Wildfire Mitigation at Southern California Edison

Brendan Kirkpatrick

Southern California Edison

A Little About Me

- California native
  - Born in Oxnard, CA (southernmost city of California's Central Coast region)
  - Raised in Sonoma, CA (famed wine town ~1hr north of San Francisco)
- Graduated Cal State Long Beach with BSEE in 2010
- Hired as an Apparatus Engineer at SCE in 2010
  - Equipment specs, standards, training development, field support
- Now Engineering Manager in Apparatus Engineering
  - Team developed and implemented significant portions of SCE's Wildfire Mitigation Portfolio starting ~2018 through present

Why Does Wildfire Mitigation Matter?

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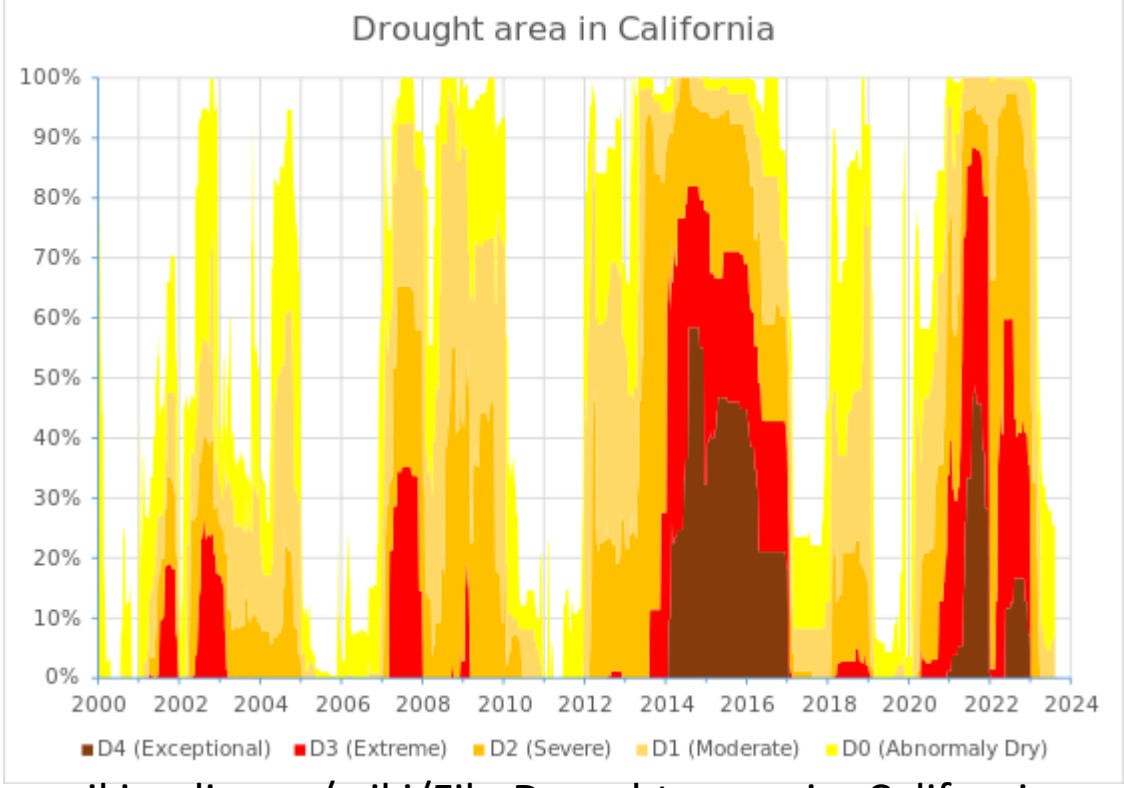


https://en.wikipedia.org/wiki/File:Drought_area_in_California.svg

- Climate Change
  - Higher temperatures
  - Frequent and intense drought conditions
- "Wildland Urban Interface"
- Legal Consequences
  - Inverse Condemnation & Strict Liability:

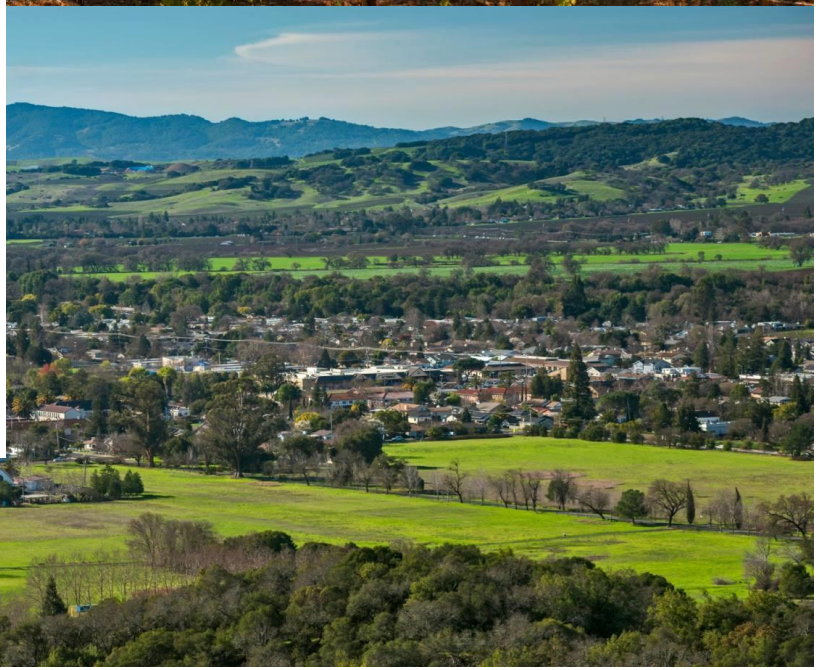
    "[…] electric utilities can be held liable for damages caused by their equipment, including power lines and transformers, regardless of whether they acted in accordance with safety standards and regulations […] California's unique attachment of strict liability to inverse condemnation is not seen in other states that experience frequent wildfires."

    "[…] a utility that acted prudently may recover from its ratepayers the wildfire liabilities that resulted from its equipment. If the utility's actions were deemed negligent […] losses can be solely borne by the shareholders."

https://www.publicadvocates.cpuc.ca.gov/-/media/cal-advocates-website/files/reports/230407-caladvocates-wildfire-safety-inverse-condemnation-policy-paper.pdf

Why Does Wildfire Mitigation Matter *to Me?*

Where Were You on Oct 8, 2017?



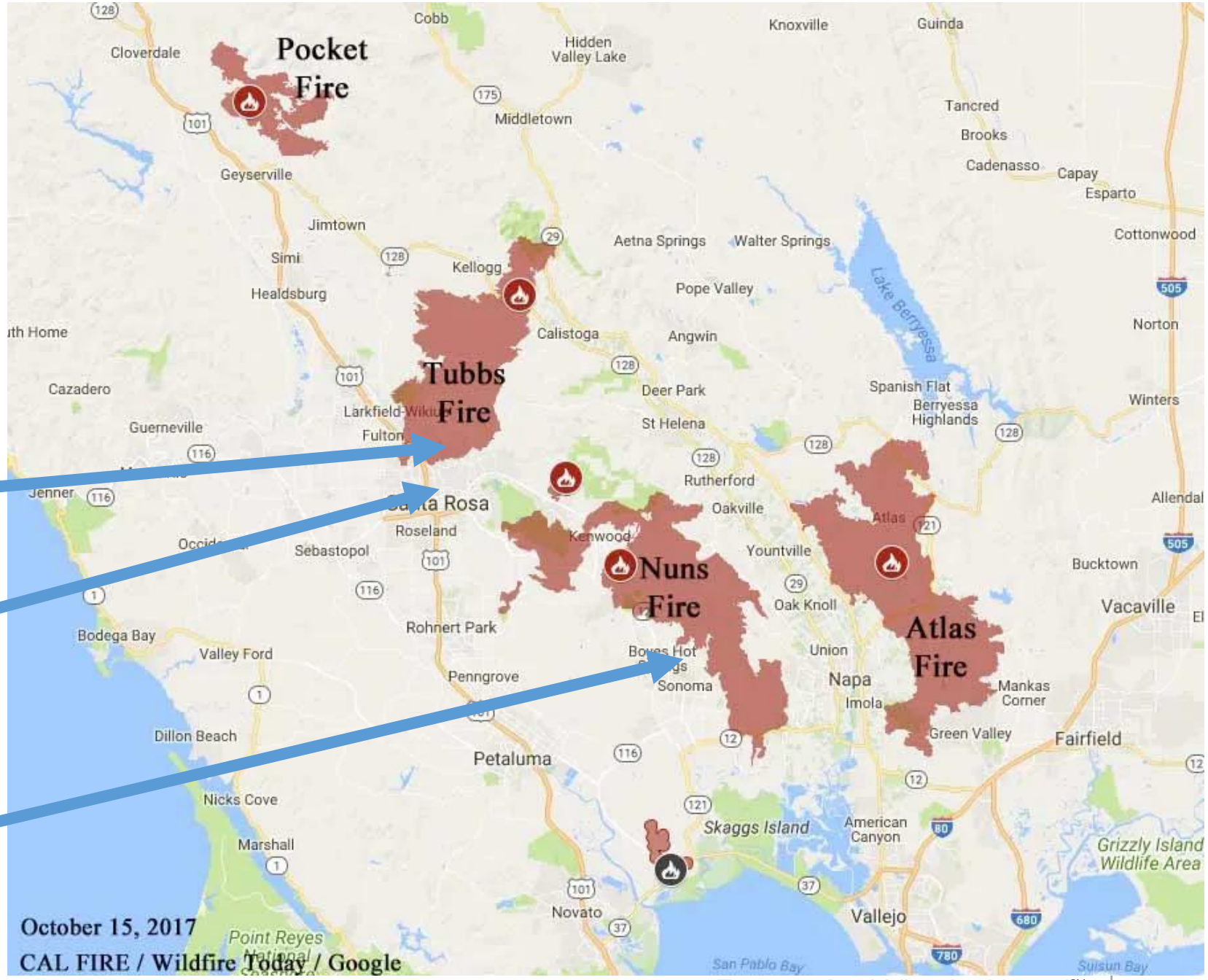
2017 Northern California Fires

>240,000 acres burned
8,900 buildings destroyed
44 deaths
192 injuries
~$15 billion in losses/costs

