist that could result in a wildfire.
- The line must be patrolled and energized when there is no longer a risk of wildfire.

A Red Flag Warning issued by the National Weather Service

Low humidity levels of 30% and below.

Forecasted high winds above 19 mph and gusts above 30–40 mph.



Condition of dry material on the ground and low moisture content of vegetation.

Fault Responsive Relay Applications

Limit the Energy at the Arc

- Relay settings adjustments
- Automatic reclosing
- Impedance-based protection
- Advanced fault detection methods

These solutions can be used as a **first line of defense** in a layered protection approach

Primary aim is to quickly **detect and isolate faults** with a minimal impact on reliability

HAAS study: C. Warner, D. Callaway, and M. Fowlie, “Risk-Cost Tradeoffs in Power Sector Wildfire Prevention,” Energy Institute at Haas, WP 347, Feb. 2024 https://haas.berkeley.edu/wp-content/uploads/WP347.pdf

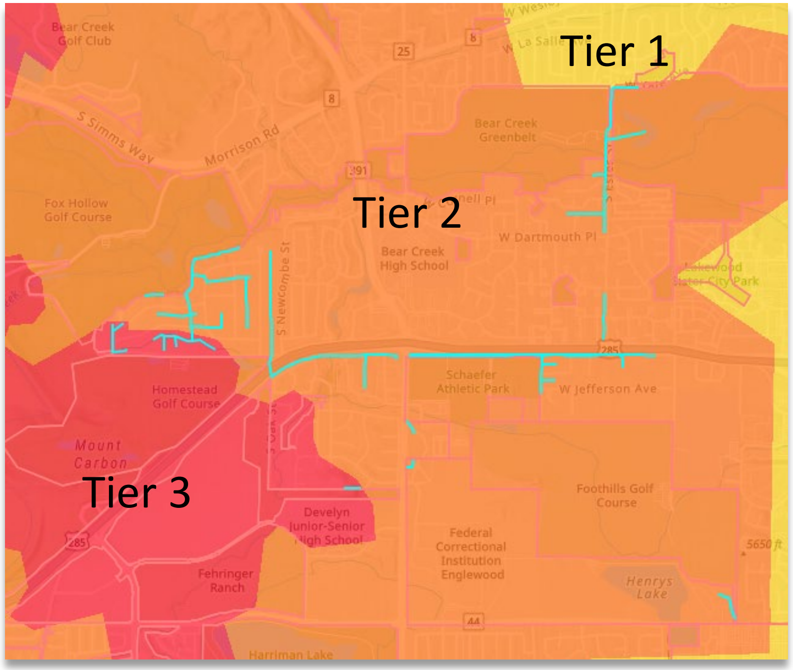
Fault Responsive Relay Applications

Line Recloser Placement

Add line reclosers to:

1. Separate fire risk zones.
2. Coordinate with fast clearing.
3. Enable advance sensing and detection.
4. Provide fault location.

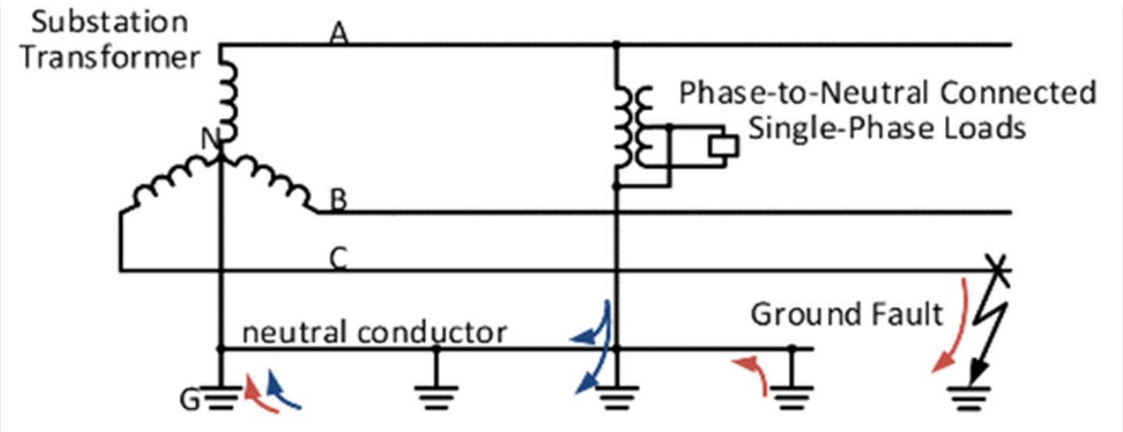
Wildfire risk zones

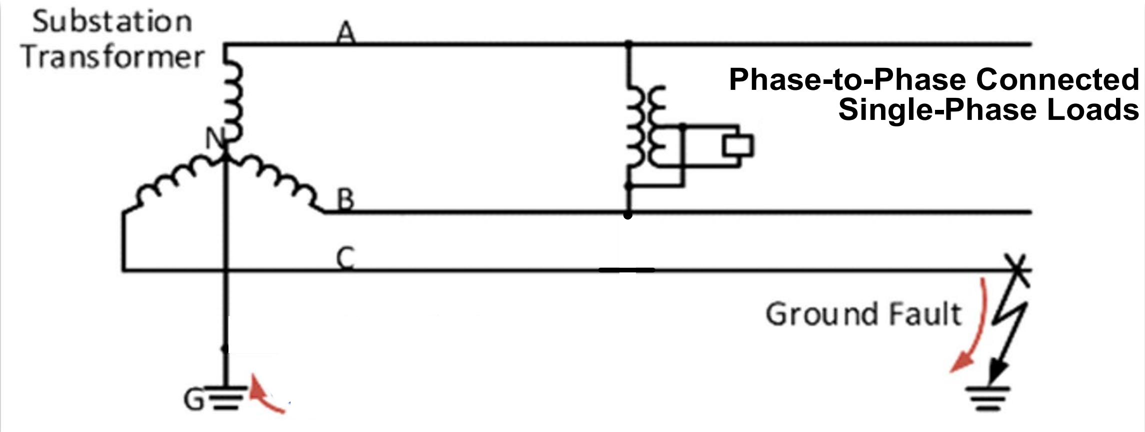


Faults in Tier 2–3 zones should be cleared within required operating time limits.

Fault Responsive Relay Applications

4-Wire and 3-Wire Systems





4-Wire:

Common in North America
Line-to-neutral loads
Unbalanced load flow considerations
Desensitized ground relay

3-Wire:

Common internationally
Line-to-line loads
Minimal unbalanced load flow
Very sensitive ground relay

Fault Responsive Relay Applications

Instantaneous Clearing of Faults

How ignitions become wildfires

Fault duration and magnitude

Proximity to dry fuel

Weather conditions

Grounding quality

- ✓ **Detect and clear** a fault faster.
- ✓ **Reduce** single-phase fuse operation.
- ✓ **Detect** a higher-impedance fault.
- ✓ **Apply** a Definite Time element (phase and ground) or a similar curve, with blocking of reclosing on these faults.
- ✓ **Study** N-1 and ties on the feeder.

