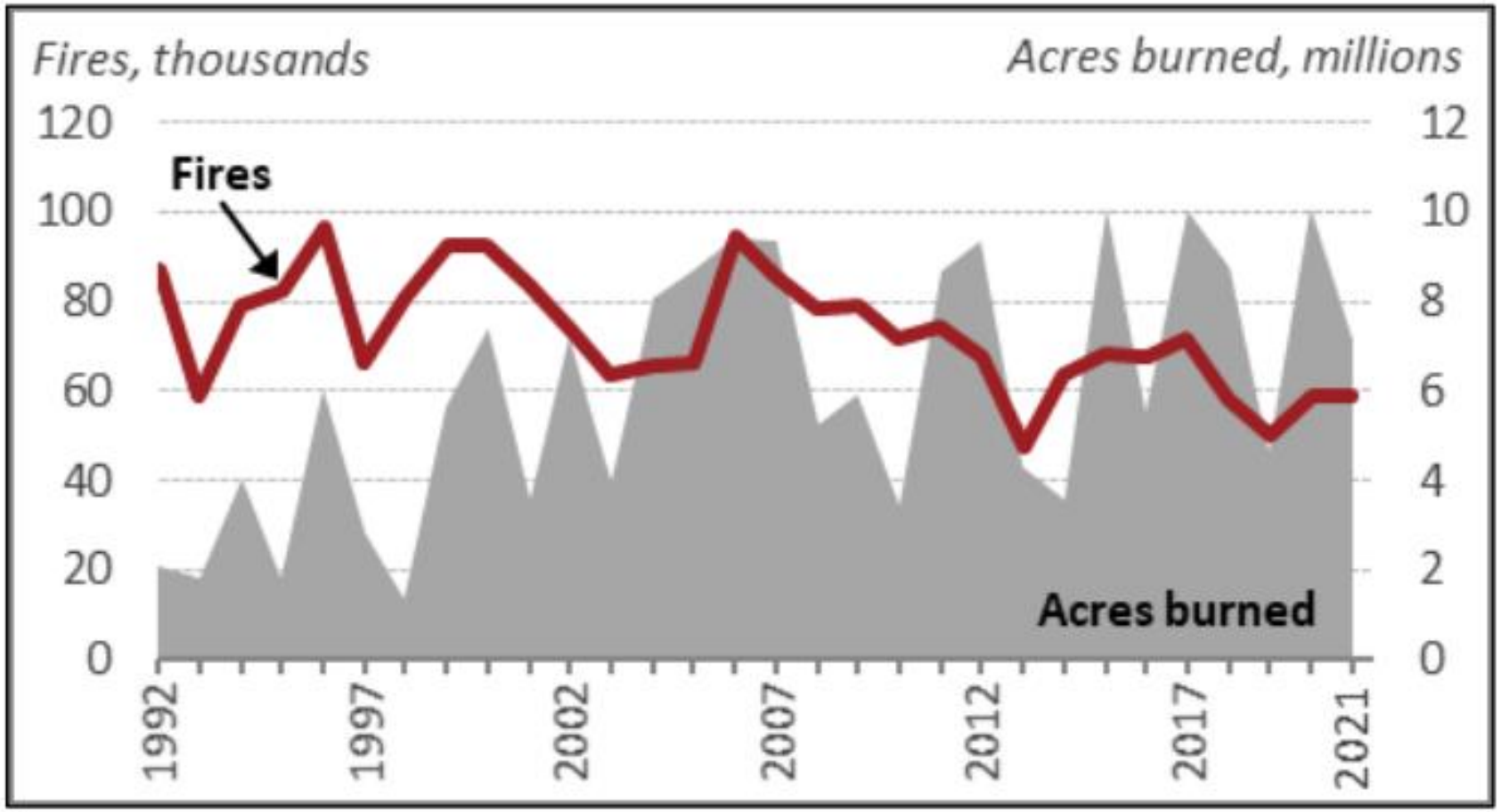
Distributed Intelligence for High Impedance Fault (HIF) Detection to Improve Public Safety

Yanfeng Gong, PhD

Schweitzer Engineering Laboratories Inc

Wildfire Mitigation is a Growing Concern



Source: National Interagency Fire Center

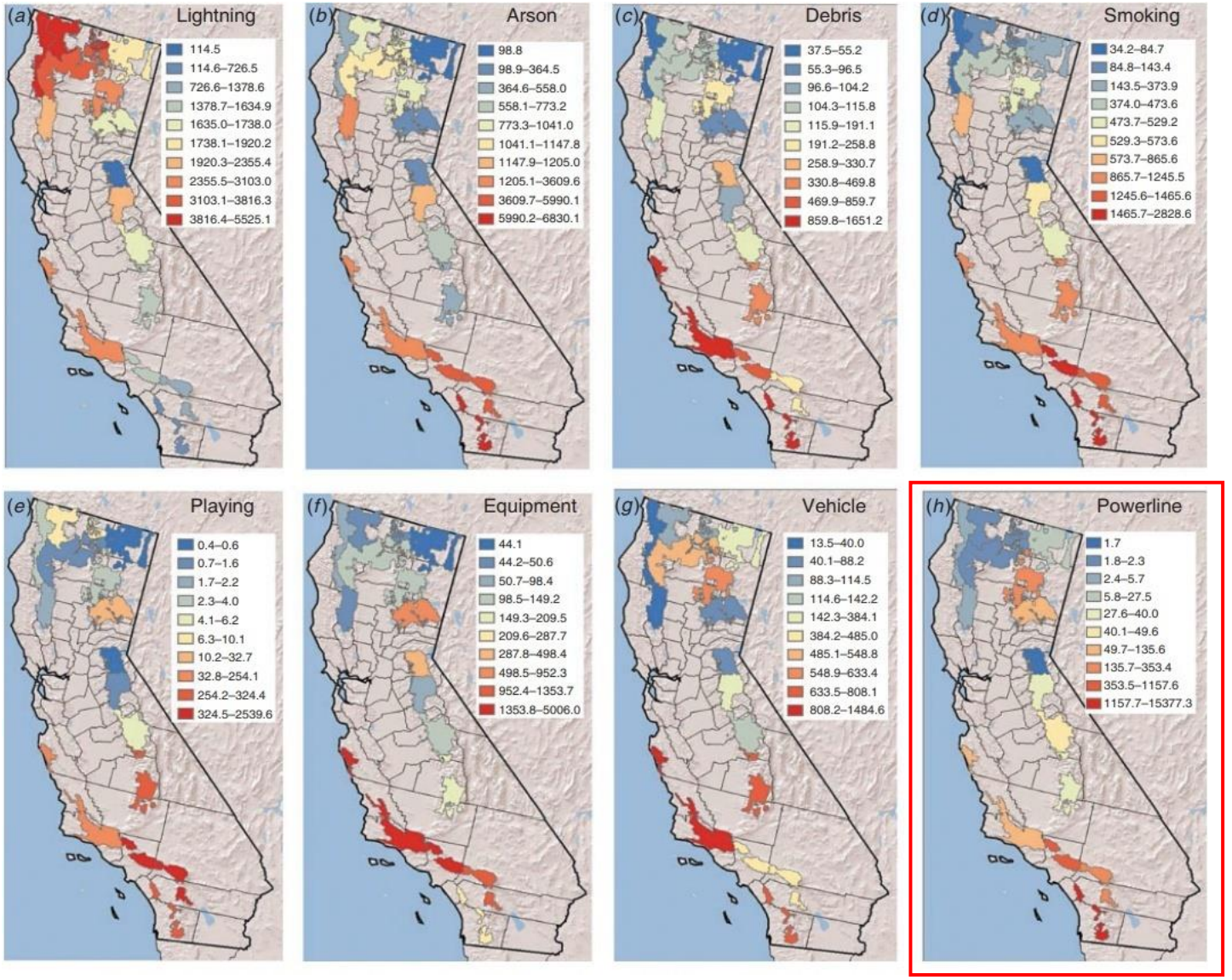
California Wildfire Statistics

Interval	Fires	Acres
2021 Combined	8,835	2,568,948
2020 Combined	8,648	4,304,379
5 year average	8607	1,618,833

