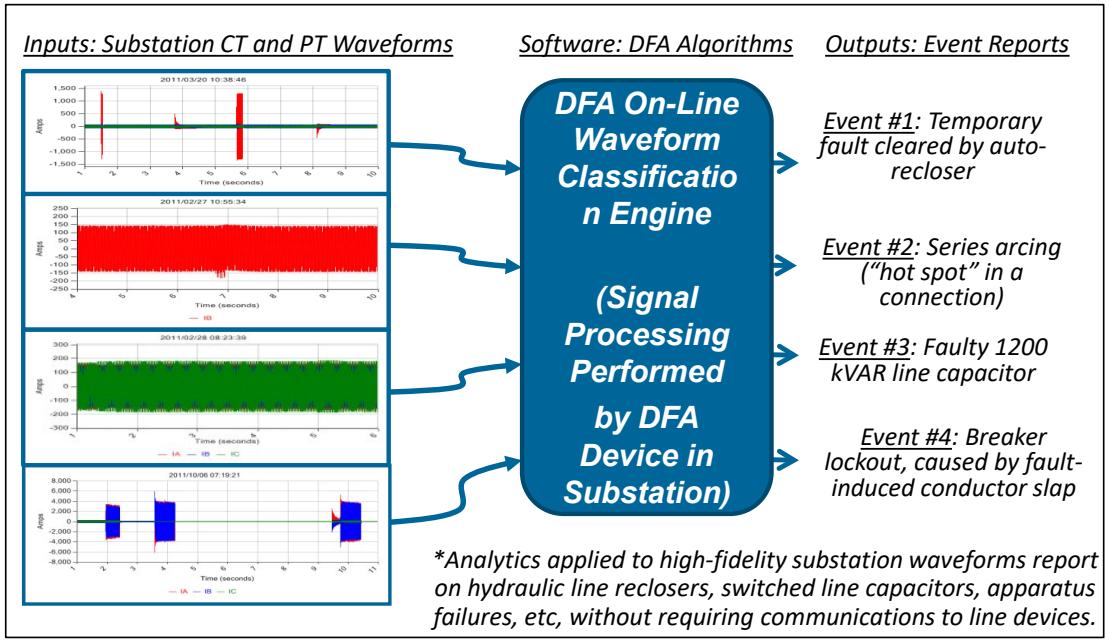
Distribution Fault Anticipation (DFA)

- Technology developed by Texas A&M Engineering, with substantial early support from EPRI and EPRI-member host sites.
  - DFA algorithms are based on more than 2000 circuit-years of field data.
- The DFA hardware/software platform analyzes high-fidelity electrical signals to detect line events, including incipient failures.
- DFA clusters and categorizes events and generates waveforms, enabling preemptive repairs that reduce ignition risks and improve reliability and power quality.

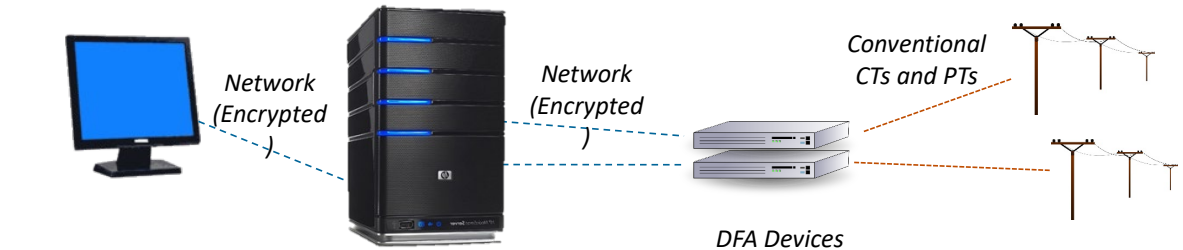
DFA Operating Fundamentals

- DFA hardware continuously monitors conventional electrical signals, like relays, but with substantially higher fidelity and sensitivity.
  - High fidelity and sensitivity are necessary to detect low-current, incipient conditions before they escalate into conventional faults.
- Based on learnings from more than 2000 circuit-years of data, DFA software analyzes the electrical data to differentiate specific types of line events, including multiple types of incipient failures.
- DFA system software automates the process of analyzing vast amounts of data, to deliver pre-processed, actionable alerts to users.