Fault Responsive Relay Applications

Industry Comparisons of Fast Tripping

	Utility 1	Utility 2	Utility 3	Utility 4	Utility 5	Utility 6
Voltages (kV)	4, 12, 17, 21	4, 12, 16, 33	4, 12	4.2–20.8	13.2, 24, 34	12, 25
Configuration/ Grounding	3-wire uni-ground, 4-wire multi-ground	3-wire uni-ground, 4-wire multi-ground	3-wire uni-ground, 3-wire multi-ground via line-installed ground banks, 4-wire multi-ground	3-wire delta, 3-wire uni-ground, 4-wire wye	4-wire multi-ground	4-wire multi-ground
Fast Trip	Yes	Yes	Yes	Yes	Yes	Testing and pilot
Reclosing	Disabled	Disabled	Disabled	Disabled	Profile dependent	Disabled
Fast Trip Designation	Enhanced Powerline Safety Settings (EPSS)	Fast Curve (FC) Settings	Sensitive Relay Profile (SRP)	Sophisticated Program Control Settings (SPCS)	Fire Safety Mode (FSM)	N/A

Results of Fast Tripping on Ignitions

2022 Expansion of Fast Trip Settings

2022 program expansion

100% of distribution high fire-risk area line miles protected

1.82 M customers protected

374% increase compared to 2021

Despite 31% more days in R3+ conditions there was a:

68% reduction in ignitions*

88% reduction in fire size from ignitions**

*Data is approximate; *Based on 2022 performance for CPUC-reportable ignitions in HFTD compared to 2018–2020 weather-normalized performance; **Relative to 2018–2020 average excluding pre-EPSS Zogg Fire event.*

- In 2022, use of EPSS expanded to all distribution lines in high fire-risk areas.
- Expansion drove improvements and these settings helped to prevent wildfires, even with higher risk conditions.

Fault Responsive Relay Applications

Communication-aided Protection Methods

- Step-distance-based communication systems (i.e., POTT)
- Transmission line current differential (LCD)
- Time-domain and traveling-wave protection (TW)

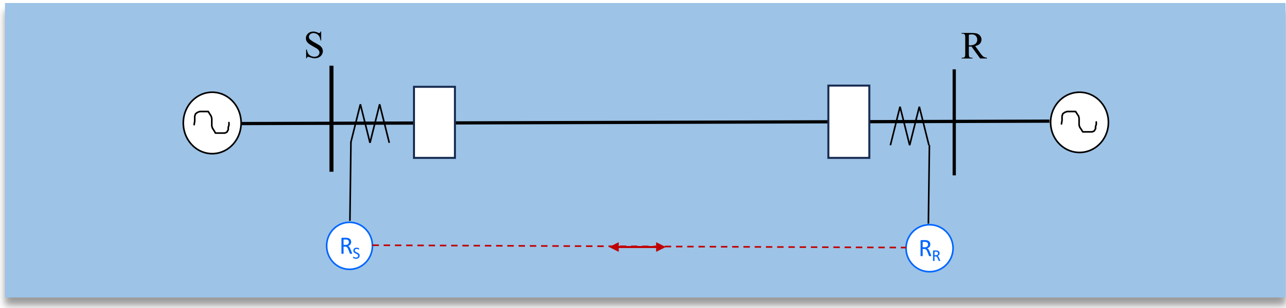
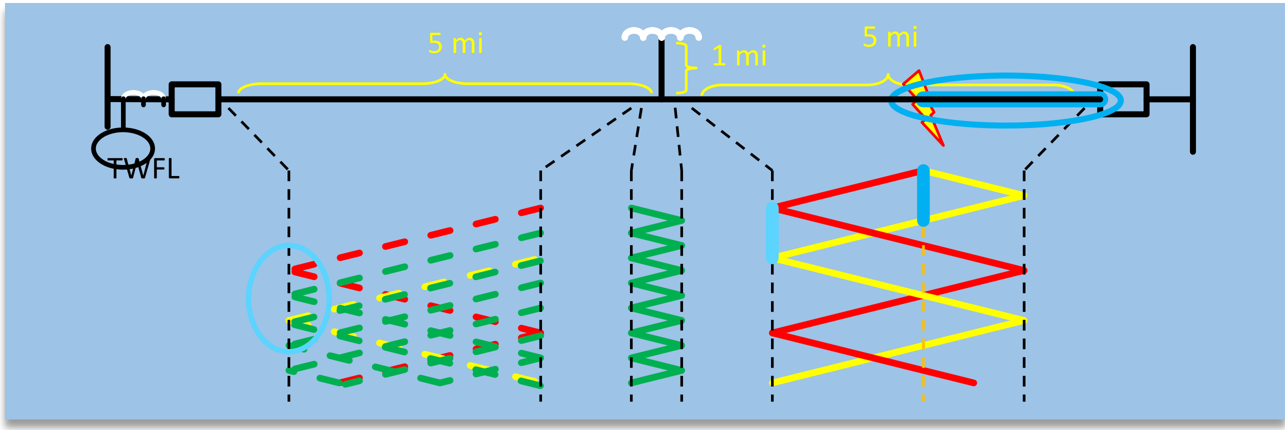


