Automated Power System Waveform Analytics for Improved Visibility, Situational Awareness, and Operational Efficiency

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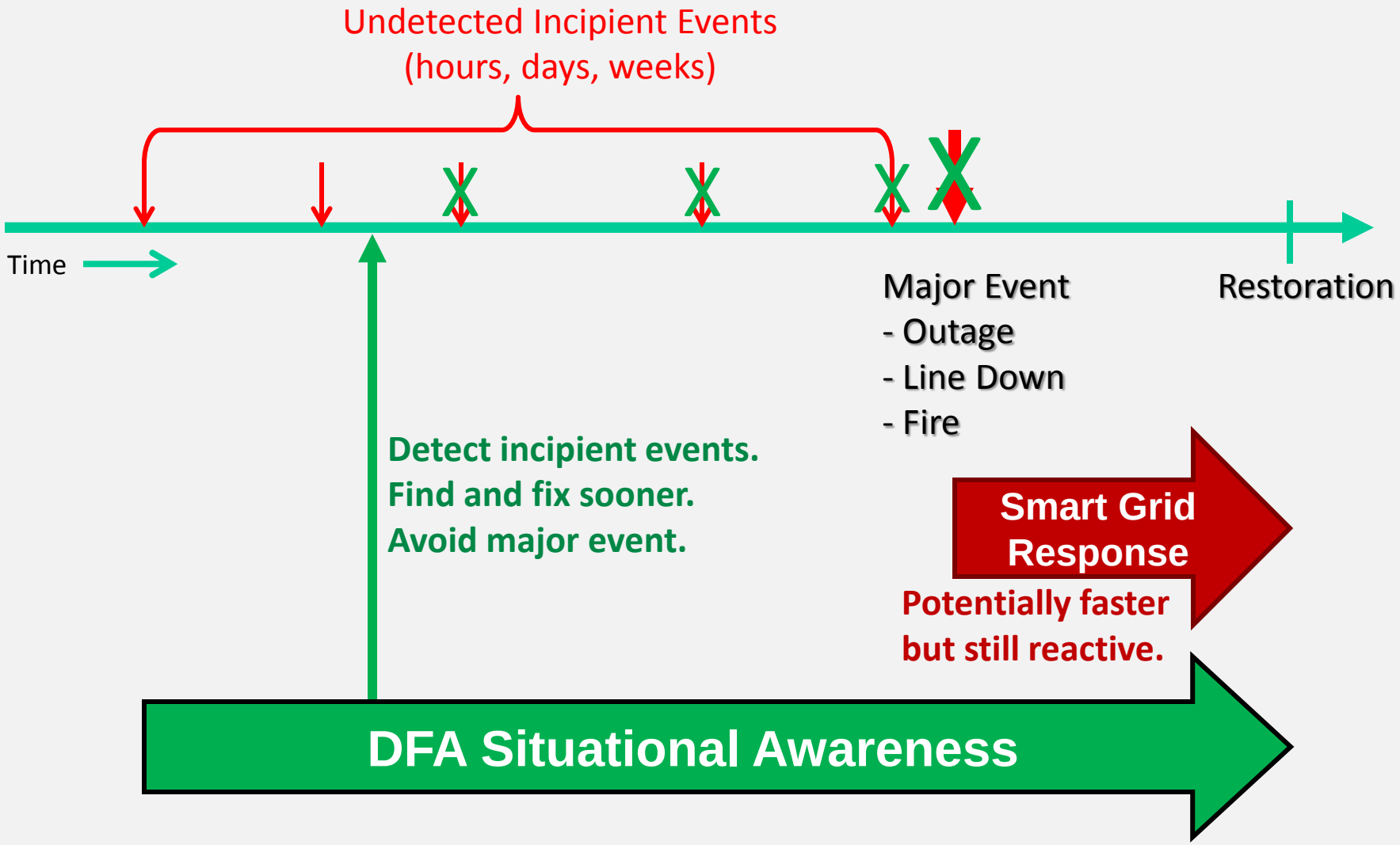
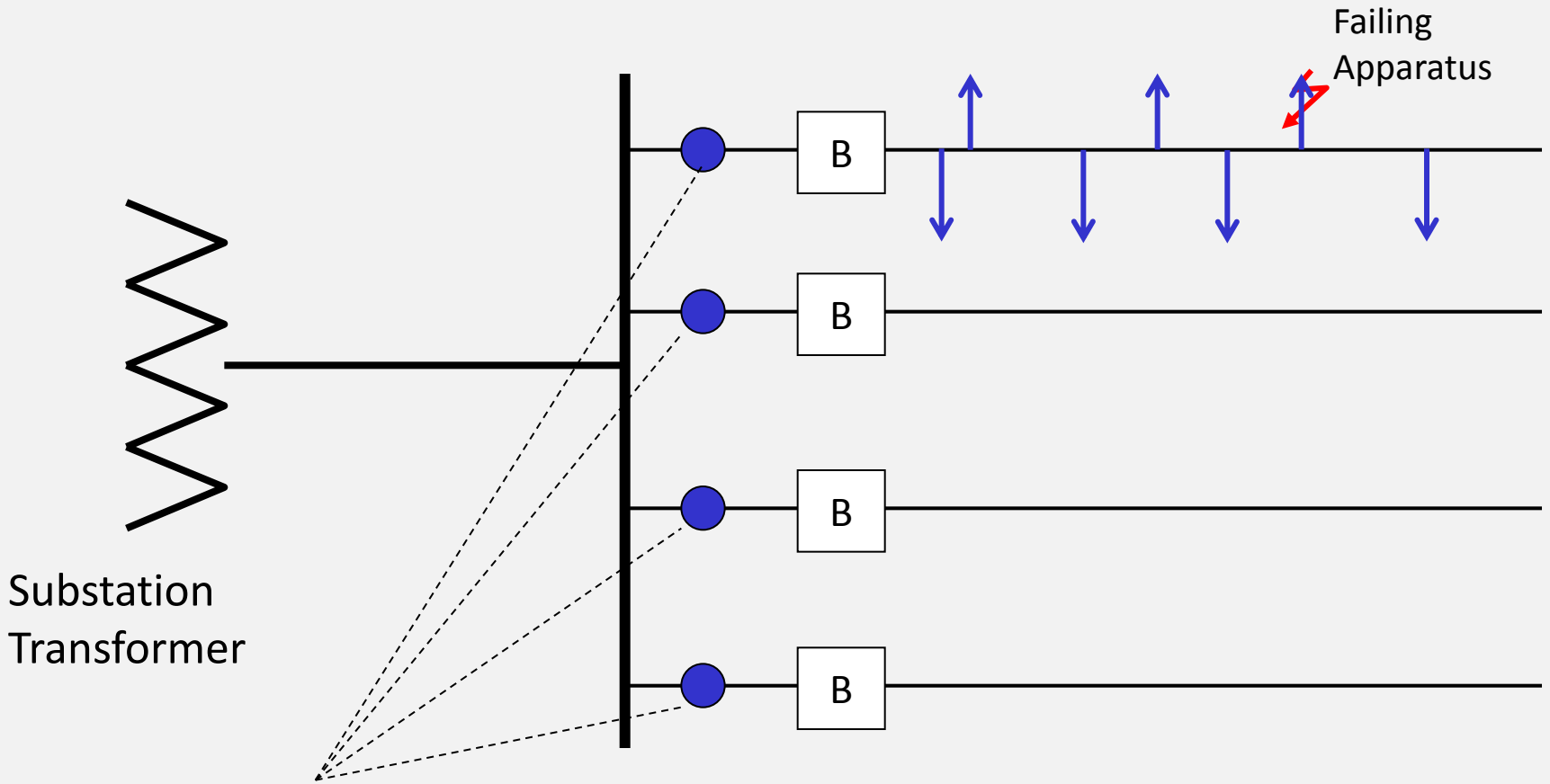
Situational Awareness or "Visibility"
(Conventional vs. Smart Grid vs. DFA)