Behind the Scenes – DFA Software



DFA System Architecture



Each substation-installed DFA Device monitors an entire circuit 24x7 by analyzing conventional CT and PT waveforms with advanced software and sending results to a central DFA Master Station. Personnel access DFA results via DFA Web, a browser-based website provided by the DFA Master Station.

Non-Anticipatory Uses of DFA

- DFA provides a unique source of data to evaluate and troubleshoot complex new technologies, such as downed conductor detection and REFCL.
- DFA data enables analysis of “Unknown Cause” outage patrols.

Situational Awareness Sensor Technology – Overview

Line Sensors / cFCI's

- Single phase, conductor mounted harvesting device; generally requiring 25 amps continuous power (line sensor) or battery-powered (cFCI)
- Continuously monitoring to capture overcurrent events
- Generates alerts and waveforms thru to PI and DMS; these alerts are usable in fault locator models like CYME to estimate disturbance location

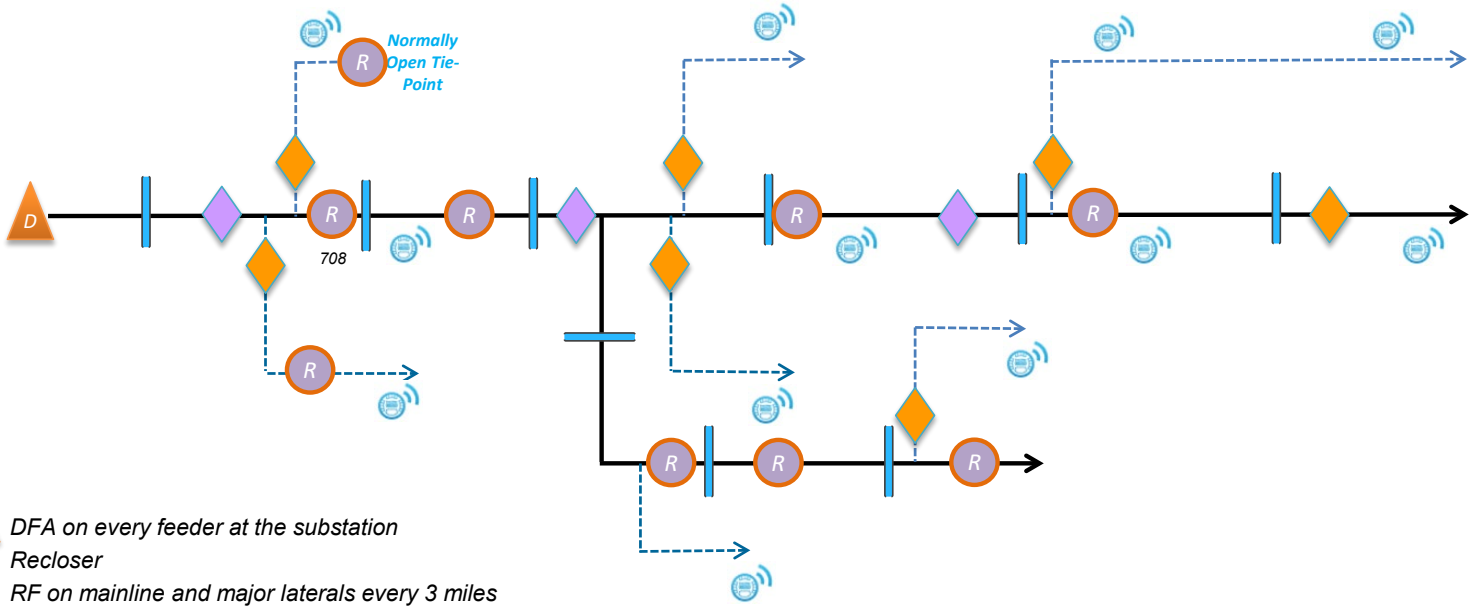
EFD – Early Fault Detection

- RF sensors mounted underneath conductor; 3 miles between sensor sets
- Sensors work in coordination from set-to-set; samples on a duty cycle basis
- Display matrix identifies concentrated patterns of discharge to a single span

DFA – Distribution Fault Anticipation

- Substation CT / PT-based device measuring volts, amps and arcing
- Monitors magnitude, phase, harmonics, real and reactive power, cycle-to-cycle deltas in these values
- Clusters and categorizes events and generates waveforms; these alerts are usable in fault locator models like CYME to estimate disturbance location

