Advanced Monitoring Tools to Improve Distribution System Visibility and Reduce Faults and Outages

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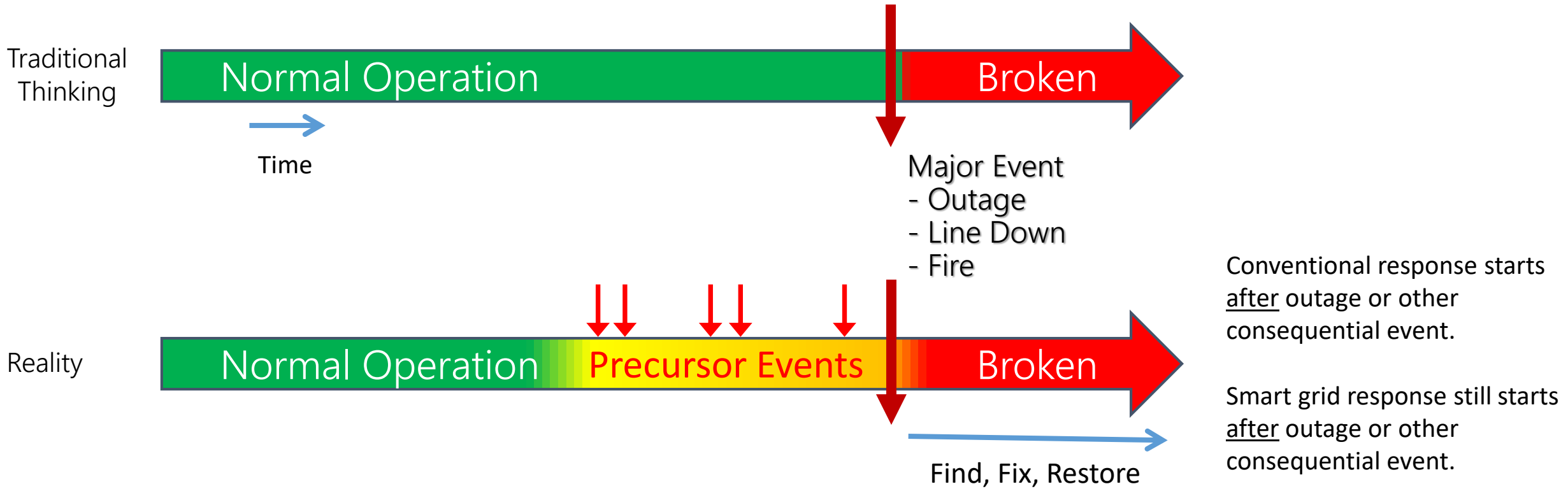
Presentation Overview

- Distribution operations – current practice and limitations
- Distribution Fault Anticipation (DFA) technology
- Texas Power Line-Caused Wildfire Mitigation project
- Bluebonnet’s operational use of DFA technology

Distribution Reliability – Facts and Observations

- Distribution constitutes well over 90% of the line miles in the US.
- Distribution causes most of the reliability problems (interruptions and outages) and power quality problems that customers experience.
- Distribution circuits are aging.
- Resources are constrained and becoming more so.
  - Fewer people; less experience
  - Fewer dollars for maintenance and upgrades
- We must assume that there will be no mass replacement of distribution infrastructure in next 20-30 years.

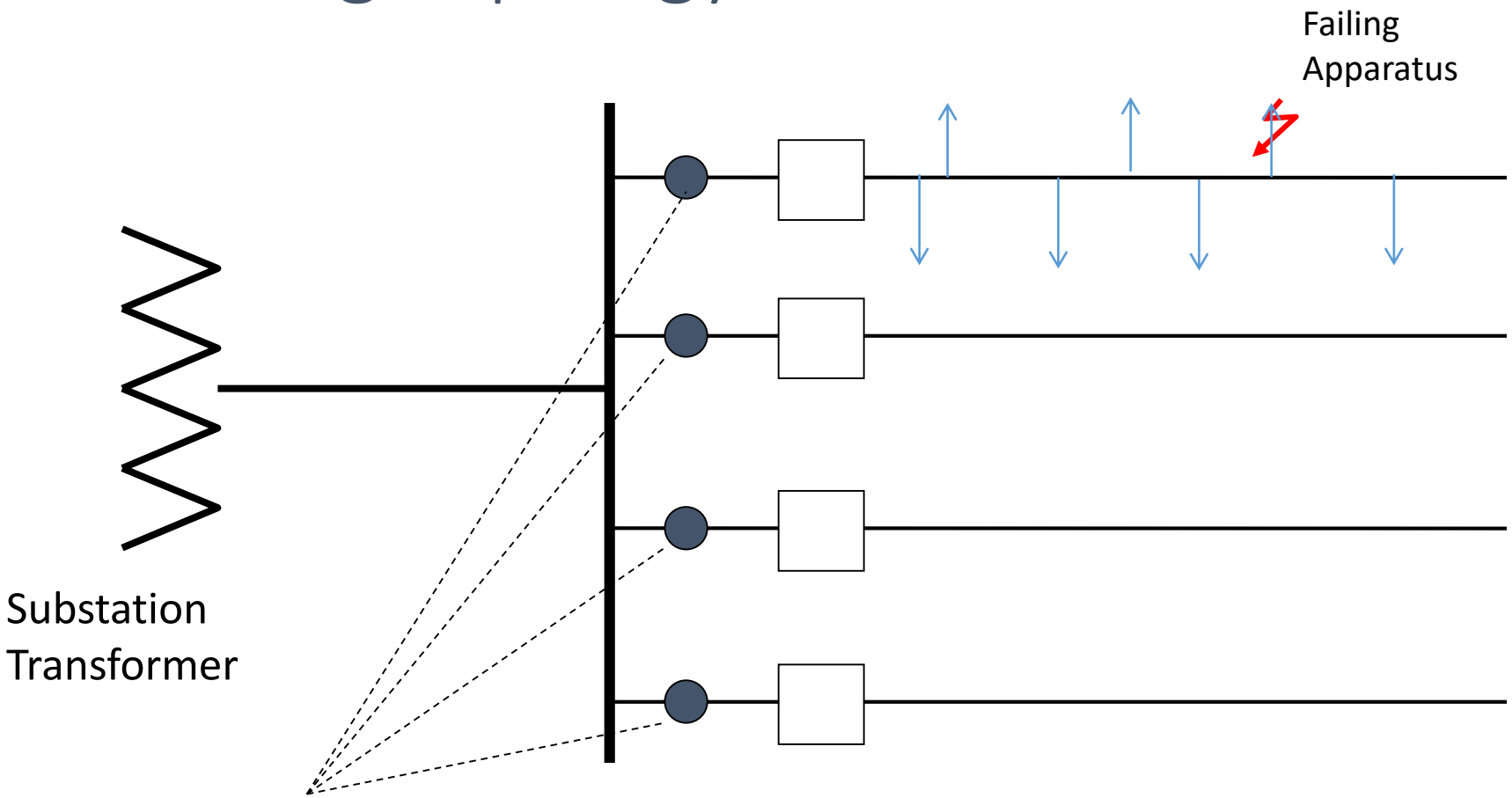
Distribution Circuit Operating Paradigms