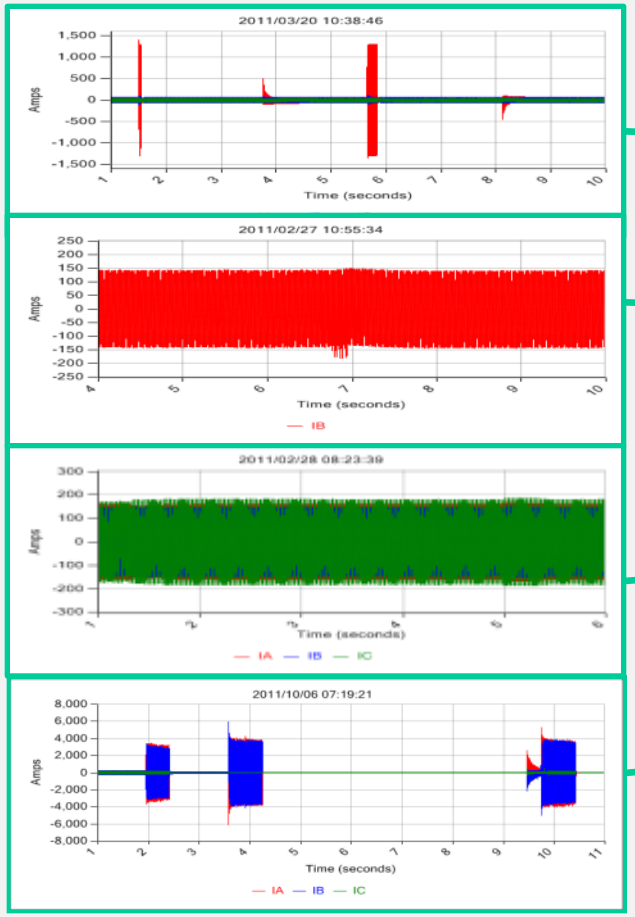
Monitoring Topology



High-fidelity DFA devices, connected to conventional CTs and PTs, one per feeder.

Waveform-Based Analytics – Behind the Scenes

Inputs: Substation CT and PT Waveforms



Waveform Analytics

On-Line Signal Processing and Pattern Recognition Analytics

(Performed by Device in Substation)

Outputs

- Line recloser* tripped 8% of phase-A load twice, but reclosed and did not cause outage
- Failing hot-line clamp on phase B*
- Failed 1200 kVAR line capacitor* (phase B inoperable)
- Breaker lockout caused by fault-induced conductor slap

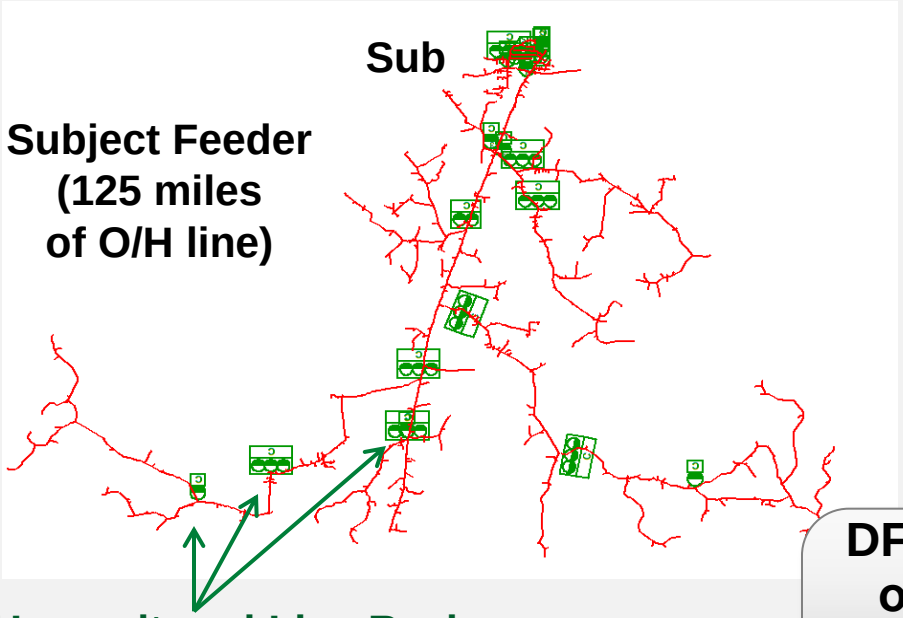
*Analytics applied to high-fidelity substation waveforms report on hydraulic line reclosers, switched line capacitors, apparatus failures, etc, without requiring communications to line devices.