Figure 4.3.2. Line-current differential



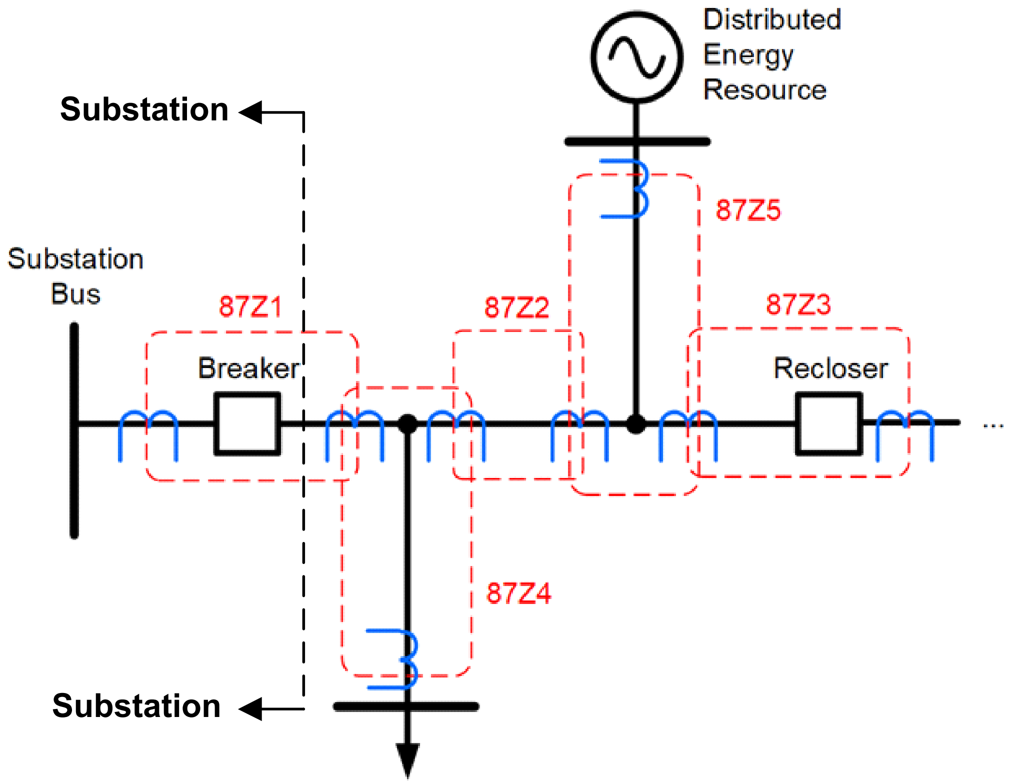
TW for complex line topologies

Fault Responsive Relay Applications

Distribution Differential and Passive Measurements

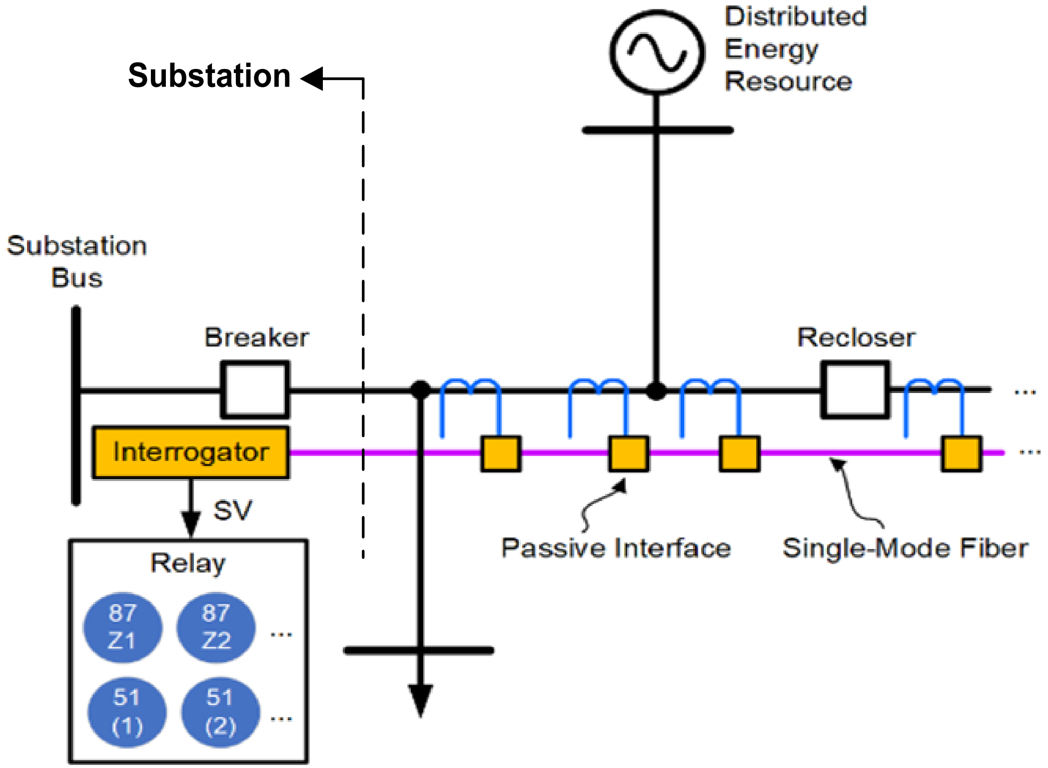
Traditional approach

Complex and costly



Passive measurement

Utilizes advanced techniques



High-Impedance Fault Detection

Pulse Counting

Arcing produces a wide spectrum of even-, odd-, and inter-harmonic energy along the power line that extends into the MHz range.

Detection strategies:

- Derive the high-frequency signal component including even and odd harmonics in the range of sub-harmonic to 1 MHz.
- Tune the response of the detection algorithms.
- Apply logic to differentiate an HIF condition from switching operations and noisy loads.
- Detect intermittent arcing (i.e., pulse counting).

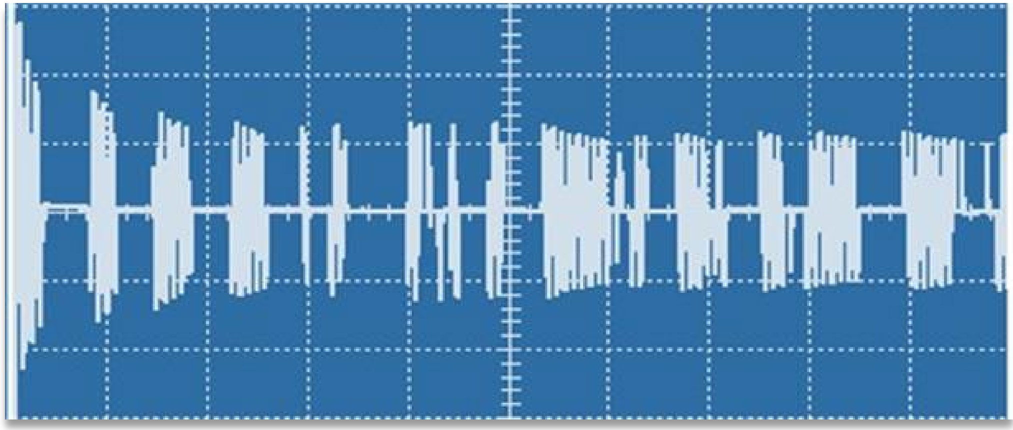


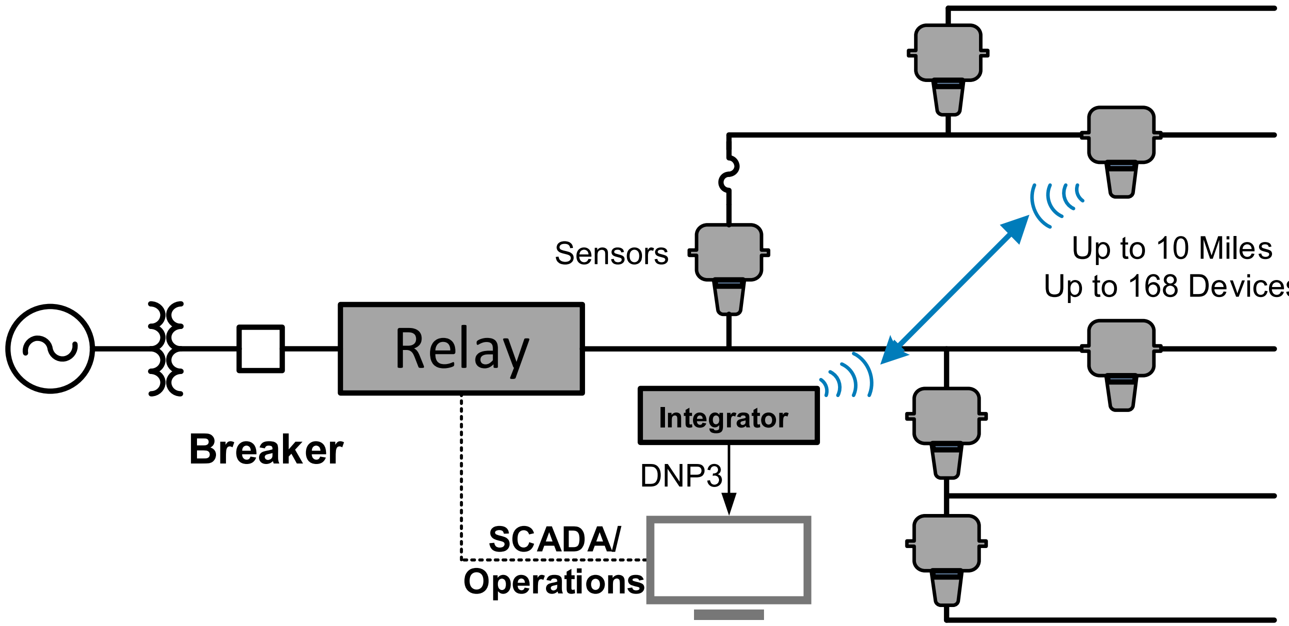
Diagram 5.1 Example of time-varying, intermittent, and harmonic-rich HIF current waveform

High-Impedance Fault Detection

Fault and Load Sensors

Sensor-based methods including advanced analytics can be used on the distribution system for fault detection and location.