Vision – Illustrative Circuit When Fully Implemented



- *DFA on every feeder at the substation*
- *Recloser*
- *RF on mainline and major laterals every 3 miles*
- *Full power sensors at higher amps*
- *cFCI on tap laterals and at lower amps*
- *Smarter meters at every customer (higher sampling, smarter last gasp, waveforms, edge analytics)*

Vision Roadmap

Revolutionary Technology

Automation, Integration & Analytics

Evolutionary Technology

Short Term (2020 – 2023)

Deploy existing devices; nurture emerging technology

- Accelerate line sensor and DFA deployment
- Deploy inexpensive cFCI's
- Select and begin integration of analytics platform with IT
- Move RF sensors to viability

Mid Term (2024 – 2027)

Deploy new technologies and integrate analytics

- Deploy RF sensors on 100 feeders
- Move Smarter Meters to viability
- Integrate SCADA data in ADMS into analytics platform
- Extend analytics to auto detection

Long Term (2028 – 2032)

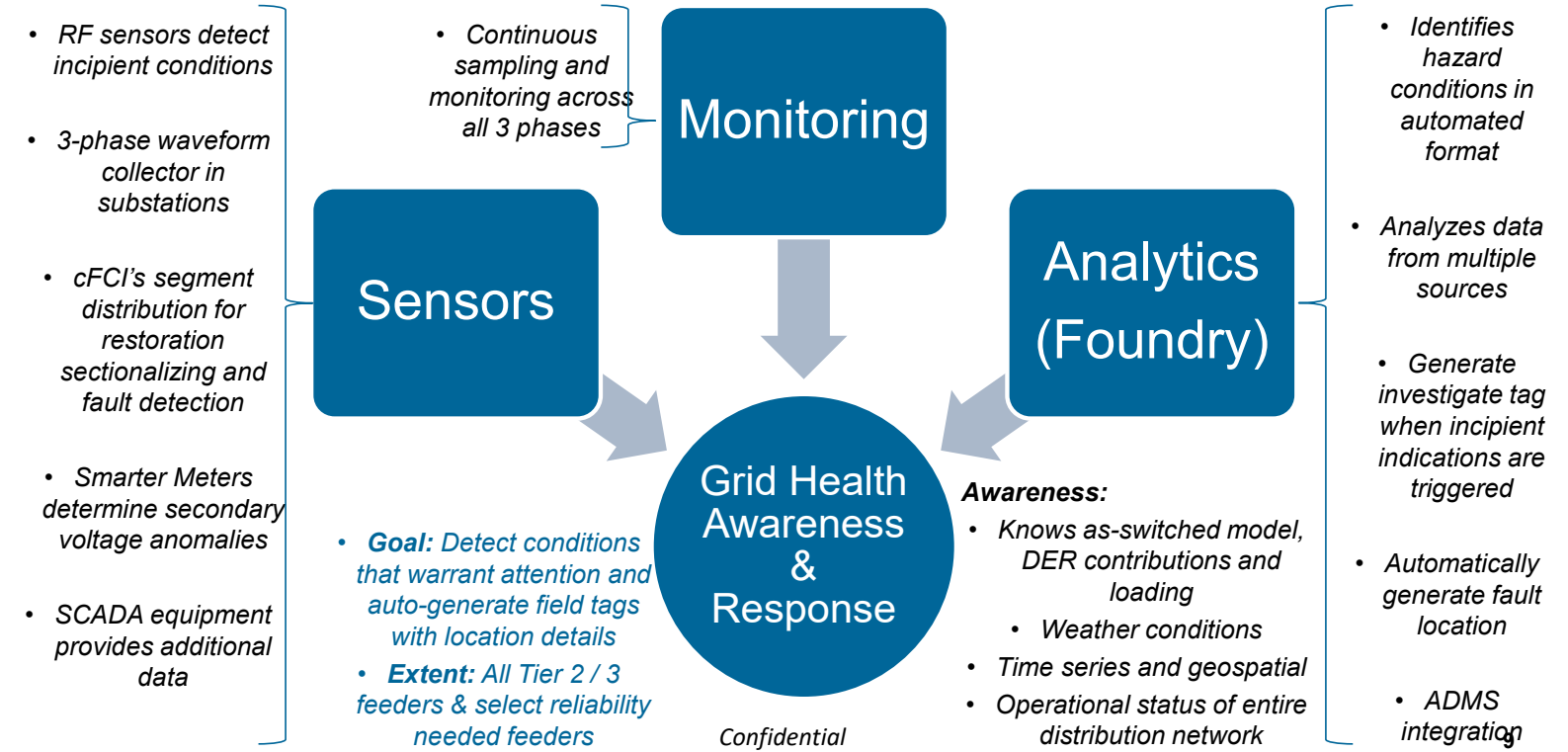
Enable future analyses and foster innovation

