Wildfire Risks and Mitigation Strategies on Transmission and Distribution Systems

June 6, 2024

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Agenda

- Introduction
- The Economics of Protection Methods for Wildfire Risk Management in T&D Systems
- IEEE D45 Technical Report
- Discussion About Regulatory Environment in Australia
- Q&A

Introduction

- Wildfires (Bush Fires or Forest Fires) have become more frequent and more damaging in recent years.

- The impact of fires is made worse by the increased development in Wildland Urban Interface areas.

- Electrical equipment is not the largest cause of wildfires but the fires that they cause tend to become larger and more damaging due to their relationship to the environmental conditions at the time of ignition (i.e., high temperatures, dry fuel, and high wind conditions).

Introduction

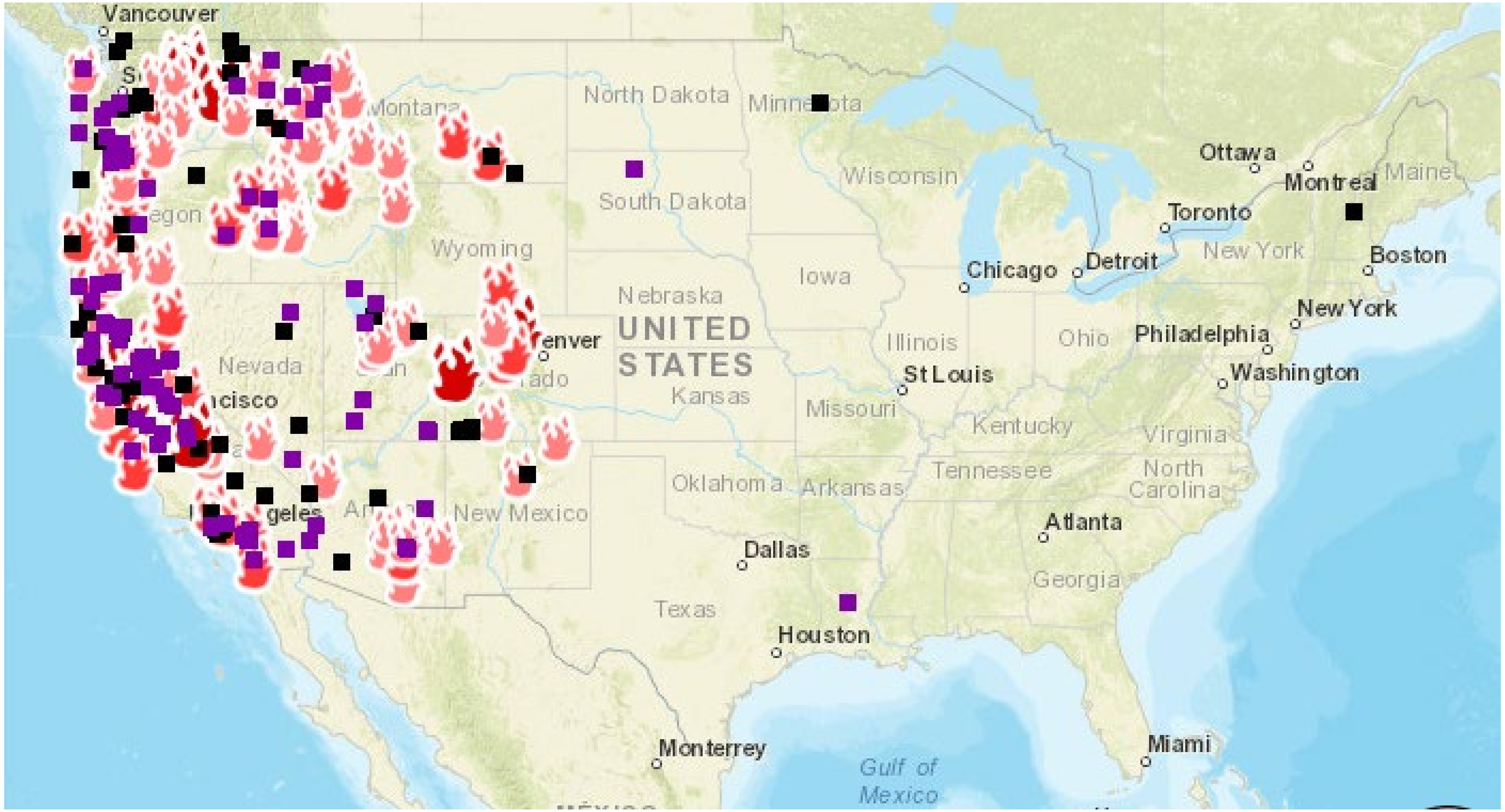
Location	Victoria, Australia
Statistics	
Date(s)	7 February – 14 March 2009 Multiple Fires
Burned area	450,000 hectares (1,100,000 acres)[1]
Cause	Various confirmed sources including: Power lines[2] Arson[3] Lightning[4] Machinery[5]
Land use	Urban/Rural Fringe Areas, Farmland, and Forest Reserves/National Parks
Buildings destroyed	3,500+ (2,029 houses)
Deaths	173[6][7][8]
Non-fatal injuries	414[9]

With costs approaching $100 billion, the fires are Australia's costliest natural disaster.

January 16, 2020

Introduction

United States Forest Service - 09/09/2020 Active Wildfire Map

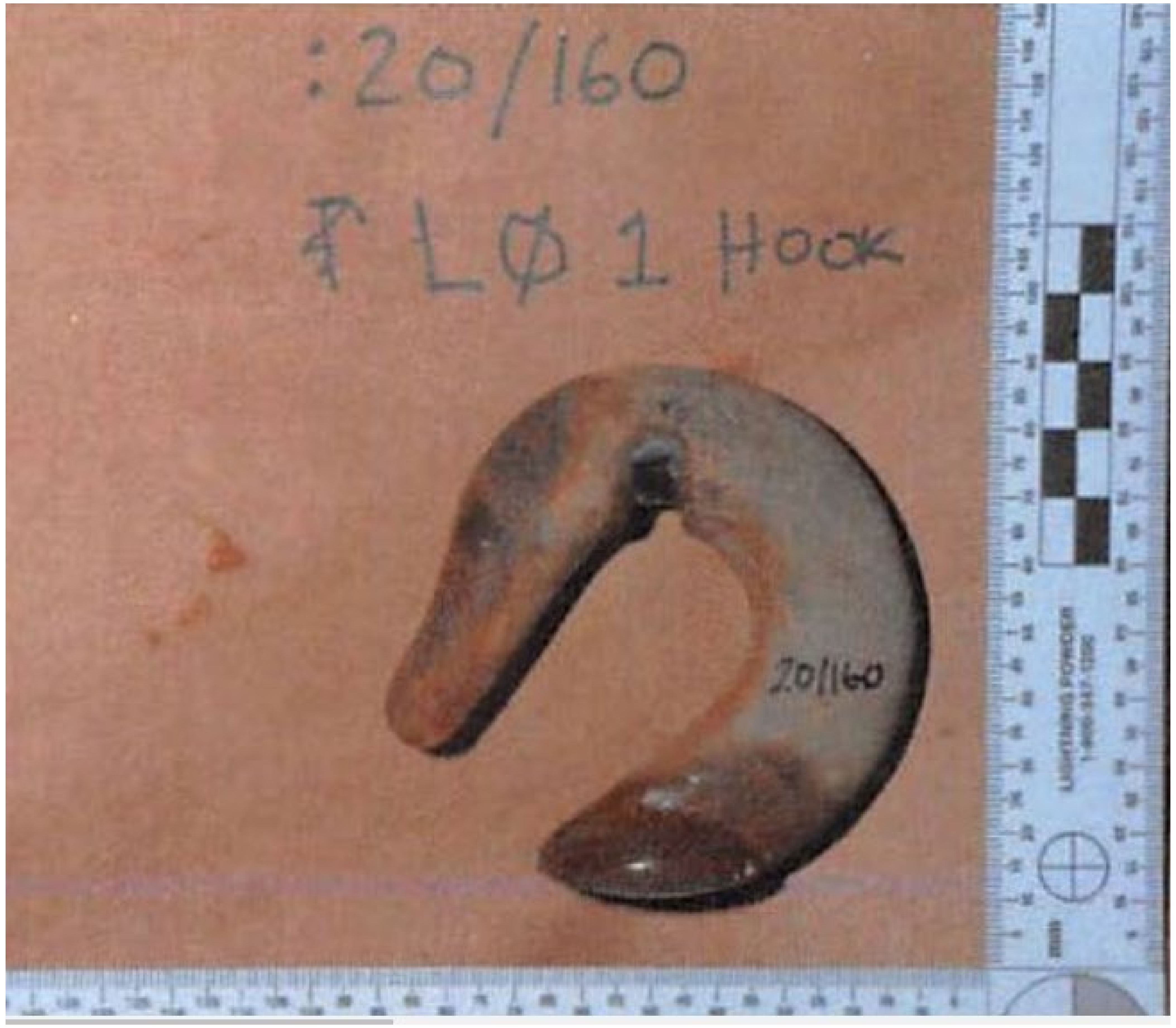


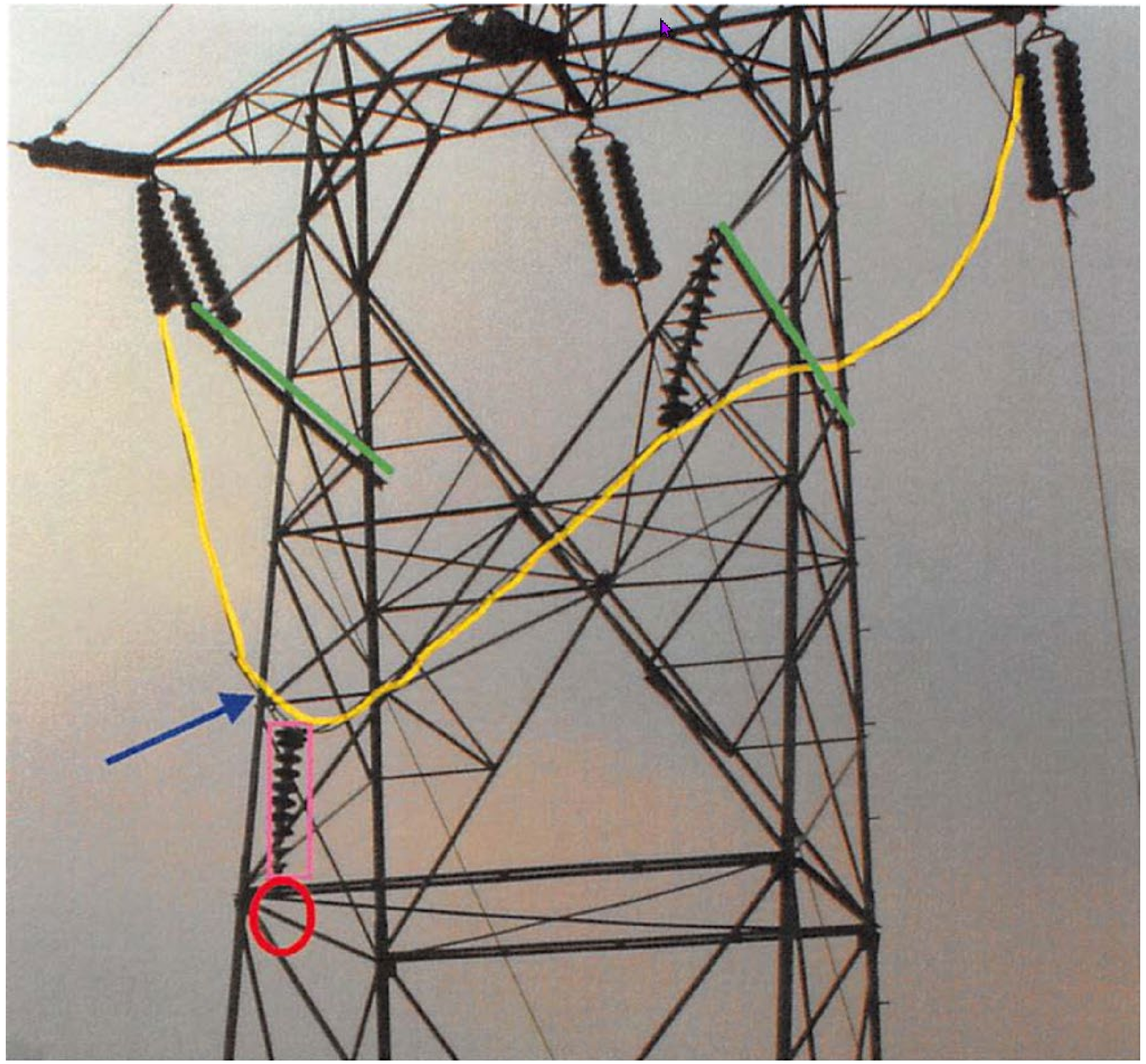
Regionally Important

Seasonally Important

Introduction

Distribution Risk vs Transmission Risk - Camp Fire - 115 kV Phase to Tower Fault





Introduction

Wildfires and their impacts are increasing

Judge Approves [Utility's] Bankruptcy Exit

A federal judge has approved [Uitility's] plan to exit bankruptcy, to compensate victims of a series of wildfires in the state that left more than 100 people dead in 2017 and 2018.