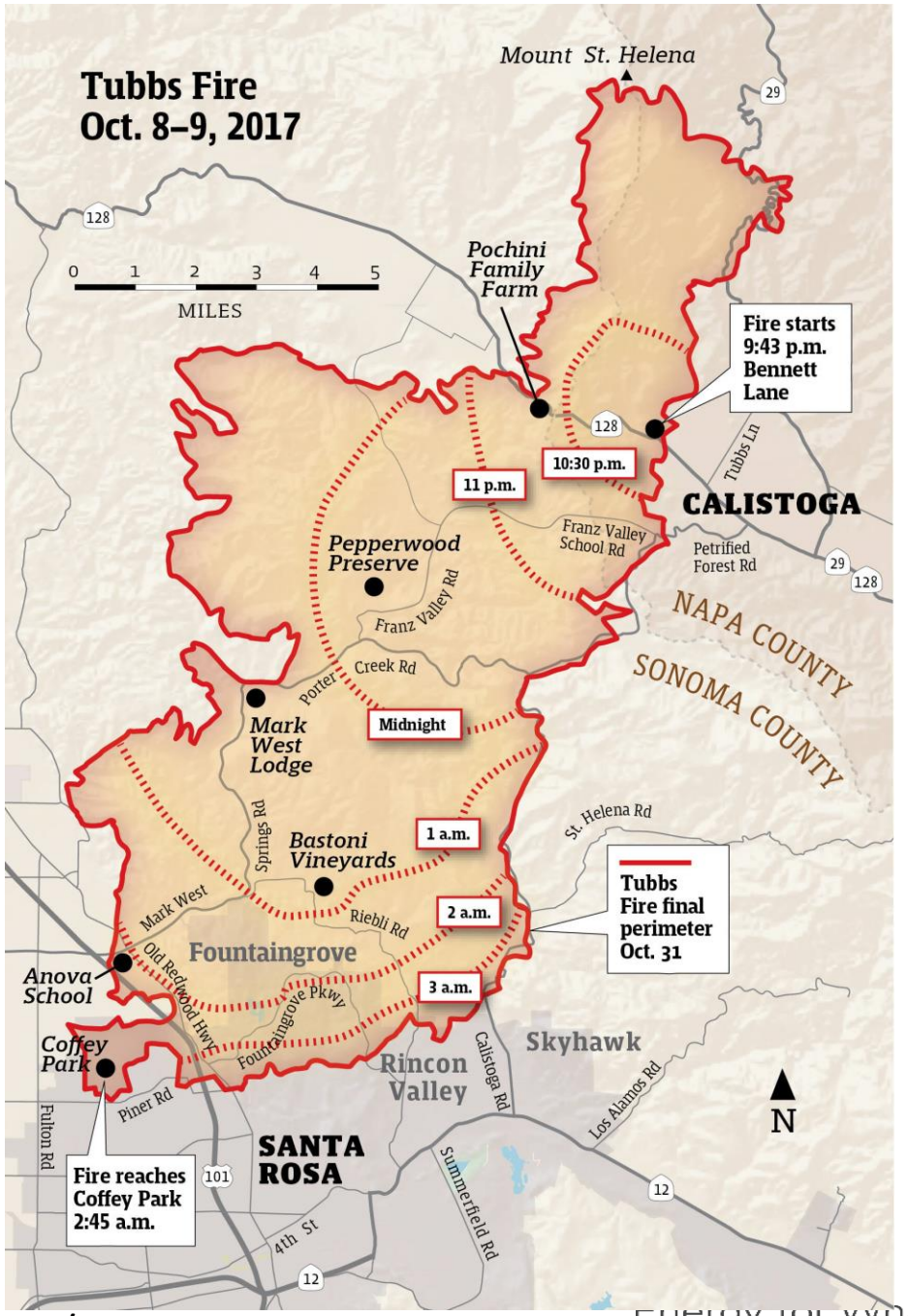
Dad's work (HP/Agilent/Keysight Fountaingrove Campus)

My high school

My parent's home

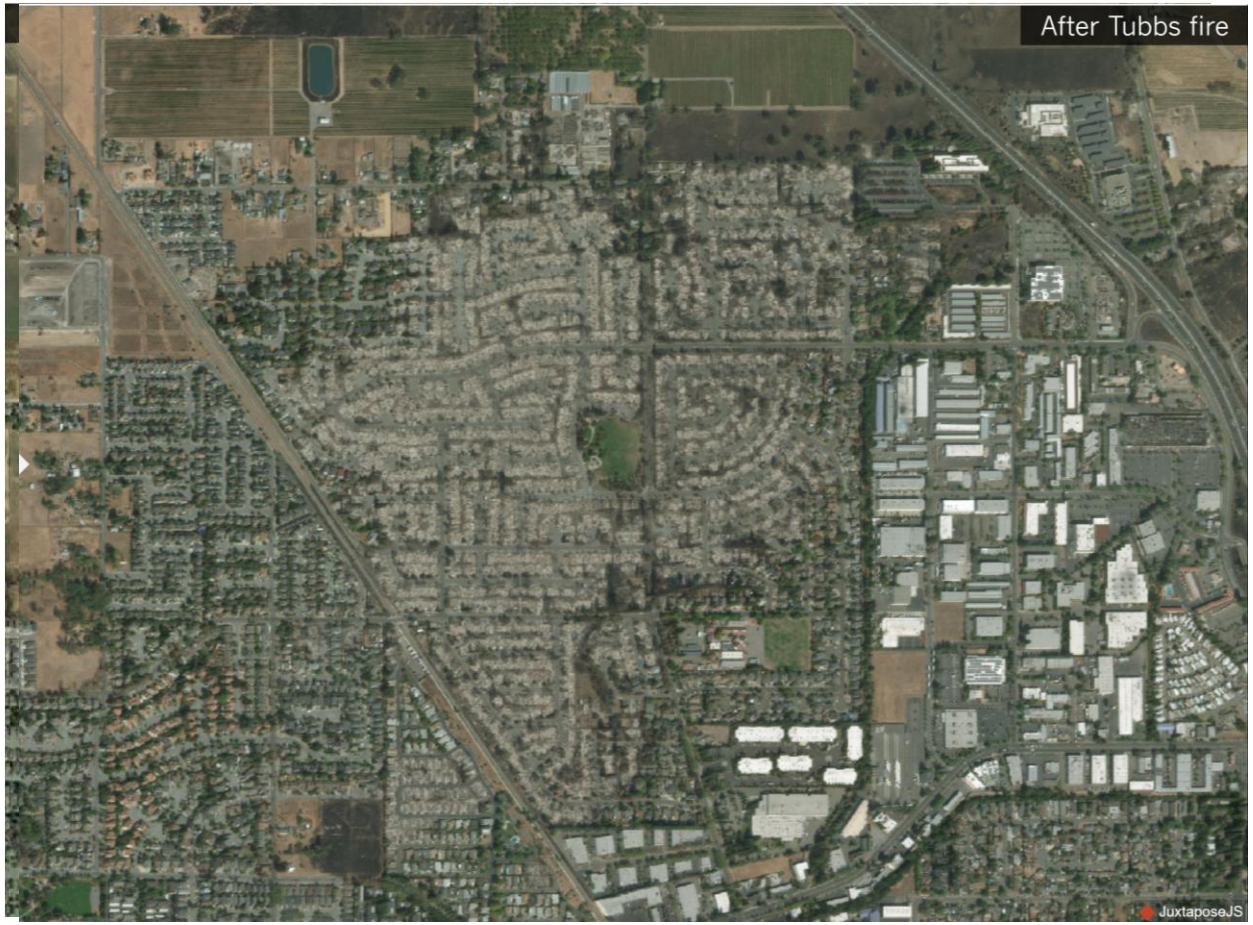


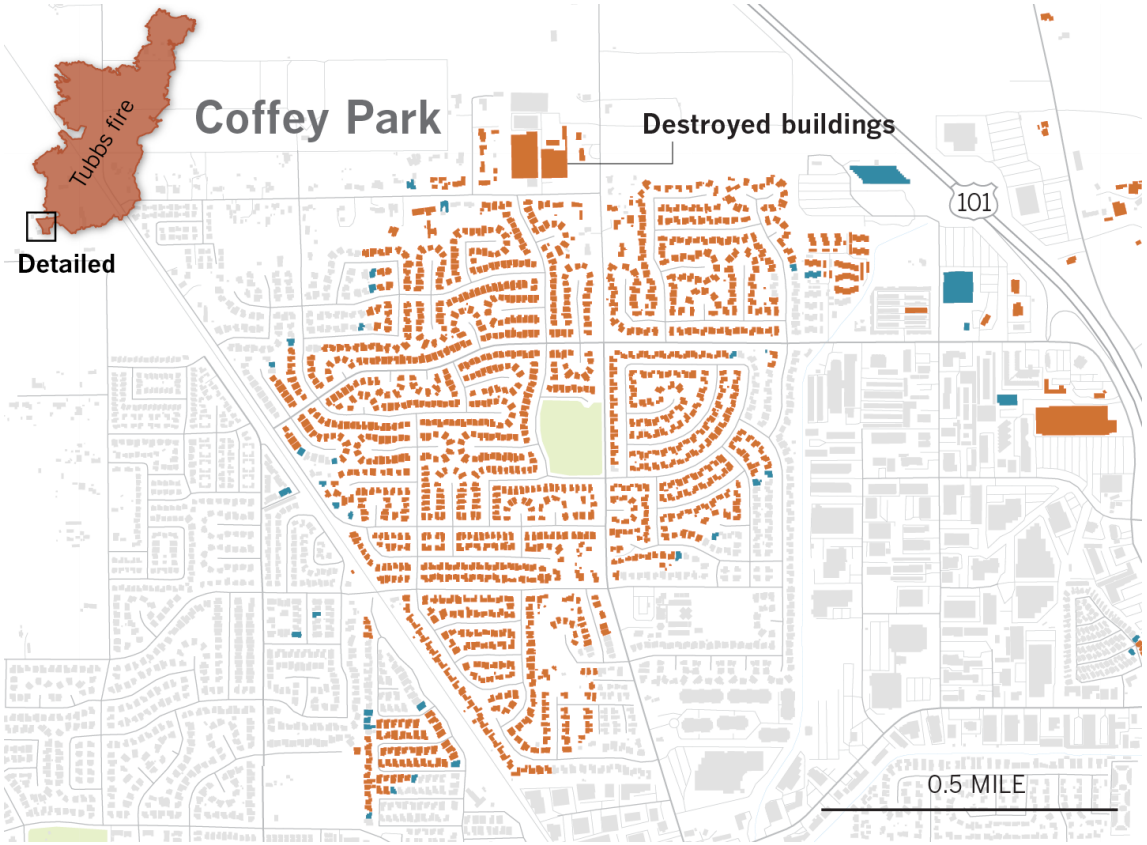
"On the night of Oct. 8, 2017, the Tubbs Fire raged from Calistoga to the Coffey Park neighborhood in Santa Rosa, almost 12 miles in just five hours"



https://www.pressdemocrat.com/article/news/tubbs-fire-map/

~1,500 residences destroyed in Coffey Park neighborhood of Santa Rosa



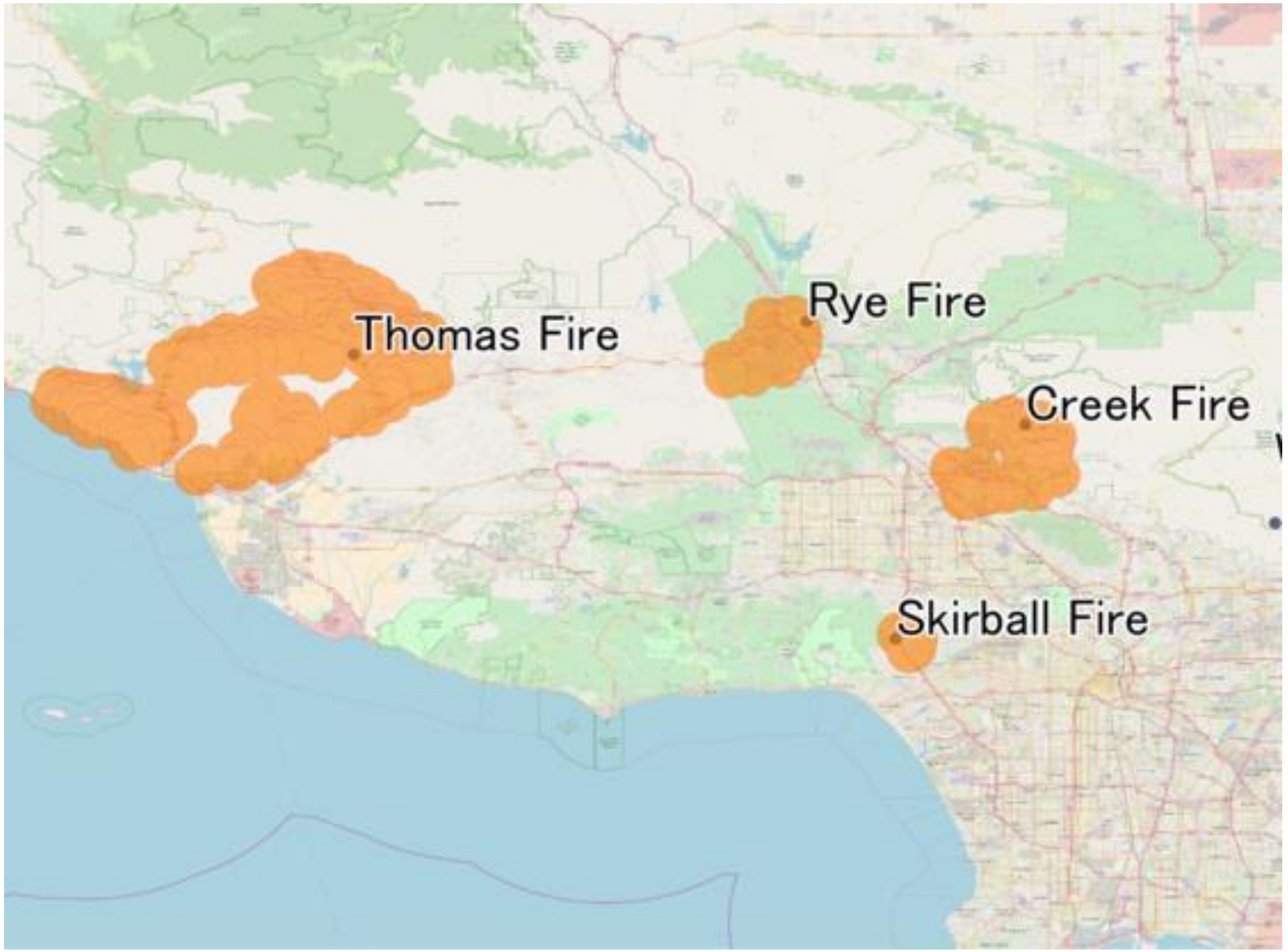


https://www.latimes.com/projects/la-me-northern-california-fires-structures/

Christmas in Coffey Park, 2017

2017 Southern California Fires

>300,000 acres burned
1,355 buildings destroyed
2 deaths
19 injuries
~$3.5 billion in losses/costs