- Fault/load transmitter (sensor) data is first integrated into SCADA before being sent to the HIF detection relay.
- Alternatively, the relay can receive the data directly by installing the receiver at the fault detection location.



Fault/load transmitter and receiver application

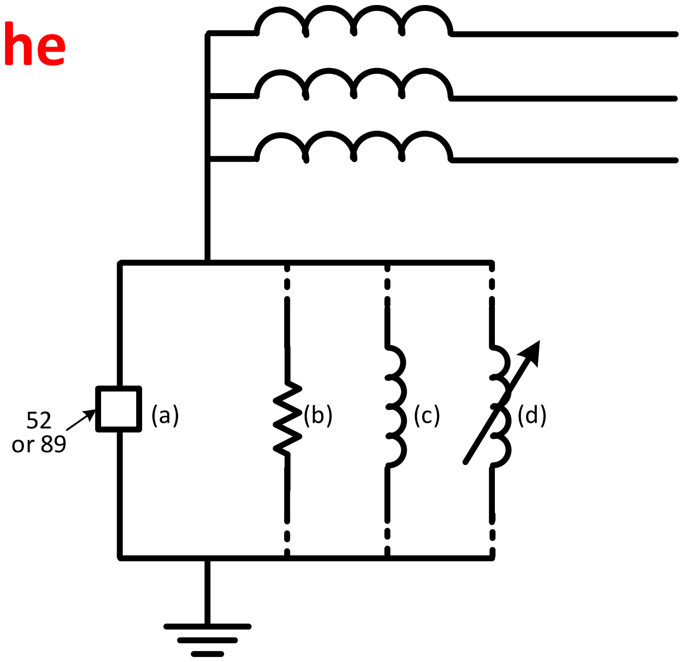
Neutral Grounding Methods

Reduction of Ground Faults to Less than 0.5 A

When applying delta or high-impedance grounding methods, the effects of temporary over voltages on equipment and the impact on detecting ground faults must be considered.

System types:

- Multipoint-grounded wye
- **Uni-grounded wye**
- Delta, ungrounded
- Delta, grounded
- Wye-grounded with high-impedance grounding.



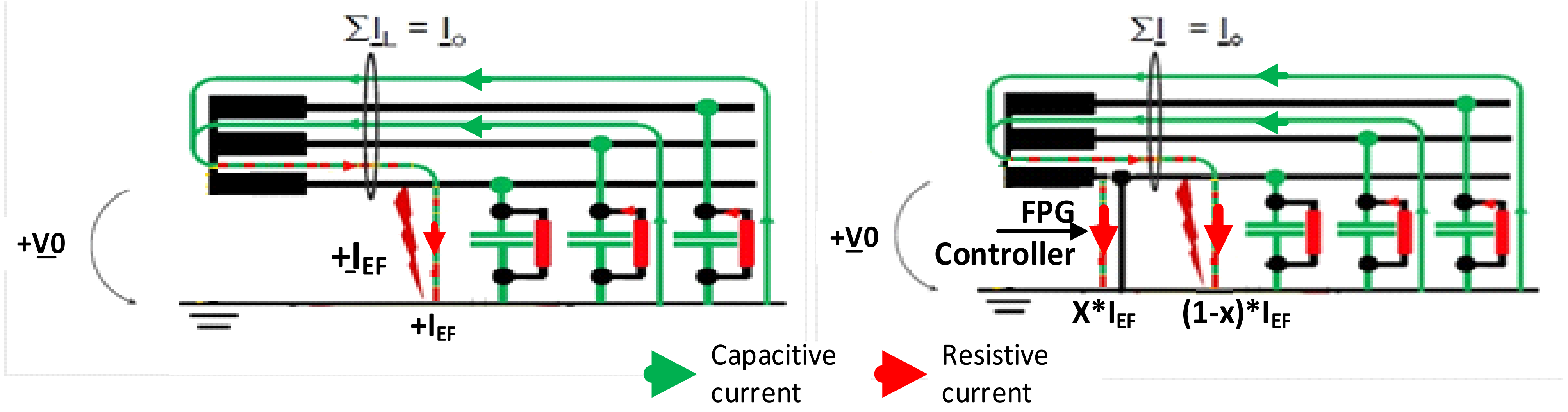
High-resistance/reactance/ compensated ground

Neutral Grounding Methods

Isolated Neutral with Faulted Phase Grounding

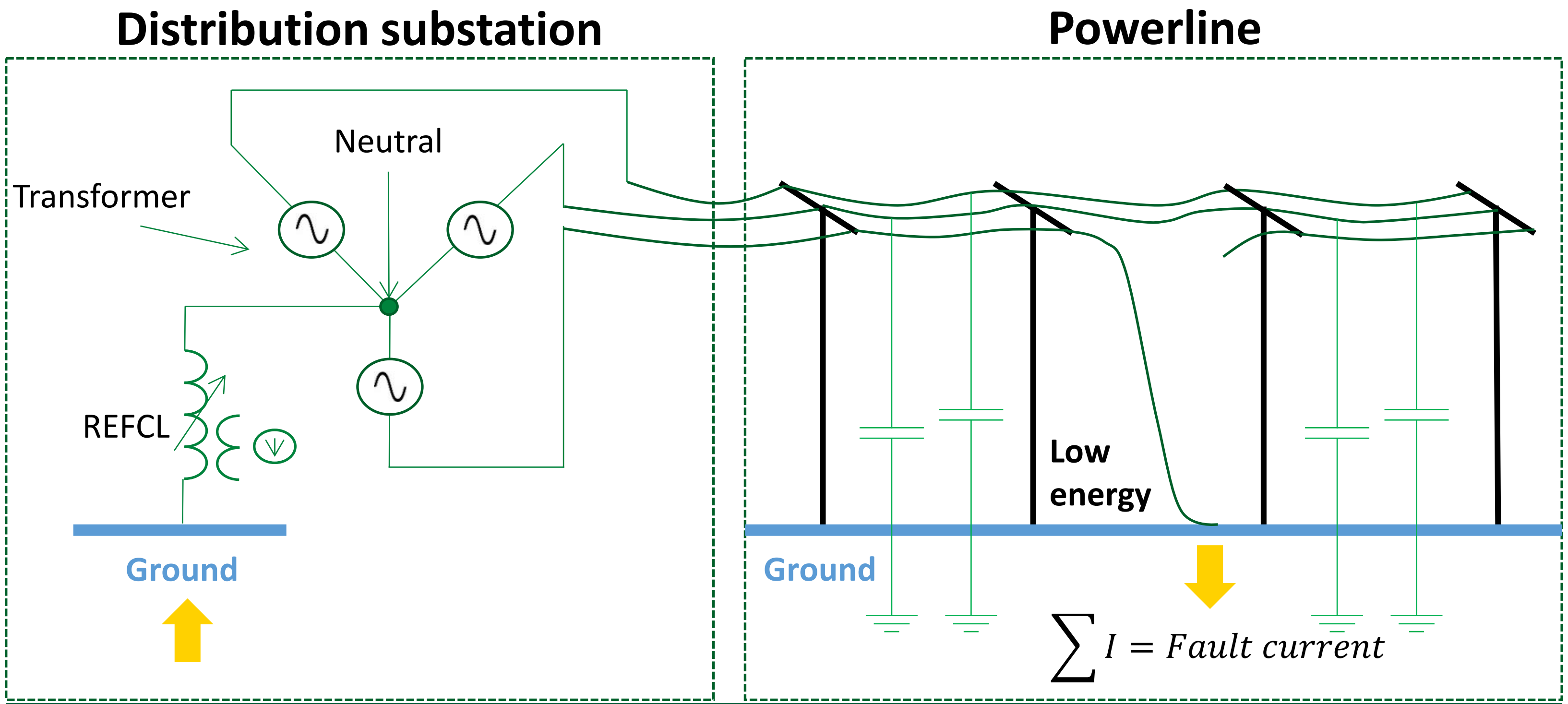
When a ground fault is detected, the FPG controller initiates a single-pole close in the substation that connects the faulted phase to the substation's ground.

