

2023-2025 WMP Joint IOU Covered Conductor Working Group

**New Technologies
Workstream**

**Topic:
REFCL**



RAPID EARTH FAULT CURRENT LIMITER (REFCL)

REFCL detects single line to ground faults such as when a power line falls to earth and almost instantly reduces the energy released.

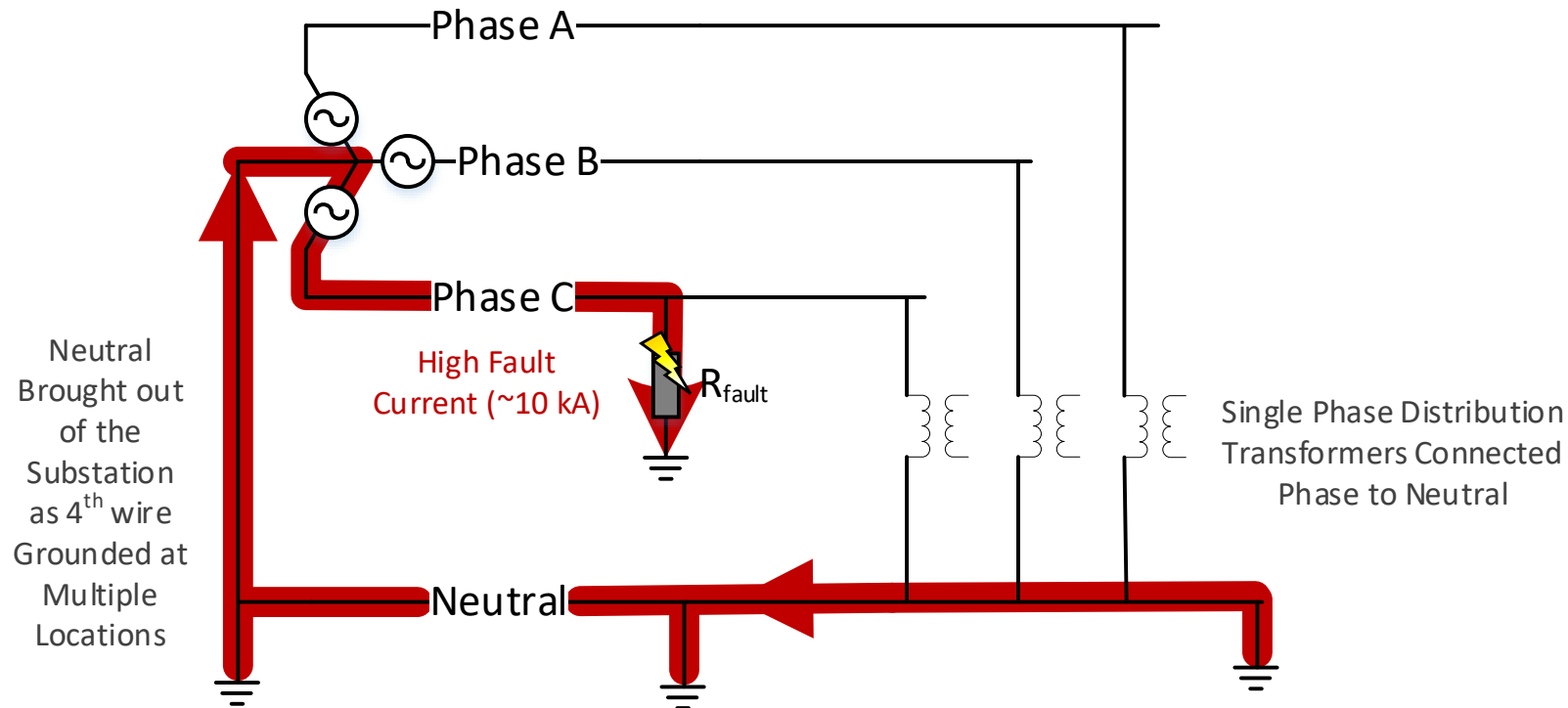
REFCL is extensively deployed in Australia:

- Australia began using REFCL in response to the 2009 Black Saturday bushfires (173 fatalities, 1.1 million acres burned)
- In 2015, State of Victoria regulators calculated REFCL to reduce ignition risk by 48-70%
- In 2023, program on track to be completed with 19,000 miles in service