Layered Wildfire Mitigation Approach

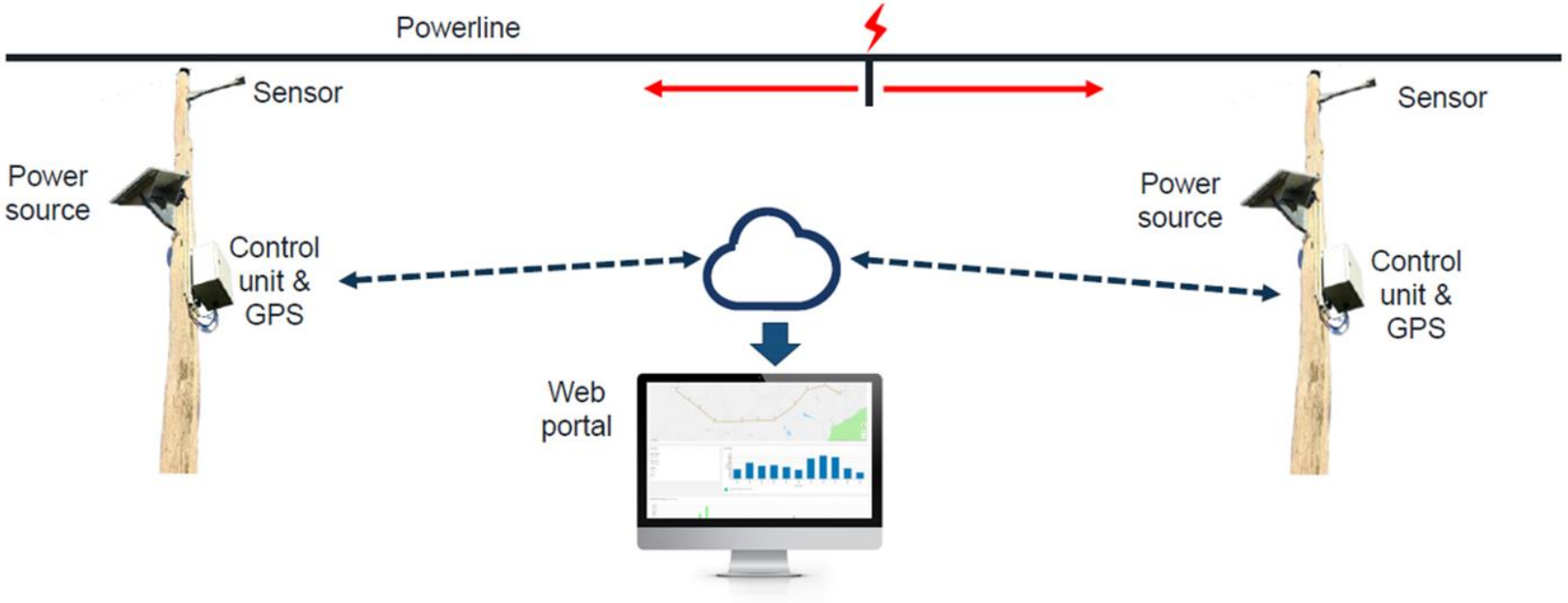
- Detect
  - Weather Stations
  - Inspections
  - **“Incipient Fault” Detection Technologies**
- Prevent
  - Vegetation Management
  - Covered Conductor
  - Targeted Undergrounding
  - Public Safety Power Shutoff
- Respond
  - “Fast Curve” Protection Settings
  - Current Limiting Fusing
  - **REFCL**

Detect – Incipient Fault Detection

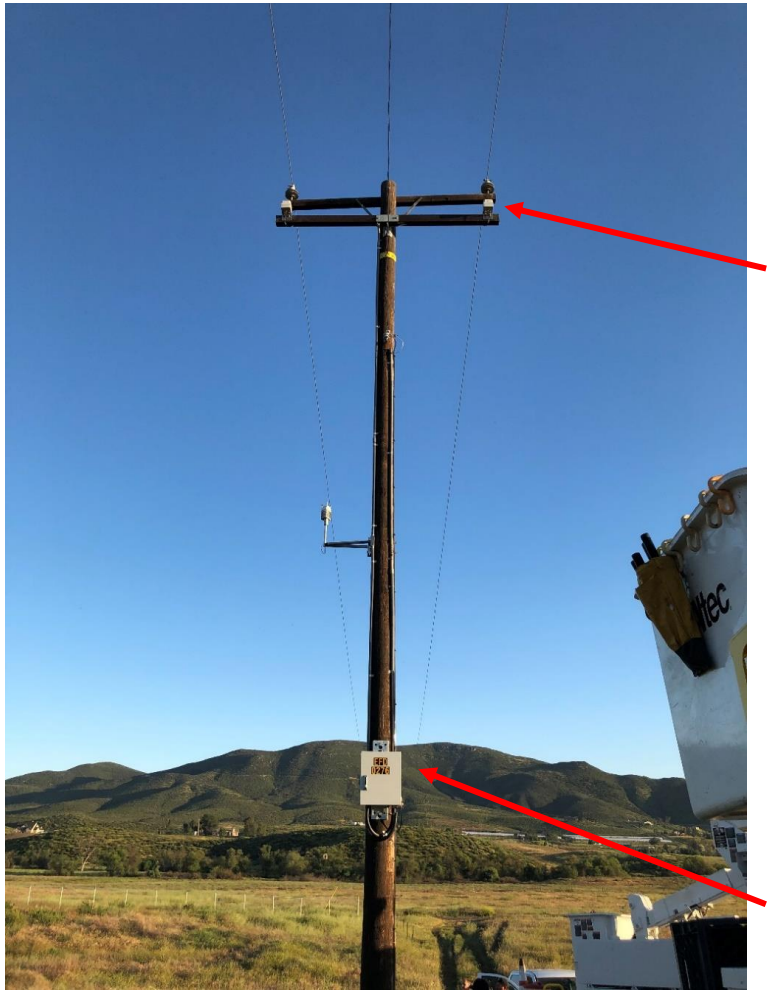
Detect – Early Fault Detection (EFD)

EARLY FAULT DETECTION (EFD) uses radio frequency sensors placed on power poles to “listen” for abnormal radio frequency signals on power lines that indicate potential problems, such as frayed power lines, tracking, arcing and vegetation contact, to help prevent potential ignitions before the equipment fails.

Radio frequency (RF) sensors are placed below overhead lines – every 3 miles for distribution and every 5 miles for transmission.



EFD Construction Examples: Distribution And Transmission Systems



~250 Distribution Sensors, Aug 2023

~15 Transmission Sensors, Aug 2023

Early Fault Detection Findings: Gunshot Damage

- EFD led to discovery of damaged conductor
- Damage not visually apparent to naked eye, required walking the line and close inspection with binoculars/hi-zoom camera to identify mid-span location of event

Early Fault Detection Findings: Wire Damage Close-up

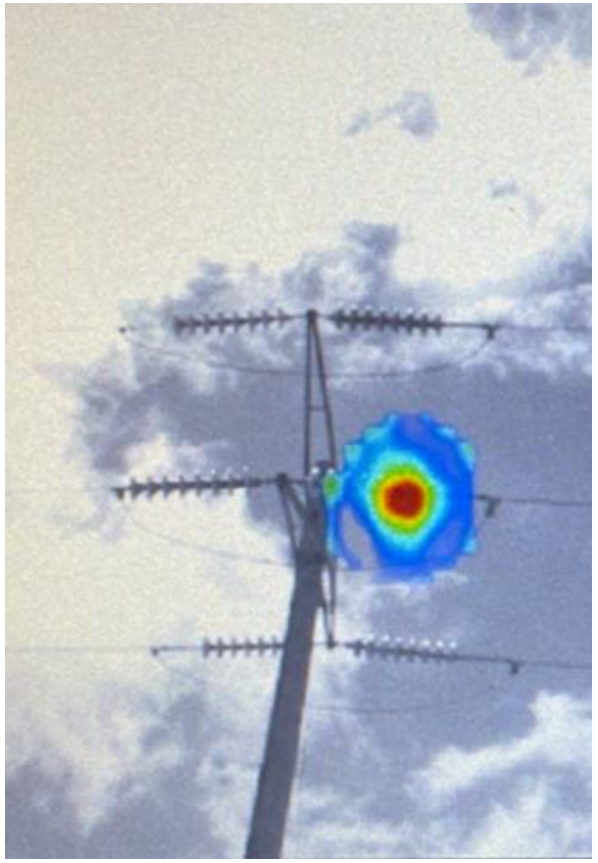
- Close-up of conductor from gunshot damage
- Investigation showed presence of lead at location suggesting gunshot damage
- Proactive conductor replacement mitigated risk of in-service failure

Early Fault Detection Findings: Surge Arrester Tap Separation

- Connection to surge arrester located behind the fuse holder was found arcing
- Initial inspection did not identify cause, the EFD sensors reported an increase in energy and detection frequency weeks later
- A follow-up site visit found the arcing connection/wire that was repaired, which resolved further EFD detection activity at location
- Proactive replacement prevented an in-service failure

Video captures sound from equipment

Early Fault Detection Findings:
Pairing With Other Visual Inspection Tools To Enhance Detections