This reduces the ground fault current at the fault site by 90 percent or more, depending on the ratio of the ground fault contact resistance to that of the substation ground grid resistance,



Compensated Neutral Schemes

Rapid Earth Fault Current Limiter (REFCL)



Future with REFCL: Less than 0.5 A

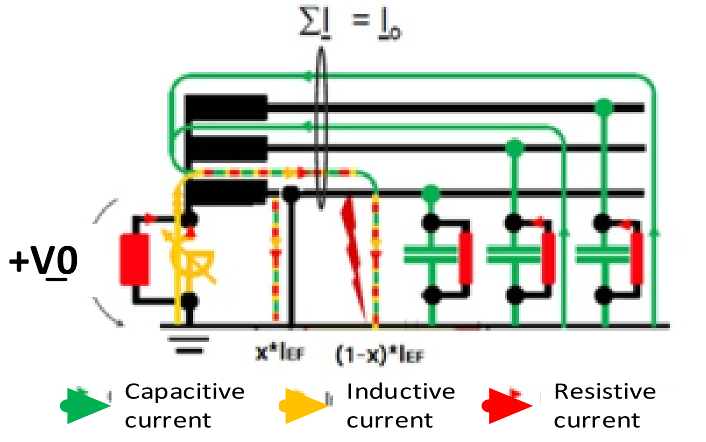
Source: PowerCore Australia's Control and Ops REFCL Guidebook

Note: Compensated neutral schemes also referred to as Petersen Coils were first developed in Germany by Waldemar Petersen in the early 1900's and appear in AIEE papers beginning in 1922.

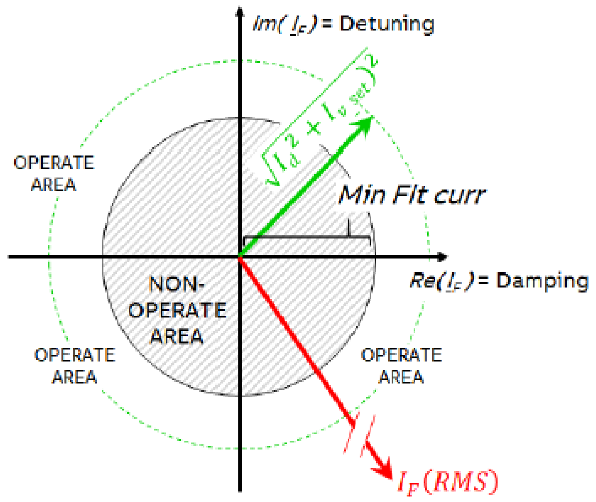
Compensated Neutral Schemes

Specialized Methods

- Directional residual overcurrent methods
- Fault inception transient methods
- Charge voltage (qu) methods
- Transient reactive power methods
- Admittance methods
- Multi-frequency admittance methods
- Change in admittance methods
- Change in negative-sequence current methods
- Harmonics