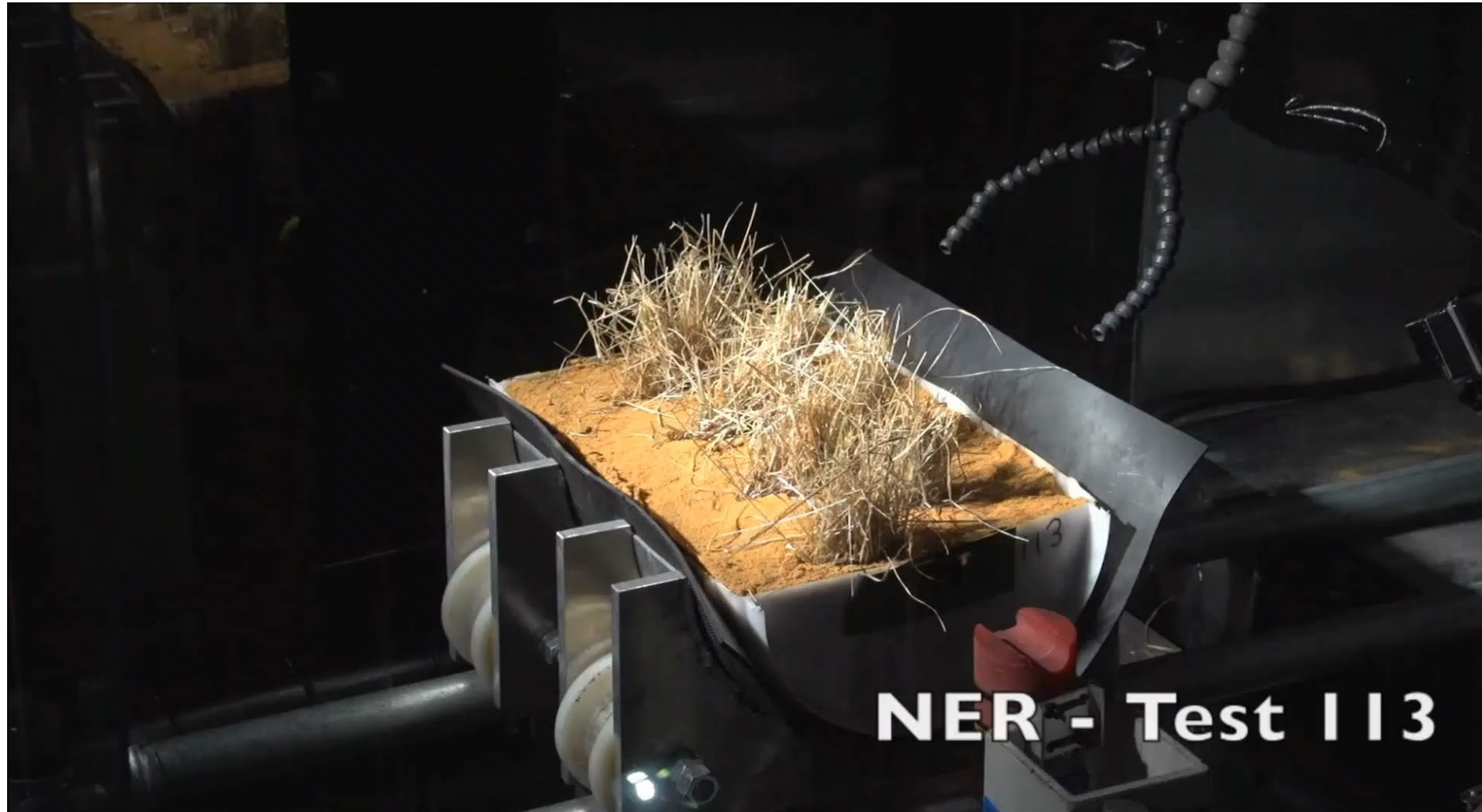
REFCL equipment installed at an SCE substation

TRANSFORMER GROUNDING – SOLIDLY GROUNDED MULTI-GROUNDED (4-WIRE)



- Typical 4-wire multi-grounded network with phase-to-neutral connected transformers
- Ground fault current levels can be multiples of thousands of amps
- REFCL systems require 3-wire networks (as detailed on following slides), phase to neutral connected transformers on existing 4-wire systems, amongst other complexities can vary cost significantly for REFCL substation applications