The action authorized $13.5 billion in compensation for more than 70,000 businesses and homeowners for losses sustained during the fires, which officials said were started by [Utility's] equipment. The company will emerge from bankruptcy with about $40 billion in debt, after agreeing to settle claims from people, insurers, and local government agencies for $25.5 billion.

..w York Times

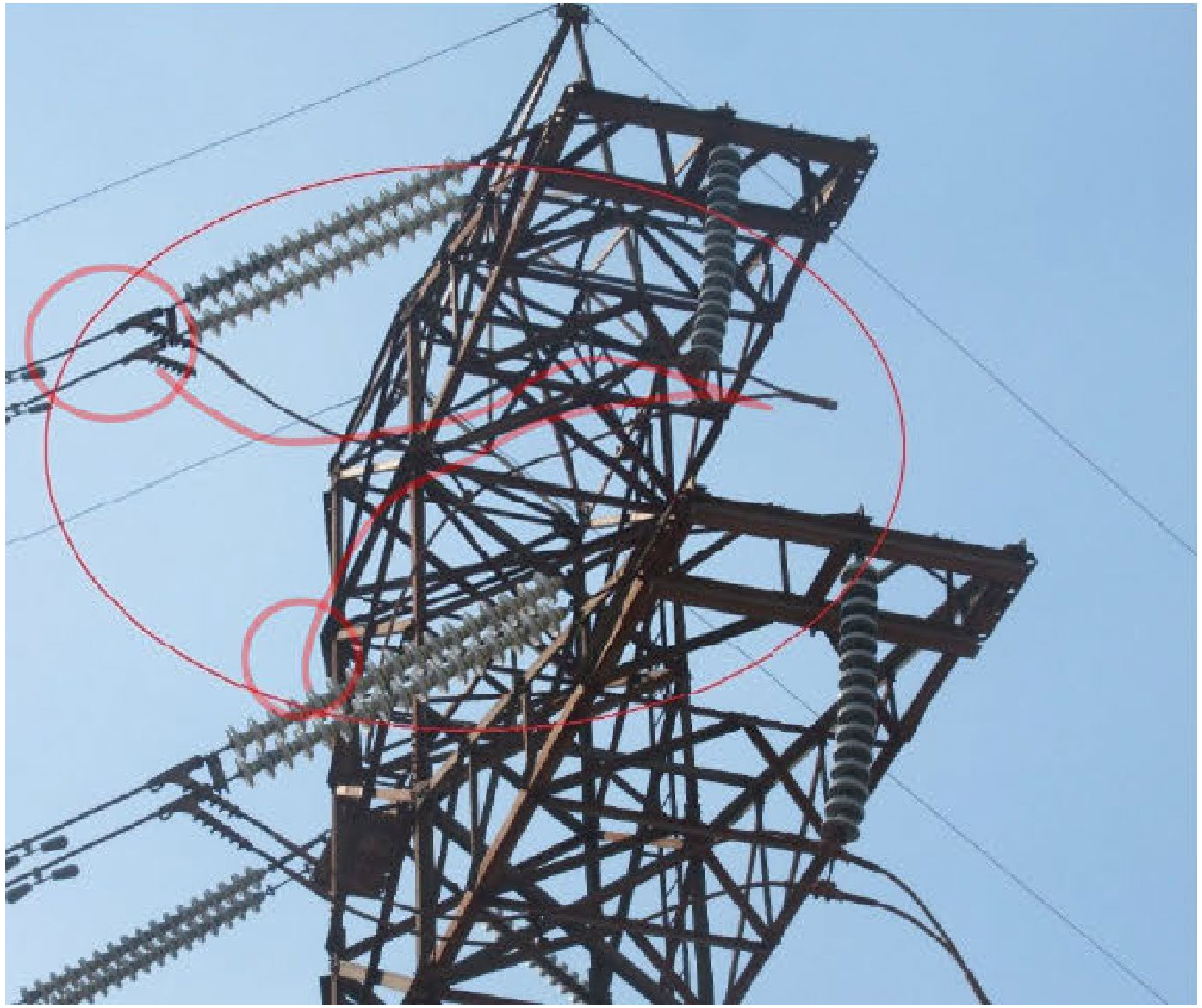
. Pleads Guilty to 84 Counts of .slaughter in Camp Fire Case

.alifornia utility's transmission line started the 2018 fire tha d dozens and destroyed the town of Paradise.

Introduction

Distribution Risk vs Transmission Risk - Kincade Fire - 230 kV Phase to Tower Fault

- 374 Structures Destroyed.
- More than 185,000 people evacuated
- Estimated Property Damage $385 Million



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June 6,2024

The Economics of Protection Methods for Wildfire Risk Management in T&D Systems

Ali Arabnya

Wildfire Risk Management Strategy: Deep Defense

The deep defense (or defense-in-depth) approach in risk management is a paradigm that has its origins in ancient military strategy, which relies on multiple lines of defense rather than a single frontline.

An effective wildfire risk management should achieve following objectives:

- ✓ Operational resilience
- ✓ Financial resilience

Picture Credit: *Mike Eliason, Santa Barbara County Fire Department, AP / IEEE Spectrum*

Three Lines of Defense for Wildfire Risk Management

A three-lines-of-defense (3LD) framework for end-to-end wildfire risk management can facilitate an optimal resource allocation for wildfire resilience building by utilities.

1st Line of Defense

Wildfire Prevention

Wildfire prediction
Situational awareness
Limiting fire-inducing faults
System hardening
Grid asset management
Vegetation management

2nd Line of Defense

Wildfire Risk Mitigation and Proactive Response

Deployment of wildfire trackers
Preemptive de-energization
Effective suppression tactics
Real-time wildfire monitoring
Emergency grid operations
Technologies to minimize impact

3rd Line of Defense

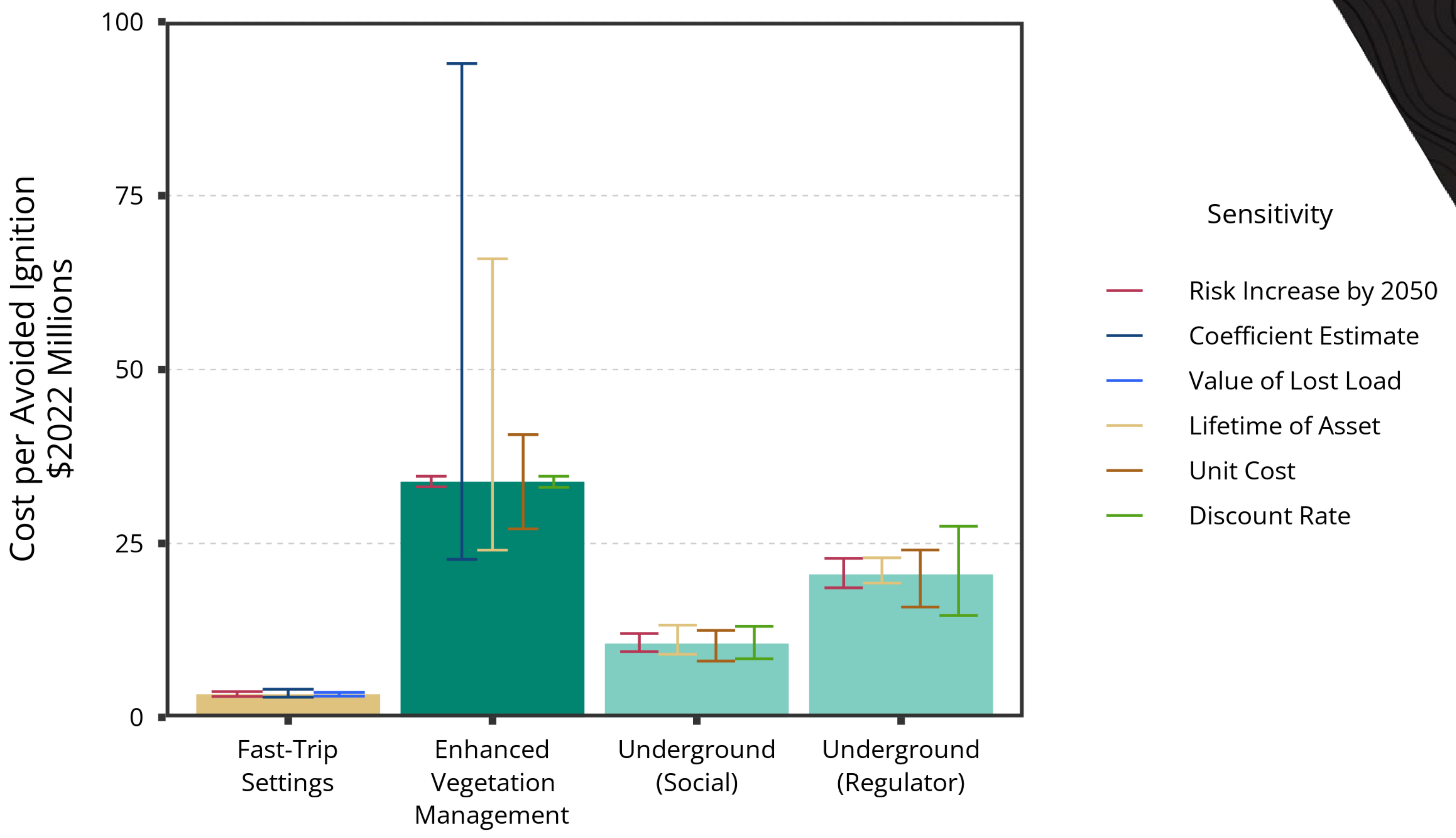
Recovery Preparedness

Recovery logistics
Energy contingency plans
Disaster risk financing
Community engagement

Source: Ali Arabnya et al., Three lines of defense for wildfire risk management in electric power grids: A review. IEEE Access. 2021.

Counterfactual Risk Analysis

- A data-driven counterfactual risk analysis can measure the success metrics for protection methods in reducing wildfire.
- Incremental (marginal) cost analysis of wildfire mitigation strategies (including protection methods) can determine the true cost difference between various alternatives.



Picture Credit: Cody Warner et al., Risk-Cost Tradeoffs in Power Sector Wildfire Prevention. The Energy Institute at Haas, 2024.

The Economics of Protection Methods: Fast-Trip Settings

The Fast-trip settings should be co-optimized with other mitigation strategies using a risk-based approach:

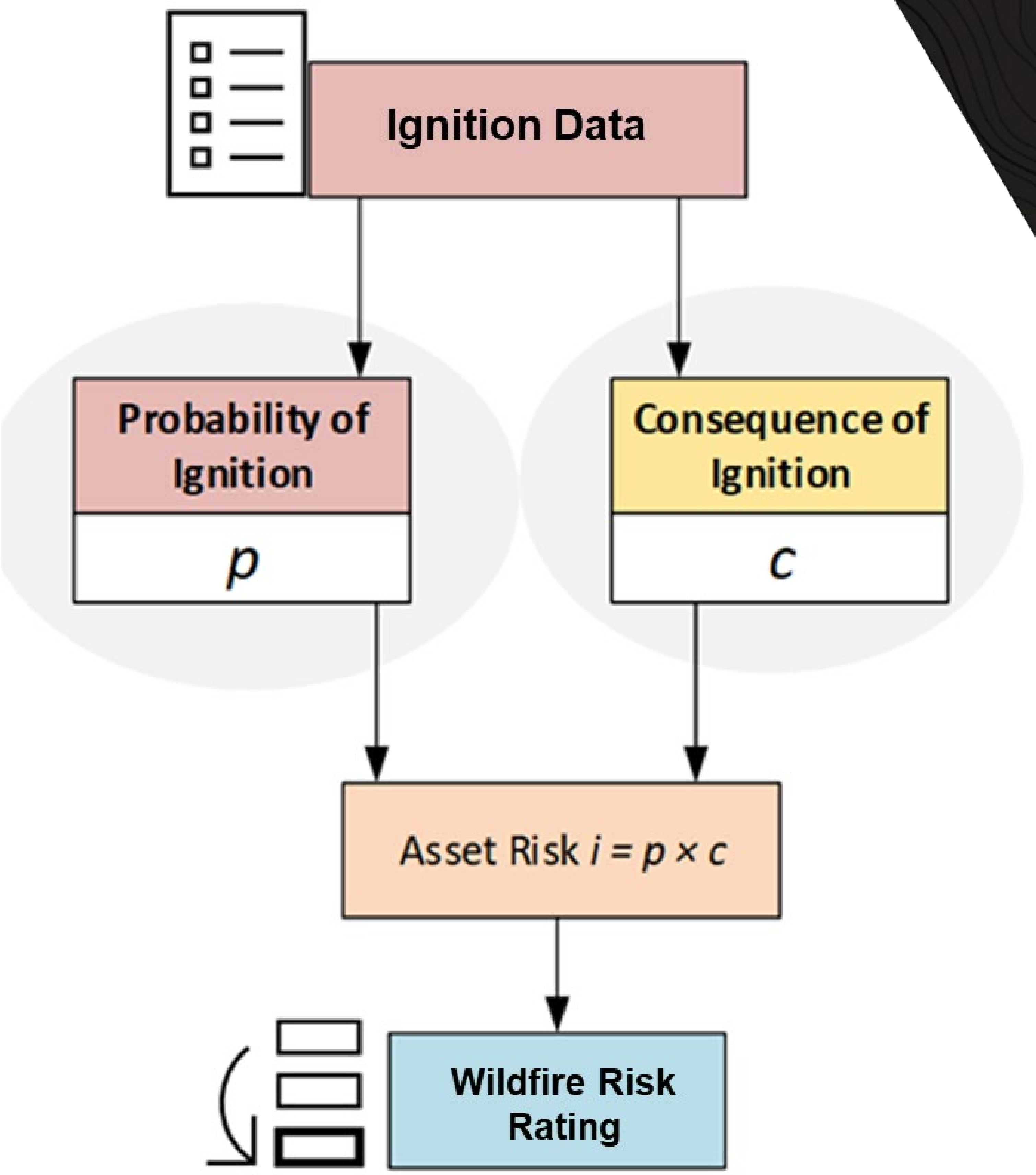
$$\textbf{Minimize:} \sum_{i}^{n} \Pr(ignition)_i \times (Consequence)_i$$

Subject to:

$$Undergrounding\ Cost \leq C_{UG}$$

$$Vegetation\ Management\ Cost \leq C_{VM}$$

$$(Hours\ of\ FastTrip\ Outages) \times (Value\ of\ Lost\ Load) \leq C_{FT}$$



Industry Perspective: The Emerging Trends

Some of the recent challenges and wildfire risk management objectives set by utility executives are, as follows:

- ✓ How to reduce the financial exposure from wildfire events by 90%, asked an electric utility CFO? What's the price tag to achieve that goal?
- ✓ How can Probabilistic Risk Assessment (PRA) methods from nuclear safety codes be leveraged to reduce wildfire ignition risk in an electric utility by *x* percent?
- ✓ How a utility can reach its wildfire risk reduction goals using PSPS without compromising their SAIDI and SAIFI reliability metrics?

Achieving these multi-objective goals require protection methods to work in sync with other risk reduction strategies considering their microeconomic dynamics in utility businesses.

IEEE PSRC D45 WG, Technical Report - Document protection methods used to reduce wildfire risks due to transmission and distribution lines.

Jonathan Sykes, PE, IEEE Fellow
Quanta Technology

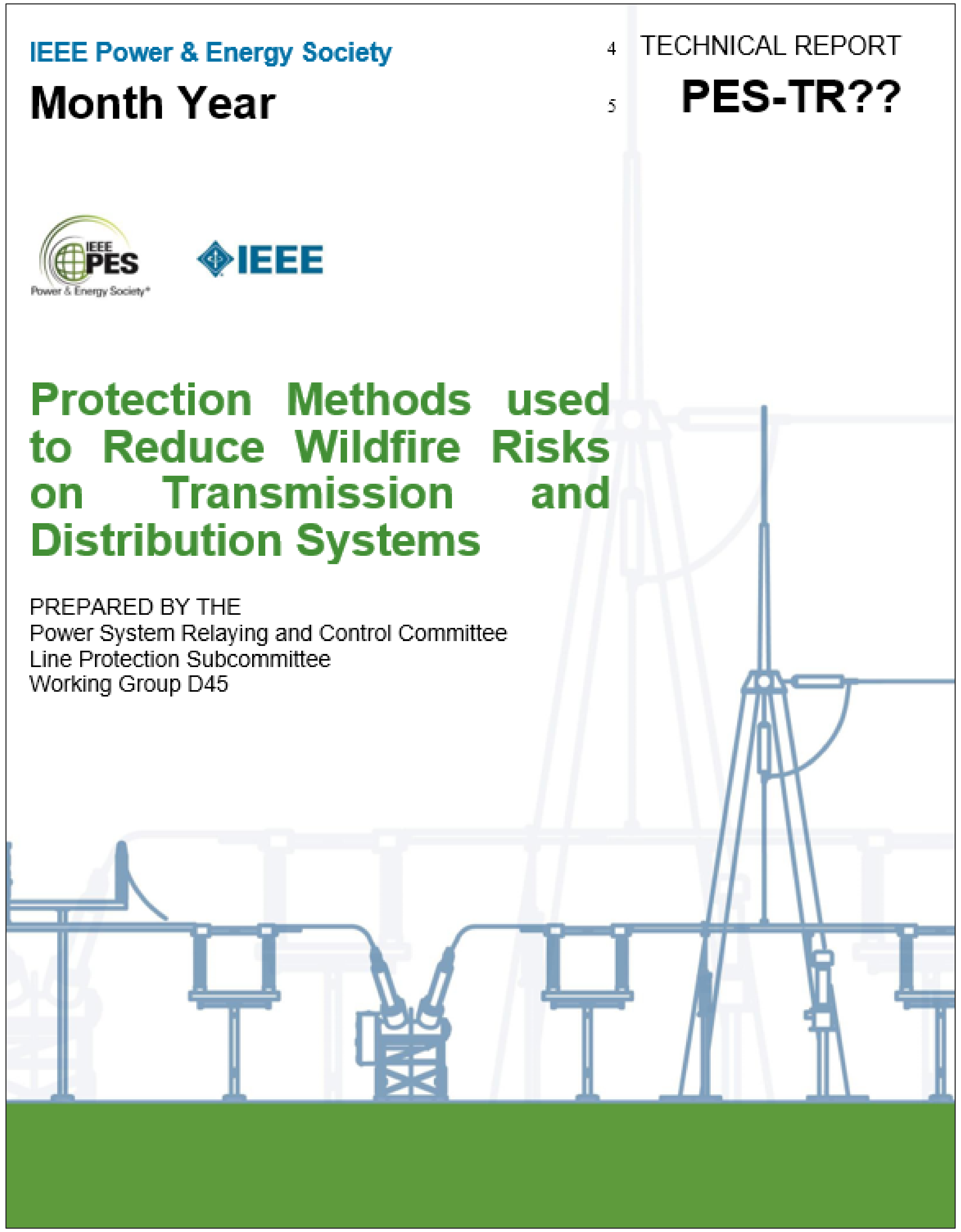
Scott Hayes, PE, Principle Engr.
PG&E

June 06, 2024
WECC Vancouver Washington

IEEE PES PSRC Work Group D45

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
- **Output:** Technical Paper approximately Jan 2025
- **Team consists of** Utilities, Consultants, Academia, and Manufactures


IEEE Power & Energy Society

Month Year

TECHNICAL REPORT

PES-TR??

Protection Methods used to Reduce Wildfire Risks on Transmission and Distribution Systems

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

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Table of Contents (Abbreviated)

Fault Behavior and Ignition Risk

- The capacity of electricity to start wildfire is as old as lightning, and the fire ignition risks associated with modern electrical equipment led to the creation of the National Electrical Code (NEC), produced by the National Fire Protection Association (NFPA) beginning in 1897.
- At a fundamental level, fire ignition risk increases with an increase in fault energy.
- **Fault energy is a function of the magnitude of fault current and the duration of the fault**, but the variety of fault conditions that occur on the power system factored in with fuel bed and climate conditions make for a much more complicated picture.

Fault Behavior and Ignition Risk

- The heat energy of an electrical arc = I^2Rt (**Formula for fire ignition risk is much more complicated.)**
- Voltage absence highlights the similarity between transmission and distribution lines with respect to fault behavior and ignition risk.
- It is the energy at the arc that can ignite the fuel that the arc comes in contact with.
- This energy can be lower but present longer or higher and present for a brief time. Both situations can produce enough heat to ignite fuel that could be present.
- There are also a variety of physical factors that decrease the ignition risk profile of transmission lines versus distribution, including
    - the proximity of trees and other vegetation to the lines as well as growth beneath the lines,
    - height above ground,
    - conductor spacing, and
    - the stoutness of transmission construction over distribution.

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Fault Behavior and Ignition Risk

Ignition Probability

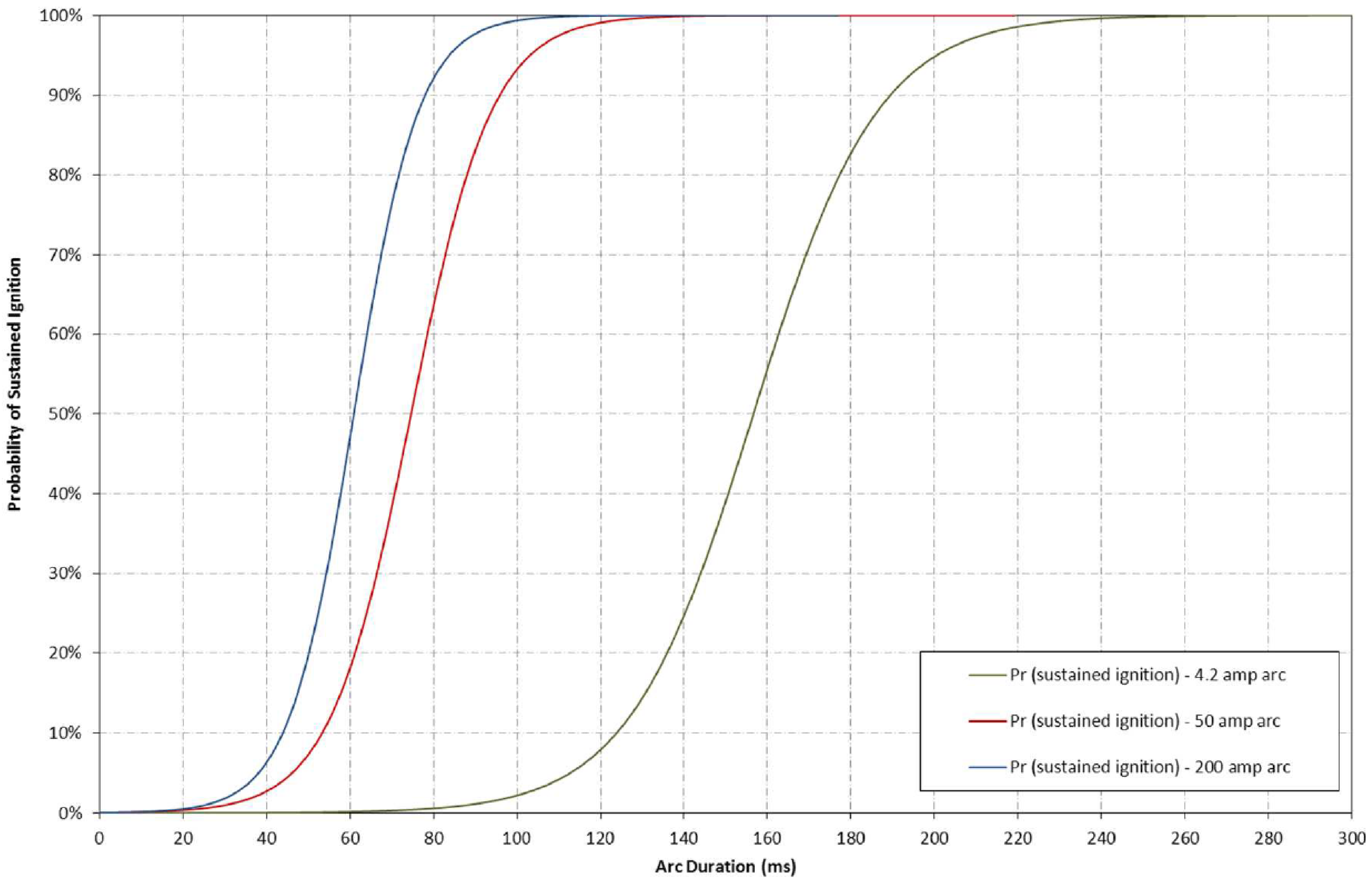

Figure 1. Ignition probability against arc duration for 4.2, 50 and 200 amp arcs at 45°C and 10 kph wind speed for hay/straw at 5% moisture