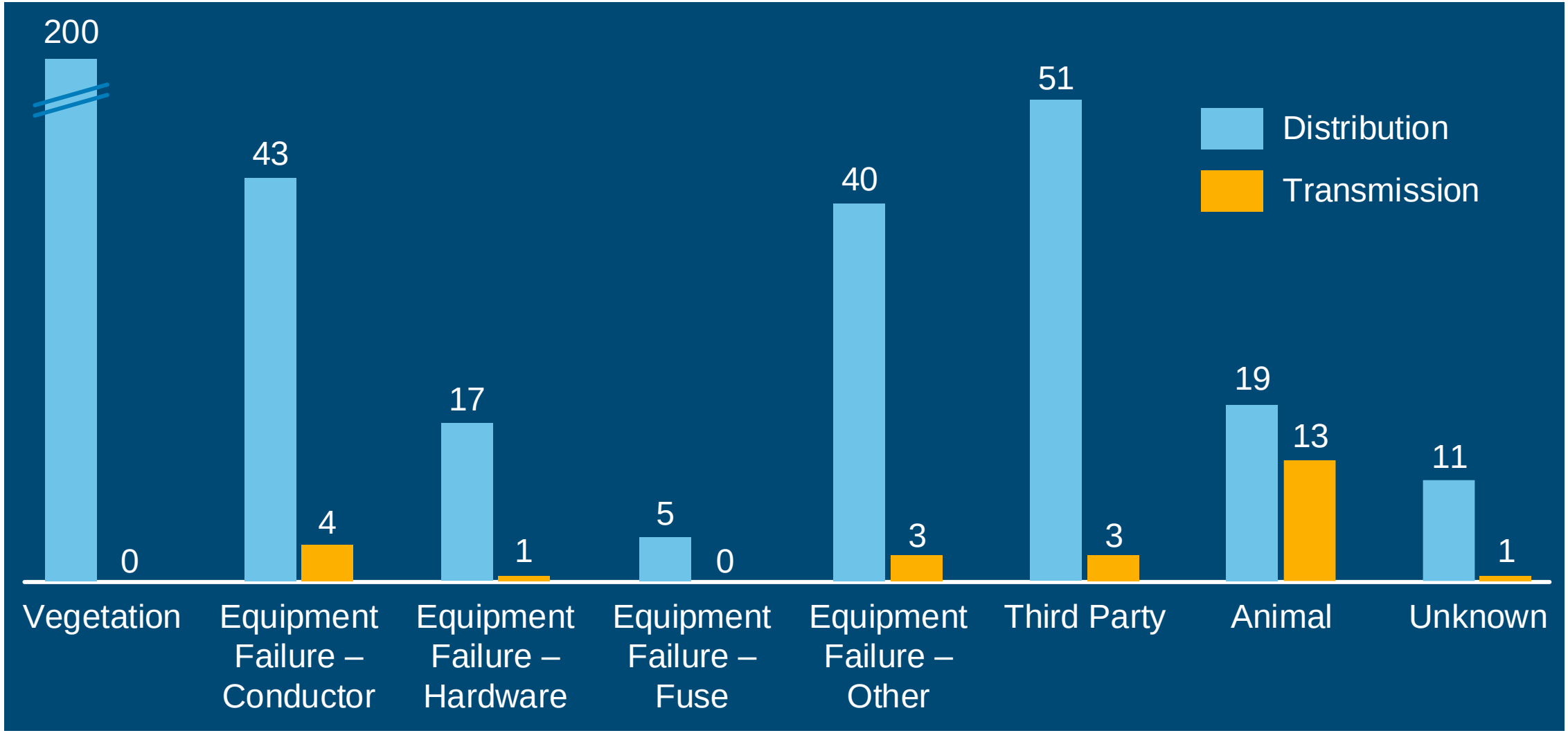
Source: www.ca.gov

Wildfire Ignition Sources

Area burned by different ignition sources on USFS protected lands in California, 1910–2016 (hectares burned per year per million hectares)

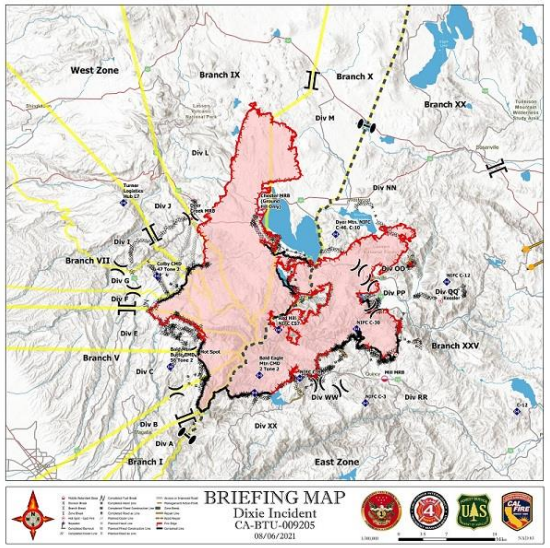


Wildfire Ignition Sources (Power Systems)



California 2021 July 13 Dixie Fire

- Burned 963,309 acres of land
- Destroyed 1311 structure and damaged 94
- The largest non-complex wildfire in California history
- The second largest in US history
- Smoke caused unhealthy air quality over much of western United states
- Suppression cost is over $650 million

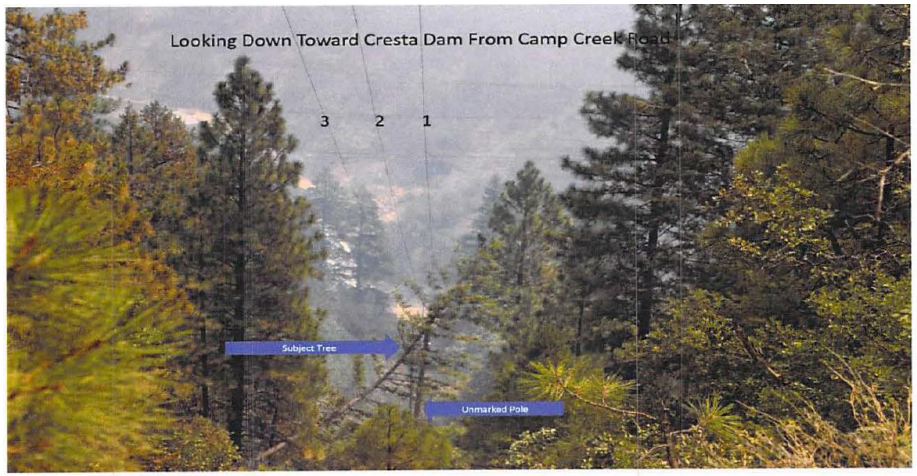


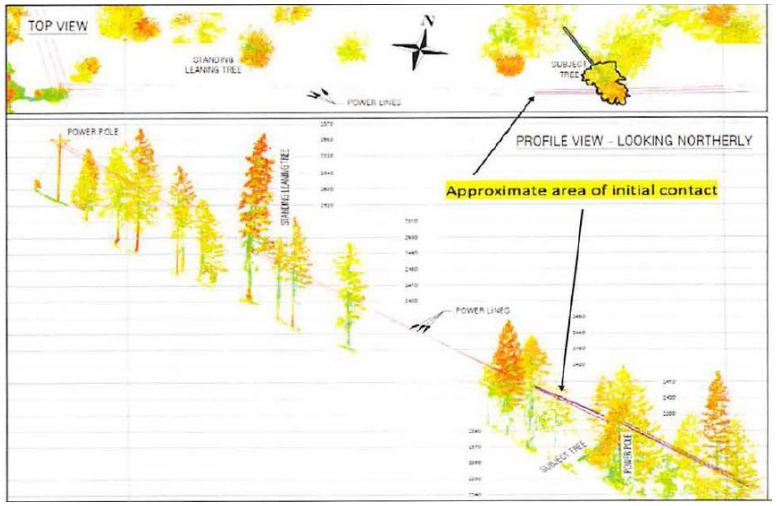
Sequency of Event (July 13, 2021)*

- **6:48AM**: 65’ tall, damaged and decayed tree fell and contacted 12 kV distribution circuit
- Two of the three fuses blew up initial contact with conductor, the third fuse remained close and kept a phase energized
- The tree being in contact with energized conductor and the ground created a high impedance fault (HIF)
- The HIF caused the heat and arcing to ignite fuel bed over the course of 10 hours
- **4:55PM**: Utility lineman arrived at scene and discovered the fire
- **Oct 25**: fire 100% contained

*: California Department of Forestry and Fire Protection Investigation Report

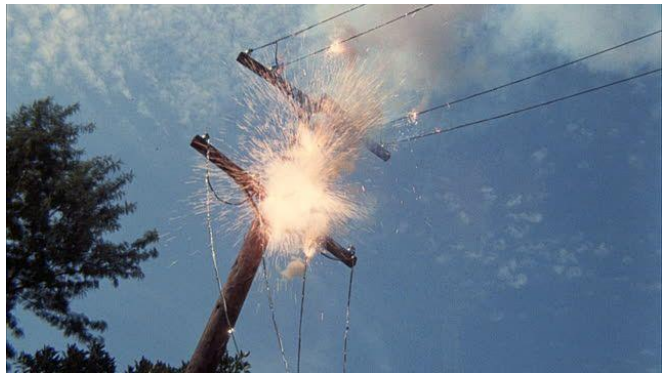
Forensic Evidence*





Common Power Line Faults Could Trigger Wild-fire

- Molten metal objects ejection due to energized conductor collision
- Phase-to-ground fault due to energized conductor touching vegetation (vegetation overgrow, falling conductor, …)
- Phase-to-phase fault due to vegetation across energized conductors (vegetation overgrow, high wind, …)