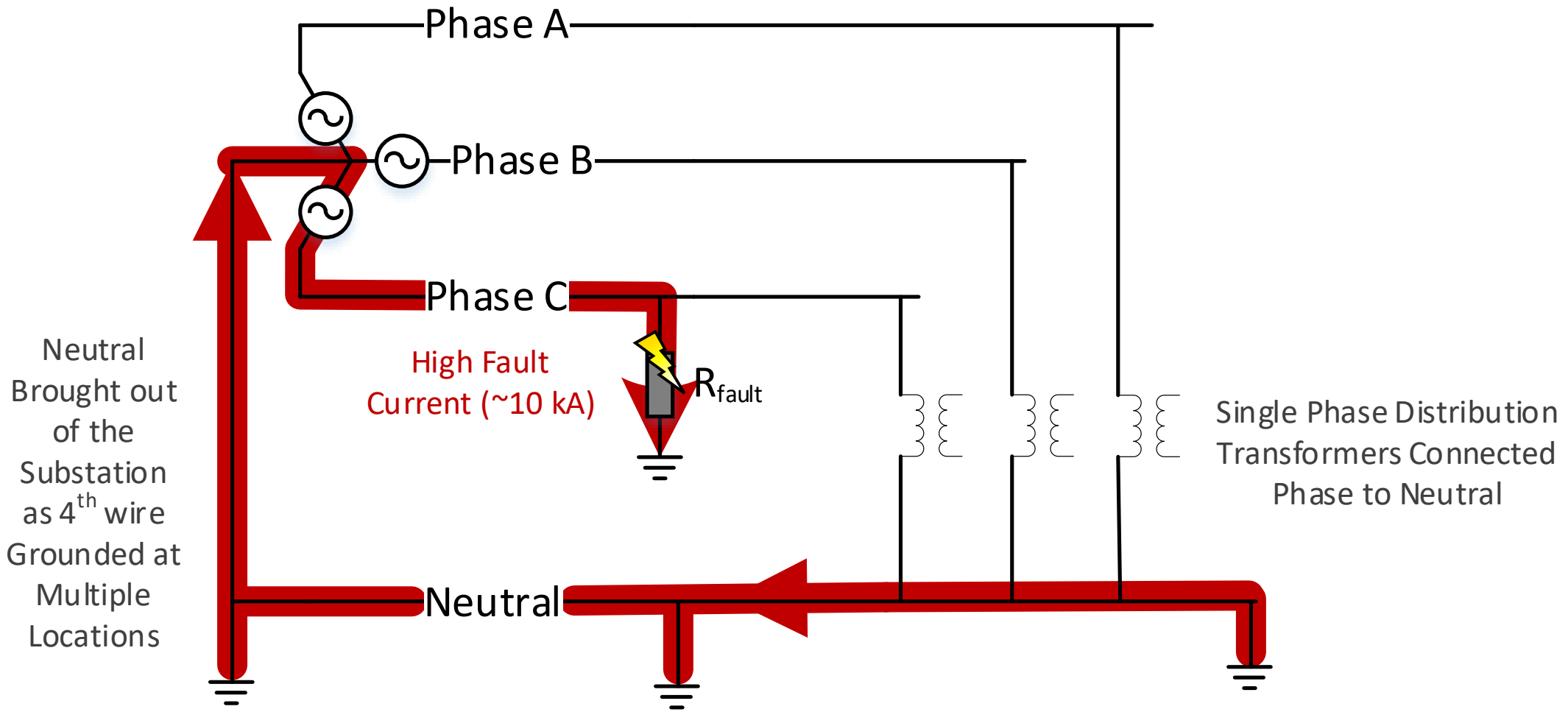


SCE's pilot evaluation for EFD has found the sensors can identify degradation or undesirable conditions on the monitored system that may not have progressed to a point where visual identification of the concern is apparent. Additional tooling, such as the acoustic camera shown above, has proven valuable in locating the cause of the EFD alert in some cases.

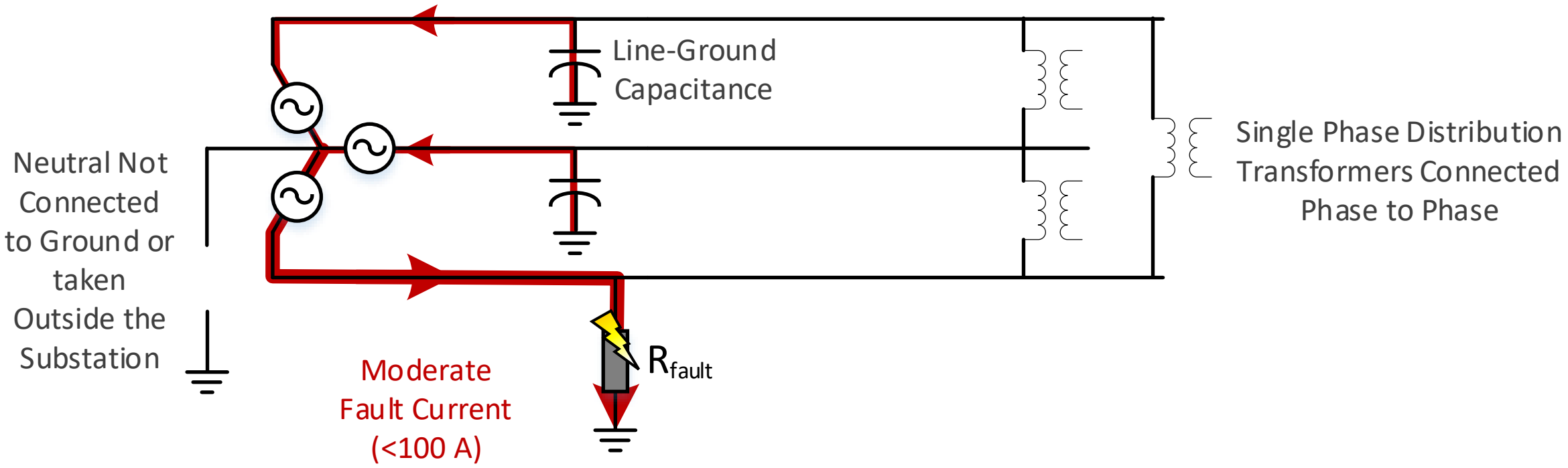
Respond – Rapid Earth Fault Current Limiter (REFCL)