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

Particle Counts

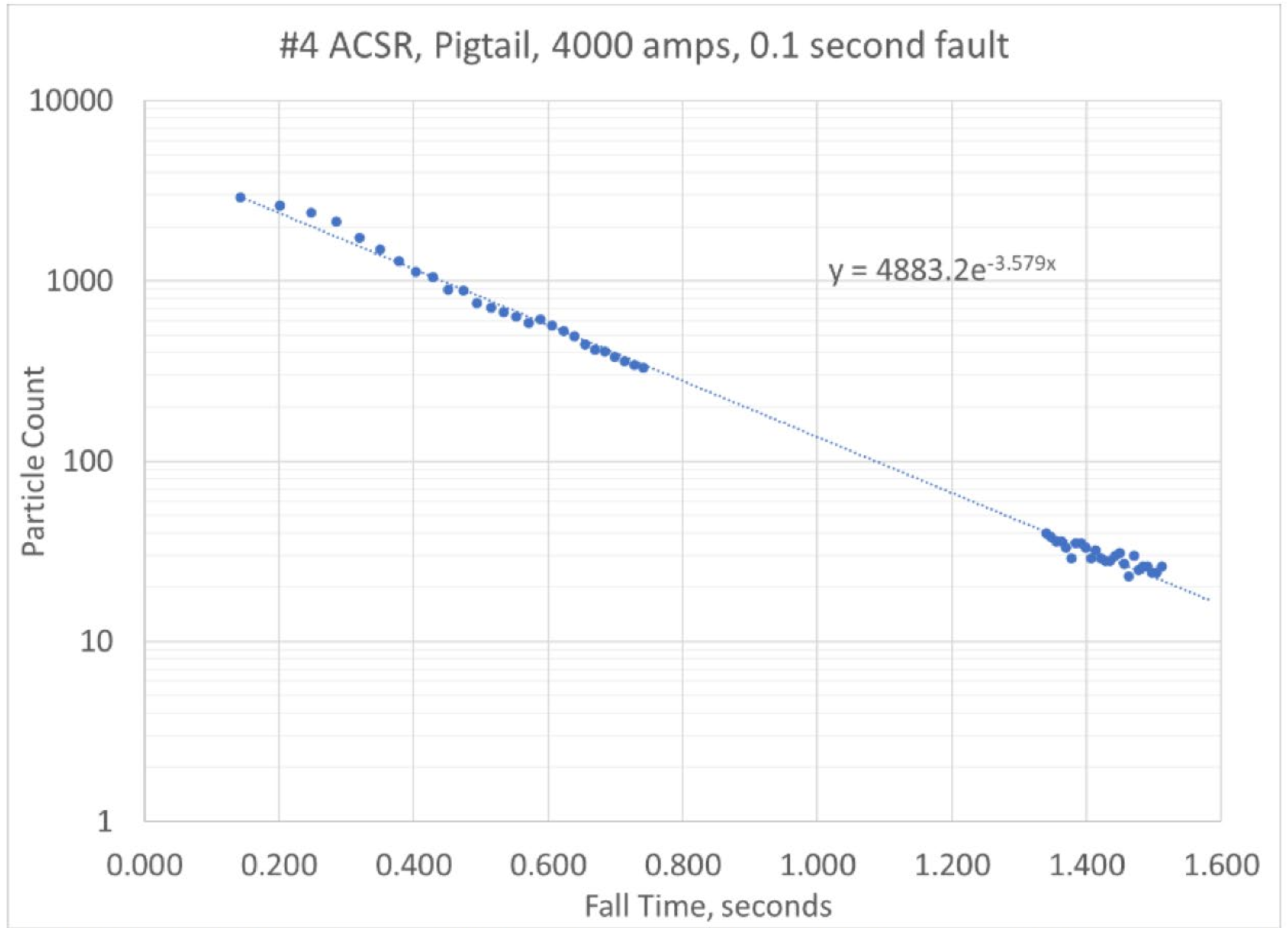

Figure 11. Particle Count vs. Fall Time (seconds) for the Cage and Lift tests combined, 0.1 second fault time, for #4 ACSR, Pigtail Configuration.

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

Fault Behavior and Ignition Risk

- There are to many variables to determine the exact risk.
- The electrical grid extends thousands of miles throughout the forest and has millions of arc possibilities.
- Each point of the arc can present very different risk characteristics.
- For over 100 years the grid has used overcurrent and impedance-based detection methods to detect and isolate the fault on the line.
- The protection of the electrical grid focused on the isolation of the fault with as little interruption to the rest of grid as possible.
- Relays were coordinated with intentional time delays to allow coordination between zones of protection.
- **Some faults were cleared with an intentional time delay.**

The longer the fault or arc lasts the more heat energy is present and the greater risk of a wildfire.

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Fault Responsive Relay Applications

- Distributed Energy Resources (DER) on the Distribution System
- Relay Setting Change Methods:
  - **Increase fault detection, selectivity, sensitivity, and relay operation time**
  - Fuse Saving or Fuse Blowing Coordinator
  - Reclosing
- Communication Aided Protection Methods
  - Step Distance Based Communication Systems
  - Transmission Line Current Differential (LCD)
  - Distribution Line Differential (DLD)
  - Time-domain and Traveling Wave Protection
  - Sensor Based Methods

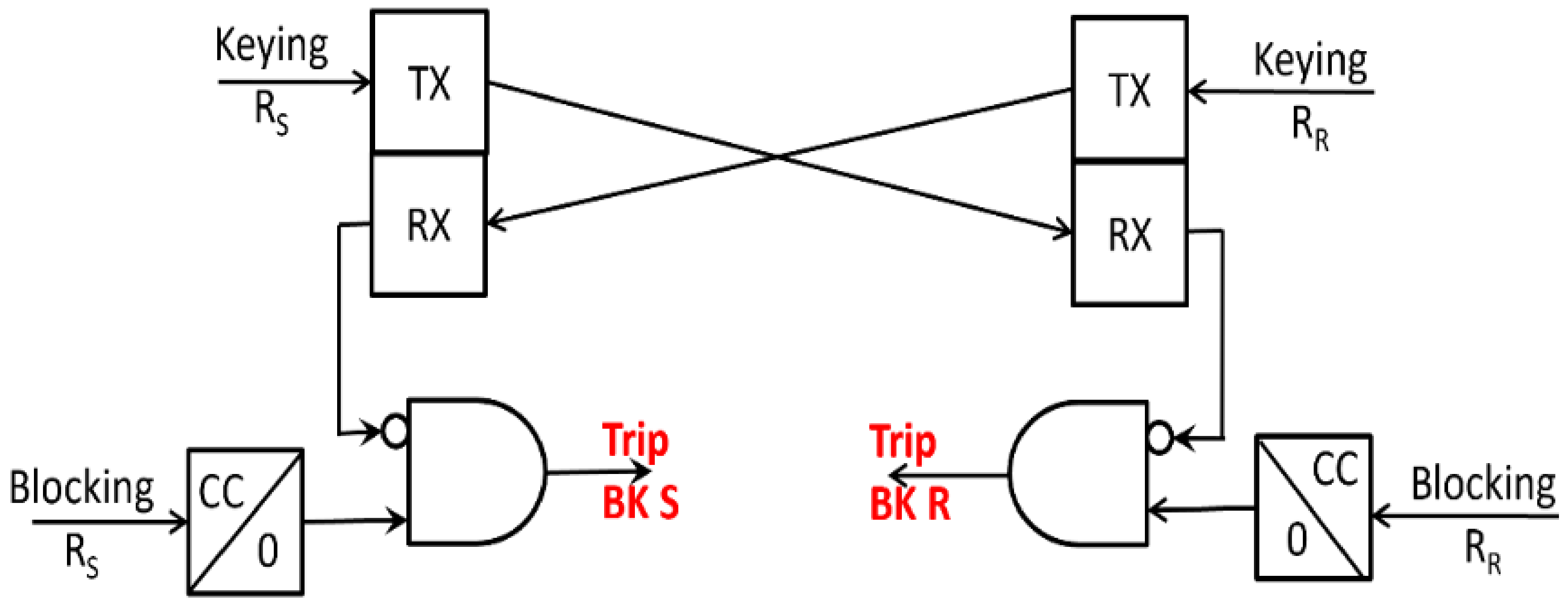

Figure 4.2. Simplified Step Distance Communication Scheme

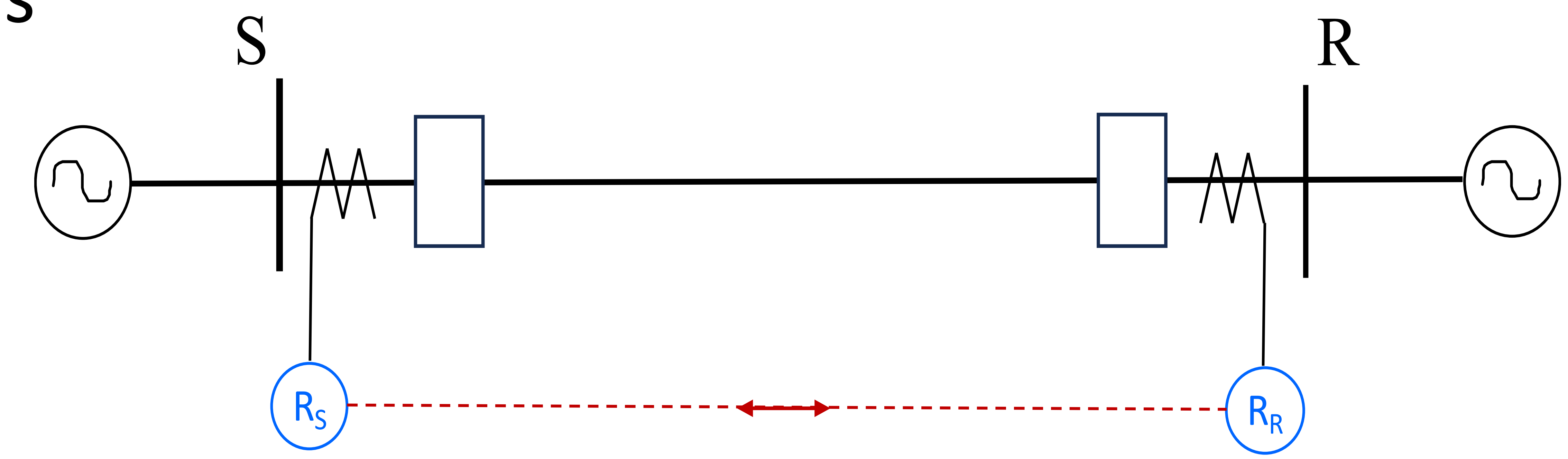

Figure #5. Line Current Differential.

HAAS Working Paper - February 19 (berkeley.edu)