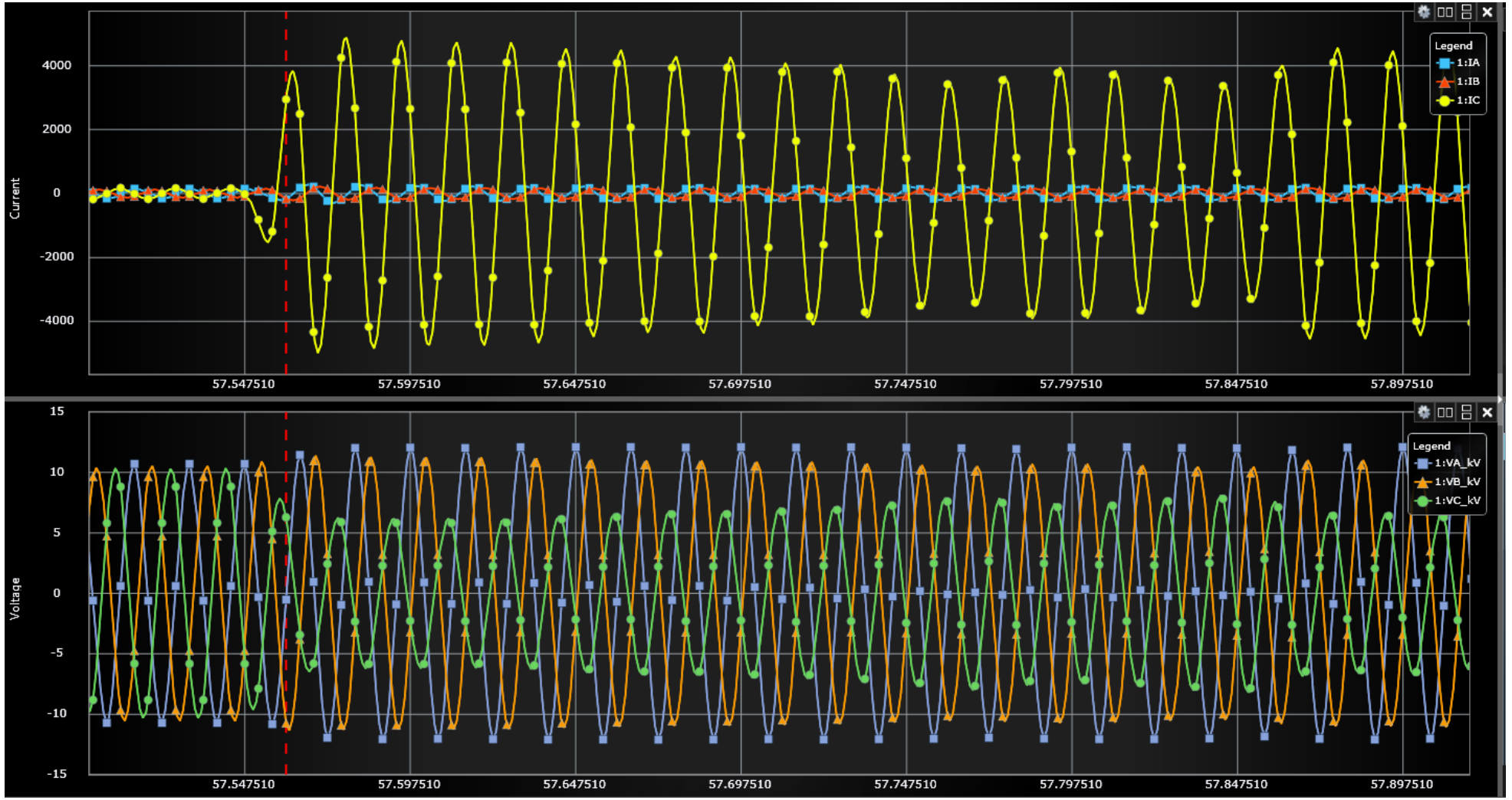


Fault Current Magnitude and Duration to Start Fire*

- Probability of sustained ignition depends on arc current magnitude and duration, airflow speed, fuel type, fuel moisture content, air temperature and relative humidity
- Under the *worst case* condition, sustained ignition is 50% probable for arc durations around *60ms* at *200 amps*, *75ms* at *50 amps* and *155ms* at *4.2 amps* *
- If powerline earth-fault protection systems were to detect and respond to *0.5 Amp* faults within *two seconds*, fire risk in 'branch touching wire' faults in worst case conditions would be reduced *tenfold* compared to current levels*

*Source: Vegetation Conduction Ignition Test Report, Powerline bushfire safety program, Victoria, Australia