Fault with CN and FPG

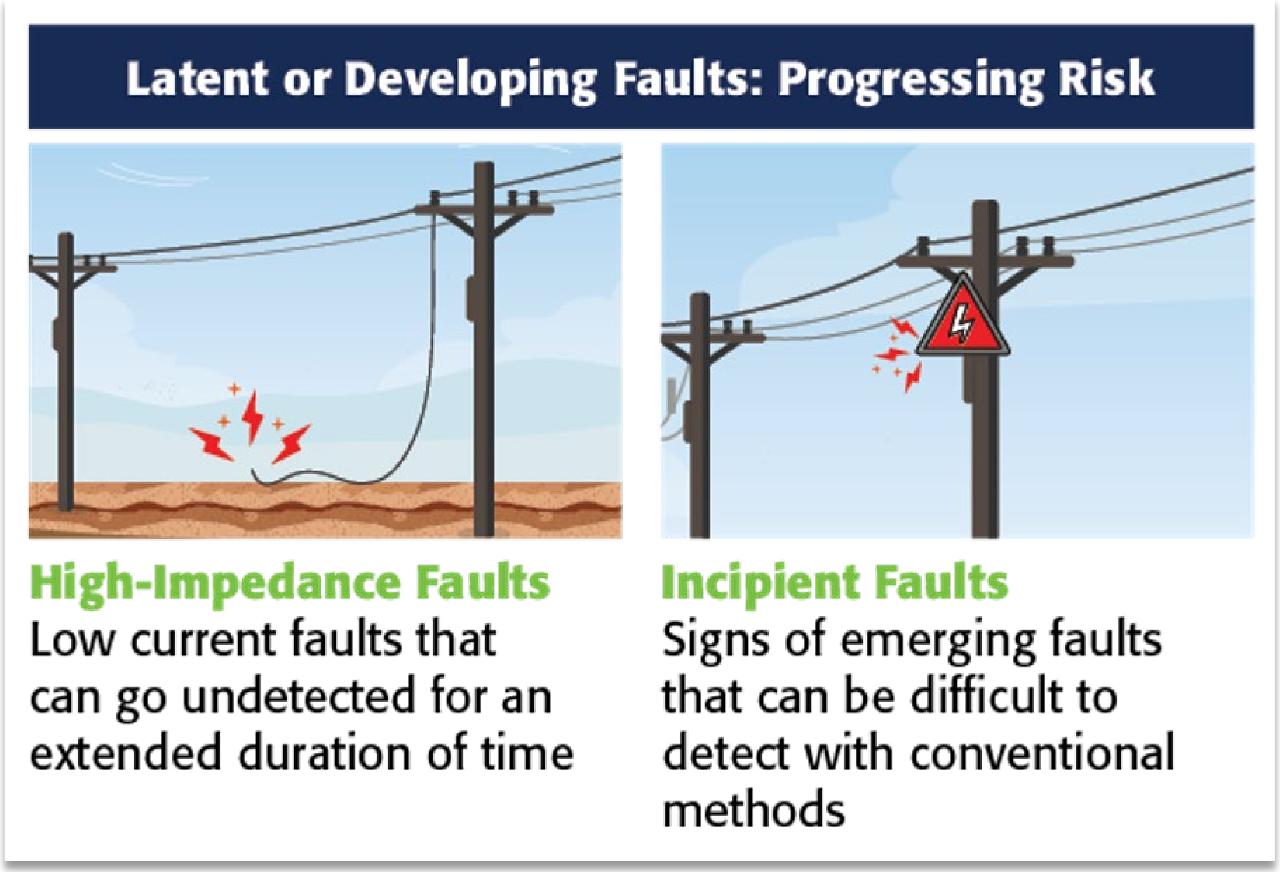


Change in Negative Sequence

Incipient Faults

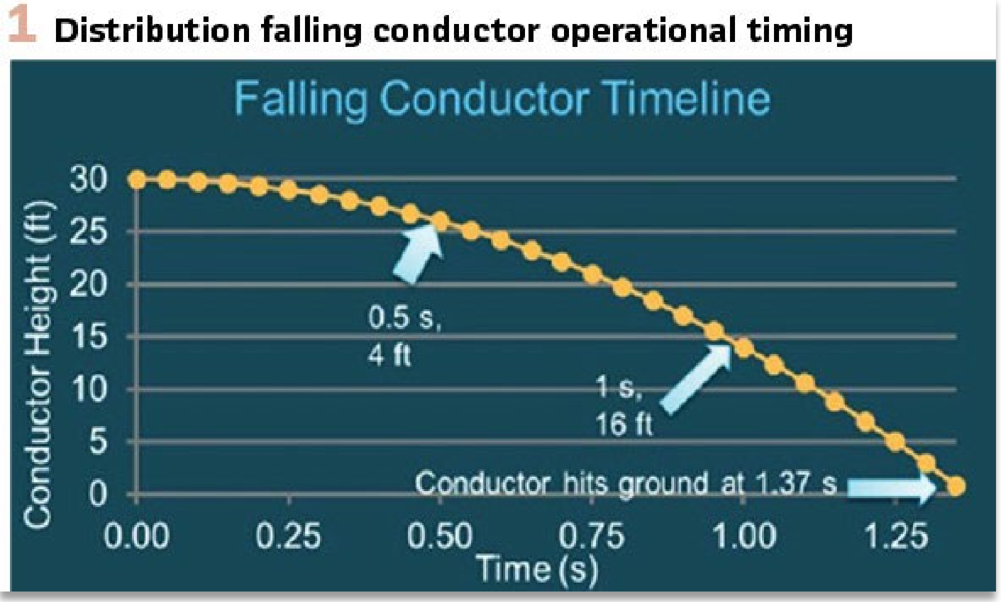
Latent or Developing Faults

- Latent faults feature ignition risk that worsens over time and may have currents too low to be detected by traditional methods.
- If left untreated, these can also lead to failure and are referred to as **incipient faults.**



Incipient Fault Detection

Falling Conductor Detection (FCP), Broken Conductor Detection (BCD), Open-Phase Methods



Falling Conductor Protection (FCP) systems, developed around 2014, detect the electrical signature of circuit voltage and/or current changes.

There is adequate time to deenergize the circuit well before the conductors reach the ground:

- A distribution conductor 33 feet in the air takes about 1.4 seconds to reach the ground.

Voltage sensing is commonly used for distribution and current sensing for transmission.

Incipient Fault Detection

Catch a Problem Prior to Ignition

The gold standard sought by the industry includes methods to detect incipient faults with enough time to act before high-current faults occur.

Principles used for the technologies and solutions for incipient fault detection can be classified under the following categories:

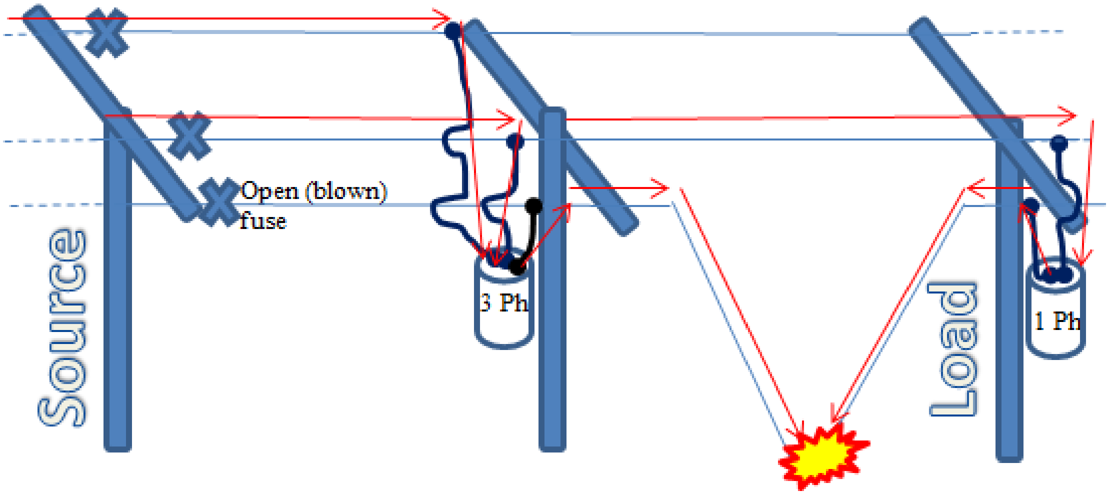
- Pattern recognition
- Fiber-based line monitoring methods
- Corona discharge detection / partial discharge analysis
- Video monitoring based
- Remote sensing and LiDAR-based

Impact of Fuses on Fire Risk

Fuses Are Typically the Most Common Protective Device Installed in Overhead Distribution Systems

Various types include:

- Single-phase devices
- Expulsion fuses
- Non-expulsion fuses
- Current-limiting fuses
- Electronic interrupters.



Single-phase fuse operation

Backfeed issue: If three-phase or phase-to-phase transformers are connected on the load side of the blown fuse, it can result in low-level currents flowing that have been known to ignite fires. This is sometimes called a backfed fault.

Impact of Fuses on Fire Risk

Fuse Saving and Fuse Blowing

- **Fuse-saving strategies** permit an upstream device to overreach the sensitivity of the fuse and trip before the fuse has a chance to operate (melt open (blow)). On the automatic reclose of the line, the sensitive element of the relay is blocked, and the fuse is allowed to blow.
- **Fuse-blowing strategies** permit fuses to operate immediately, before the upstream relay.

Considerations:

1. Certain types of fuses may eject hot gases or particles that pose ignition risks.
2. Disabling the automatic reclosing function (in fuse-savings schemes) can help reduce this ignition risk.
3. Advanced versions of this strategy, using sensors installed on feeders, can dynamically determine when reclosing should be allowed based on environmental conditions and fault-clear detection.

Summary

Working Group D45 is committed to advancing protection methods that balance wildfire safety with power system reliability.

Key takeaways

Wildfire ignition risk from transmission and distribution faults is increasing with extreme weather conditions.

Fault energy (current × time) directly affects ignition probability — faster detection and clearing reduces risk.

Layered protection methods — relays, reclosing strategies, grounding practices, and fault detection — are most effective.