Unreported Intermittent Faults

Possible recurrent fault	C	Single-Phase reclose, 510 Amps	2 (18 days)	09/28/11 13:45:22

Change page: 1 Change page: 1 Go Page size: 2 Change Displaying page 1 of 1, items 1 to 2 of 2.

Event Type	Phases	Comments	Occurred
Single-Phase reclose	C	F-(3.0c,510A,CG)-T-(0,0,19)%-2.1s-C	09/28/11 13:45:22
Single-Phase reclose	C	F-(3.0c,510A,CG)-T-(0,0,21)%-2.0s-C	09/10/11 14:19:25



- Distribution feeder; conventional overhead construction; 125 miles; numerous reclosers
- Normal operating conditions; no active customer complaints; fair weather.
- 9/28/2011: On-line DFA waveform analytics detected that the "same" fault had occurred twice in the past 18 days. The system responded by generating the line-item report shown above.
- Drilling down into the report provided details of the two fault events.

DFA waveform analytics often provide the only notice of these recurrent "blinks." The analytics also provide location information – even for faults that have not caused outages yet.

Unreported Intermittent Faults (cont'd)

Possible recurrent fault	C	Single-Phase reclose, 510 Amps	2 (18 days)	09/28/11 13:45:22

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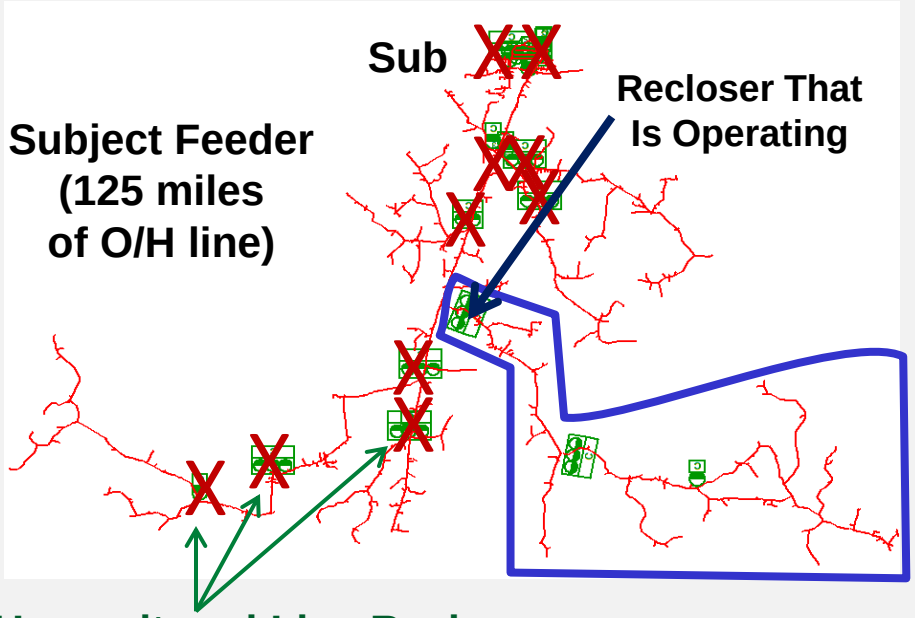

To Locate Fault: First identify which recloser is operating, by comparing analytics outputs to model.

- Faults were on phase C.
  - Eliminate segments w/o phase-C.
- Operations were single-phase.
  - Eliminate three-phase reclosers.
- First-shot open intervals: 2.0s and 2.1s
  - Eliminate reclosers with first-shot open intervals other than 2 seconds.
- Momentary load loss: 21% and 19%
  - Eliminate reclosers carrying much different load.
- This process identifies which recloser is operating, replacing the time-consuming practice of checking counters. In this particular case, this reduced the search area by 76%.

Unreported Intermittent Faults (cont'd)

Possible recurrent fault	C	Single-Phase reclose, 510 Amps	2 (18 days)	09/28/11 13:45:22

Change page: 1 | Change page: 1 Go | Page size: 2 Change | Displaying page 1 of 1, items 1 to 2 of 2.