Electric System Transformer Grounding: 4 Levels of Ground Fault Current

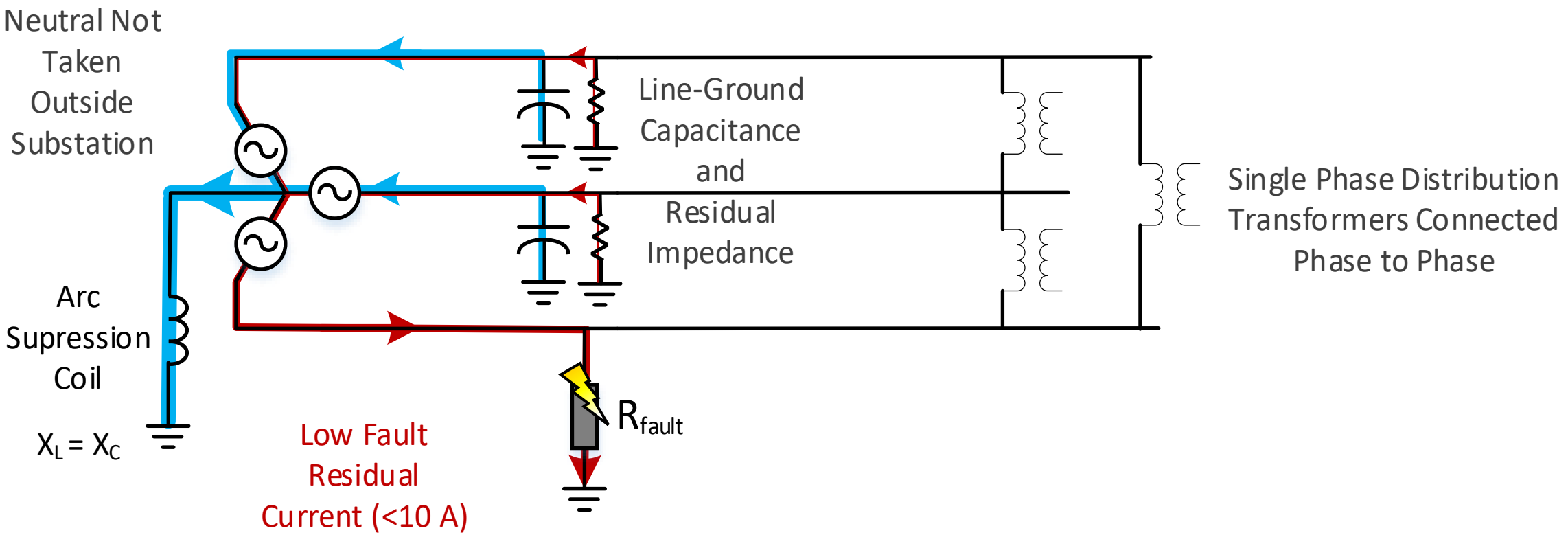
Solidly Grounded 4-Wire System



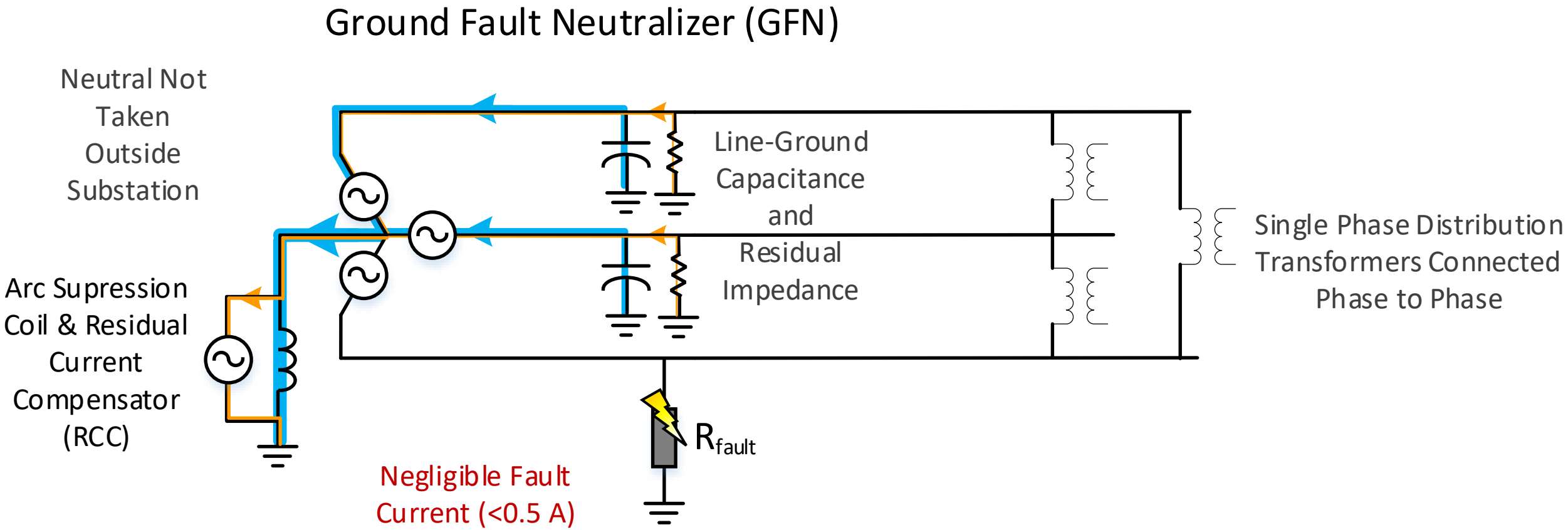
Ungrounded System



Resonant Grounded System



System with Ground Fault Neutralizer



REFCL Background

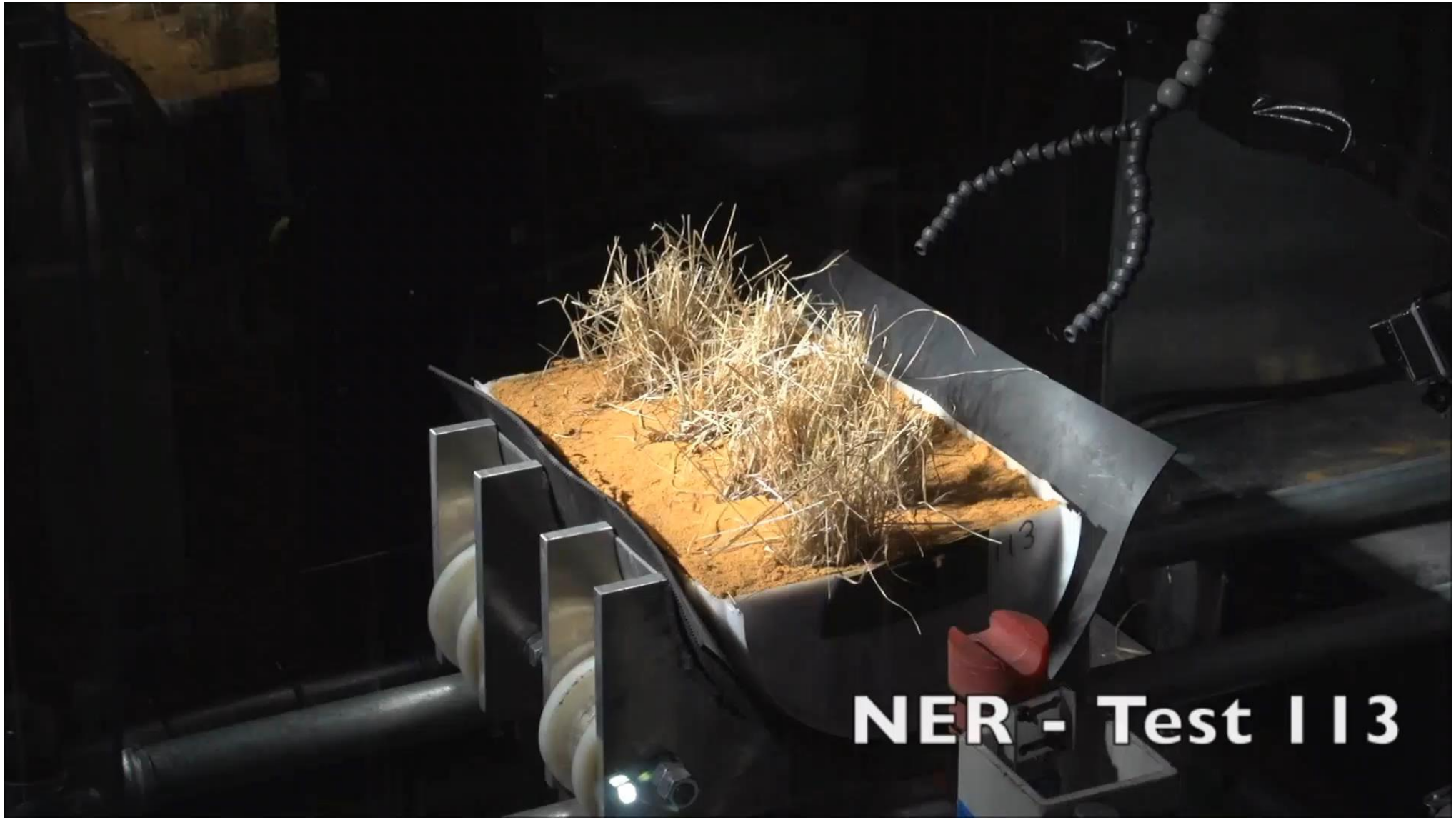
- Wildfire Risk in California has forced international benchmarking for safest design practices
- Many international utilities build much different distribution systems, some of which address many seemingly unsolvable safety concerns
  - Northern European grids designed around maximum ground fault currents of less than 10A while detecting 5,000-ohm faults
  - Victoria Australia, the Rapid Earth Fault Current Limiter (REFCL) Program existing record holder for both the most sensitive protection, detecting 25,400-ohm faults, and lowest energy release from ground faults
- SCE is scaling up systems based on principles learned from these utilities
  - Installation of equipment to reduce worst case energy release from ground faults
  - Installation of equipment to balance distribution networks to the point that 0.5 ampere ground faults can be detected.

Australian Rapid Earth Fault Current Limiter (REFCL) Program

Australian Experience

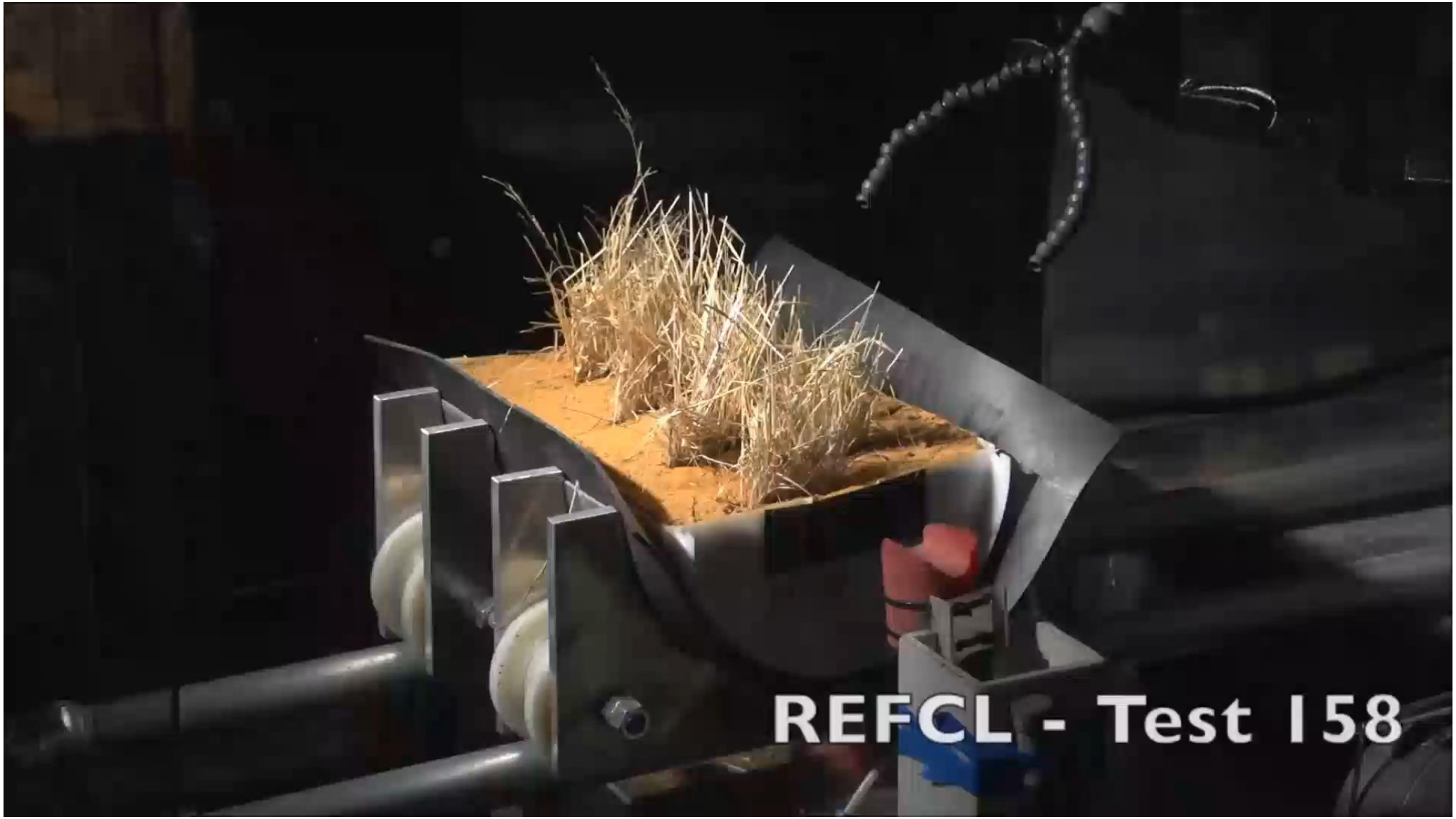
- Black Saturday bushfires in 2009
  - 173 fatalities
  - 1,100,000 acres burned
- In response Victorian government commissioned significant studies on mitigation of ignition hazards.
  - Resulting laboratory ignition testing
  - Development of operational criteria targeting 70-90% reduced ignition risk

Down Wire on Resistance Grounded System



Marxsen Consulting,

Down Wire on a Ground Fault Neutralizer Grounded System

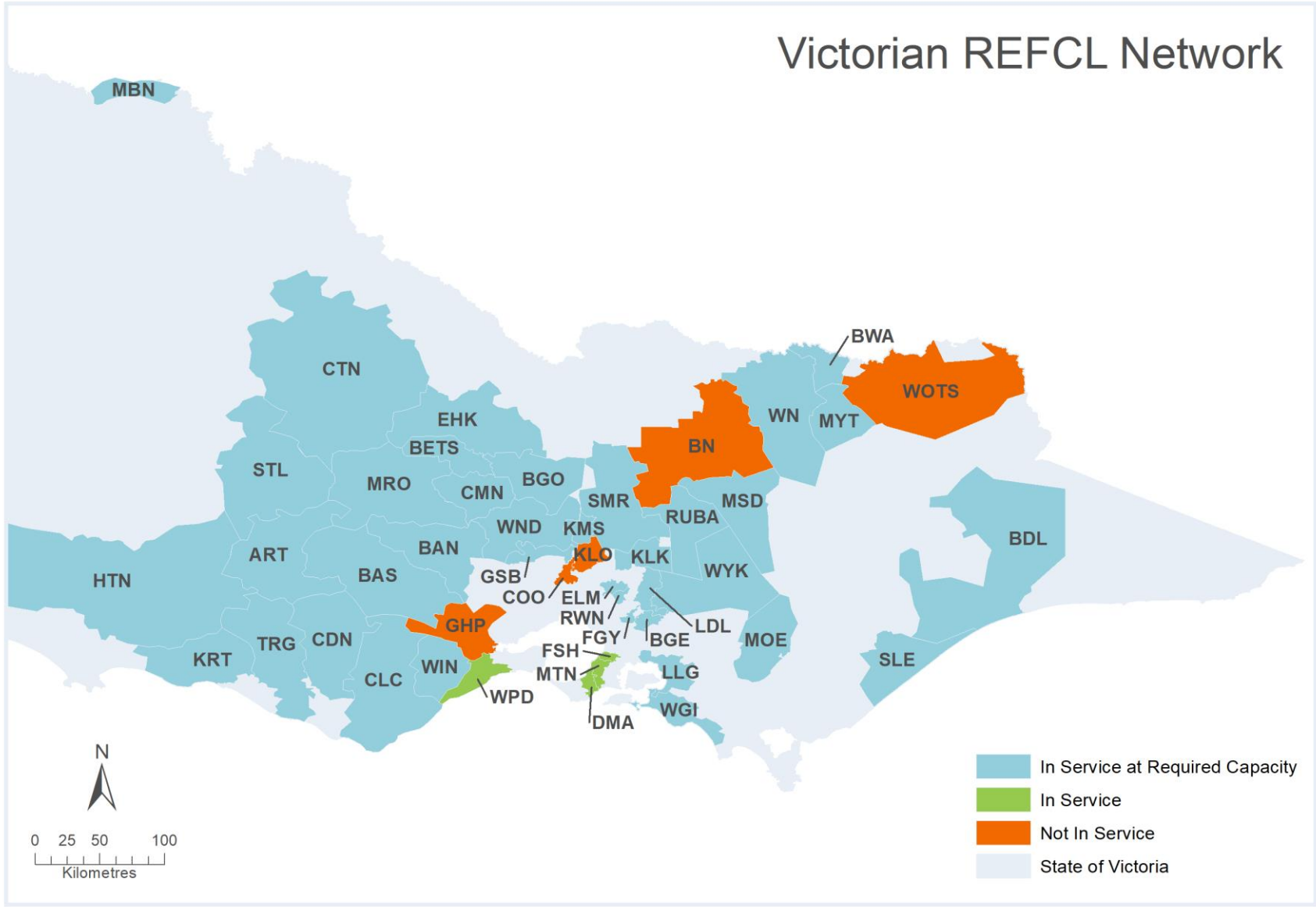


Marxsen Consulting,

Ground Fault Neutralizer Implementation in Australia

- 2014-2016 testing showed a 90% reduction in ignitions from phase to ground faults with a Rapid Earth Fault Current Limiter (REFCL)
- In 2016 regulators mandated REFCL installs at 45 substations
- First tranche completed in April 2019
  - More than 10,000 circuit miles of 22 kV system protected today
- Last tranche on track for 2023
  - Full project build out will be more than 19,000 miles
  - Powercor installations are complete on 10,500 miles
  - AusNet and Jemena expected to complete this year

Victorian REFCL Program Status – Nov 2022



https://www.esv.vic.gov.au/about-us/our-organisation/reports/rapid-earth-fault-current-limiter-refcl-reports

Challenges Installing Ground Fault Neutralizers on SCE System

- Many substations feed phase to neutral connected distribution transformers
  - All transformers supplied by the substation must be replaced with phase-to-phase transformers as a part of the upgrade
- Many substations feed only short distances of high fire circuitry
  - Risk spend efficiency of Ground Fault Neutralizer much better when 50+ miles of high fire circuitry supplied from the substation
- High cost limits application for non-fire mitigation purposes