VIDEO: DOWN WIRE ON RESISTANCE GROUNDED SYSTEM



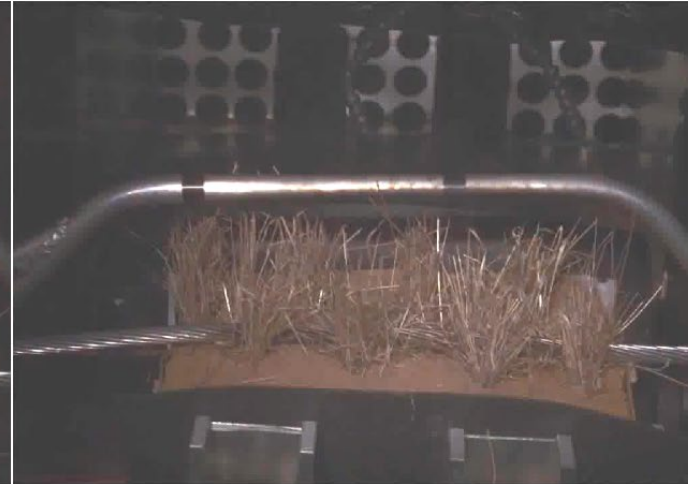
VIDEO: DOWN WIRE ON A GROUND FAULT NEUTRALIZER GROUNDED SYSTEM



AUSTRALIAN IGNITION TESTS



Normal Ground Fault



With GFN

Source: Energy Safe Victoria

<https://www.energy.vic.gov.au/safety-and-emergencies/powerline-bushfire-safety-program/network-assets-program/rapid-earth-fault-current-limiter-refcl>

GROUND FAULT NEUTRALIZER (GFN)



Source: Swedish Neutral
AB

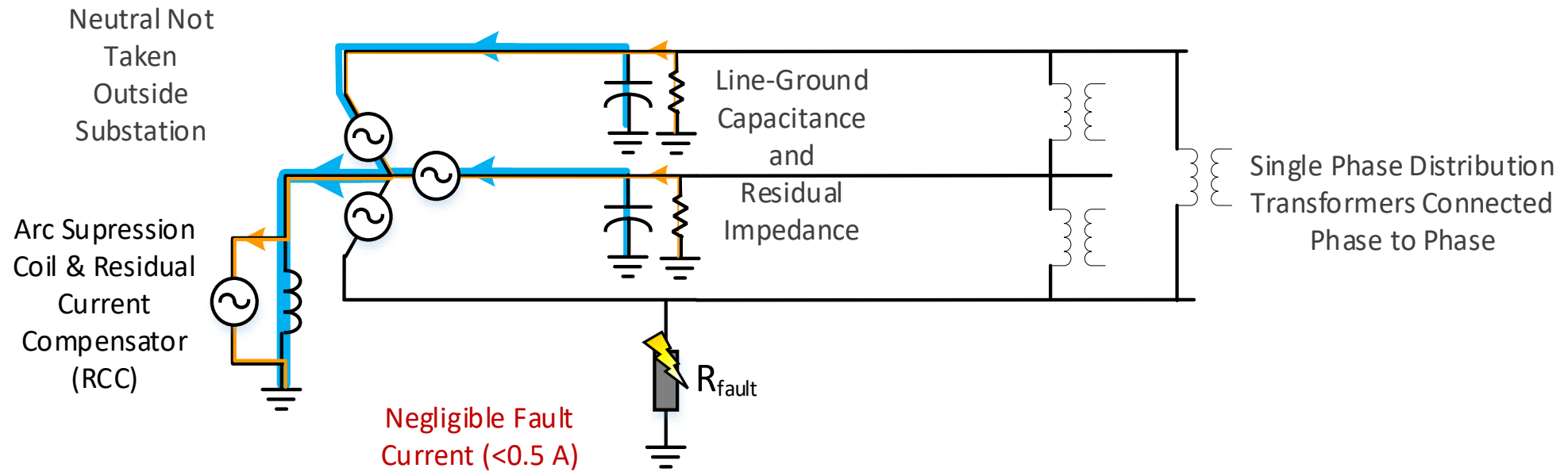
Arc Suppression Coil
Compensates reactive component
of fault