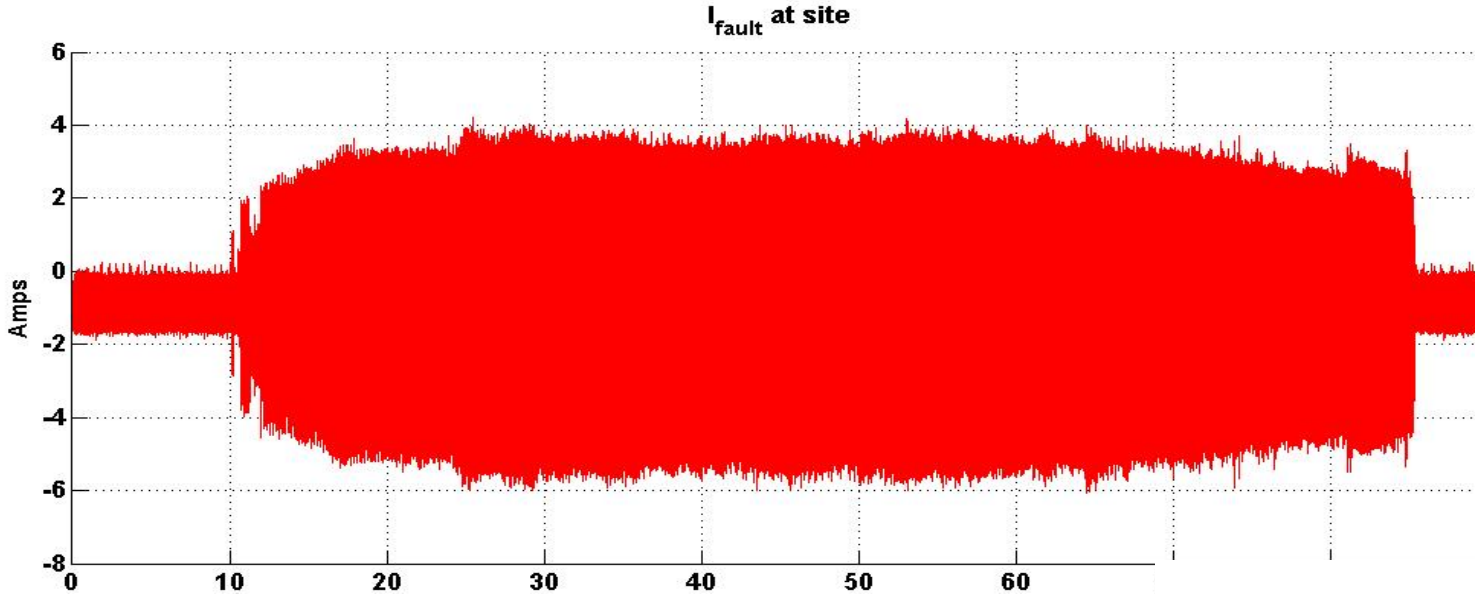
Typical Ground Fault

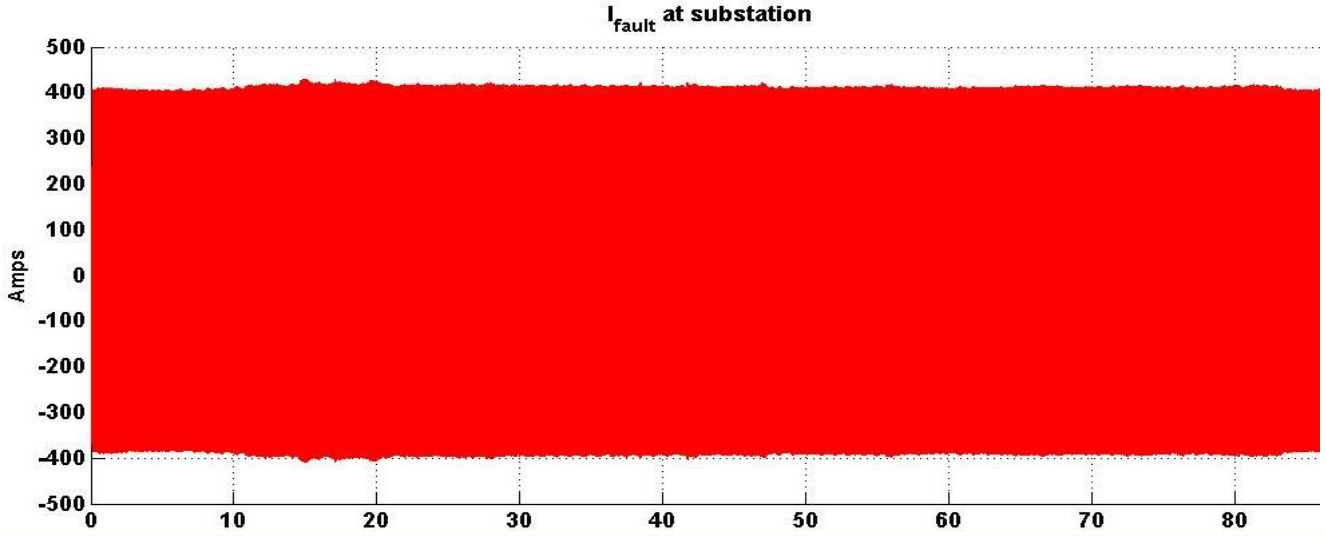


HIF Current Below Pickup of Conventional Overcurrent Element

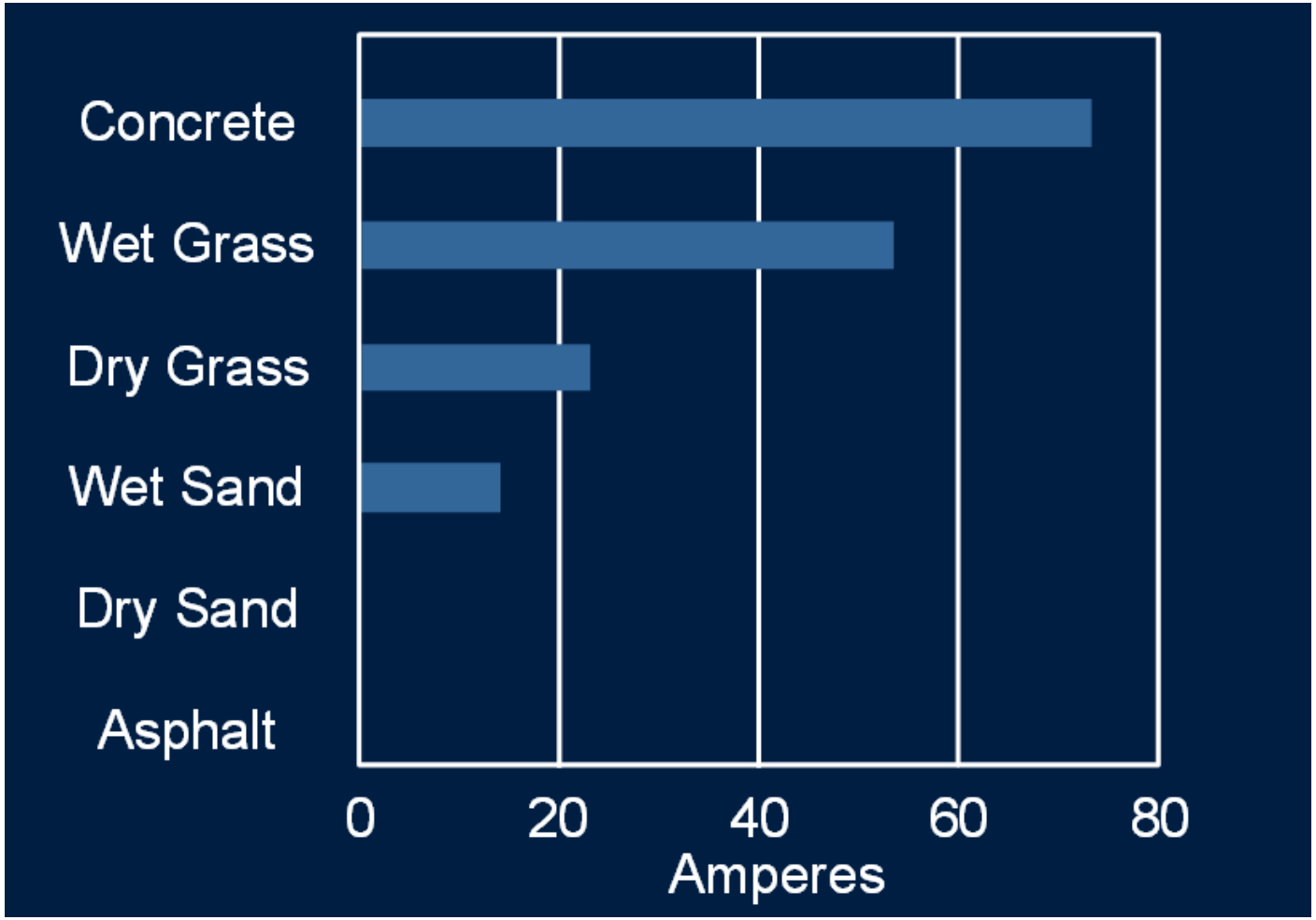
- High Impedance Faults are due to
  - Incipient insulator failures
  - Fallen conductors on concrete, tree, soil, gravel, sand, asphalt, etc.
- Fault current is less than 100 amps on grounded systems
- Rich in harmonic and non-harmonic content from random and nonlinear arcing

HIF on Gravel Surface (Staged Fault)