Key to better circuit management is awareness of actual circuit activity.

Distribution Fault Anticipation (DFA) Technology

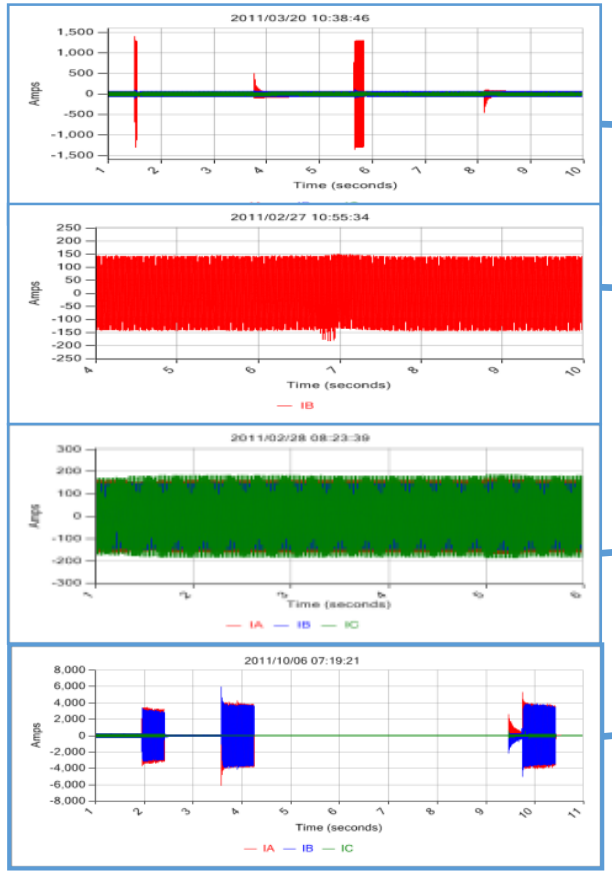
DFA Monitoring Topology



High-fidelity DFA devices connect to conventional CTs and PTs, one per distribution circuit.
Each DFA device is a single, 19” rack-mount device, with connections similar to those of a relay.

DFA Technology – Behind the Scenes

Inputs: Substation CT and PT Waveforms



Waveform Analytics

DFA On-Line Waveform Classification Engine

(Signal Processing Performed by DFA Device in Substation)

Outputs: Event Reports

Event #1: Temporary fault cleared by trip/close of line recloser

Event #2: Failing hot-line clamp

Event #3: Faulty 1200 kVAR line capacitor

Event #4: Breaker lockout, caused by fault-induced conductor slap

*Analytics applied to high-fidelity substation waveforms report on hydraulic line reclosers, switched line capacitors, apparatus failures, etc, without requiring communications to line devices.

DFA Technology – Behind the Scenes

DFA On-Line Waveform Classification Engine

(Signal Processing Performed by DFA Device in Substation)

DFA Device software technologies

- Multi-rate polyphase filter banks for phase drift compensation
- Fuzzy expert system for classification
- Fuzzy dynamic time warping for shape recognition
- Hierarchical agglomerative clustering for recurrent faults
- Finite state machine for fault SOE identification
- Shape-based and event-specific feature extraction
- Hierarchical classification architecture for feature space dimensionality reduction

The DFA on-line waveform classification engine uses sophisticated software to analyze waveforms and thereby characterize circuit events.

DFA Technology - Summary

- Conventional distribution operations are limited by lack of means to achieve visibility (or awareness) of circuit events and conditions.
- DFA technology improves visibility (or awareness) by applying an on-line sophisticated waveform classification engine to high-fidelity waveforms from CTs and PTs.
- Improved visibility enables improved operations.

Texas Power Line-Caused Wildfire Mitigation Project

How Do Power Lines Cause Fires?

Downed Conductors

Clashing Conductors

Vegetation

Failing Apparatus

Texas Power Line-Caused Wildfire Mitigation Project

- Recognizing that many wildfires result from power line events, the Texas legislature is supporting the Texas Power Line-Caused Wildfire Mitigation project, based on Texas A&M Engineering's DFA technology.
- Current Participants

Austin Energy	Bluebonnet Electric Cooperative
BTU (Bryan Texas Utilities)	Concho Valley Electric Cooperative
Mid-South Synergy Electric Cooperative	Pedernales Electric Cooperative
Sam Houston Electric Cooperative	United Cooperative Services

- Most DFA circuit monitors have been installed for 12-15 months.