Down Wire Tests

Down Wire Testing Solidly Grounded ~ 15kA Duty

Down Wire Test – Resonant Ground Testing

Wire Contact Phase to Ground – Resonant Grounded Testing

Vegetation Contact Tests

Tree Branch Contact – Resonant Grounded Testing

Energized from 12 kV Isolation Transformer

Grounded

Lichtenberg Figures

Mylar Balloon Contact Tests

Long Beach Metallic Balloon Contact

Metallic Balloon Contact – Resonant Grounded Testing

SCE Ground Fault Neutralizer Program

Neenach Ground Fault Neutralizer

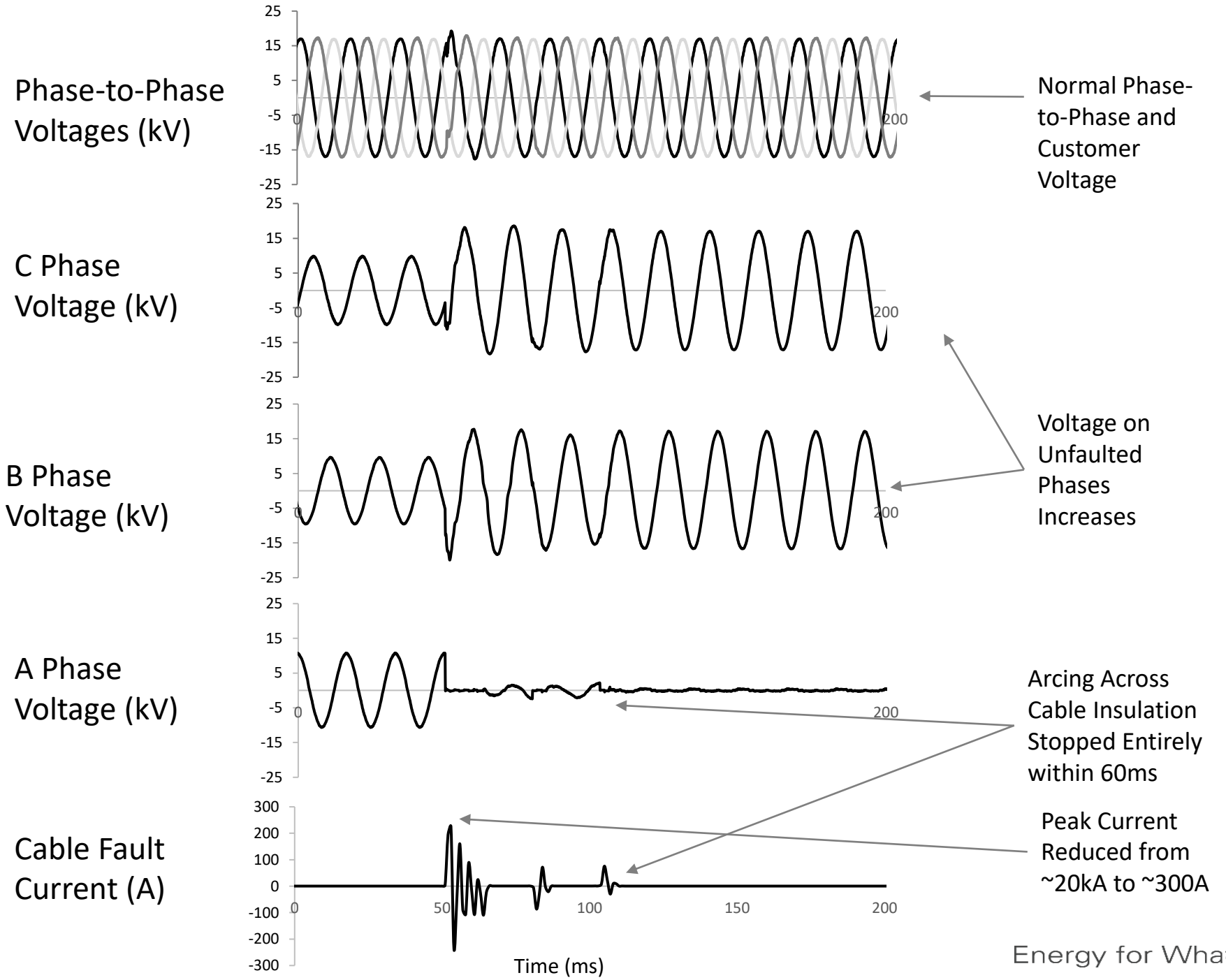
Ground Fault Neutralizer Wired in 20ft Shipping Container

Neutral Circuit Breaker

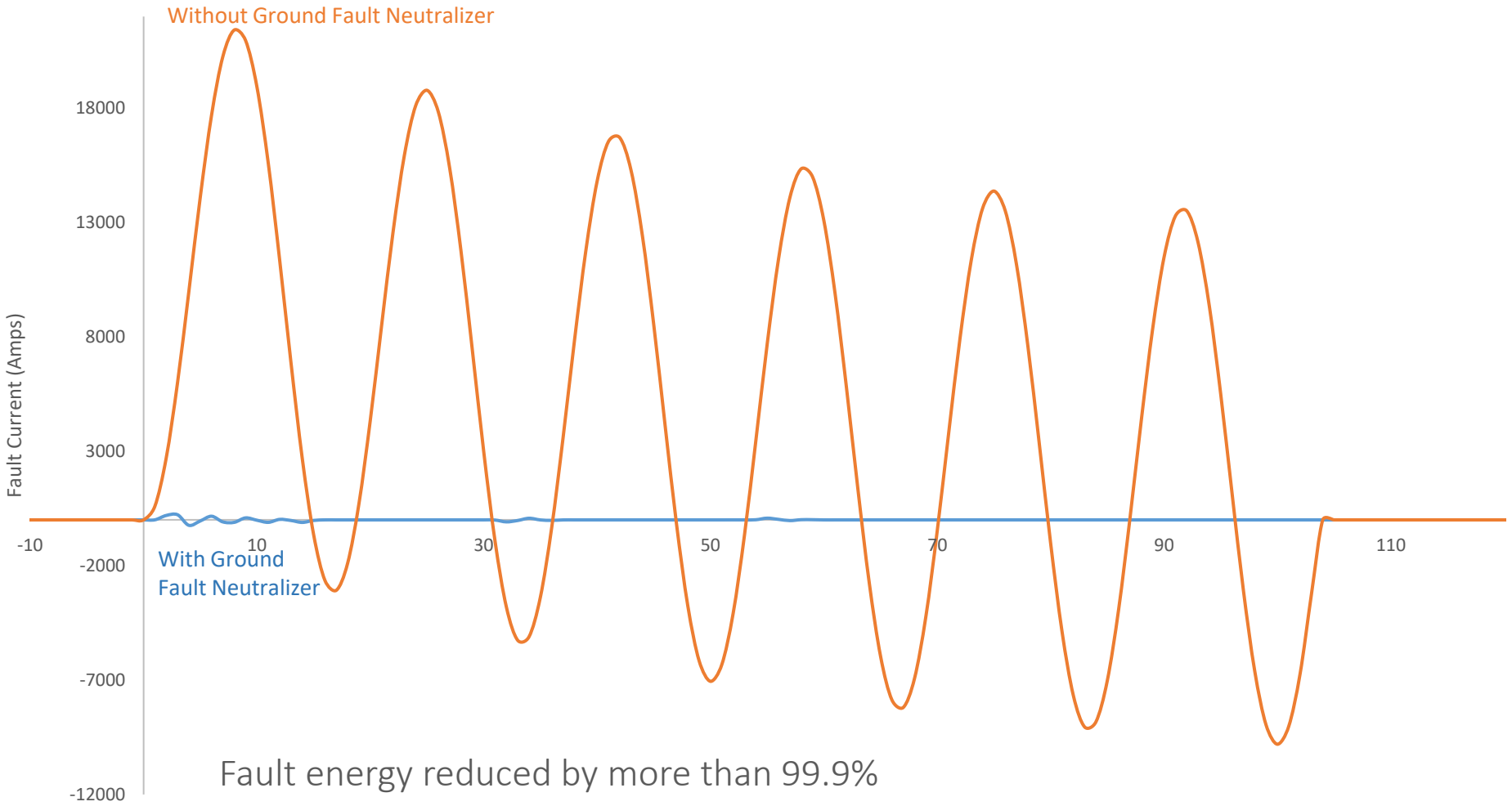
Ground Fault Test Setup

Cable Fault at Substation, Closed Recloser into Cable with Hole in Insulation

20 Second Fault initiates at 1.43, fault confirmation starts at 8.26


Phase-to-Phase Voltages (kV)
C Phase Voltage (kV)
B Phase Voltage (kV)
A Phase Voltage (kV)
Cable Fault Current (A)
Time (ms)
Normal Phase-to-Phase and Customer Voltage
Voltage on Unfaulted Phases Increases
Arcing Across Cable Insulation Stopped Entirely within 60ms
Peak Current Reduced from ~20kA to ~300A

Lowest Current Ground Fault Protection



Fault energy reduced by more than 99.9%

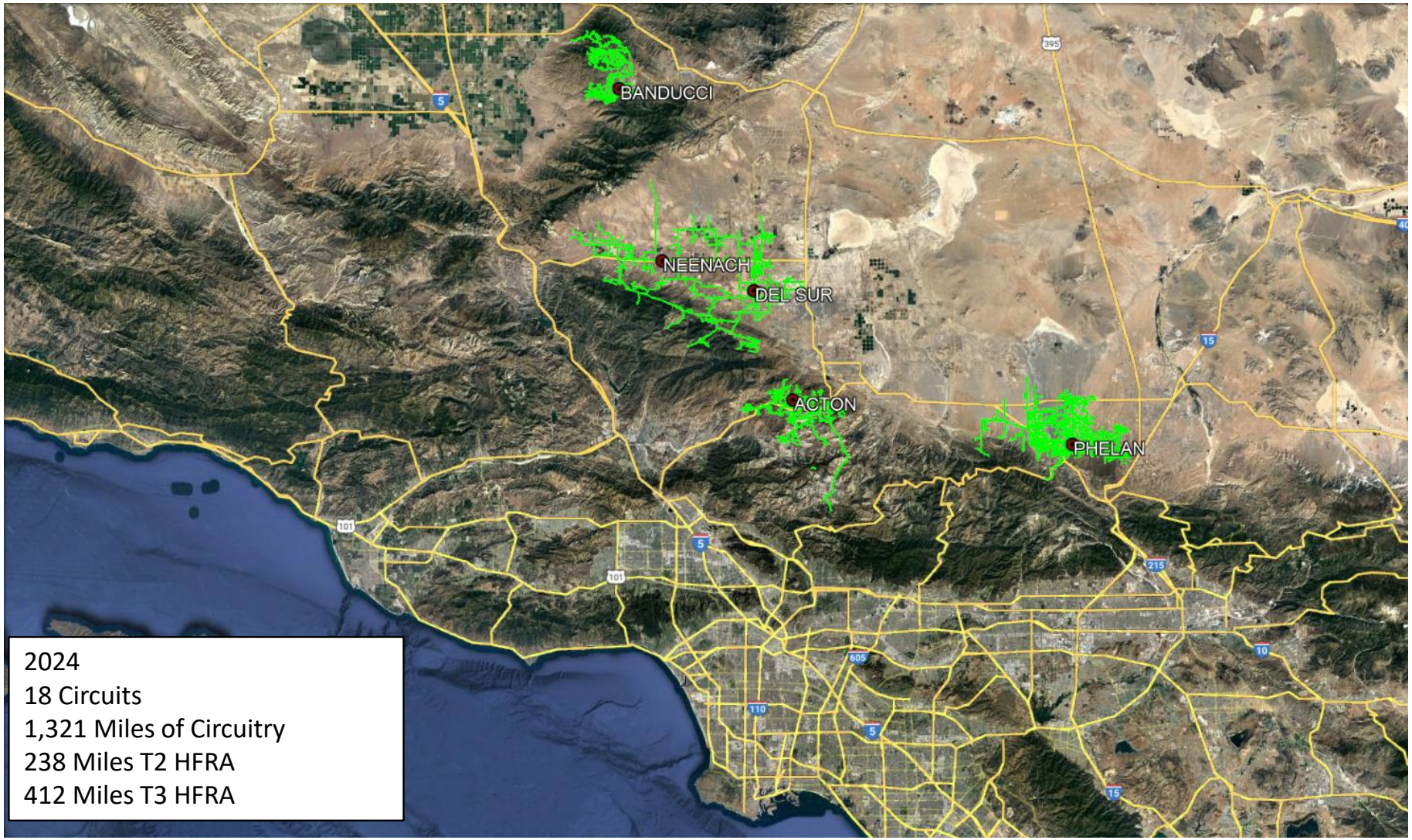
Fault energy reduced by more than 99.9%

Description	Approximate Energy Release (Joules)
Traditional Protection Settings	15,000,000-30,000,000
Fast Curve	500,000 -20,000,000
Ground Fault with Ground Fault Neutralizer (Test Results)	350 - 2,000
Wooded Kitchen Match	1,000
Covered Conductor 1 Second Contact	0.00004