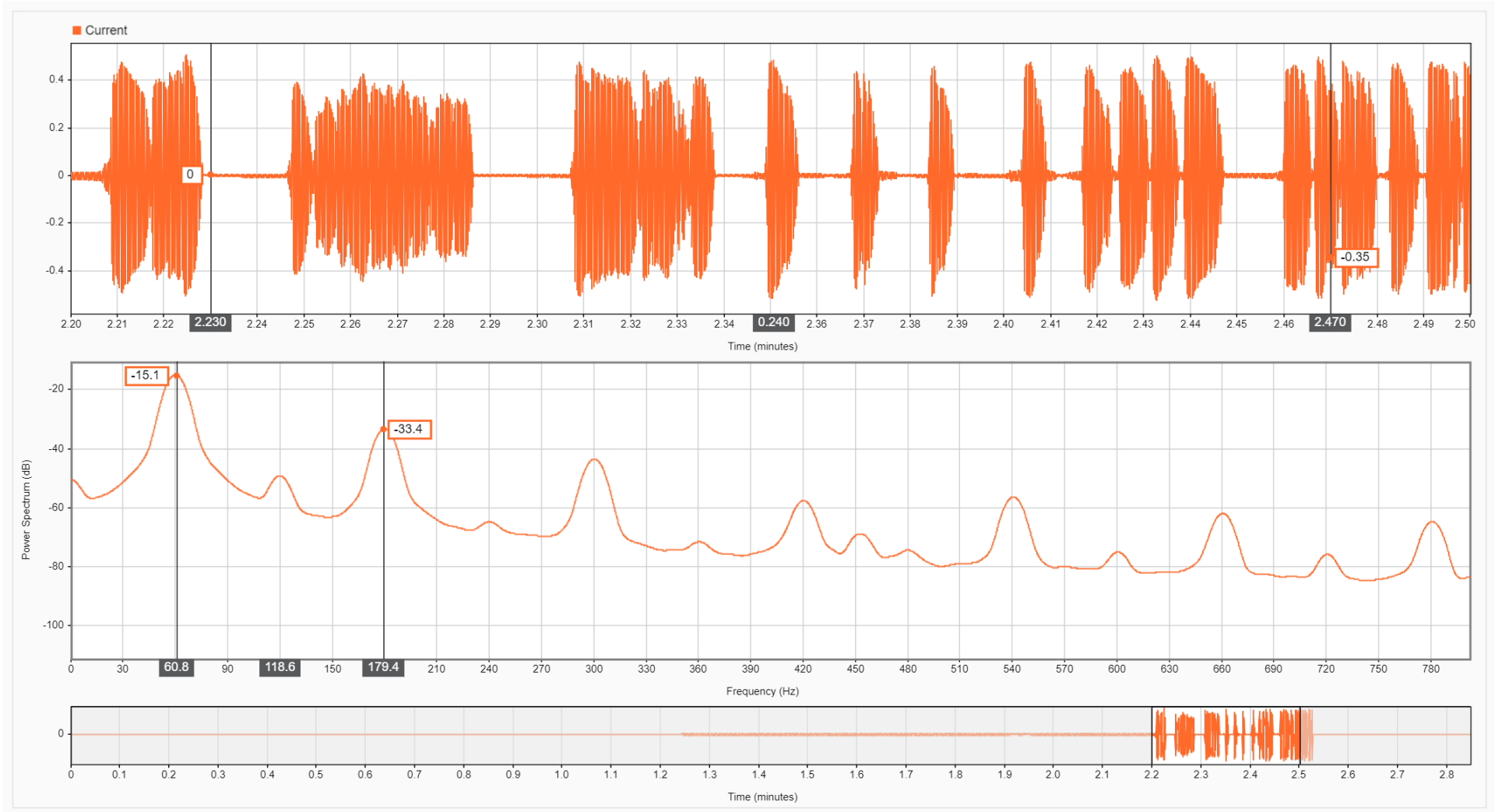




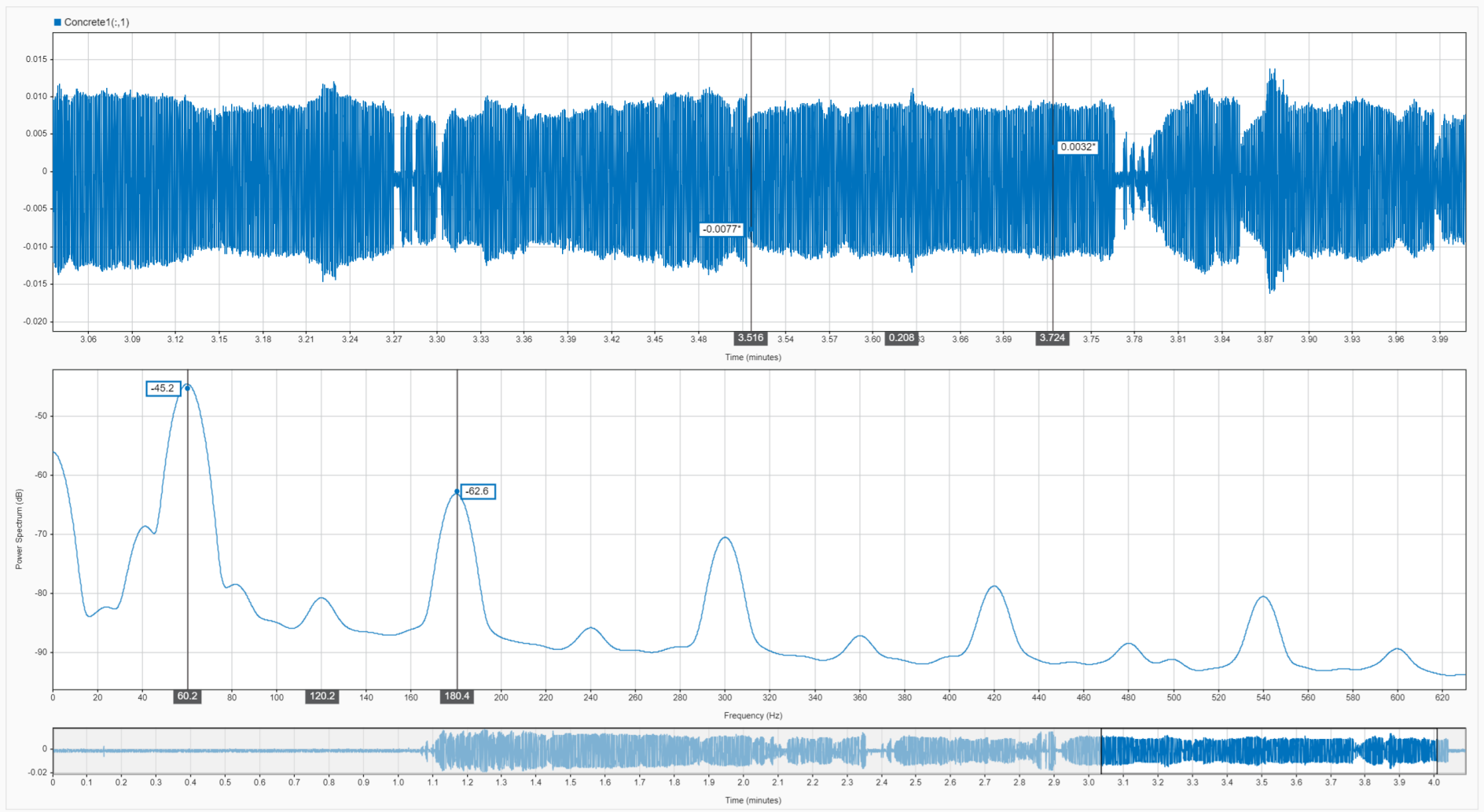
Downed Conductor Fault Current



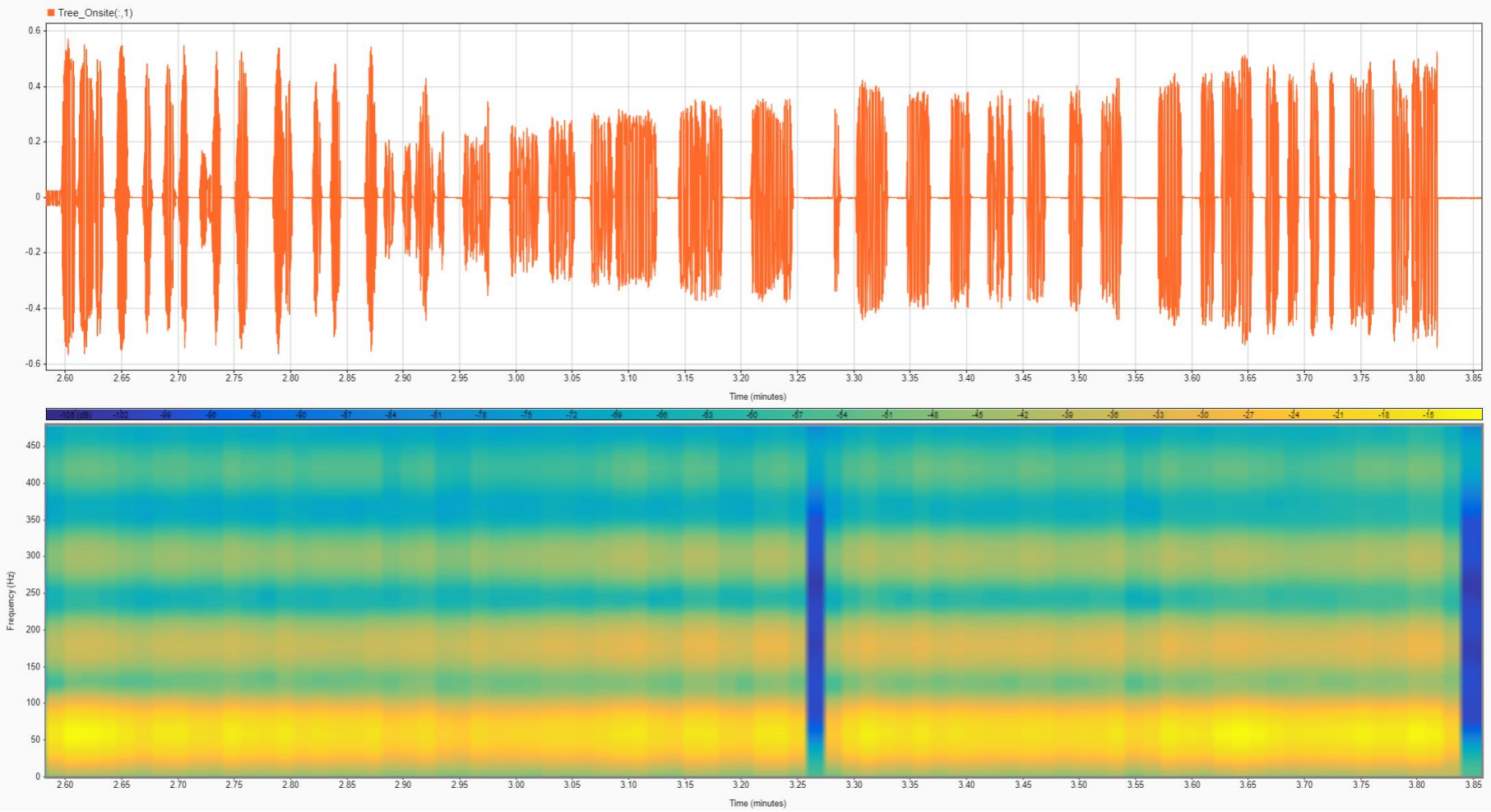
Tree Contact Arcing



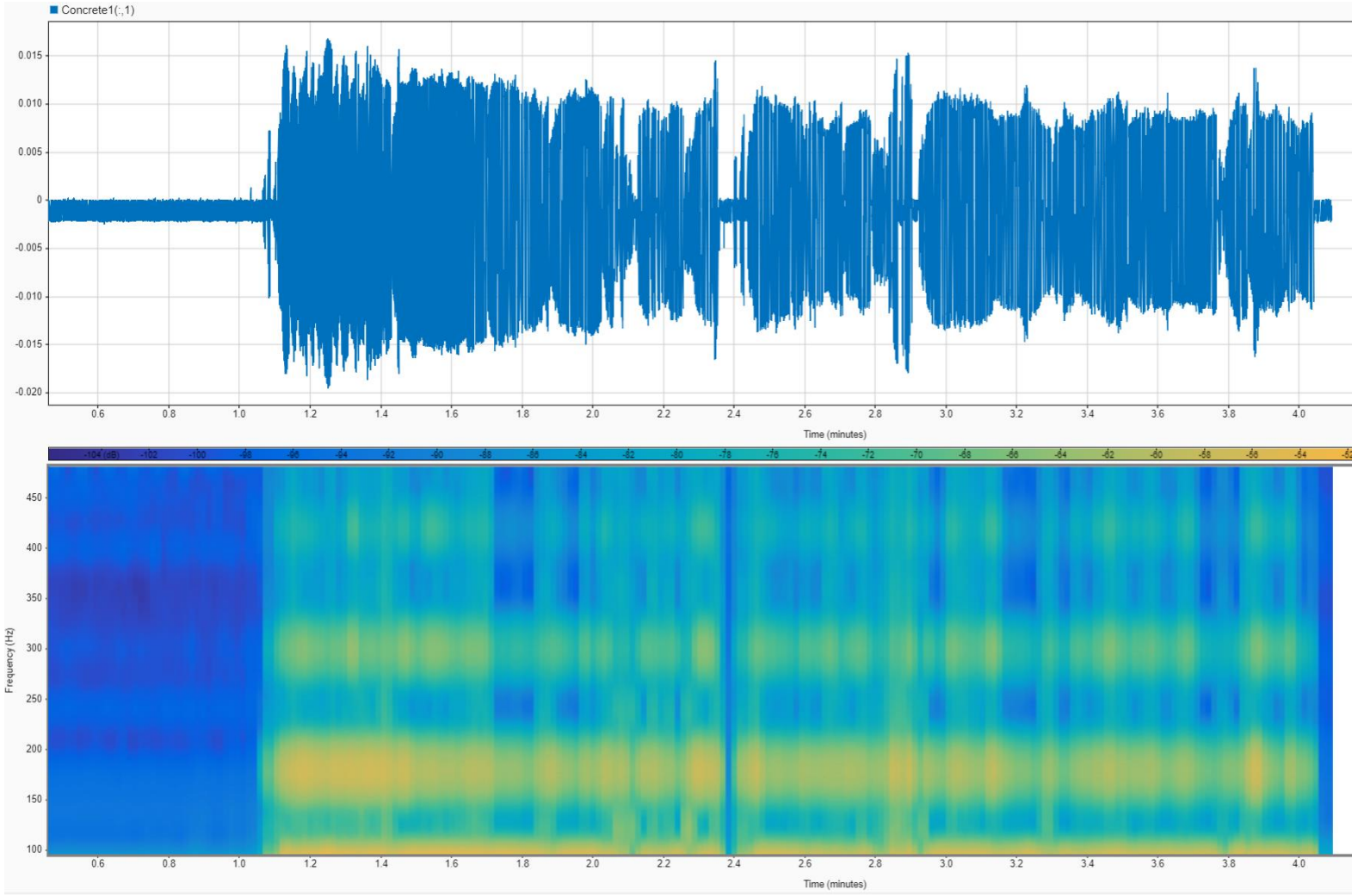
Concrete Contact Arcing



Tree Contact Arcing (Spectrogram)



Concrete Contact Arcing (Spectrogram)



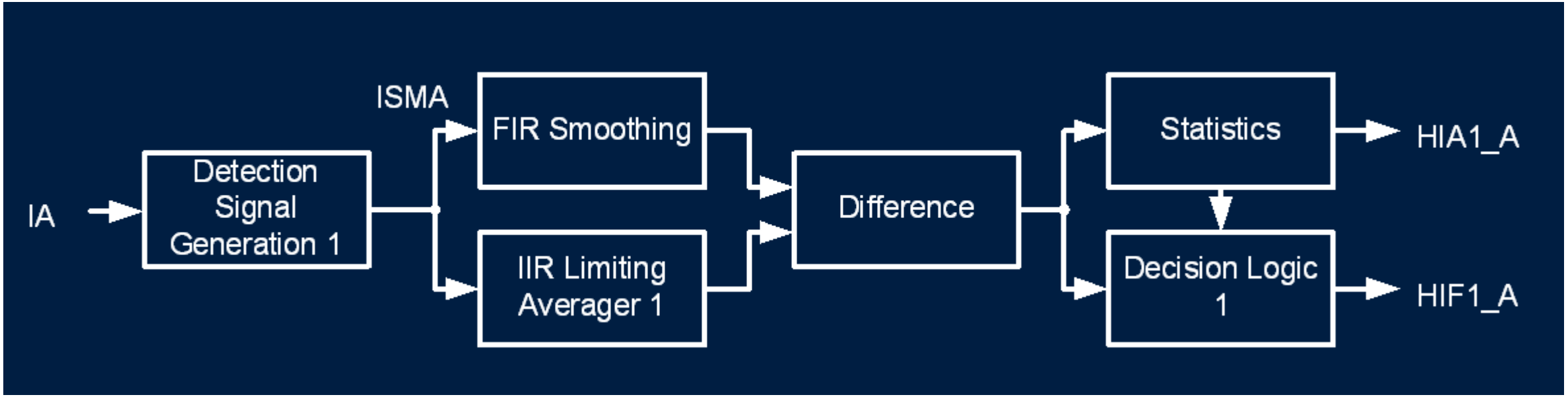
Arc-Sensing Technology(AST)

- Detect arcing
  - Odd-harmonics
  - Inter-harmonics
  - Detect three phase events
- Detect load reduction
  - Delta change in current (LR)
- Restraint on high voltage and current changes

Detection Algorithm Design

- An informative quantity that reveals HIF signatures, and nothing else
- A stable average
- An adaptive feature that tunes out feeder ambient characteristics
- A memory and decision scheme to declare arcing event