Texas Power Line-Caused Wildfire Mitigation Project

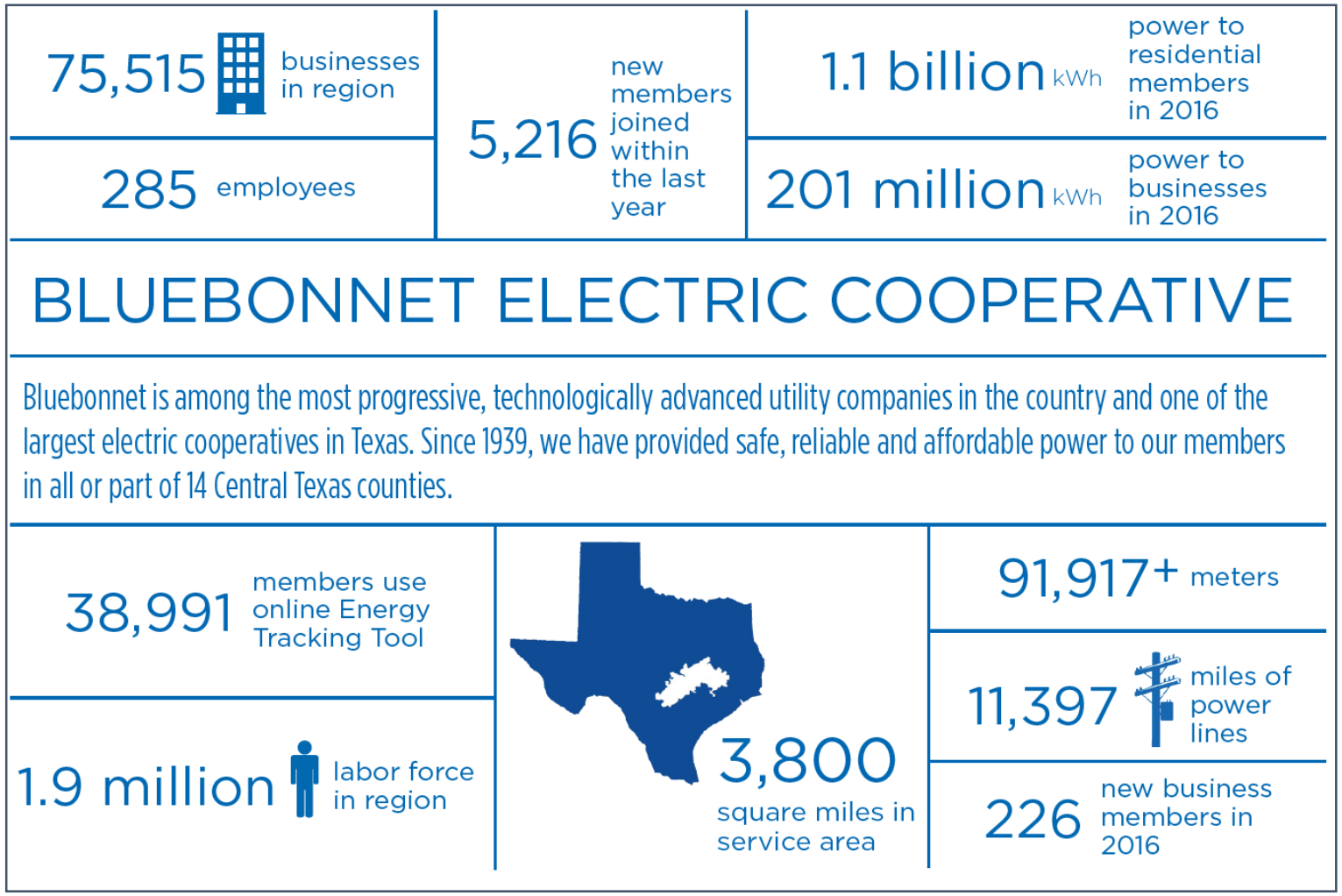
Partial List of Events Detected and Corrected by Project Participants

- Detection and location of tree branch hanging on line and causing intermittent faults.
- Detection and location of intact tree intermittently pushing conductors together.
- Detection and location of broken insulator that resulted in conductor lying on and heavily charring wooden crossarm (to be detailed Wednesday at Real World session).
- Detection and location of catastrophically failed lightning arrester.
- Detection and location of arc-tracked capacitor fuse barrel.