Residual Current
Compensator
Compensates resistive
component of fault

GFN Controller
Tunes ASC, Detects
Faults, Drives Inverter

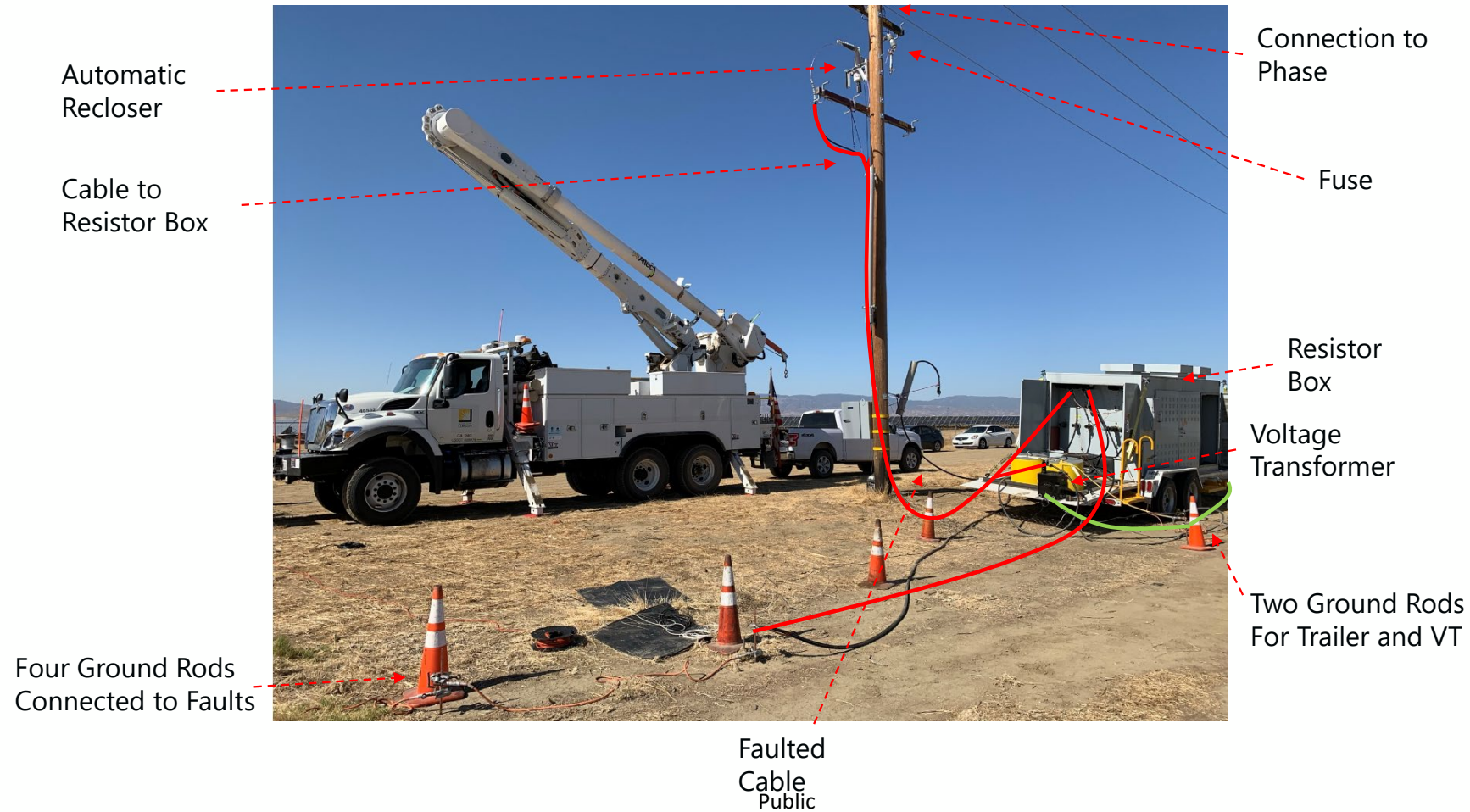
Public

TRANSFORMER GROUNDING – GROUND FAULT NEUTRALIZER



- Transformers are connected between the phases, e.g. 3-wire system design
- Current at the ground fault location significantly reduced