Event Type	Phases	Comments	Occurred
Single-Phase reclose	C	F-(3.0[illegible],510A,CG)-T-(0,[illegible],19)%-2.1s-C	09/28/11 13:45:22
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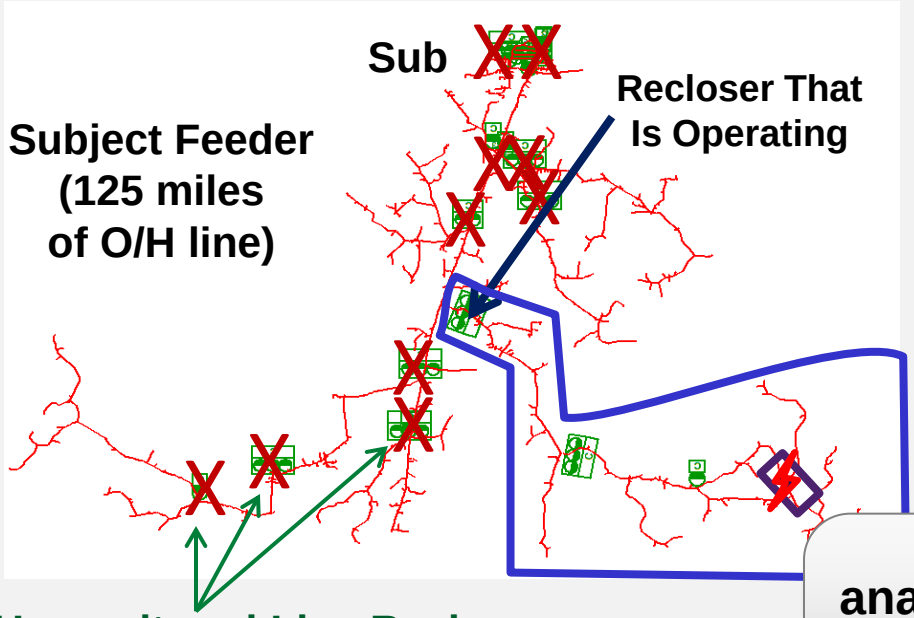
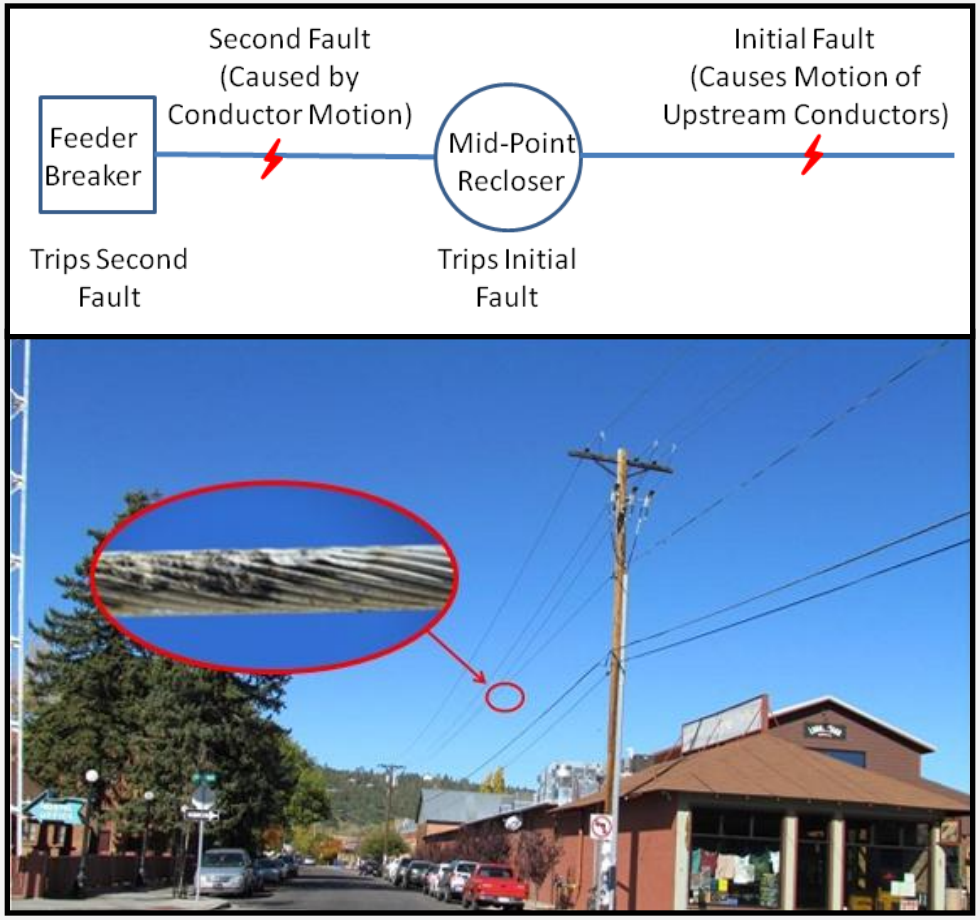