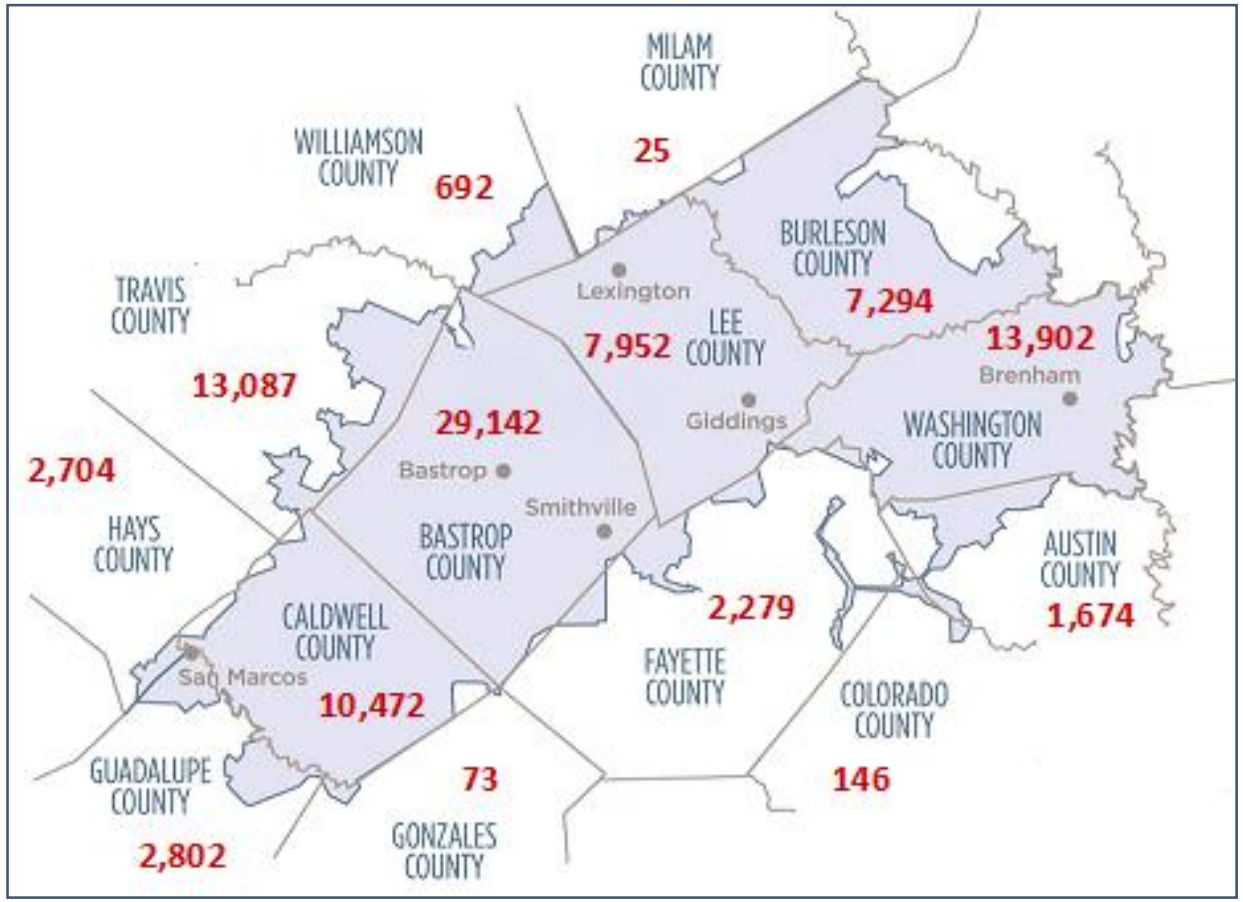
All of these event have potential for fire ignition and affect reliability and service quality.

Bluebonnet Electric Cooperative's Operational Use of DFA Technology

Bluebonnet Electric Cooperative



Bluebonnet Electric Cooperative



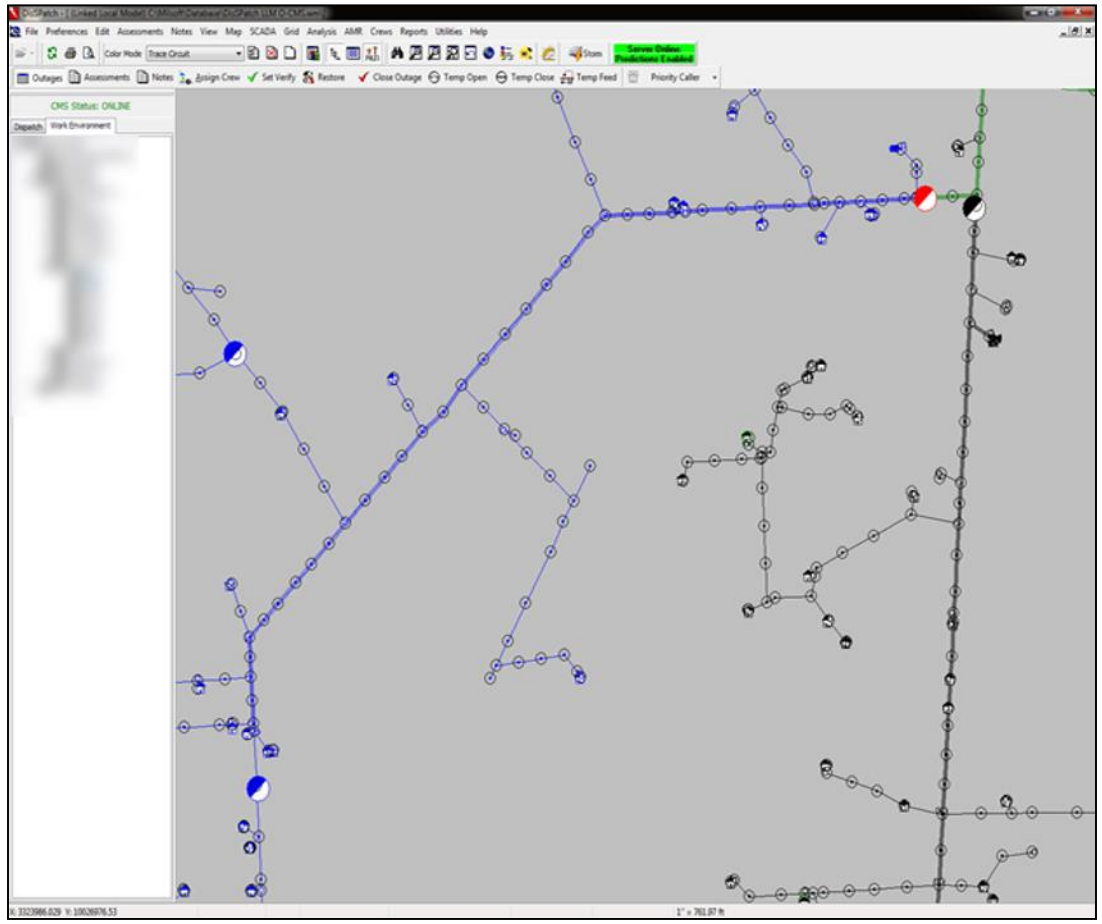
- One of largest cooperatives in Texas
- Serving members since 1939
- 91,000 meters
- 11,000 line miles
- 3,800 square miles
- 14 central Texas counties

Recent Use of DFA at Bluebonnet

- Bluebonnet operators use multiple tools to manage circuit operations.
  - A small percentage of line reclosers are monitored and can provided fault currents.
  - Milsoft-based circuit model includes device locations and can predict possible fault locations based on measured fault current levels.
  - TWACS-based meters can be pinged to confirm outage locations.
- DFA provides another tool to aid in problem identification and location.
- DFA presents “plain English” reports via secure login to a website.
- The following case studies provide high-level synopses of multiple cases where Bluebonnet has used DFA to improve response to faults, outages, and other problems.