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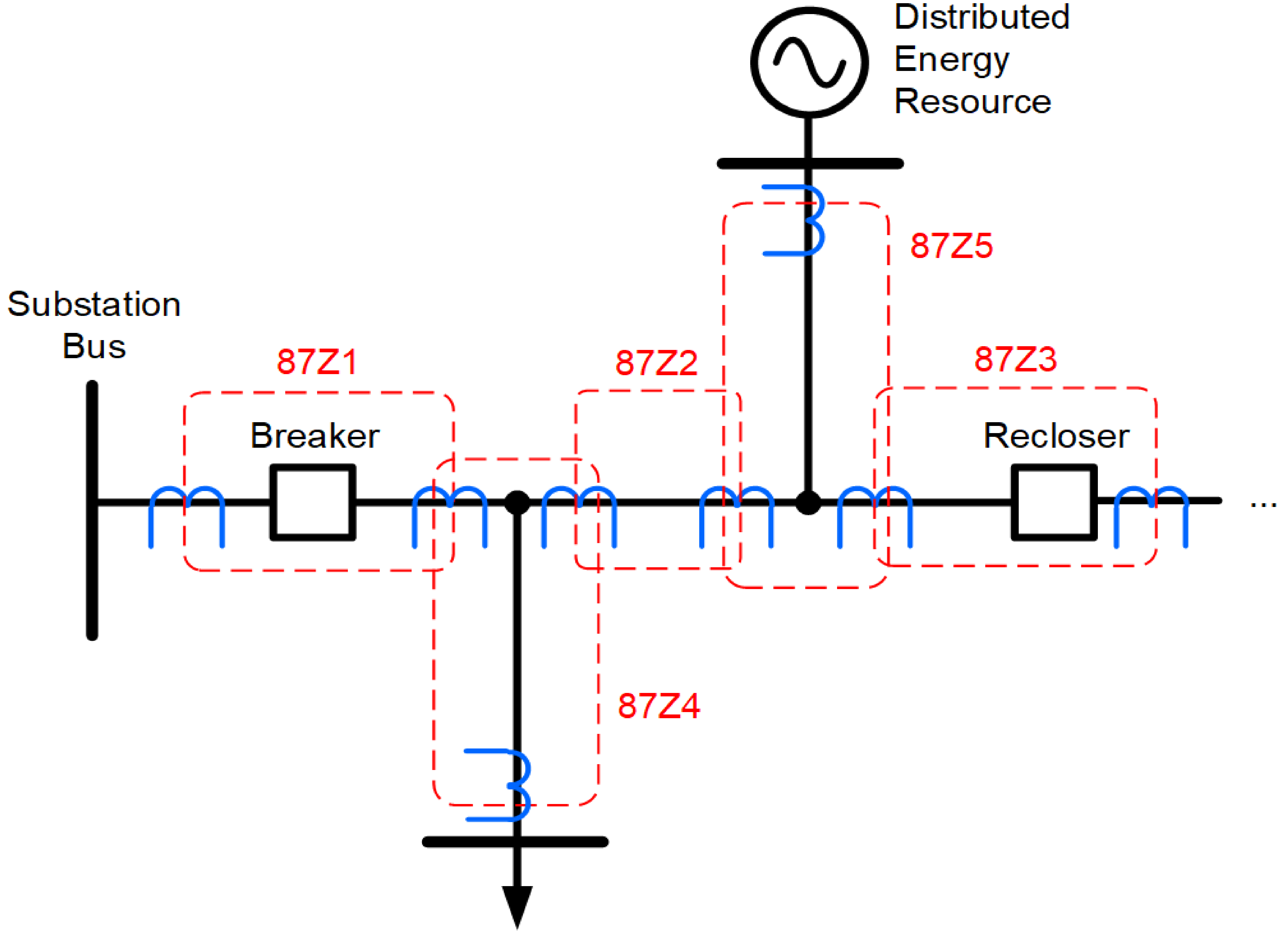
Fault Responsive Relay Applications

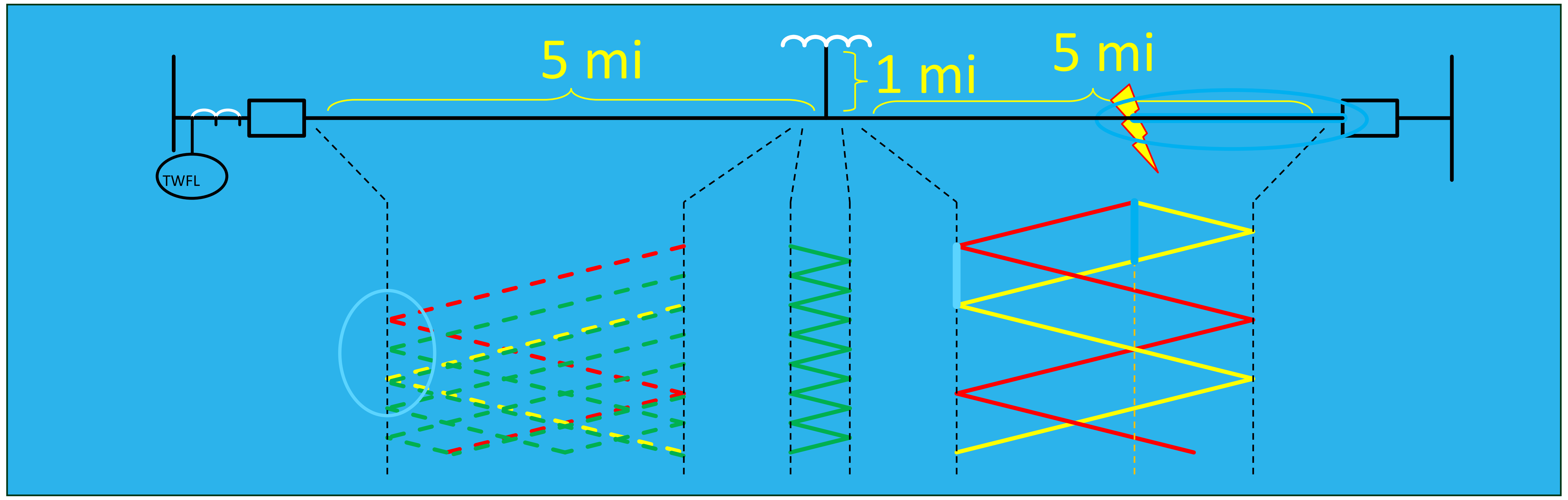
Distribution Line Differential (DLD): Passive Distributed Measurements



M. Mohemmed, P. Orr, S. Blair, N. Gordon, I. Mckeeman, A. Mohamed, and A. Bonetti, “Differential Protection of Multi-Ended Transmission Circuits Using Passive, Time-Synchronised Distributed Sensors,” proceedings of the PAC World Conference, Prague, Czech Republic, 2022.

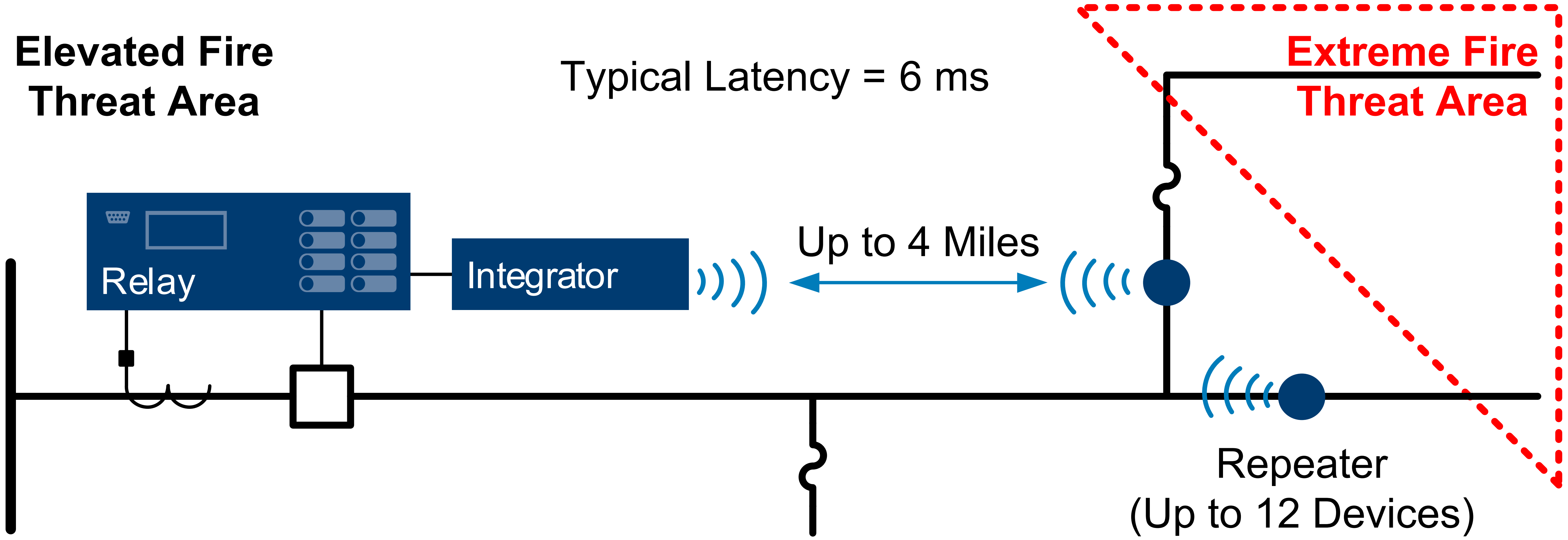
Fault Responsive Relay Applications

Time-domain and Traveling Wave Protection
- Transmission application is simpler



TW for Complex Line Topologies

Sensor Based Methods
- Positive detection and location of downed conductors



High Impedance Fault Detection

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

- The algorithms in use have these elements:
  - Current and voltage inputs from which the algorithm derives the high-frequency signal component
  - A method to separate even-, odd-, and inter-harmonics of interest in the HIF spectrum. The extent of the frequency range is from sub-harmonic to 1 MHz
  - A reference or background average or total energy quantity that provides a stable, pre-fault reference
  - Settings that tune the response of the detection algorithms. These include initial algorithm sensitivity and counter/confidence periods
  - Decision logic to differentiate an HIF condition from other system conditions, such as switching operations and noisy loads

High Impedance Fault Detection

Pulse Counting Methods

- Certain percentage of high impedance ground faults are intermittent.
  - The fault current occurs and then disappears (the fault self-extinguishes). The fault then, typically, reoccurs and then self-extinguishes again, and the process repeats multiple times with irregular intervals.
- This type of high impedance fault is extremely difficult to detect even with very low ground element settings or even typical high impedance fault detection algorithms
- Pulse Counting will detect the ground current spike or pulse and can be set to count the number of sudden increases in ground current over a set amount of time.
- Counting methods can be setup to alarm or trip for this irregular type of high impedance ground fault.

Some studies have shown that a fire can occur with .5 amps of current

Grounding Practices

- Different grounding methods can significantly reduce ground fault current levels and fire ignition risk.
- Different grounding methods can result in ground fault currents ranging from tens of thousands of amps to milliamps.
- When applying delta or high impedance grounding methods the effects of temporary overvoltages on equipment and the impact on detecting ground faults must be considered.
- Grounding Methods:
  - Multipoint Grounded Wye
  - Uni-Grounded Wye
  - Delta/Ungrounded
  - Delta/Grounded
  - High Impedance Grounding for Wye Grounded Systems

Grounding Practices

Multipoint Grounded Wye

- Multipoint grounded Wye or 4 wire systems is prevalent for medium voltage circuits in north America but is not as common internationally.
- Multipoint grounded systems support phase-to-phase and phase-to-ground connected loads. This can reduce equipment costs but typically results in high levels of ground fault current.
- High impedance grounding is usually not applied as there are many paths to ground all along the feeder. In systems with single phase transformers load unbalance is often high, requiring ground relays with high minimum trip values to avoid nuisance tripping.
- This results in less sensitivity for high impedance ground faults .

Grounding Practices

Uni-Grounded Wye

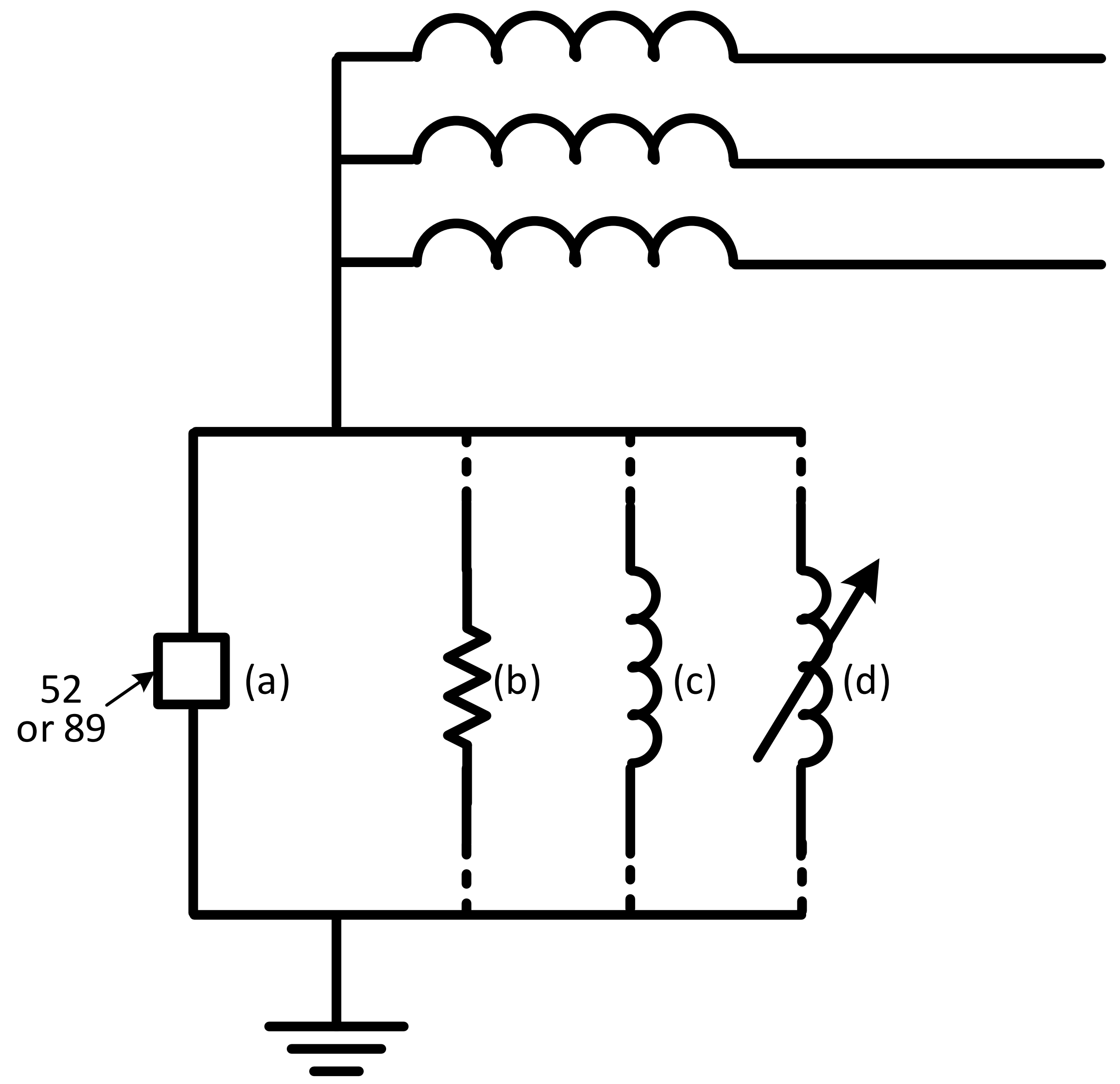
- Uni grounded Wye or 3 wire systems are less common at medium voltage in north America but are more common internationally.
- They are applied more often on transmission systems.
- This method supports phase-to-phase connected loads without an insulated neutral conductor being brought to the load.
- These systems can accommodate different grounding methods to reduce ground fault current levels by applying neutral grounding resistors, reactors or compensated neutral schemes.
- Unbalanced loads do not flow in ground relays allowing sensitive ground time overcurrent settings.