- After identifying which recloser is operating, compare analytics-generated fault currents (510A) to the feeder model. (Measured fault currents commonly match within ~1% from episode to episode.)
- Looking only downstream of the previously identified recloser, fault-magnitude analysis targeted a small search area (purple rectangle).
- Crew found failing arrester within 4 spans. Future 53-customer outage was averted.

This is not an isolated case. On-line analytics have been used multiple times to 1) detect and 2) locate incipient failures. Remember that these are failures that have not caused outages.

Feeder Lockout (4,000 Customers)

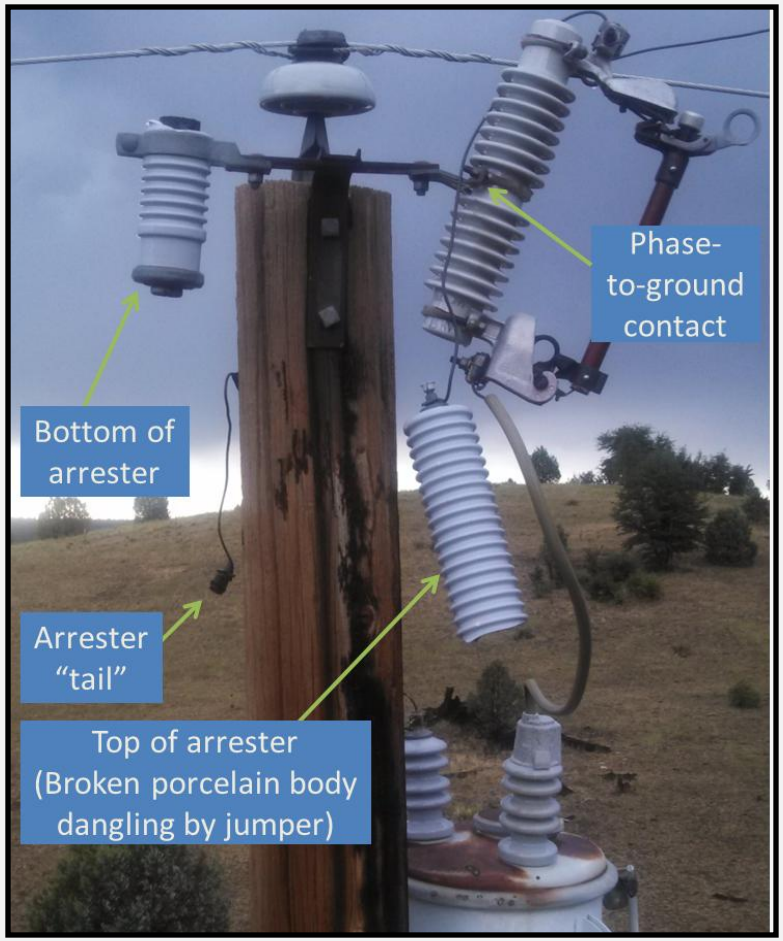
- Fault-induced conductor slap (FICS) locked out 4,000-customer feeder.
- FICS is a complex phenomenon. Investigations are manpower-intensive and often conclude with “no cause found.”
- Within minutes of the subject lockout, the DFA system reported the cause and the location parameters.
- FICS recurs in susceptible spans. Knowing that FICS occurred and finding the offending span enables remediation, so as to avoid future feeder outages.



Benefits: Reduced manpower and improved reliability.

Failed Line Apparatus

- Blown arrester caused outage in hard-to-patrol area.
- DFA data provided fault current and suggested blown arrester.
- Feeder has many miles past the tripped device. Knowing the fault current reduces search time substantially.
- Crew typically must look for broken apparatus, tree contacts, downed lines, …. Knowing cause, from waveform analytics, speeds search.



<u>Benefits</u>: Reduced manpower; fewer close-to-test attempts; and quicker restoration.