Bluebonnet Use Case #1

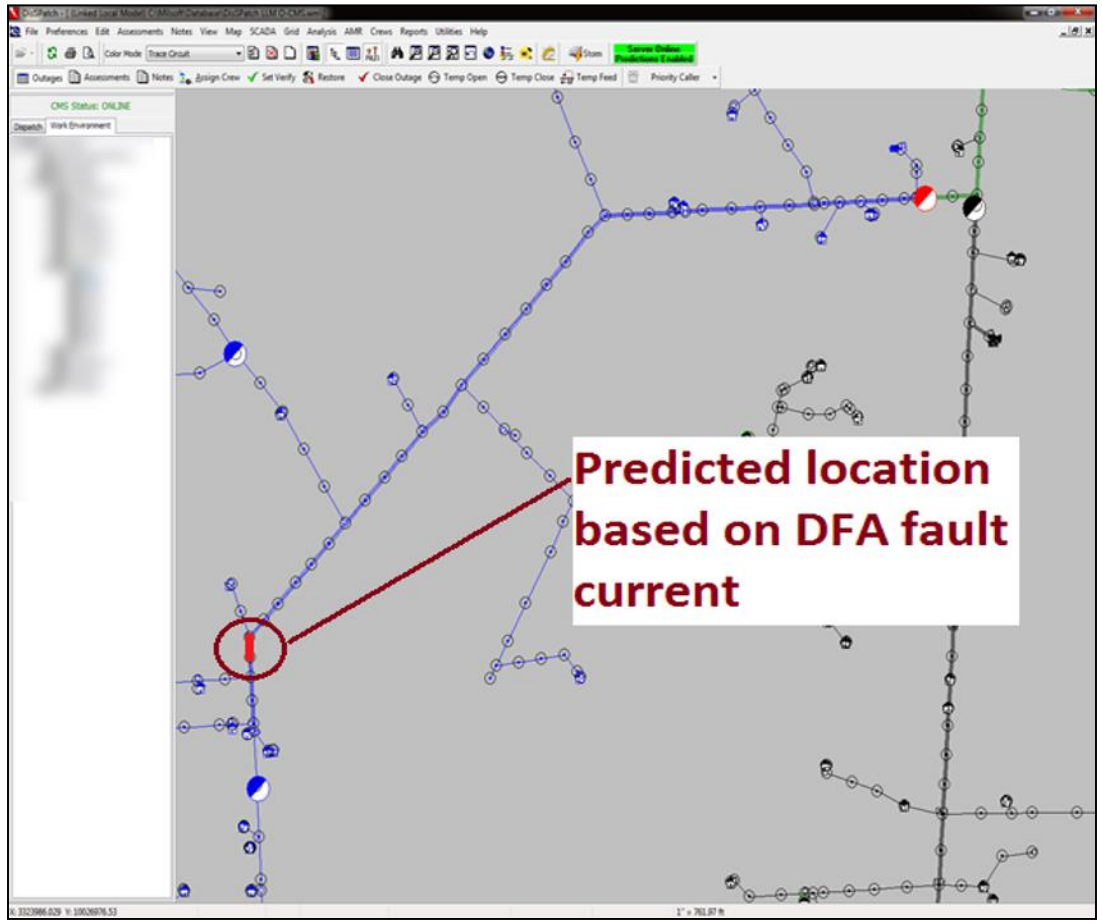
Arrester-Induced Fault and Outage



- Incident occurred on hot, fair-weather afternoon.
- Multiple members reported “blinks.” All were downstream of an unmonitored 70A recloser.
- Downstream of that recloser are 157 members and significant line miles (blue on map).
- Operator dispatched crews to search downstream of recloser.

Bluebonnet Use Case #1

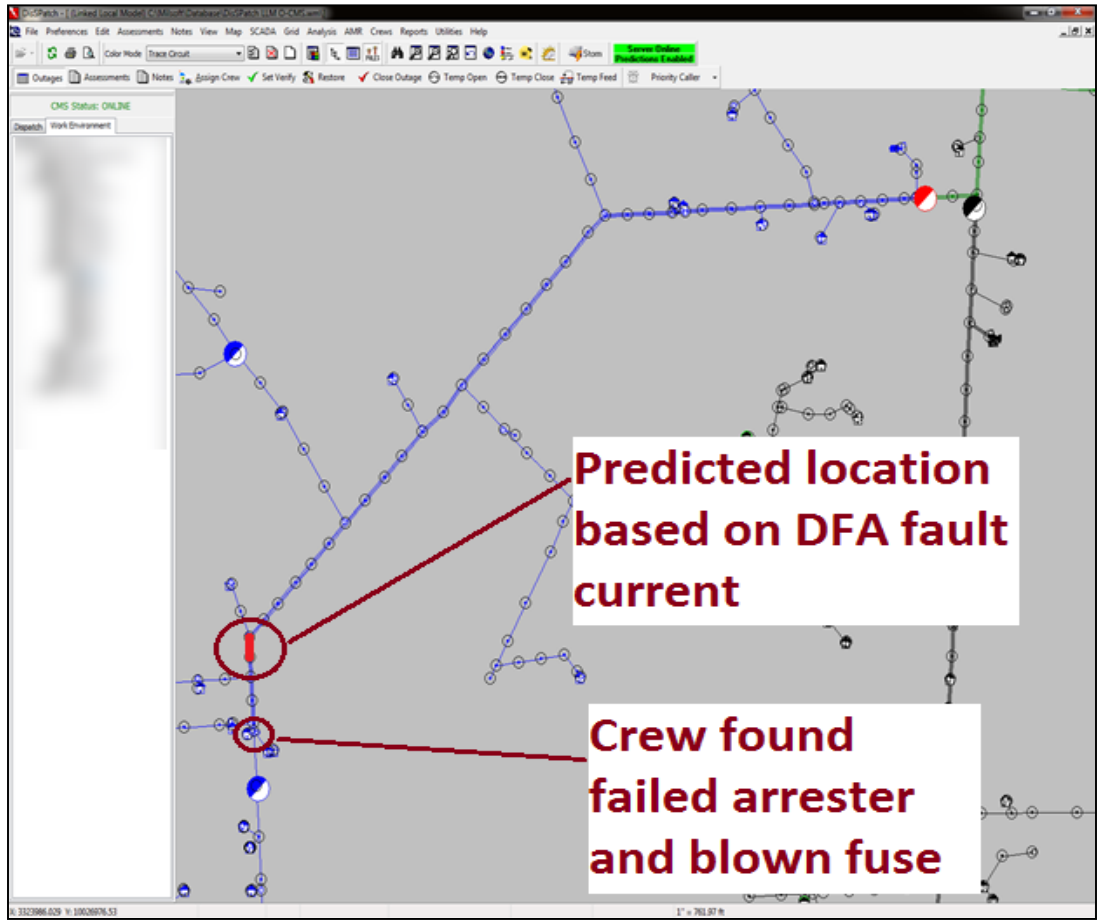
Arrester-Induced Fault and Outage (cont'd)