GROUND FAULT TEST SETUP



VIDEO EXAMPLE: CABLE FAULT AT SUBSTATION DEPICTING MINIMAL REFCL ENERGY RELEASE



Public

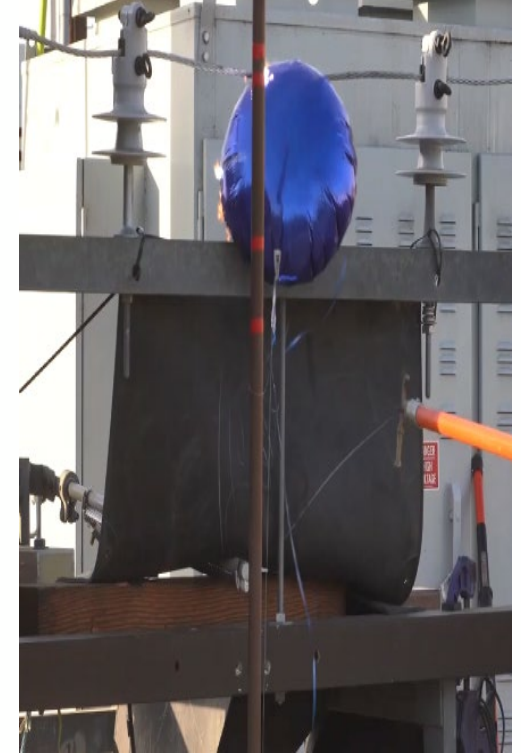
IGNITIONS FROM GROUND FAULTS MAY BE FROM DOWN CONDUCTORS BUT CAN ALSO OCCUR FROM INCANDESCENT PARTICLES FROM OTHER FAULT CAUSES SUCH AS WILDLIFE, MYLAR BALLOONS, OR VEGETATION CONTACT

Visual Example:

Mylar balloon fault energy without REFCL



Mylar balloon fault energy with REFCL



REFCL MITIGATES DISTRIBUTION SYSTEM HAZARDS BY INCREASING FAULT DETECTION SENSITIVITY AND DECREASING FAULT ENERGY

- **Public and Employee Safety**

- Electrical contact hazards for the public or employees
 - Hazards are almost entirely from phase-to-ground faults
- Arc flash
 - Majority of incidents start as phase-to-ground faults
- Underground structure explosions
 - Almost all incidents start as phase-to-ground faults

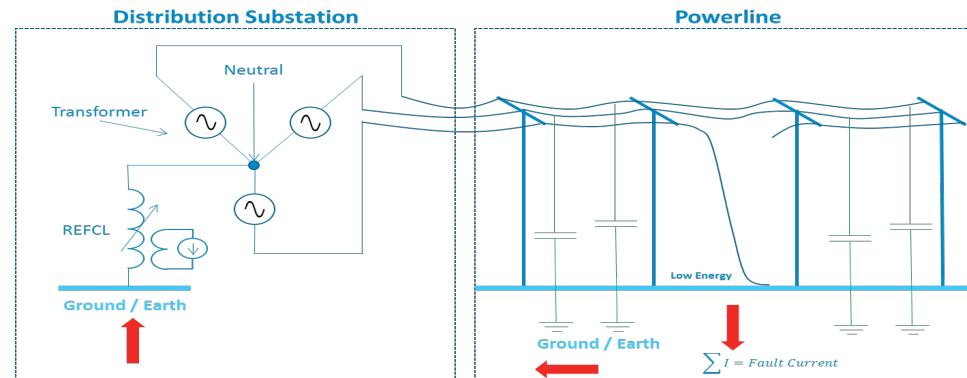
- **Wildfires**

- REFCL is expected to provide ignition risk reduction for ground faults of up to 90% for both bare and covered conductor applications
- REFCL complements CC to further reduce remaining risk