Grounding Practices

Hybrid-Grounded

- Solid Ground: The system is normally solidly grounded. This is accomplished using by closing the breaker or switch in path "a". This bypasses any other type of parallel connected ground.

- High Resistance/Reactance/Compensated Ground: The ground **switches to high resistance/reactance/ compensated** grounding in times of **high fire danger**. This is accomplished by opening the breaker or switch in path "a" which basically puts the other ground impedance in either path "b", or "c" or "d" into the circuit.



Petersen Coils & Compensated Neutral Schemes

REFCL vs GFN

Rapid Earth Fault Current Limiter (REFCL)

Resonant or Compensated Neutral Grounding System that results in extremely small ground fault currents. Not applicable to 4 wire multi grounded systems.

Ground Fault Neutralizer (GFN)

The GFN is a type of REFCL system manufactured by Swedish Neutral. It is made up of 3 key components, an Arc Suppression Coil, Residual Current Compensator and Control Cubicle. The GFN works on the principles of resonant grounding, a proven concept used extensively throughout Europe for almost 100 years.

Performance Standard (State of Victoria Australia)

Required by regulation in Australia – More later.

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Petersen Coils & Compensated Neutral Schemes

Commercial REFCL: GFN

Swedish Neutral Ground Fault Neutralizer

Source: Franz Stadmueller (F1Sl)'s EPIC 3.15 REFCL Operations slides

Arc Suppression Coil
Compensates reactive component of fault

Residual Current Compensator
Compensates resistive component of fault

GFN Controller
Tunes ASC, Detects Faults, Drives Inverter

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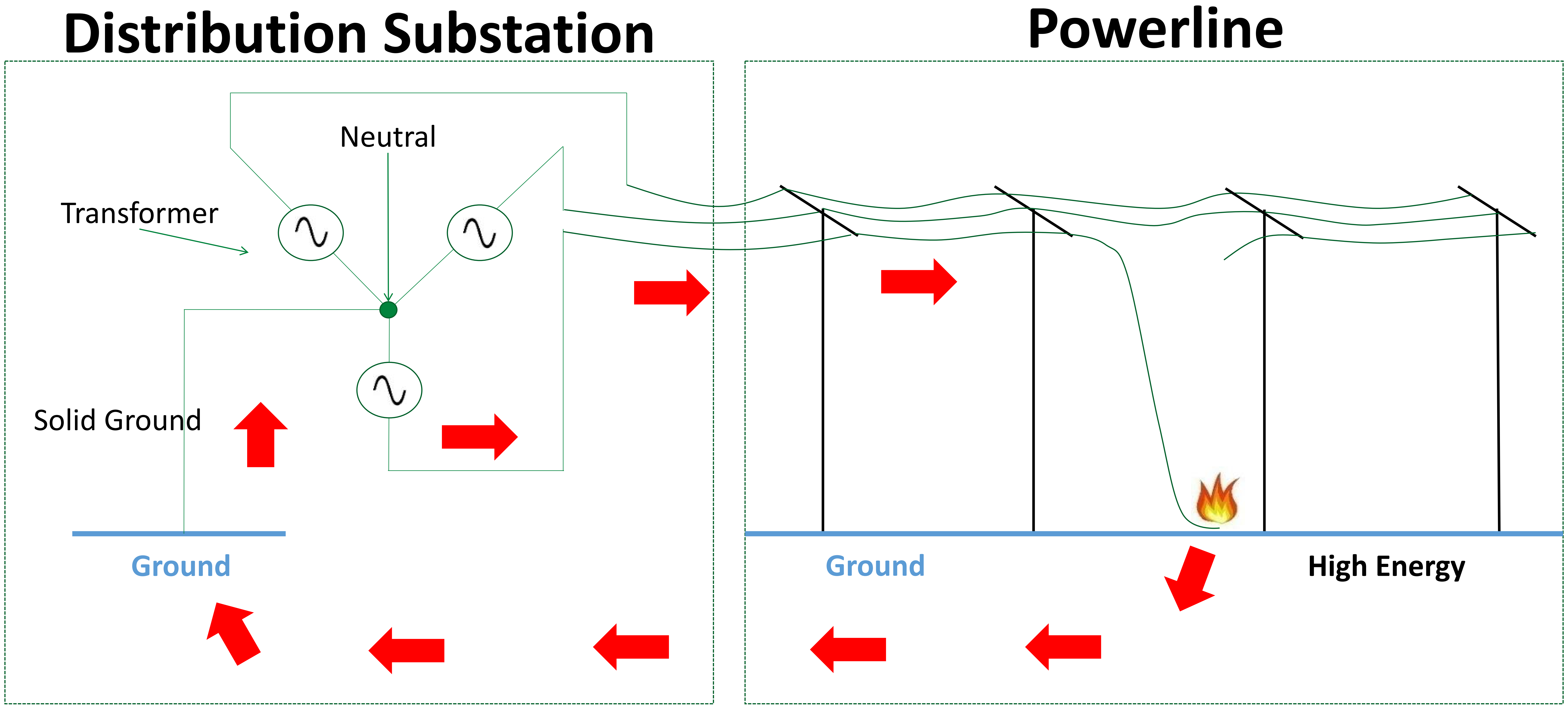
Petersen Coils & Compensated Neutral Schemes

Phase To Ground Fault

Source: PowerCore Australia's Control and Ops REFCL Guidebook



Today with solid grounding: Thousands of Amps

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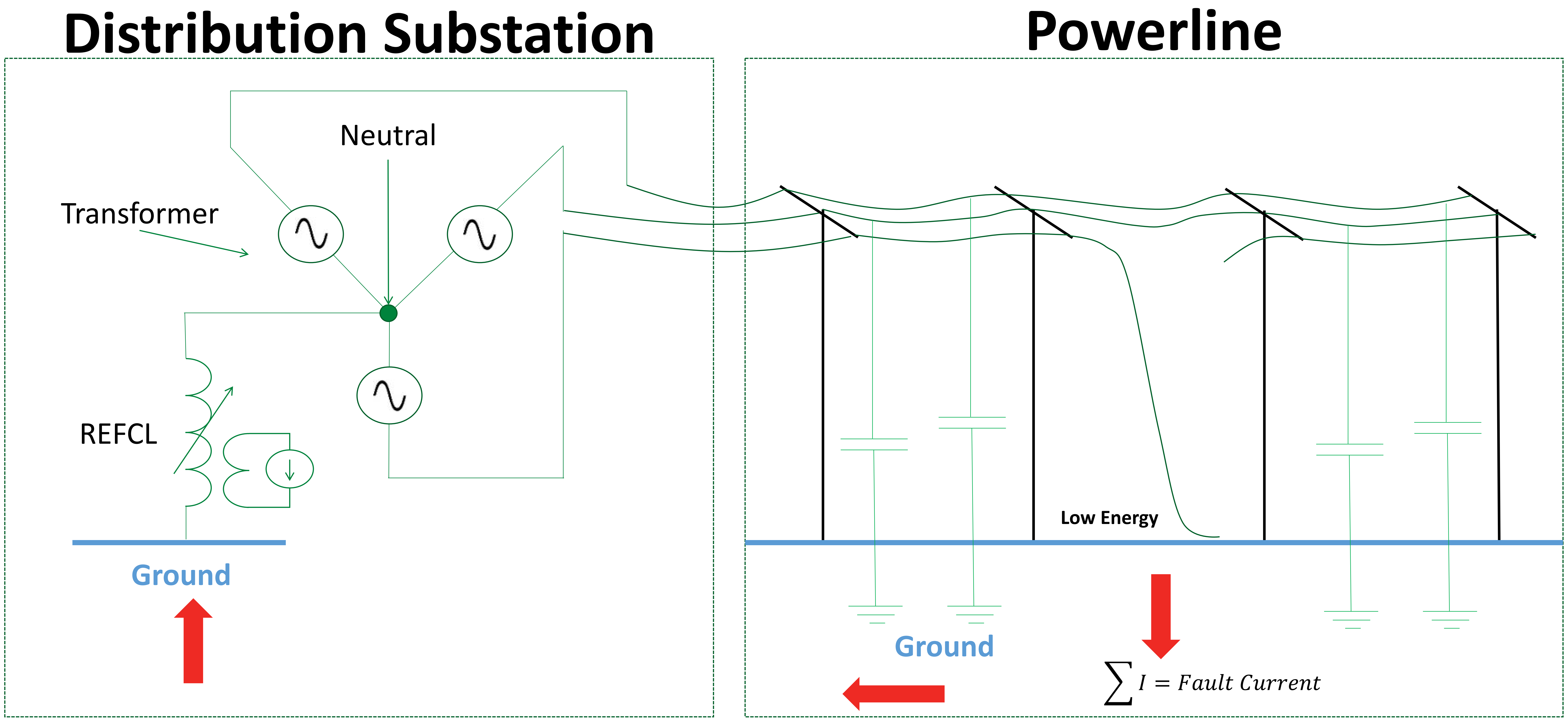
Petersen Coils & Compensated Neutral Schemes

Phase To Ground Fault



Future with REFCL: Less than 0.5 Amp

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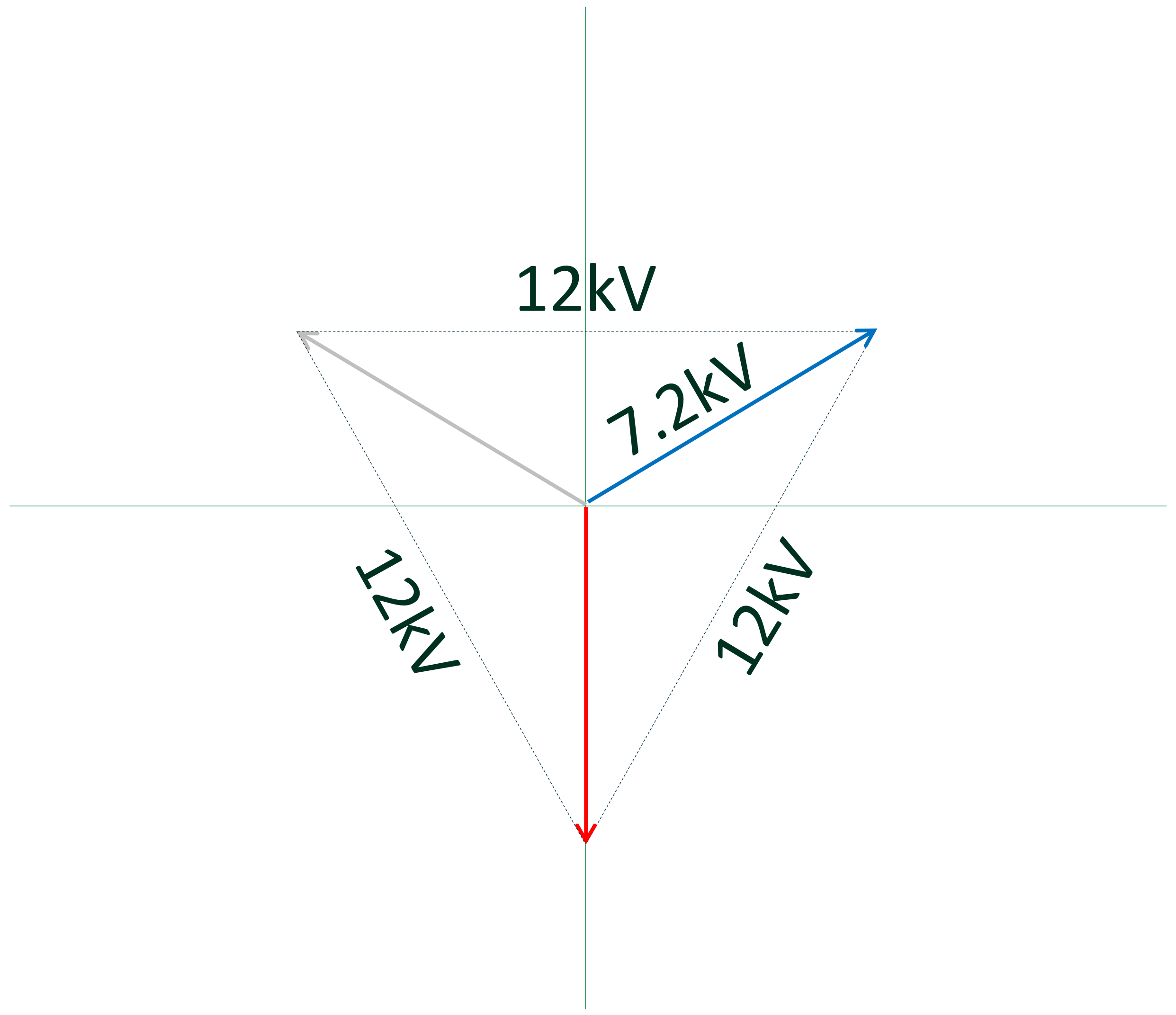
Petersen Coils & Compensated Neutral Schemes