- Operator then received DFA-based fault alert that indicated:
  - Estimated fault current
  - Probable cause: failed arrester.
  - Prediction of cause came from manual analysis by Texas A&M.
- Operator redirected crews to the search area predicted by putting the DFA fault current estimate into the circuit model.

Bluebonnet Use Case #1

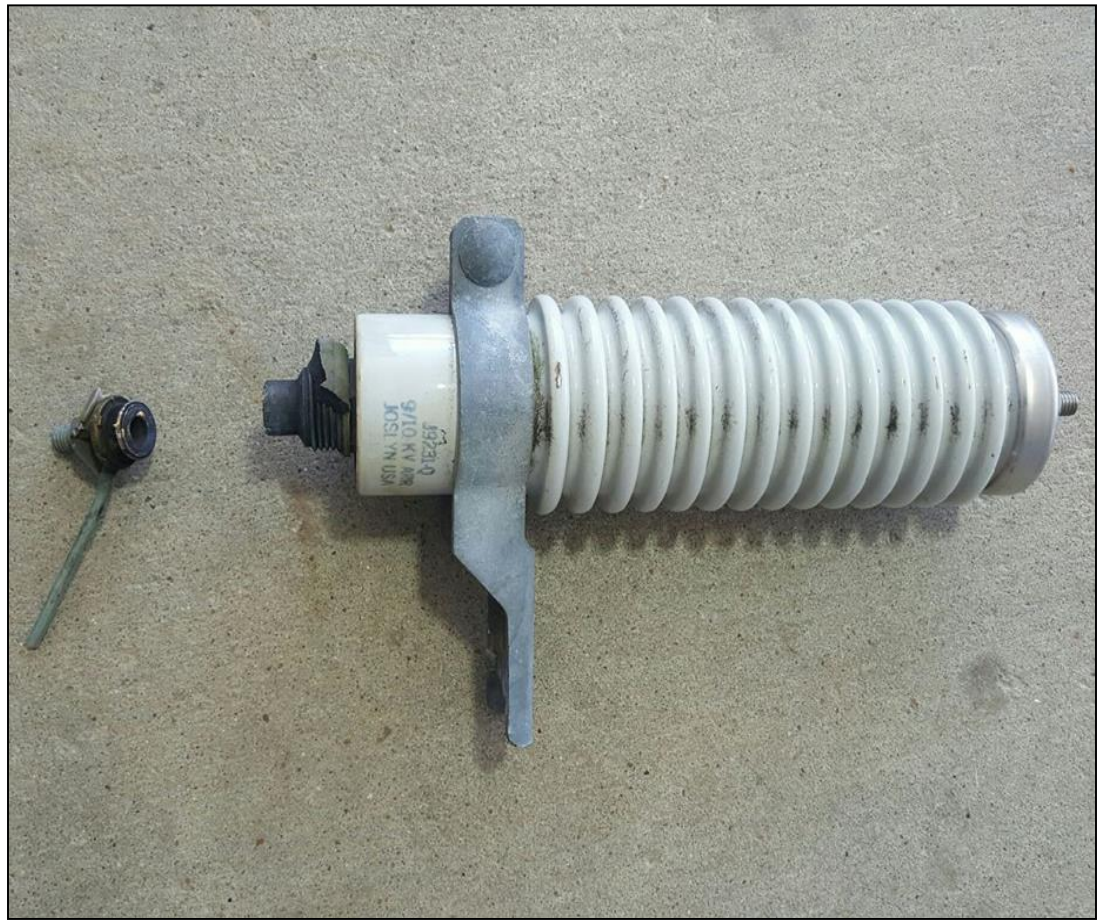
Arrester-Induced Fault and Outage (cont'd)



- The crew found a blown transformer fuse, caused by a blown arrester, three spans from the predicted location.
- Having the DFA report saved crew time (targeted search) and shortened the outage.
- Prediction of cause (failed arrester) was confirmed correct.