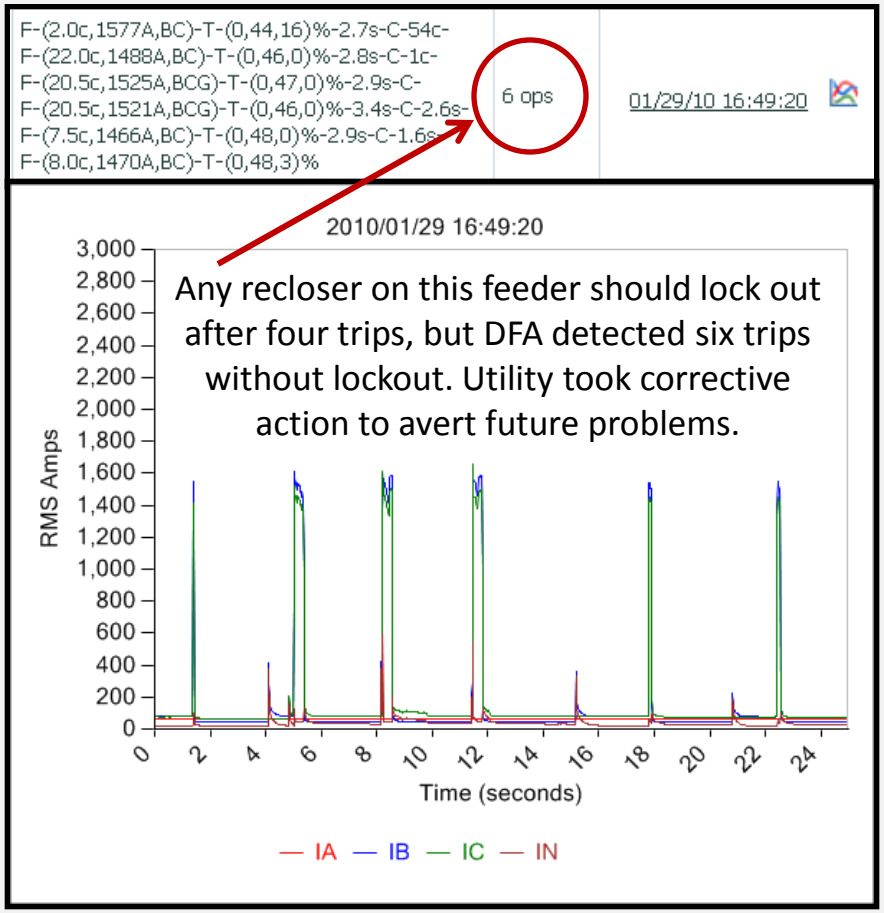
Repeated Vegetation-Caused Feeder Trips

- Momentary breaker operations occurred during two storms, three weeks apart.
- DFA provided notice that both incidents were the same fault.
- DFA also provided information to locate branches pushing phases.
- Trimming prevented future consequences, including momentary operations, feeder lockouts, line damage, and potential burn-down.

<u>Benefits</u>: Improved reliability; reduced damage; scheduled, fair-weather repairs; and improved personnel and public safety.

Management of Unmonitored Line Reclosers

- Intelligent, communicating reclosers are available, but a large population of unmonitored reclosers remains in service for the foreseeable future.
- DFA reports recloser operations, in detail, based on substation waveforms.
- DFA has revealed multiple cases of reclosers operating incorrectly.
  - Excess operations before lockout.
  - Failure to complete sequence.
- DFA provides visibility of recloser operations, particularly for utilities that test reclosers irregularly.



<u>Benefits</u>: Notice of latent problems; improved protection; improved operations; and improved safety.

Summary

- DFA technology applies sophisticated waveform analytics to high-fidelity CT and PT waveforms, to provide heightened visibility, or awareness, of feeder conditions. This enables improved reliability, operational efficiency, and safety.
- The DFA system automates the analytics process, so as to deliver actionable intelligence, not just data.
- DFA is a data-driven technology that embodies multiple functions.
- DFA provides benefits not available from “smart grid” technologies, and can function with a substation-only presence, without requiring distributed sensing, intelligence, or communications.
- Utility partners have used DFA to demonstrate the avoidance of outages and improvements in operational efficiency.