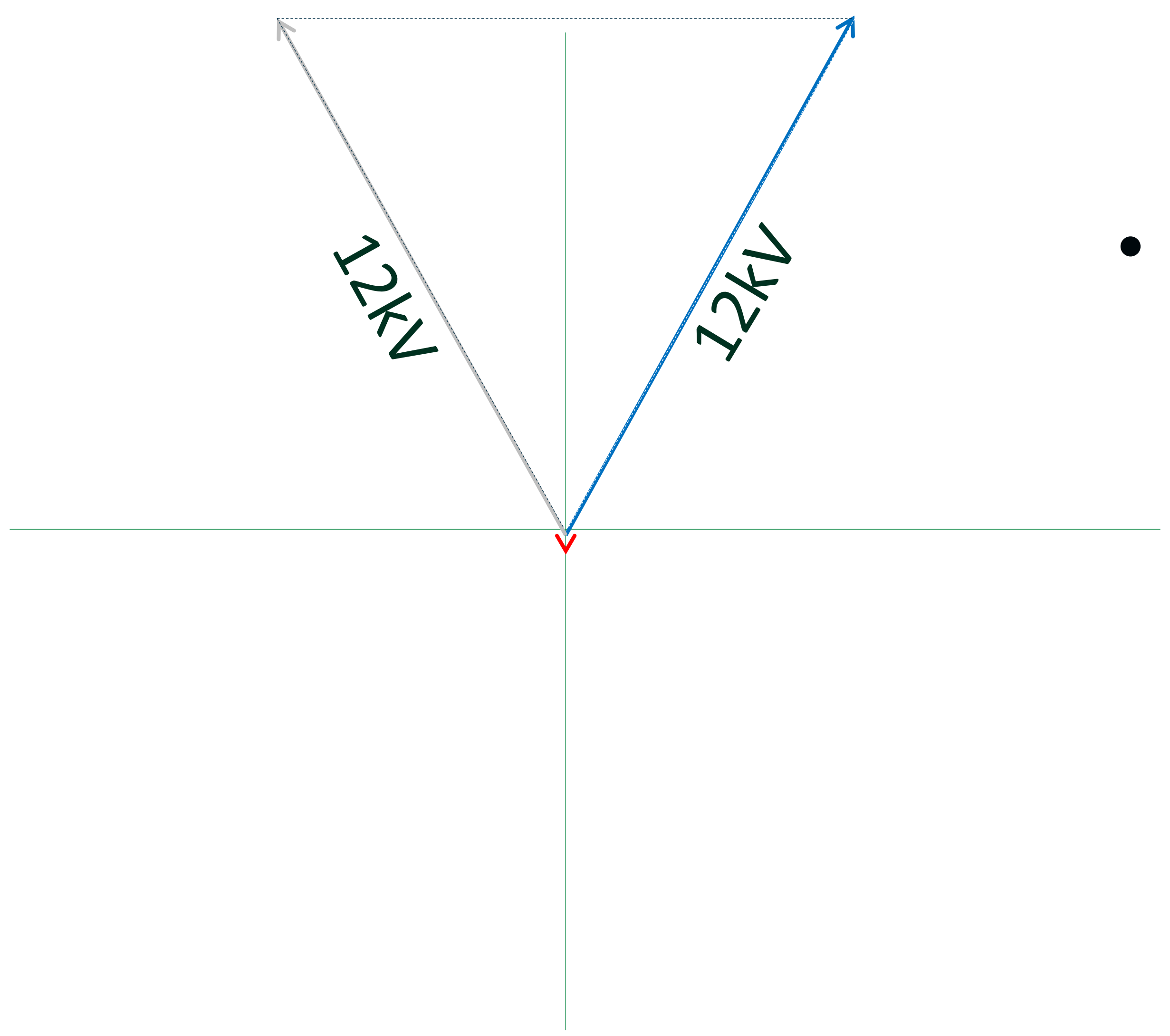
Resonant Grounding

- The ASC across the neutral, that is tuned to the network capacitance, will neutralize the unbalanced capacitive current resulted from ph-g voltage on the two healthy phases.
- A residual current due to resistive (residual) losses still exists of between 10-20 amps typically. This current is then reduced to almost zero by the RCC.

System Normal



REFCL Compensating for Red Phase Fault



- 12kV Phase to Ground on the 2 un-faulted phases
- 0kV Phase to Ground on the faulted phase, 7.2 kV Neutral to Ground

How Does GFN Work

Petersen Coils & Compensated Neutral Schemes

Distribution Ground Fault Neutralizer Results

- PG&E installed one GFN’s
- SCE installed four GFN’s
- Staged fault testing show primary fault currents ~1 amp
- Ability to detect ground faults with several thousand ohms of Zf.

Incipient Fault Detection

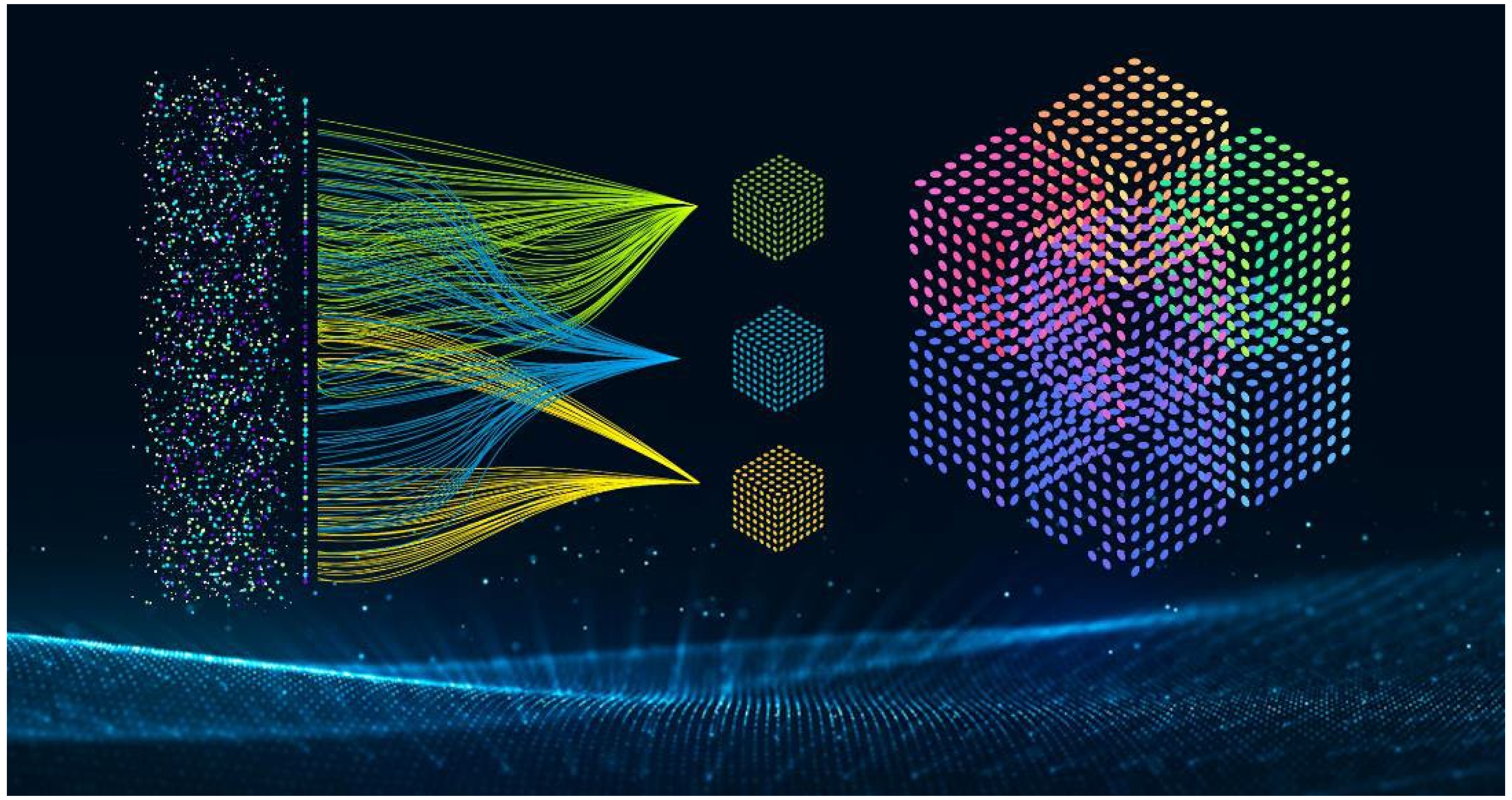
- Technologies, trials and solutions being developed or applied for incipient or “emergent” fault detection that are potential pre-cursors to fire ignition risks.
- The gold standard sought by the industry are methods to detect incipient faults with enough time to take action before high current faults occur.
- Principles used for the technologies and solutions for incipient fault detection can be classified under the following categories.
    - Pattern Recognition
    - Corona Discharge Detection / Partial Discharge Analysis
    - Remote sensing and LIDAR based
    - Video monitoring based
    - Fiber based line monitoring methods

Incipient Fault Detection

Pattern Recognition Methods

- Distribution lines are typically protected by fuses and overcurrent relays. This limits disturbance analysis to protective relay data.

- New sensor and fiber-based applications show promise for line health monitoring to identify fault precursors with enough time to find and fix some problems before a fault occurs.