Bluebonnet Use Case #1

Arrester-Induced Fault and Outage (cont'd)



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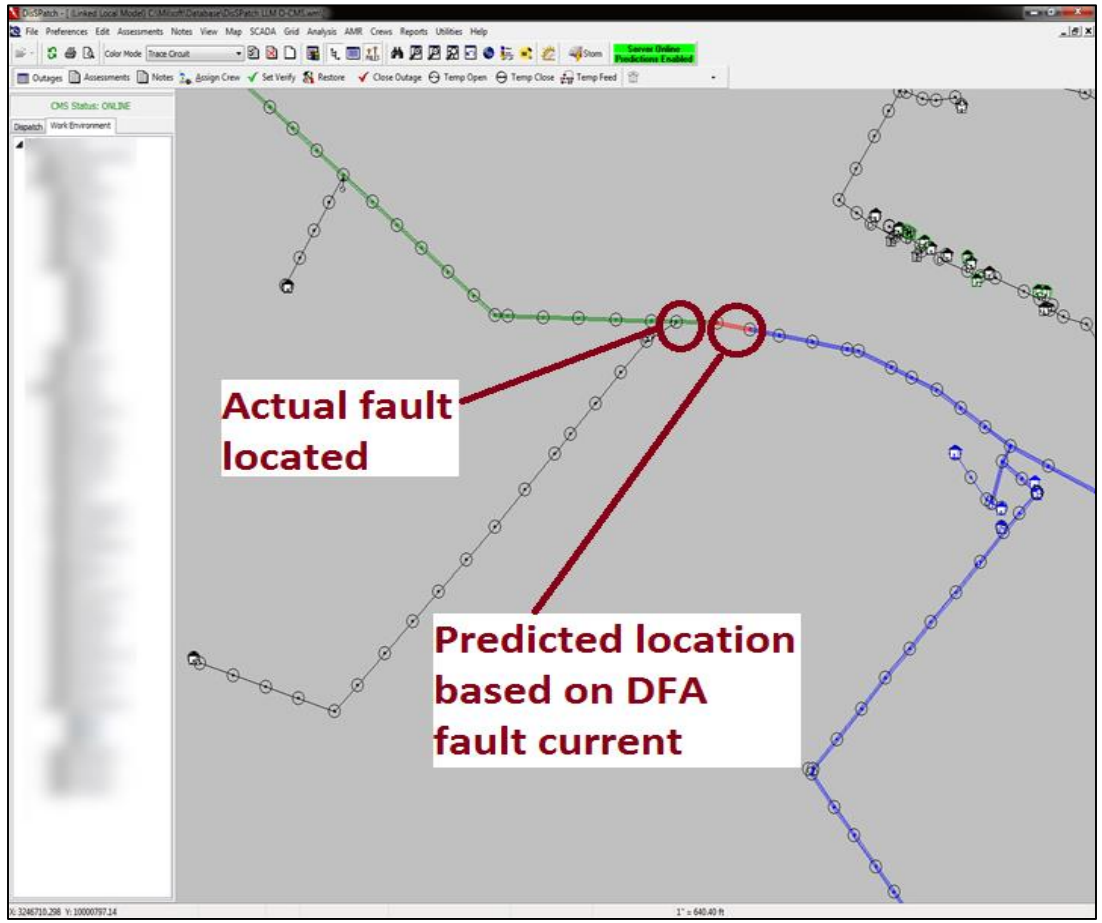
Bluebonnet Use Case #2

Outage Resolved without Member Call



- Operator noted DFA fault report and put DFA fault current estimate in model to predict location.
- Pinging meters in targeted area identified two meters out of service, one span from predicted location.
- Crew found blown line fuse.
- Meter served two water wells at an unmanned location. Without the DFA report, the outage may have persisted for a much longer period.

Bluebonnet Use Case #3

Outage Avoided (Intermittent Tree Contact)

Expand	Substation	Circuit	Seen By	Event Type	Phases	Comments	Count	Last Occurred
+	[redacted]	[redacted]	[redacted]	Single-phase recurrent fault	A	Single-phase fault, 1125 Amps	3	2016-11-21 16:14:52

Event Type	Phases	Comments	Count	Last Occurred
Single-phase reclose	A	F-(3.0c,1124A,AN)-T-(23,0,0)%-1.6s-C	1	2016-11-21 16:14:52
Single-phase reclose	A	F-(3.0c,1131A,AN)-T-(17,0,0)%-1.6s-C	1	2016-10-30 18:13:50
Single-phase reclose	A	F-(3.0c,1121A,AN)-T-(7,0,0)%-1.5s-C	1	2016-10-17 14:18:17

- DFA reports faults and trip/close operations of reclosers, including unmonitored reclosers.
- DFA maintains its circuit's fault history and looks for the "same" fault occurring multiple times.
- In the subject case, DFA reported three similar faults and trip/close operations in a period of 35 days.
  - All three were phase-A faults that drew 1125 amps +/- 1 percent and lasted three cycles before tripping.
  - In each instance, the recloser stayed open 1.5-1.6 seconds.
- During the 35-day period, the circuit experienced other faults, but those were unrelated and thus not reported as a "recurrent" fault.

Bluebonnet Use Case #3

Outage Avoided (Intermittent Tree Contact)

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Single-phase reclose	A	F-(3.0c,1121A,AN)-T-(7,0,0)%-1.5s-C	1	2016-10-17 14:18:17

- Unlike previous cases, there was no outage, so location is more difficult.
- In general, prediction of location is a two-step process:
  1. Identify which recloser is trip/closing.
  2. Use the DFA fault current estimate, along with the circuit model, to predict location(s), but consider only locations past the recloser identified in step 1.