Pilot install of REFCL System at Neenach Substation

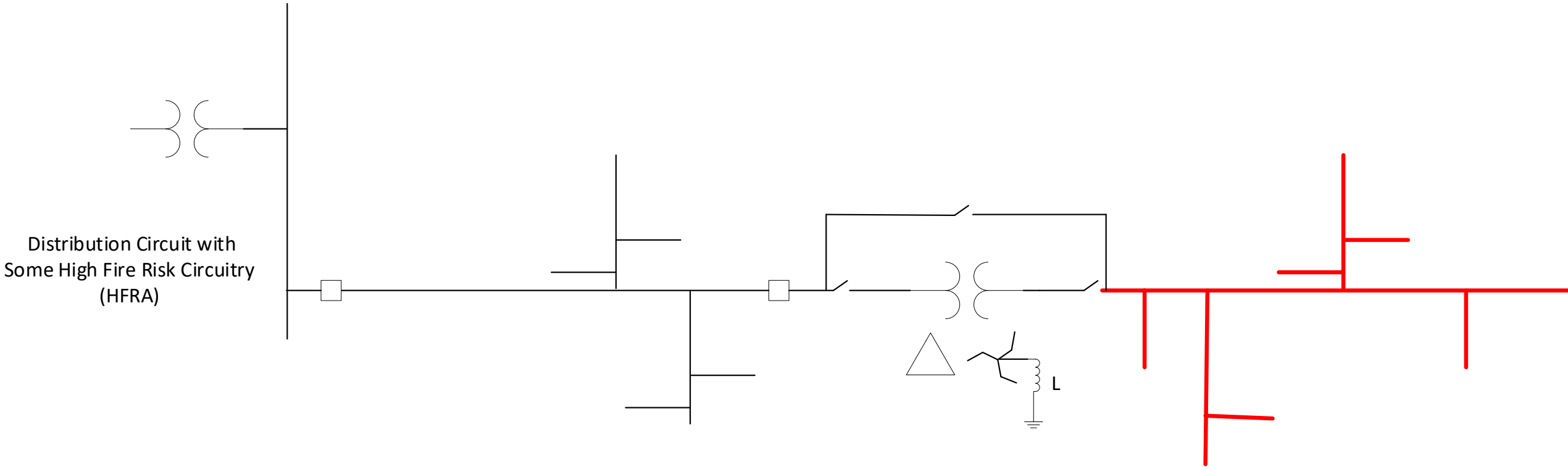
- The Ground Fault Neutralizer was installed at Neenach substation and successfully tested in 45 staged fault tests:
  - In high sensitivity settings detected 14,400-ohm faults making it the most sensitive protection on SCE system
  - Cleared cable faults in 0.75 to 5 cycles, while also reducing fault current by more than 97%
    - Energy release less than 1/5000th of fast curve

Ground Fault Neutralizer Projects



Other REFCL Programs at SCE

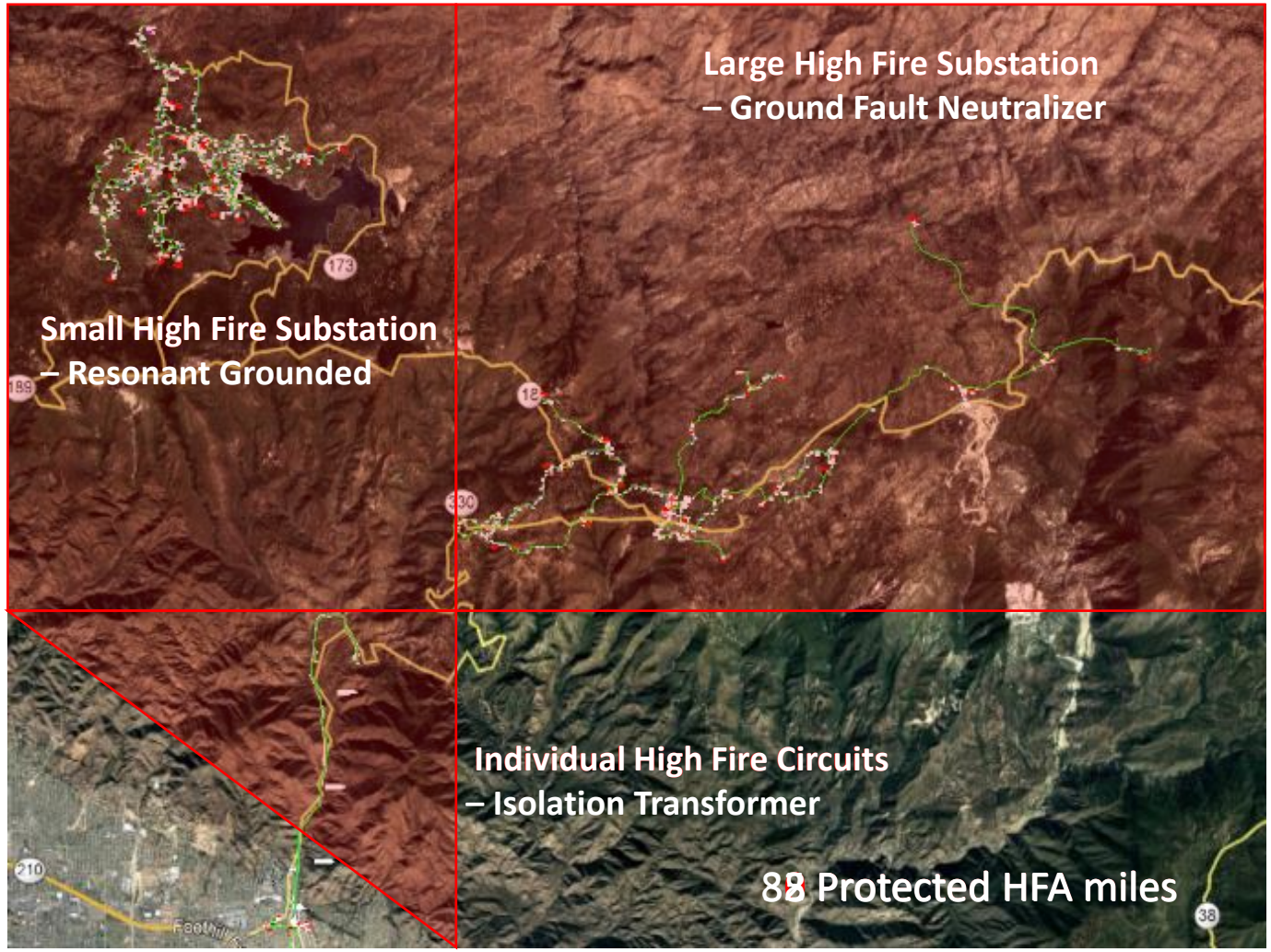
Resonant Grounded Isolation Transformers in High Fire Risk Areas



OH Reclosers with PM Isolation Transformer

Distribution Arc Suppression Coil – manual tuning

Hypothetical REFCL Implementation



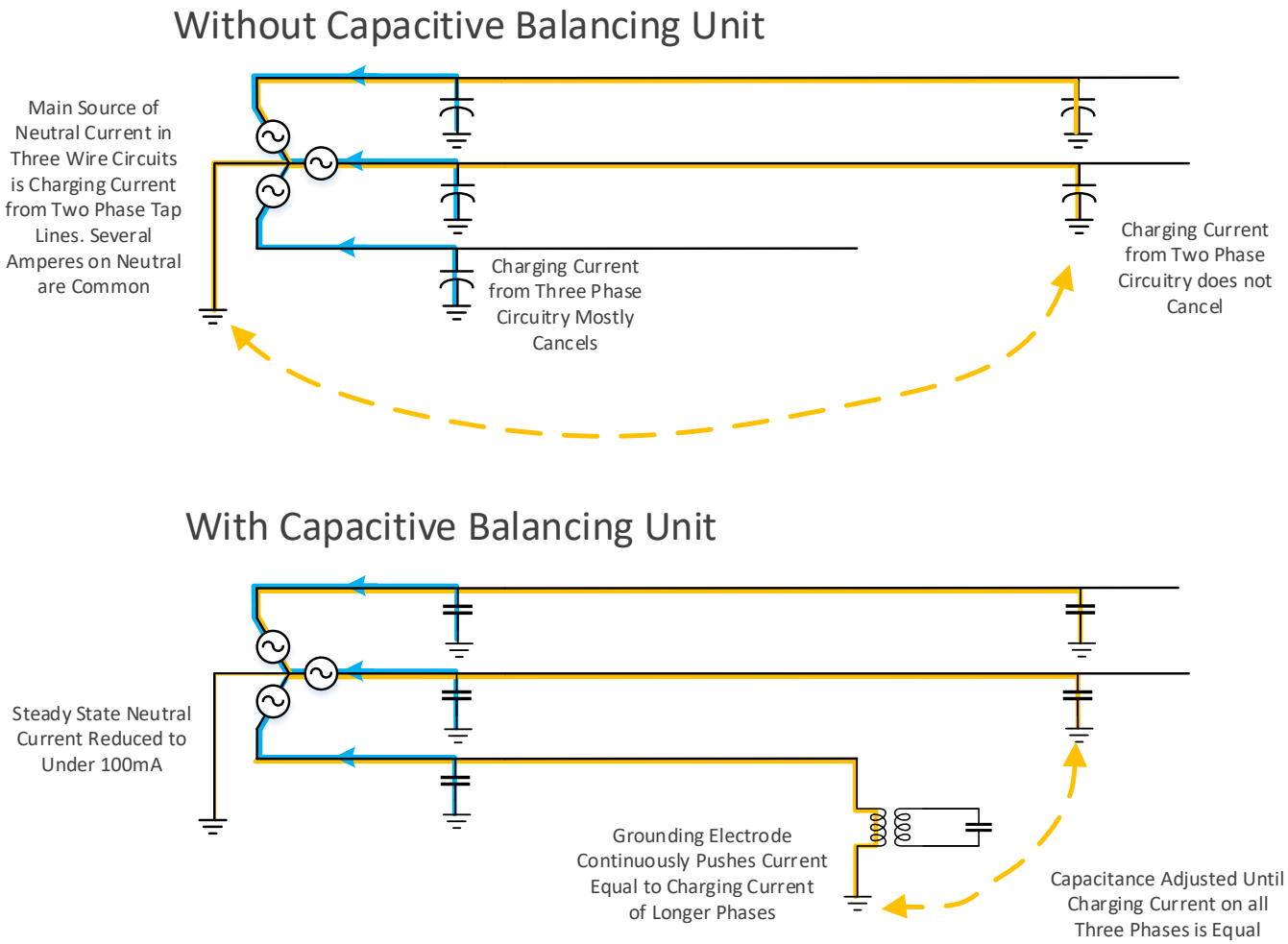
Circuit Balancing with Capacitive Balancing Units (CBU)

Circuit Balancing on REFCL Systems

- For a REFCL system to detect low-magnitude phase to ground faults noise on the neutral of the source transformer must be low.
- Specifically, we must balance the neutral current on each section of each circuit
- The main source of neutral current on three-wire systems is two-phase tap lines, particularly two-phase cable tap lines.
- To balance the current, a Capacitive Balancing Unit (CBU) is installed near the tap line to inject a current onto the third phase equivalent to what would exist if the tap line had a third phase.