- RF sensors on 500 feeders
- Deploy Smarter Meters
- Integrate advanced analytics in ADMS
- Auto detection + auto field dispatch

Confidential

Years

Vision – Comprehensive Awareness



DFA Sensor Deployment Status

Strategy – Deploy and Monitor three sensor technologies on the highest risk T2/3 feeders

- PG&E's stated 10-year Scope is ~600+ circuits, with ramping annual deployment quantities and on-going development of this technology's operational benefits

Deployment of each technology to Date (# of Tier 2/3 circuits):

Sensor Technology	Circuit Count
Line Sensors	189
DFA	79
EFD	5.5

2023 Plan:

- *Deploy Line Sensors on 40 additional HFTD 2/3 circuits (WMP commit)*
- *Complete installation of EFD Technology on 2 additional HFTD 2/3 distribution circuits*
- *Integrate Line Sensor data into Foundry – enable streamlined analysis and optimized patrol zone generation for unknown outage / EPSS outage investigations*
- *Operationalize DFA analytics - integrate alerts into Foundry, develop streamlined workflow to identify/remediate incipient issues and to support post-outage investigations. Set stage for higher volume deployments in 2024*

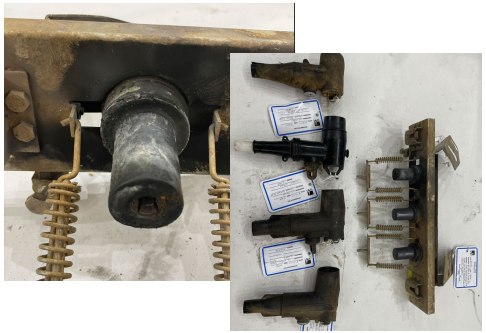
DFA Status

- *DFA sensor equipment is currently deployed on 79 circuits at sub-stations*
- *2022 Q4 - Phase 1 of correlation study (comparing historical DFA alerts to Line Sensor events and outage records) successfully completed. Study done on circuits where both DFA and Line Sensor technologies were deployed*

Category	*Equipment Issue*
vegetation	wire-on-ground (might include structural damage eg broken crossarm)
	incidental (fuse only etc.)
	structural failure
	conductor slap
animal	wire-on-ground (might include structural damage eg broken crossarm)
	incidental (fuse only etc.)
environmental: ice/snow / storm damage	wire-on-ground (might include structural damage eg broken crossarm)
	Conductor, Overhead, Bent or Twisted / Pole-Wood, Broken
	conductor slap / wire on ground
3rd party: tree cutting / vehicle	wire-on-ground (might include structural damage eg broken crossarm)
UG equipment failure due to flashing / unknown cause	UG condcutor, transformer or elbow

INITIAL USE CASE: DFA – Underground Elbow

- *Arcing underground elbows can cause repeated large unknown caused outages during EPSS enablement*
- *DFA/Line Sensor data was successfully used to locate/resolve underground elbow issues on Shingle Springs 2108 which caused multiple EPSS outages with 2000+ customer impact in May/June 2022*
- *Similar DFA signature was found on a resolved Pueblo 2103 unplanned outage in Sept 2022 (101 customers) during back-testing of DFA data*
- *Use case now developed to identify/resolve elbow flashover issues in incipient state, help avoid unplanned outages – (Successfully completed investigation on Brunswick 1104 in Dec 2022)*



INITIAL USE CASE: DFA – Fault Induced Conductor Slap (FICS)

- *FICS events can cause ignitions when secondary fault occurs*
- *Issue occurred on Rob Roy 2104 on three occasions in one day January 14, 2023. Location found using DFA and Line Sensors.*

DFA Status

2023 Plans:

- *Continue correlation studies – Further investigate DFA alerts for presence of early signatures for that can help remediate issues at incipient stage.*
- *Operationalize DFA analytics - integrate alerts into Foundry, develop streamlined workflow to identify/remediate incipient issues and to support post-outage investigations. Set stage for higher volume deployments in 2024*
- *Work with other California IOUs on determining best practices for EFD/DFA analysis*