J. A. Wischkaemper, C. L. Benner, B. D. Russell and K. M. Manivannan, "Waveform analytics-based improvements in situational awareness, feeder visibility, and operational efficiency," *2014 IEEE PES T&D Conference and Exposition*, 2014, pp. 1-5, doi: 10.1109/TDC.2014.6863349

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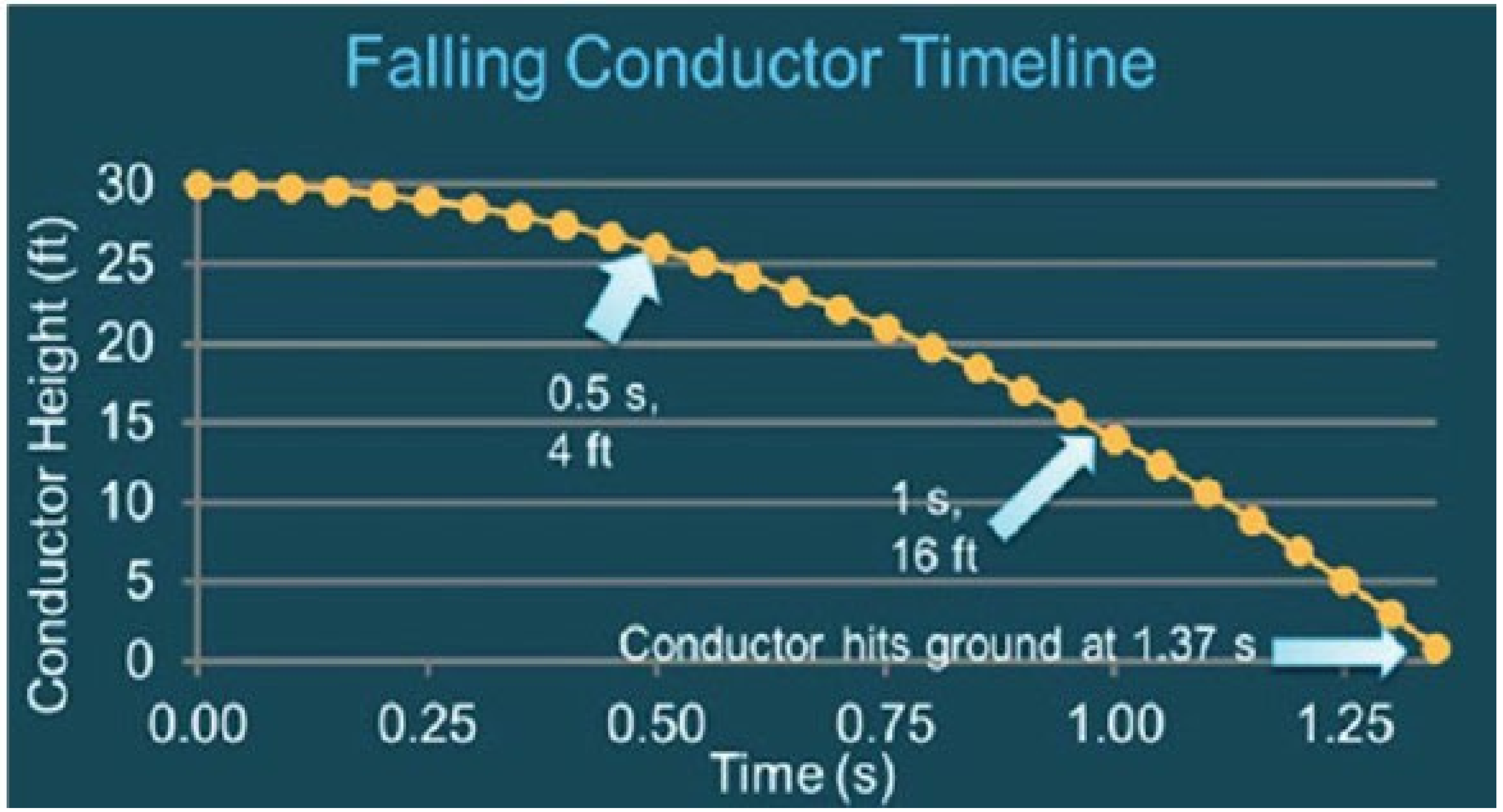
Incipient Fault Detection

Falling Conductor Detection (FCP), Open Conductor, Open Phase Methods

- Falling Conductor Protection (FCP) systems developed around 2014, detect the electrical signature of circuit voltage and/or current changes that identify a conductor that has just broken and is falling towards the ground.
- 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.

1 Distribution falling conductor operational timing

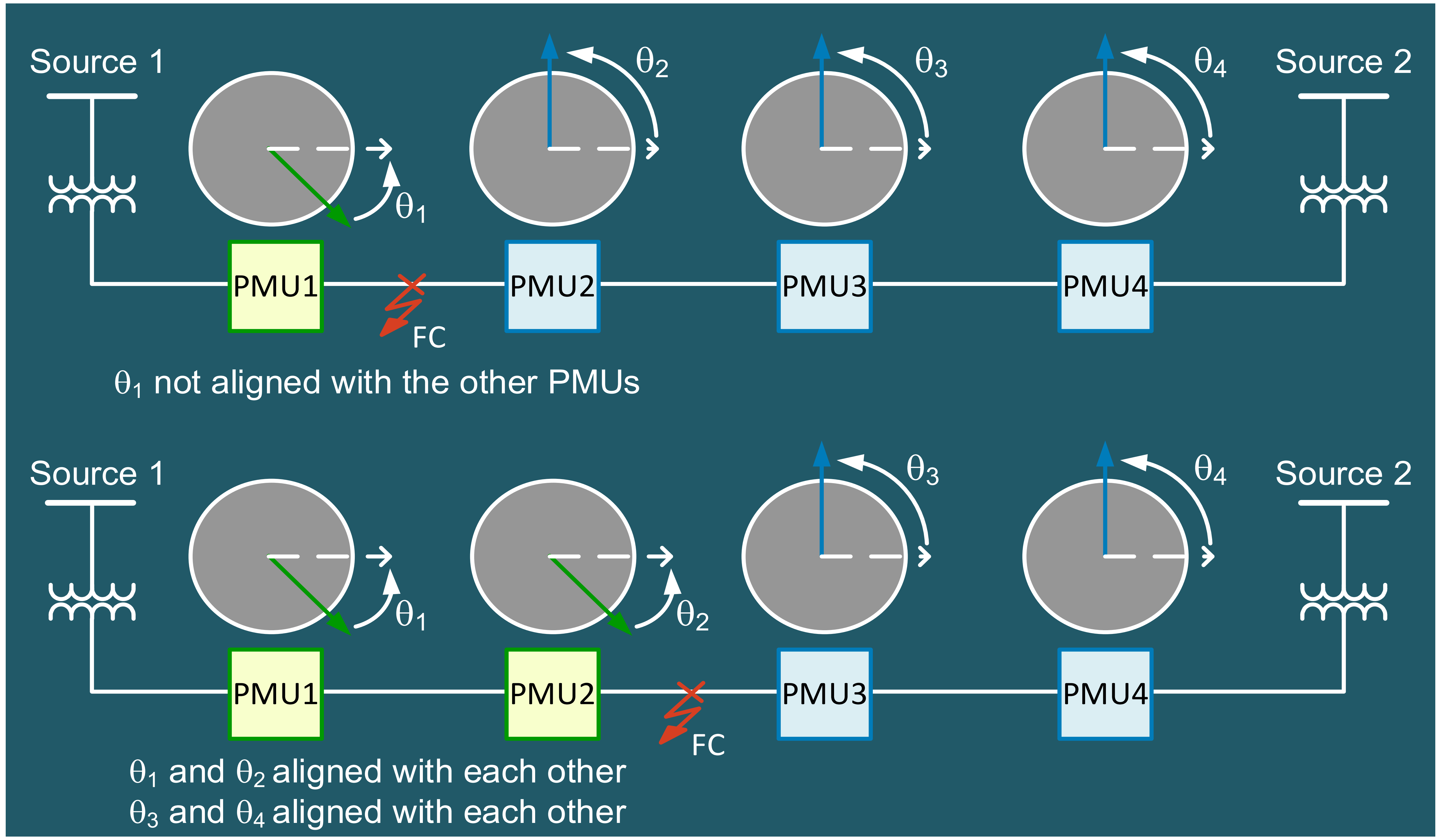


Incipient Fault Detection

Falling Conductor Detection (FCP), Open Conductor, Open Phase Methods

Measurement systems can detect the break and trip adjacent switches to isolate the failed section in 200-500 ms, so that the conductor lands deenergized and no fault or arcing occurs.

For distribution systems with DER and IBR it may require additional trip signals to be sent to all sources that might be energizing the conductors that are falling to the ground.



Impact of Fuses on Fire Risk

- Fuses are typically the most common protective device installed in overhead distribution systems.
- Various types:
  - Single Phase Devices
  - Expulsion Fuses
  - Non-Expulsion Fuses
  - Current Limiting Fuses
  - Electronic Interrupters

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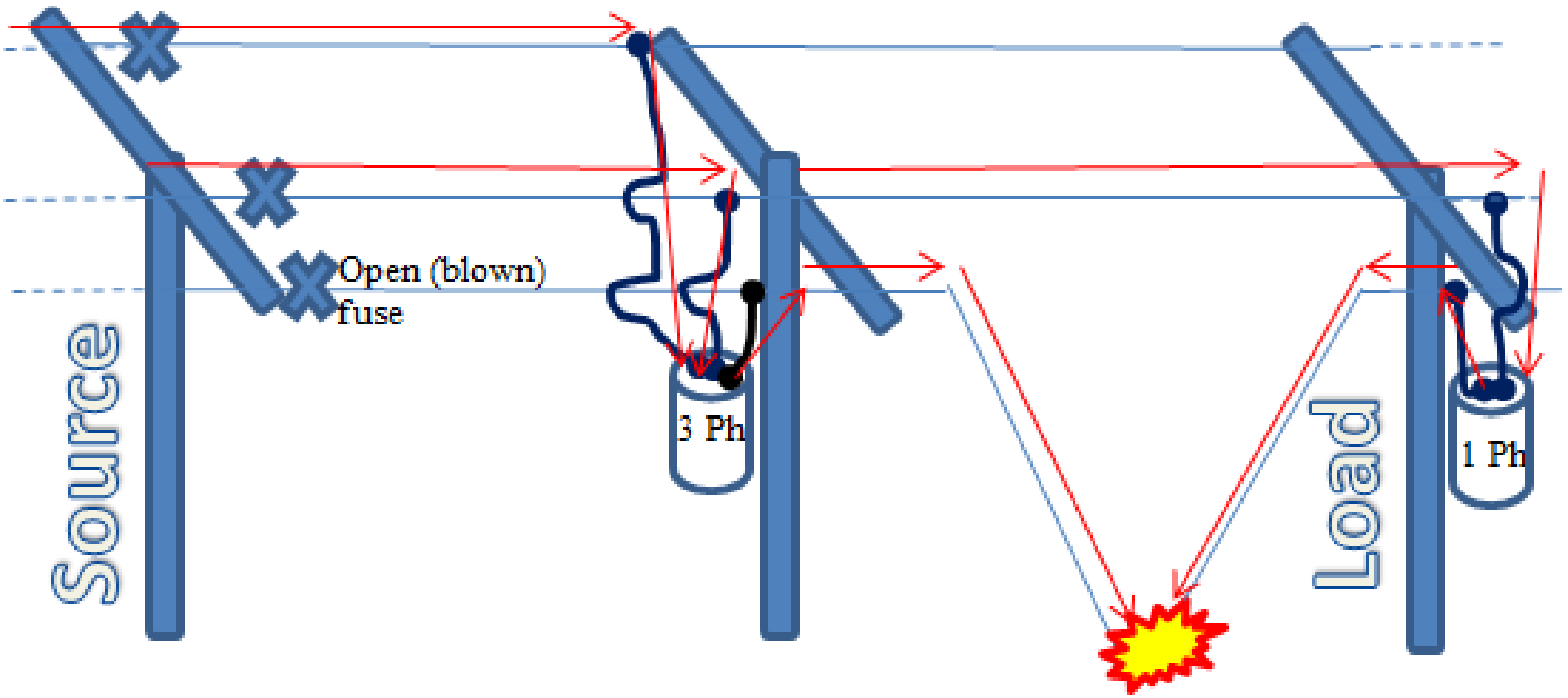
Impact of Fuses on Fire Risk

- Single phase operating devices in some cases can increase the risk of downed conductors that may remain energized and can cause fire ignition.
- 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 **back fed fault**.

Single Phase Devices



Regulatory Environment in Australia

Scott Hayes, PG&E

Jonathan Sykes, Quanta Technology

June 6, 2024

Australian Regulation

- 2016 The State of Victoria, Australia Passed Regulation 32/2016 to Reduce Bushfire Risk.
- The Regulations are Prescriptive. The regulation includes 45 Substations – Listed by Name and Lat/Lon.
- Performance Requirements are Part of the Regulation
- In 2016 Only One Vendor Could Meet The Performance Requirement.

Australian Regulation

Performance Requirement Must Be Validated By Testing Every Year

- In the event of a phase-to-ground fault on a polyphase electric line, the ability
- (a) to reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for high impedance faults to 250 volts within 2 seconds; and
- (b) to reduce the voltage on the faulted conductor in relation to the station earth when measured at the corresponding zone substation for low impedance faults to
  - (i) 1900 volts within 85 milliseconds; and
  - (ii) 750 volts within 500 milliseconds; and
  - (iii) 250 volts within 2 seconds; and
- (c) during diagnostic tests for high impedance faults, to limit
  - (i) fault current to 0·5 amps or less; and
  - (ii) the thermal energy on the electric line to a maximum I2t value of 0·10;

Regulatory Framework in the USA

- Veg Management Laws -Vary by State.
- California Utilities are not allowed to cut healthy trees outside of Rights of Way. Some ROW are 30 feet wide with 100- to 300-foot-tall trees
- Liability Laws – Vary by State
- California has GO 95 which applies to hardware failures and vegetation contacts– Faults are generally considers a violation due to Utility “Failing to Maintain its Facilities Safely…”

Credit: *Getty Images*

Thank you!

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Eric Udren, Quanta Technology

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