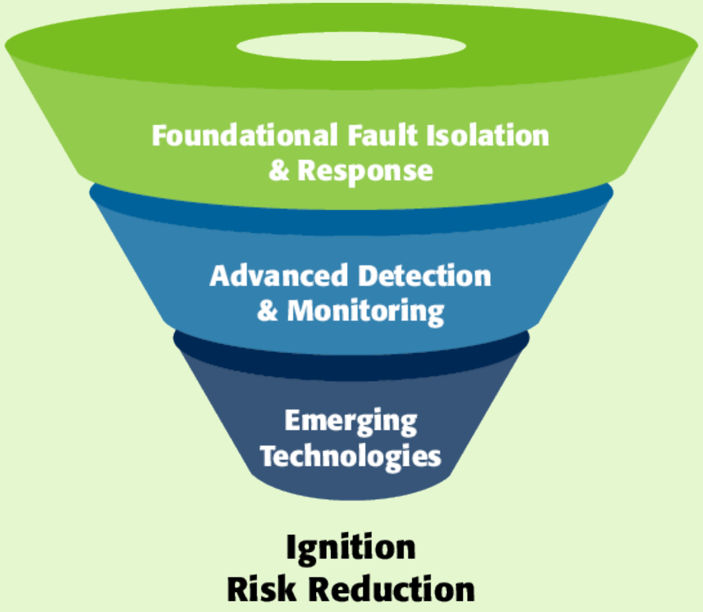
Enhanced sensing (HIF detection, falling conductor protection, REFCL) provides earlier identification of hazardous conditions.

Continued IEEE PES PSRC research and industry testing are needed to develop ignition risk formulas and guide best practices.

The Big Picture

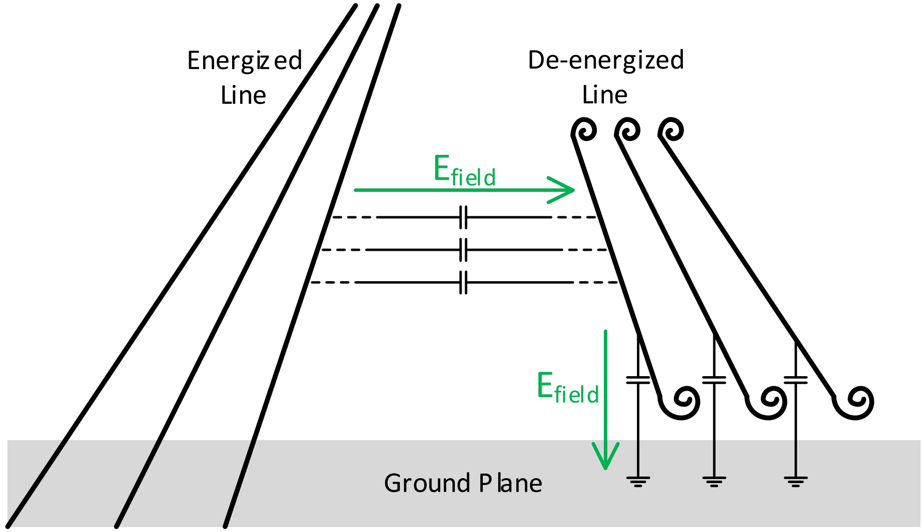
Use Layers of Protection

All fault detection methods have specific limitations, so using a **strategically layered defense approach** is vital to cover various system needs.



Induction Risk

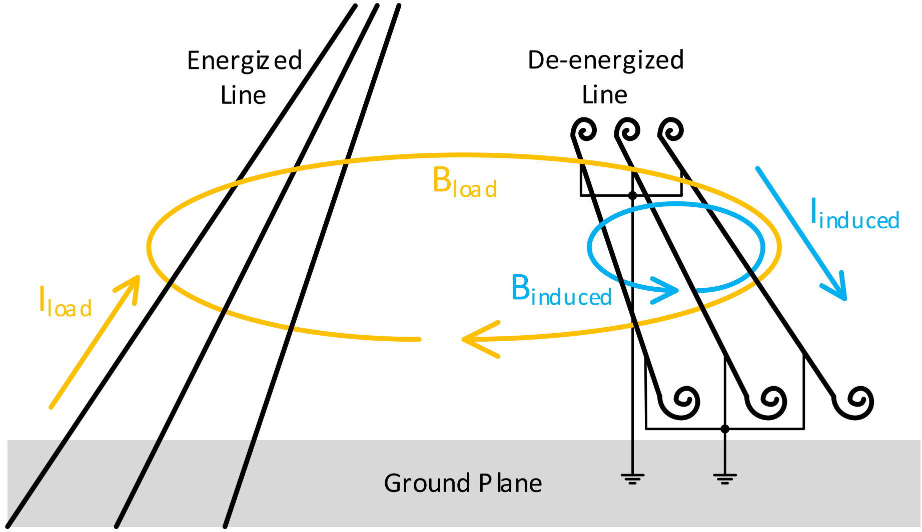
Mutually Coupled De-energized Lines



Electric field induction

For typical lines:

- High-induced voltage (~$V_{energized}$)
- Low-induced 'fault' current (~line length)
- High Thevenin Z

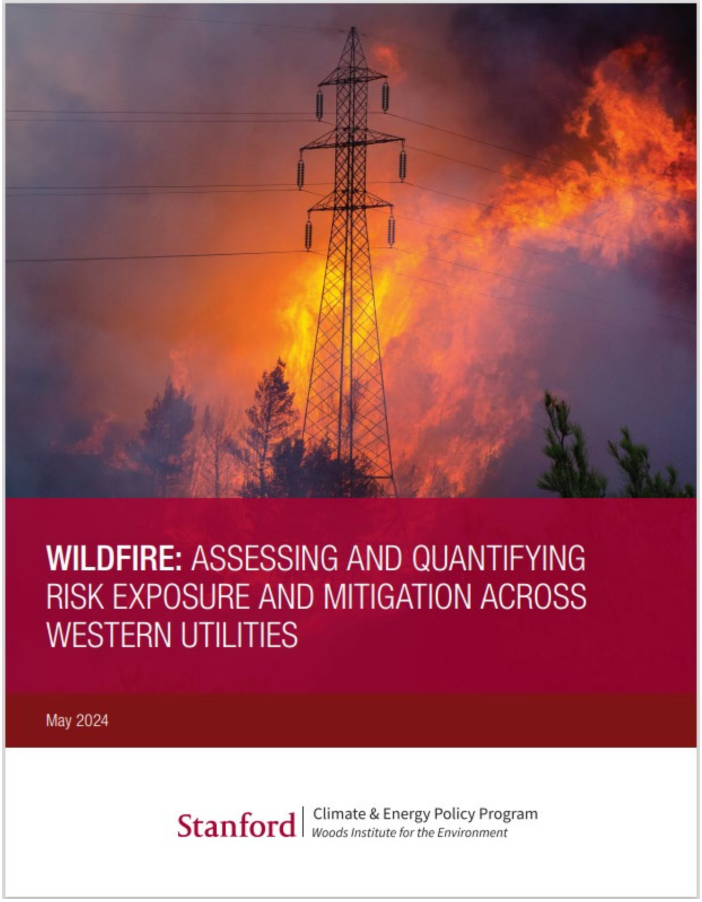


Magnetic field induction

- **For typical lines:**
  - Low-induced voltage (~line length)
  - High-induced 'fault' current (~$I_{energized}$)
  - Low Thevenin Z
- **Very large voltage and current during fault**
- **Fire risk at location of grounds**

How prepared are you ?

Do you have an action plan to mitigate the risk?