GFN FAULT SENSITIVITY

• Neutral Voltage

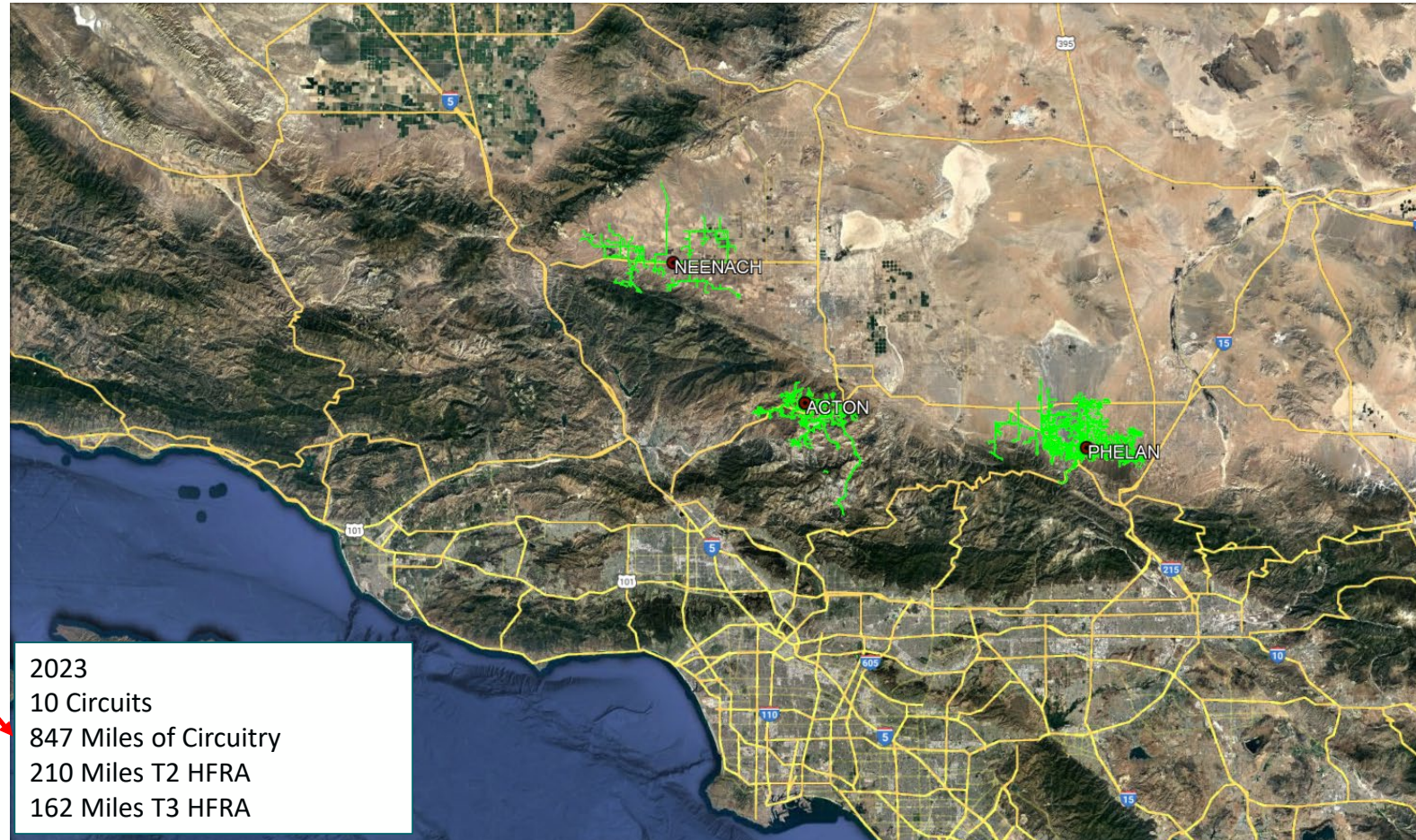
- GFN Fault Sensitivity dependent on standing neutral voltage
- Neutral voltage caused from neutral current and system damping
- New equipment installed "Capacitive Balancing Unit" to reduce neutral current
- Sensitivity below 1A is costly to achieve with diminishing returns
- If standing neutral voltage is too high, GFN must be cut-out



SCE GROUND FAULT NEUTRALIZER PROJECTS

Green highlight represents circuitry on SCE's network for the following three REFCL substations:
Neenach (Commissioned)
Acton (In Construction)
Phelan (In Construction)

These REFCL applications provide mitigations for circuitry as shown -



PG&E GROUND FAULT NEUTRALIZER PROJECT

Calistoga Field Demonstration Project

- 100 Amp GFN
- 2 circuits
- 160 circuit miles



Public