Odd-Harmonics Based HIF Detection Algorithm

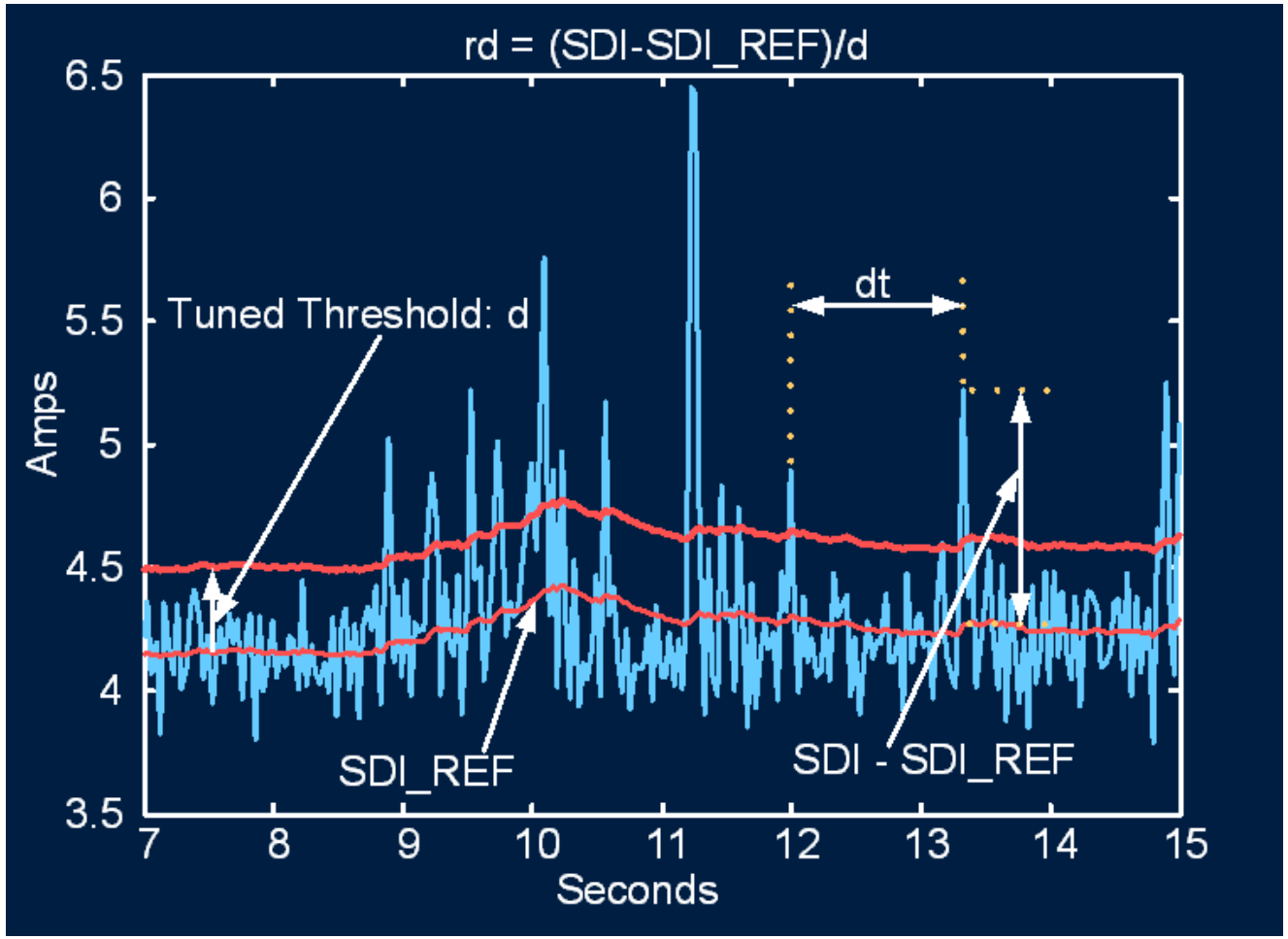


Adaptive Tuning

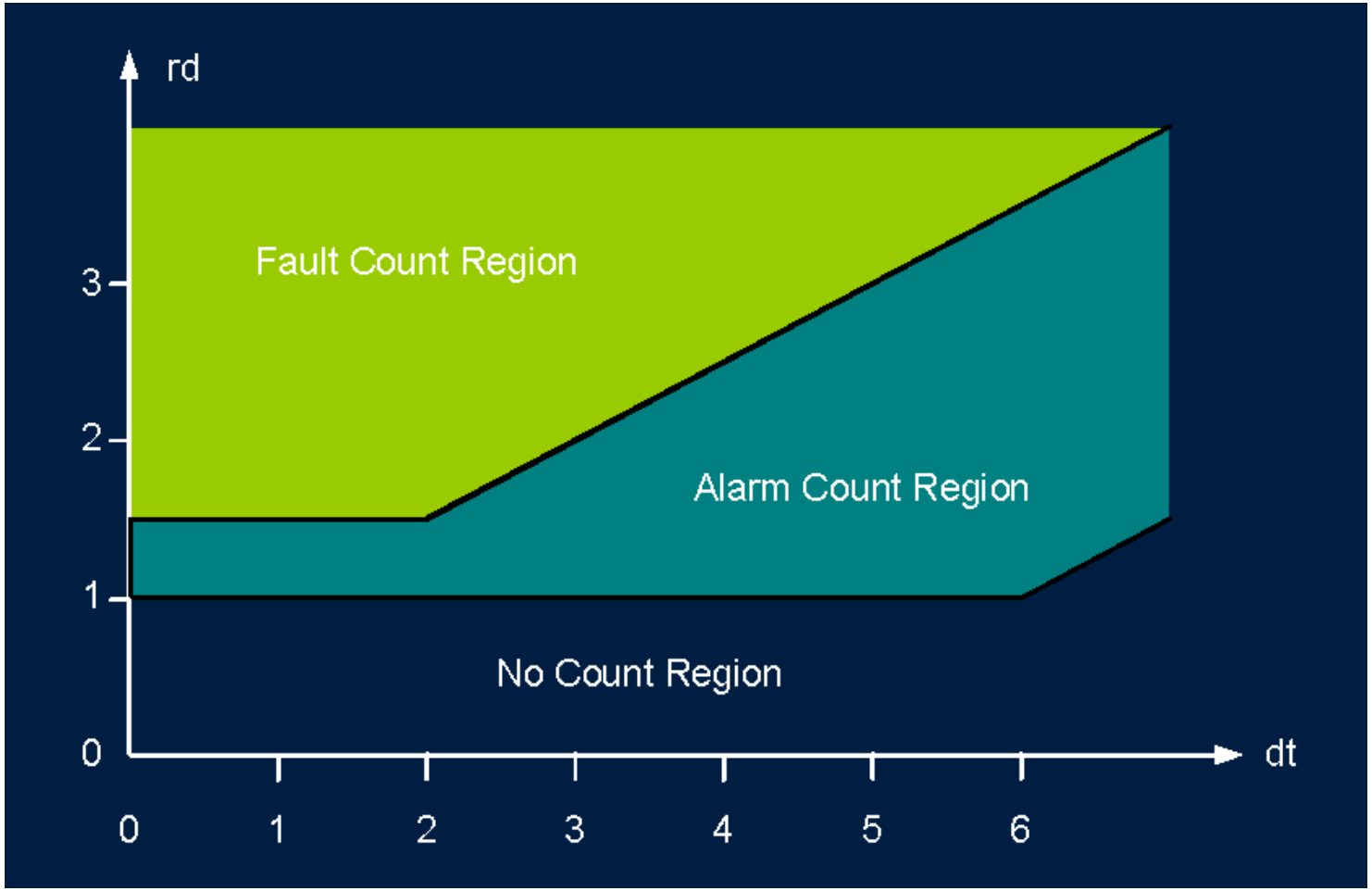
- Different feeder load has different impact on detection
- Impractical for user to characterize these impacts
- Adaptive tuning
  - Characterizes Sum of Difference Current(SDI) on individual feeder load
  - Adapts to feeder ambient noise
  - Increases fault-detection security