Bluebonnet Use Case #3

Outage Avoided (Intermittent Tree Contact)

Expand	Substation	Circuit	Seen By	Event Type	Phases	Comments	Count	Last Occurred
+	[redacted]	[redacted]	[redacted]	Single-phase recurrent fault	A	Single-phase fault, 1125 Amps	3	2016-11-21 16:14:52

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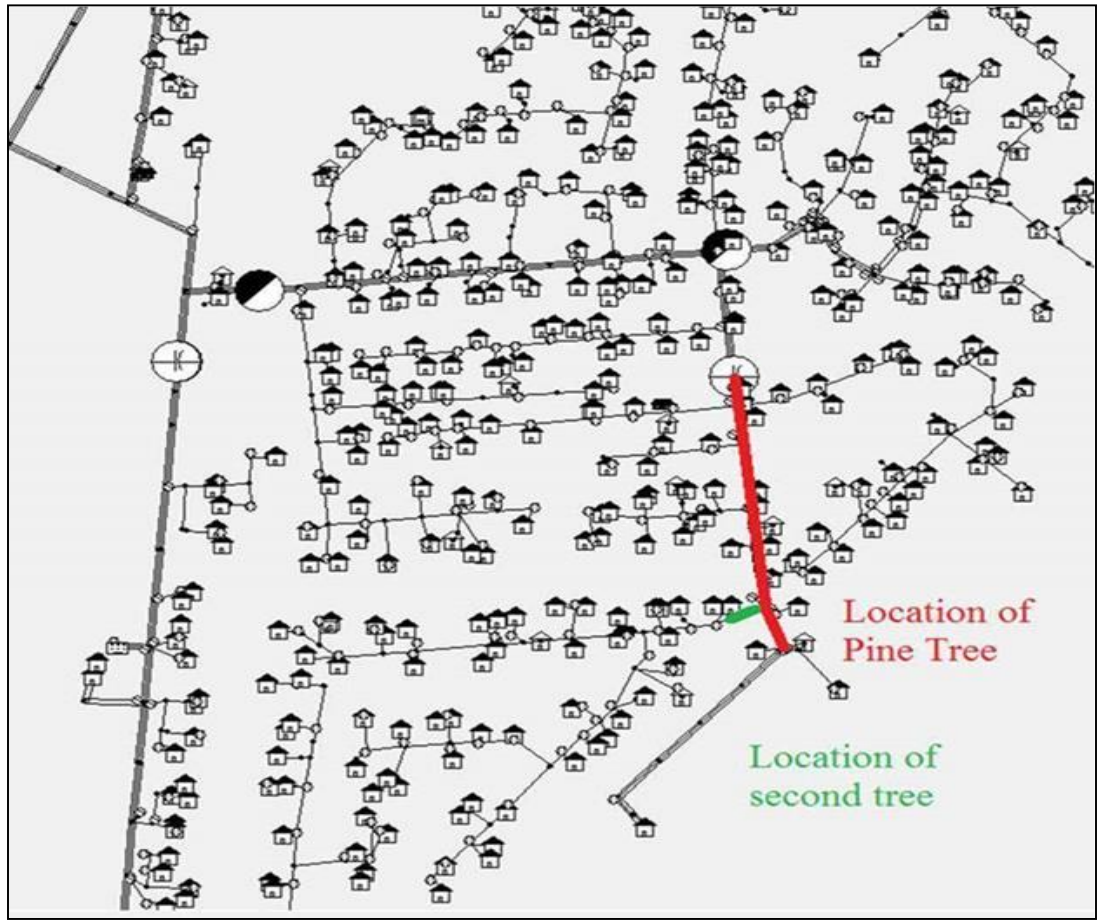
Single-phase reclose	A	F-(3.0c,1121A,AN)-T-(7,0,0)%-1.5s-C	1	2016-10-17 14:18:17

- Based on various factors, a specific unmonitored 100A recloser was suspected.
- Bluebonnet's TWACS-based AMR provides "blink" counts with one-day granularity.
- The "blink" report for meters beyond the suspect recloser showed four "blinks," three of them coincident with the days DFA indicated the recurrent fault. (The other was an unrelated fault that happened to operate the same recloser.)

Bluebonnet Use Case #3

Outage Avoided (Intermittent Tree Contact)



- Putting DFA-estimated fault current in the circuit model, and considering points only beyond the 100A recloser, targeted the search to the area shown in red.
- In that area, two trees were found close enough to the line to lean in during wind.
- Prior to pruning, DFA reported a fourth fault in the same recurrent-fault cluster, which was verified by a new blink count.
- Simple pruning solved the problem.
- Left uncorrected, the condition likely would have caused an outage for 63 members.

Bluebonnet Use Case #4

Reporting of Routine Capacitor Bank Failures

Expand	Substation	Circuit	Seen By	Event Type	Phases	A kvar	B kvar	C kvar	Count	Last Occurred
+	[redacted]	[redacted]	[redacted]	CAP: Unbalanced	BC	1	146	150	17 (47 days)	2016-10-04 12:48:11
+	[redacted]	[redacted]	[redacted]	CAP: Unbalanced	AB	104	103	1	14 (38 days)	2016-10-04 10:25:45
+	[redacted]	[redacted]	[redacted]	CAP: Unbalanced	CA	104	1	99	27 (38 days)	2016-10-04 09:37:11

- DFA capacitor report indicated issues with three unmonitored, switched capacitors:
  - Circuit T3, 450 kvar bank, phase A inoperable
  - Circuit T5, 300 kvar bank, phase C inoperable
  - Circuit A11, 300 kvar bank, phase B inoperable
- Operator wrote work orders and crews found and corrected the three issues predicted by DFA.
- Details (phases, bank sizes) provided by DFA were confirmed to be correct.

Bluebonnet Use Case #5

Detection of Capacitor Bank Fault

[redacted]	[redacted]	Fault: Capacitor failure	B	2358 Amps	N/A	2016-11-08 14:34:03

- DFA detected capacitor fault that resulted in loss of one phase.
- The next day Bluebonnet dispatched a crew.
- Crew found a failed phase capacitor. DFA-reported fault current was accurate for capacitor location.

Summary of Recent Use of DFA at Bluebonnet

- Bluebonnet operators have begun using DFA, along with existing tools, to manage circuit operations.
- DFA provides fault current estimates in some situations where Bluebonnet otherwise does not have fault current estimates, all based on substation-only DFA monitoring of conventional CTs and PTs.
- For events investigated, Bluebonnet estimates that DFA-reported fault currents, used in conjunction with Bluebonnet's circuit models, put search crews within four pole spans 80% of the time.
- Bluebonnet also finds DFA capacitor reports accurate and valuable.
- DFA is enabling Bluebonnet to respond to outages sooner and, in some cases, to respond before outages occur.

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