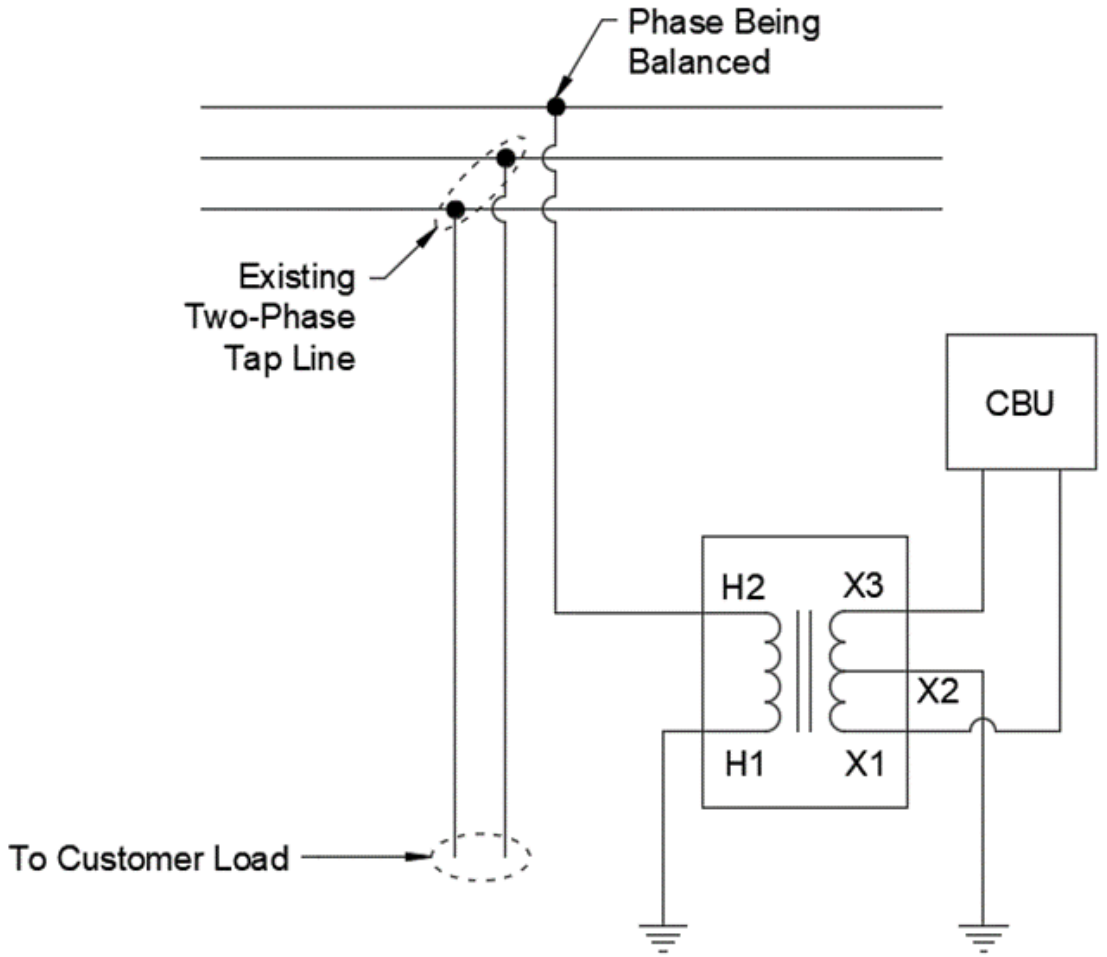
Circuit Balancing with Capacitive Balancing Units

- Charging current on a phase is proportional to the length of conductor/cable on that phase.
- In a system with two-phase tap lines, there will be an imbalance in length of conductor between phases and therefore an imbalance in charging current.
- The CBU installed is installed on the phase(s) with less conductor
- The capacitors can be individually switched on until the CBU pushes current equal to the additional charging current of the longer phases.



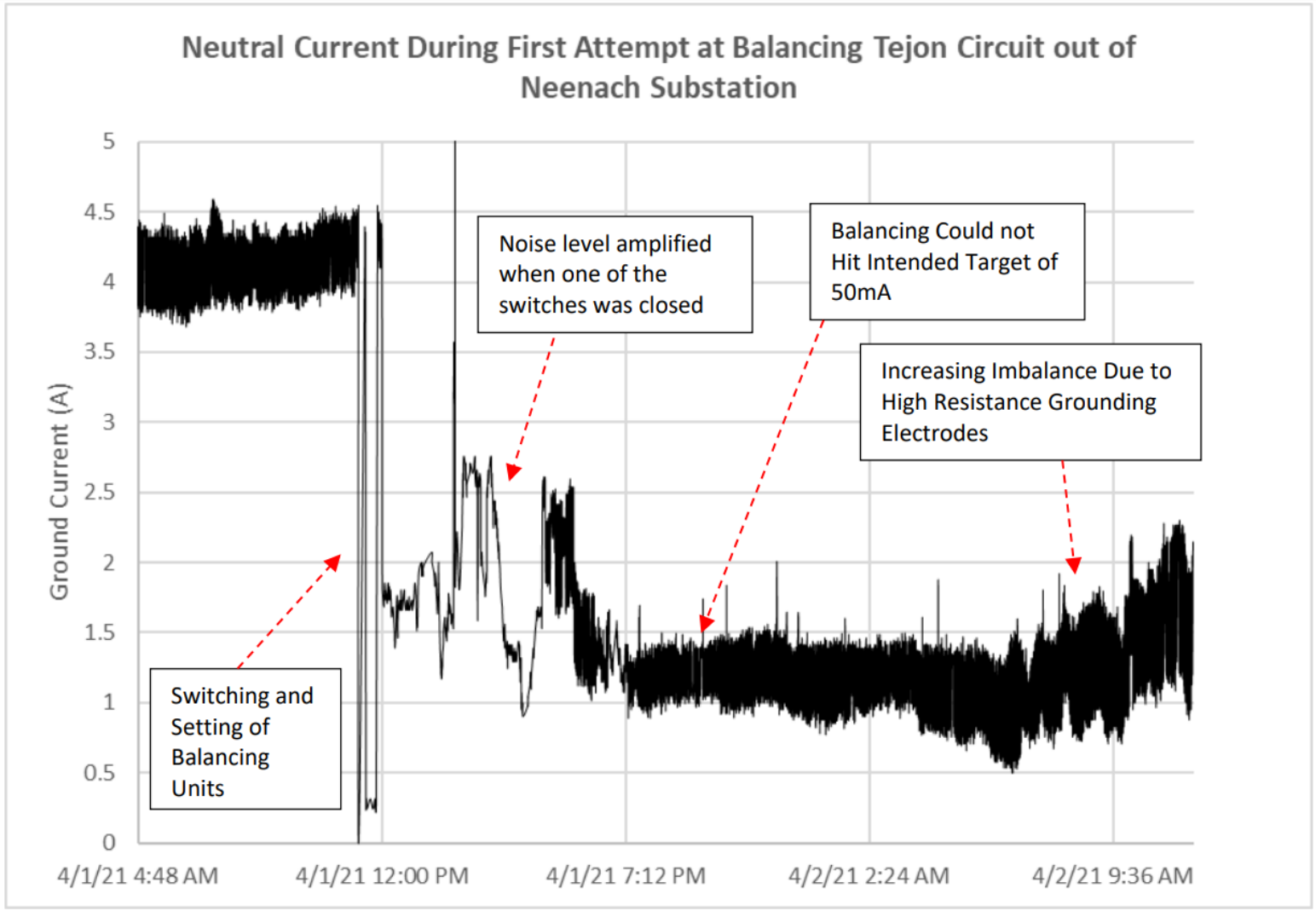
CBU Connections

- CBUs consist of three main components:
  - Distribution Transformer
  - Secondary Voltage Capacitors
  - Grounding Electrode
- Primary winding of transformer is connected to one phase and a grounding electrode.
- Secondary of transformer is connected to CBU capacitors.



Manual Capacitive Balancing Units Installed at Neenach

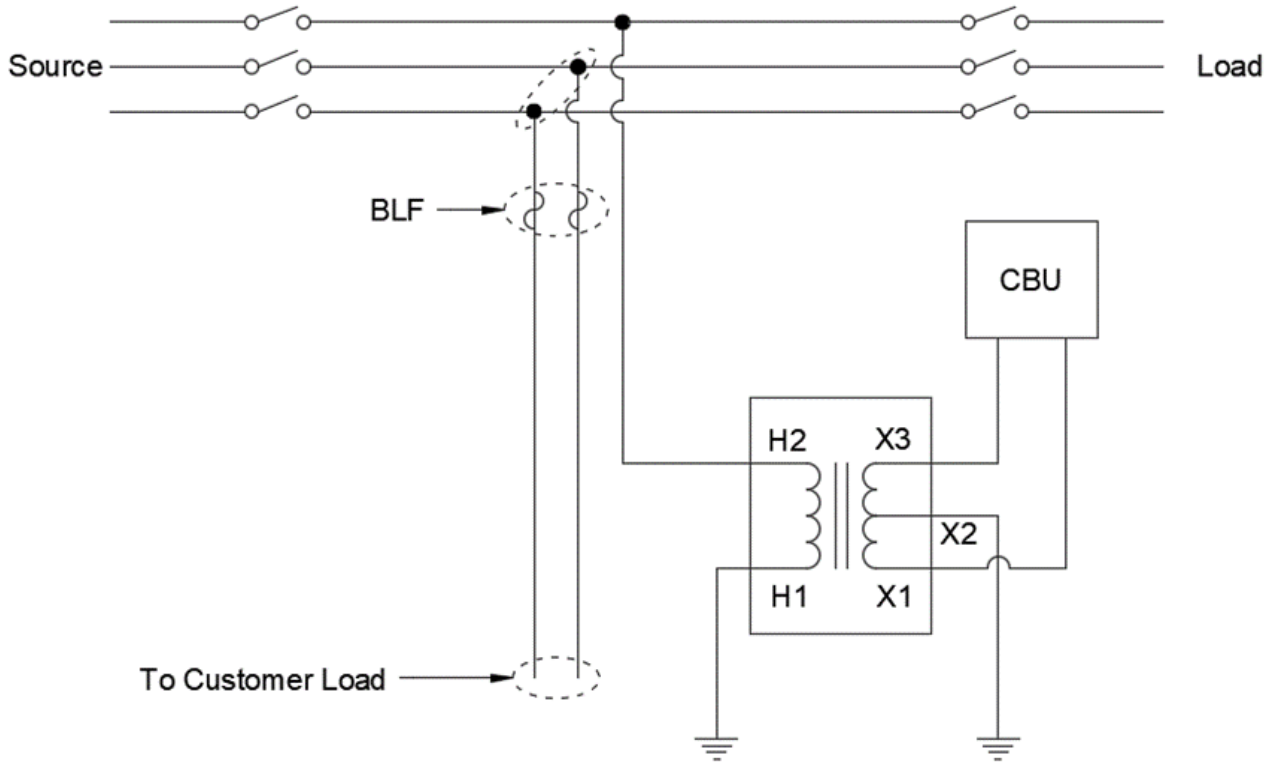
Circuits Started Coming Unbalanced after CBUs First Set



Remotely Operated Capacitive Balancing Units Installed at Acton/Phelan

Branch Line Reclosers with CBUs

- Single-phase switching on a REFCL system can be seen as a ground fault.
  - Disconnecting one phase of a tap line introduces an imbalance of charging current.
- Fuses on branch lines are a potential cause of nuisance tripping.
- Branch Line Reclosers (BLR) or other gang-operated devices can be used to mitigate this issue.



Questions