[Woods_CEPP_Wildire_White_Paper_FINAL.pdf]

Key takeaways

1. Have you done an assessment?
2. Do you know where the elevated risks are in your service territory?
3. How do you compare with the industry?
4. Do you have a Wildfire Mitigation Plan (WMP), PSPS procedure, fast trip settings, weather tracking, or restoration plan?
5. What is you FEMA Wildfire Risk Ratings

IEEE Initiative and RFP

Probability Equations

Fault Energy = I^2 T*R

Fire-ignition risk ≠ I^2 T*R

Australian Testing $P_I = \dfrac{1}{1 + e^{-(-7.85+0.129t)}}$

P_I =Probability of Ignition at 200 amps

California Testing of Molten Particle Production

$$P_{397Al}(I, f, t) = (0.006842\, I)^4 f^2\, exp\big((0.79\, f\, -\, 3.845)t\big)$$

IEEE Initiative and RFP

Fault Behavior and Ignition Risks

Ignition probability

Australian tests – arc on dry fuel

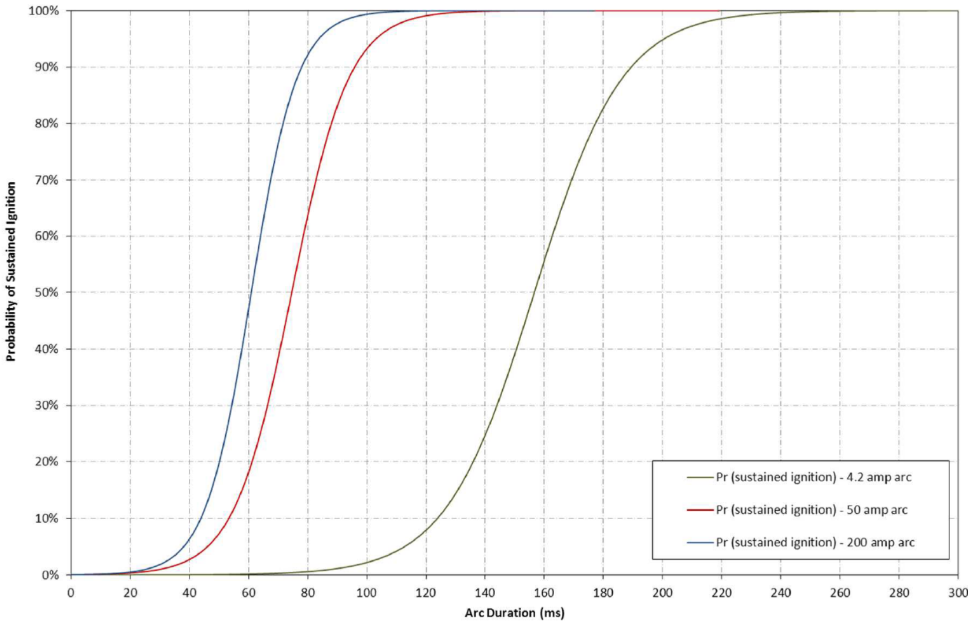


Figure 1. Ignition probability against arc duration for 4.2, 50 and 200 amp arcs at 45°C and 10 kph wind speed for hay/straw at 5% moisture

https://www.researchgate.net/publication/283486798_Probability_of_Bushfire_Ignition_from_Electric_Arc_Faults

Particle counts

PG&E tests – overhead arcing faults

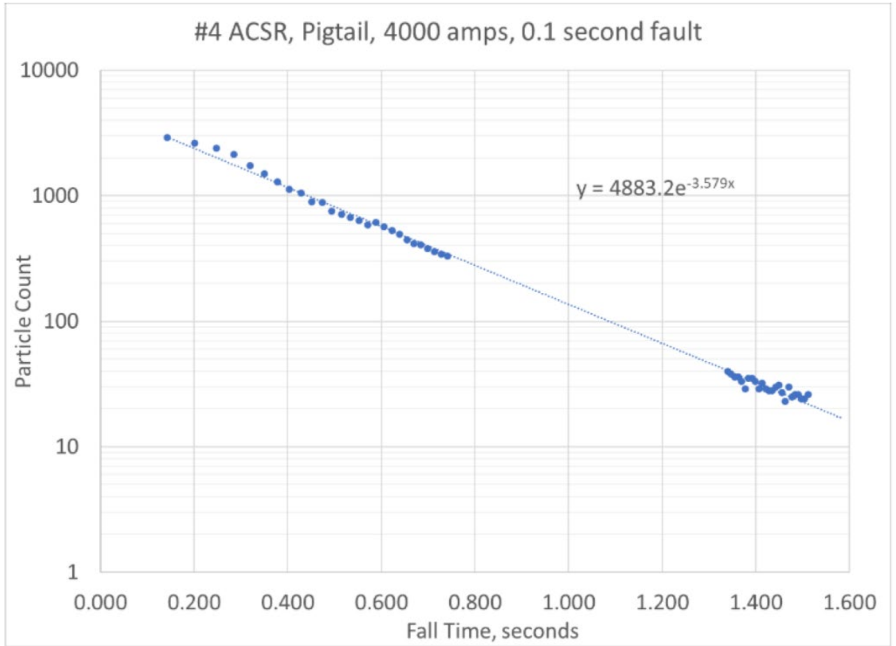


Figure 11. Particle Count vs. Fall Time (seconds) for the Cage and Lift tests combined, 0.1 second fault time, for #4 ACSR, Pigtail Configuration.

Assessment of Hot and Flaming Particles and Fire Risk from High Current Faults, Western Protective Relaying Conference 2022

IEEE Initiative and RFP

Ignition Risk Testing

Currently, no industry formulas exist to calculate probability of ignition for fault current and fault-clearing time. *This can lead to less effective efforts to reduce risk.*

Additional industry testing is needed to better quantify fire ignition risk

The IEEE PES Executive Committee recently approved issuing an RFP for medium-voltage, high-current fault testing to develop ignition-risk formulas.

Three formula types:

1. Wire on ground (low-Z/high-Z faults).
2. Overhead arcing faults (i.e., conductor clashing or conductor slap faults).
3. Overhead faults involving biological materials (i.e., branches, birds, squirrels).

IEEE Initiative and RFP

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June 26, 2025

IEEE Power & Energy Society Launches Initiative to Develop Wildfire Ignition Risk Formulas for Overhead Utility Faults

Piscataway, N.J., June 26, 2025 – IEEE Power & Energy Society (PES) is seeking proposals to fund research and testing aimed at reducing wildfire ignition risk. This high-current testing initiative focuses on developing ignition risk formulas for faults occurring on overhead electric utility lines.

It is generally accepted that wildfire ignition risk from electrical faults is a function of fault current magnitude and clearing time, but no standard industry equations exist for ignition risk versus fault current or clearing time. A more quantitative approach to evaluating wildfire ignition risk would allow utilities and grid operators to better assess the effectiveness of mitigation and the tradeoffs involved.

This proposal calls for an industry consortium to conduct extensive testing at a high-current test facility at medium voltage levels to develop general fire ignition risk formulas for three basic fault types.

The deadline to submit proposals is 16 July 2025.

Any organizations, labs, or institutions interested in learning more about this project or reviewing the official request for proposal (RFP), please contact Abira Altvater, IEEE PES Program Manager, at abira.altvater@ieee.org.

###

IEEE Power & Energy Society Launches Initiative to Develop Wildfire Ignition Risk Formulas for Overhead Utility Faults

FERC Order to NERC on Wildfire Report

- FERC issued order to NERC on September 10 on Wildfires.
- Docket No. RD25-9-000
- Submit a report on “Best practices to reduce the risk of wildfire ignition from the Bulk Power System.”
- Short timeline with report due on 5/1/2026.
- NERC Invite only Workshop in January

Questions