Trending and Memory

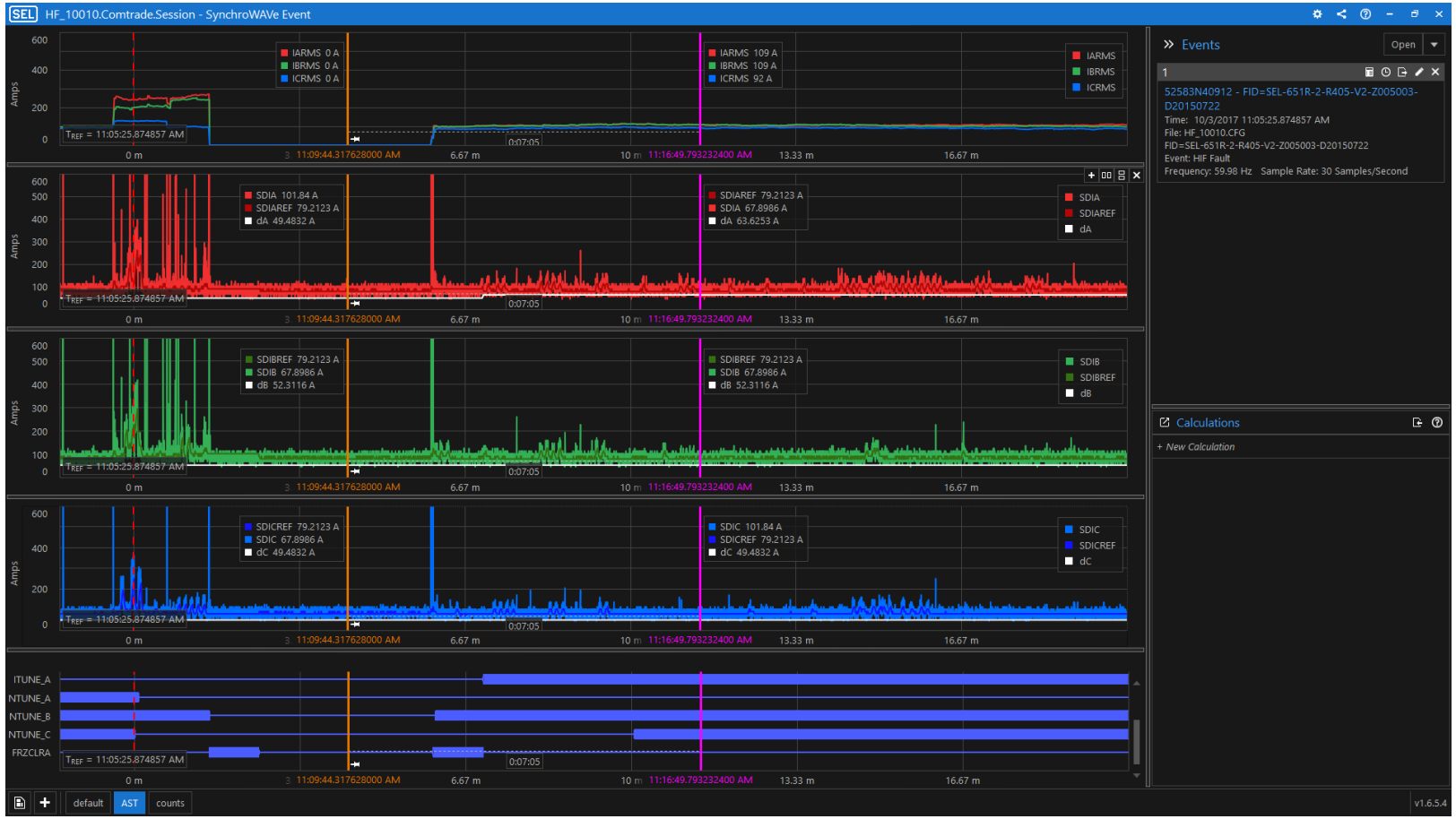
How Much and How Often



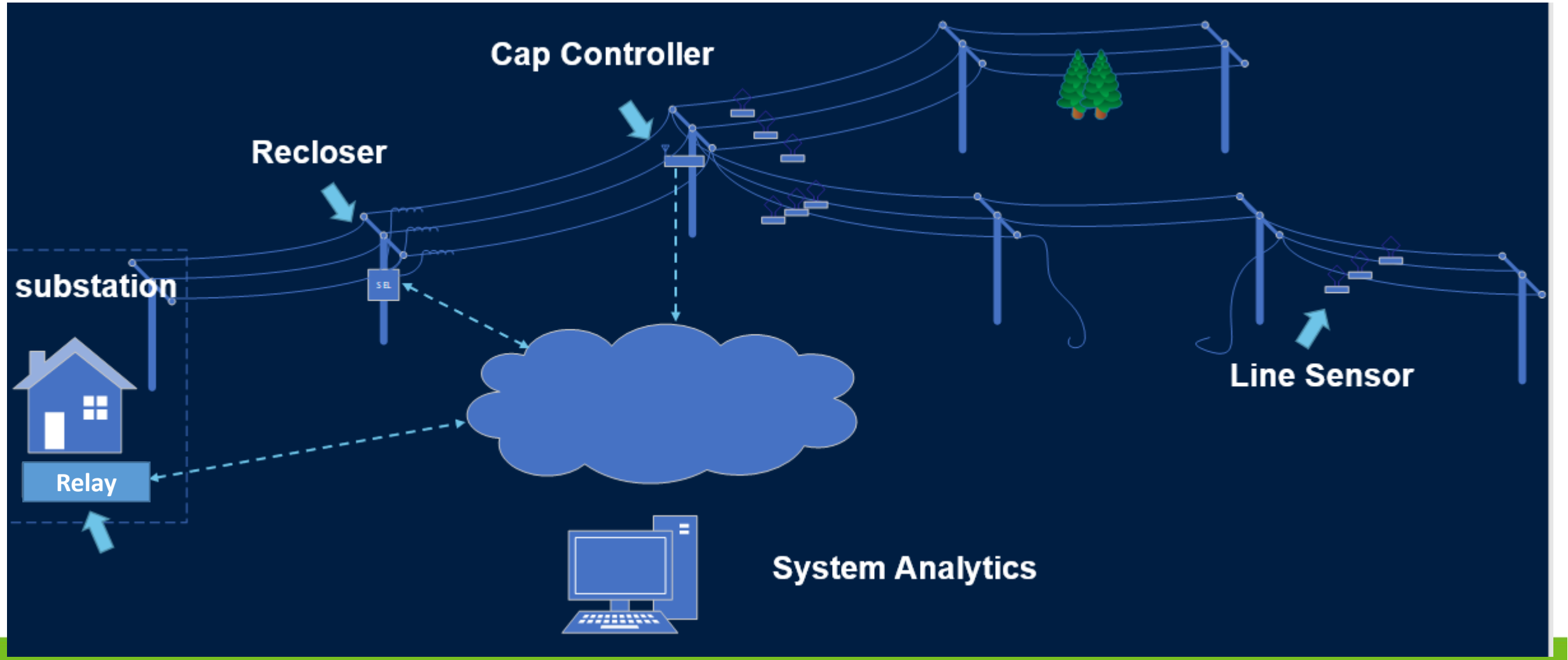
Decision Logic – Counting Scheme



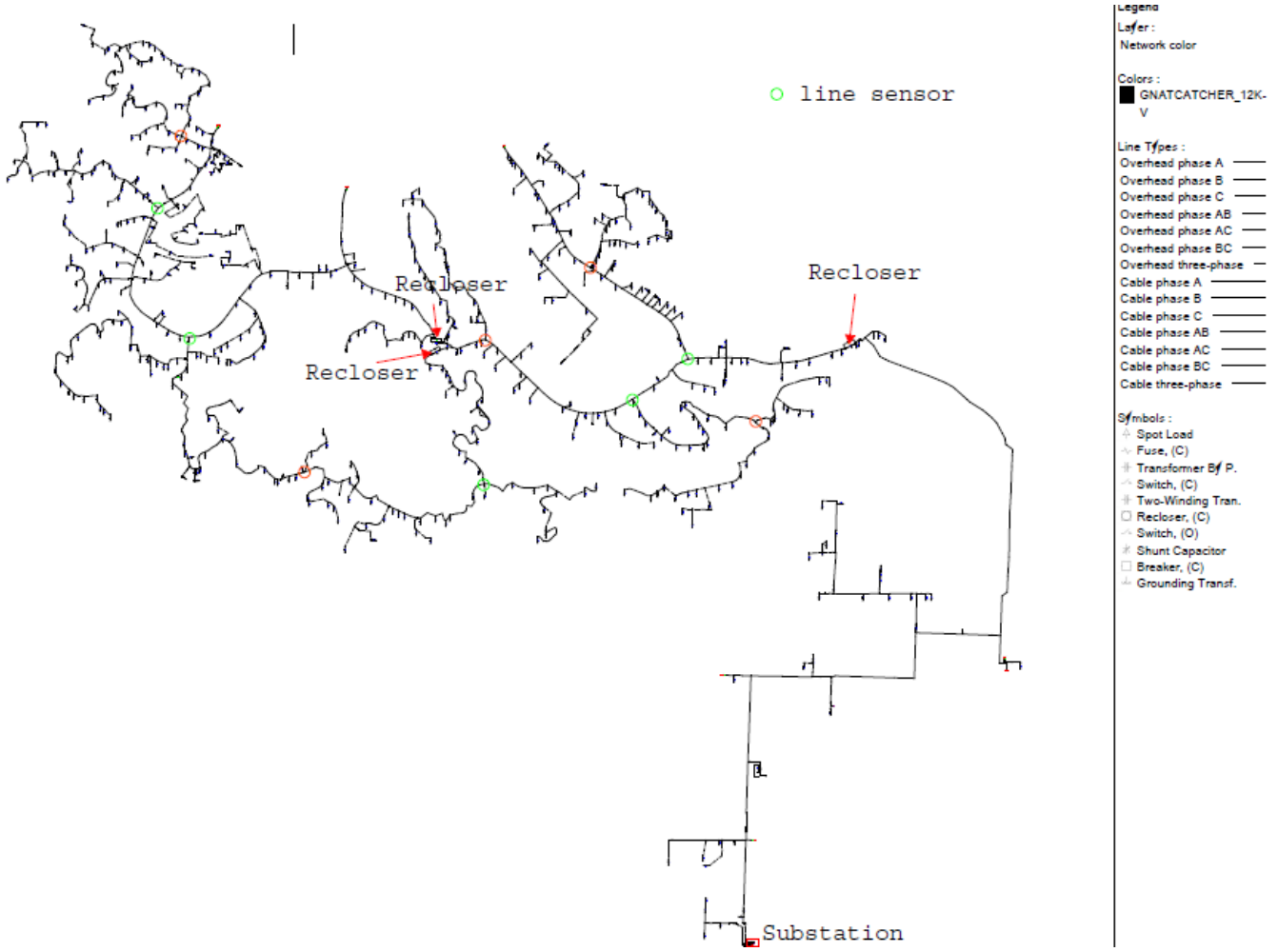
Utility Confirmed Down Conduct HIF Event



Distributed Intelligence to Improve HIF Detection



Intelligent Device Deployment Illustration



How to Improve HIF Detection Reliability

- Being close to the fault
- Improve measurement accuracy and resolution
- Using multiple data sources (relay, reclose controller, line sensor, …)
- Advance analytics
  - No deterministic mathematic models (vs phasor-based relay algorithm)
  - Pattern recognition, machine learning, AI
  - More reliable training data improve accuracy

Thank you & Questions