Improved Industrial Plant Reliability and Safety Enabled by Real-Time Distribution Circuit Diagnostics

Presented to the 70th Annual
Conference for Protective Relay Engineers
Texas A&M University, College Station, Texas
06 April 2017

Carl L. Benner, P.E.
Research Assoc. Professor
Texas A&M Engineering
carl.benner@tamu.edu
979-676-0499

Presentation Overview

- Technology background
- Examples from utility systems
  - Medium voltage
  - Low voltage
- Application to industrial environments

Background

- Power System Automation Laboratory
  - Department of Electrical and Computer Engineering, Texas A&M University
- Distribution Fault Anticipation (DFA) technology R&D
  - Initial research sponsored by EPRI, starting in 1997
  - More than $10M invested by EPRI, the state of Texas, and utilities
  - Heavy involvement by more than a dozen utility companies
    - Instrumented 70 circuits with specialized, Internet-based data recorders
    - Collected more than 1000 circuit-years of data and correlated results with field findings
    - <u>Result</u>: Largest existing database of electrical data from naturally occurring failure and misoperations events
  - Development of sophisticated suite of algorithms (a/k/a on-line waveform classification engine) for automatically identifying events

Conductor-to-conductor contact results in concentrated, high-temperature arcing that melts conductors. Such contact has broken multiple strands in this conductor.

Example: Fault Induced Conductor Slap (FICS)

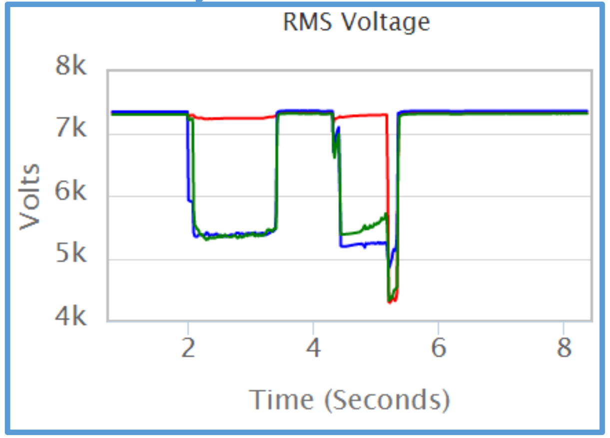
- Utility rarely knows it is happening.
- It is seldom diagnosed or fixed.

Why Does It Matter?

- Dissatisfied customers.
- Repeated power quality problems.
- Repeated outages.
- Progressive damage, leading to more severe problems, including downed conductors.
- With DFA: Fully diagnosable and fixable.

Dissatisfied Customers

PQ Problems



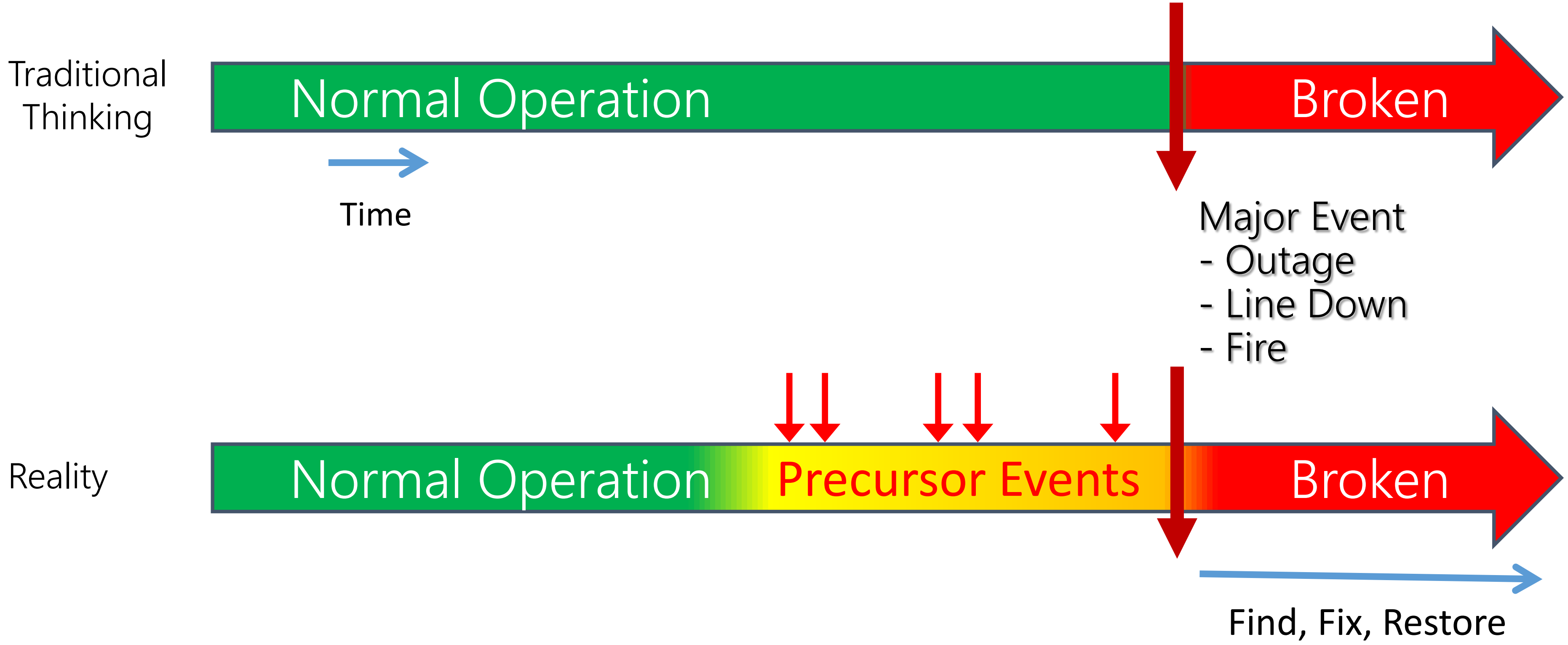
Outages

Downed Conductors

Common Goals of Utilities and Industrial Facilities

- Utility companies seek to provide reliable but affordable service.
- Industrial facilities often have even greater requirement for power quality and reliability.
  - Unplanned events can cause substantial losses.
  - Unplanned events can present safety hazards.
- Both need better tools to provide visibility regarding circuit events and conditions and thereby to operate better.

Distribution Circuit Operating Paradigms



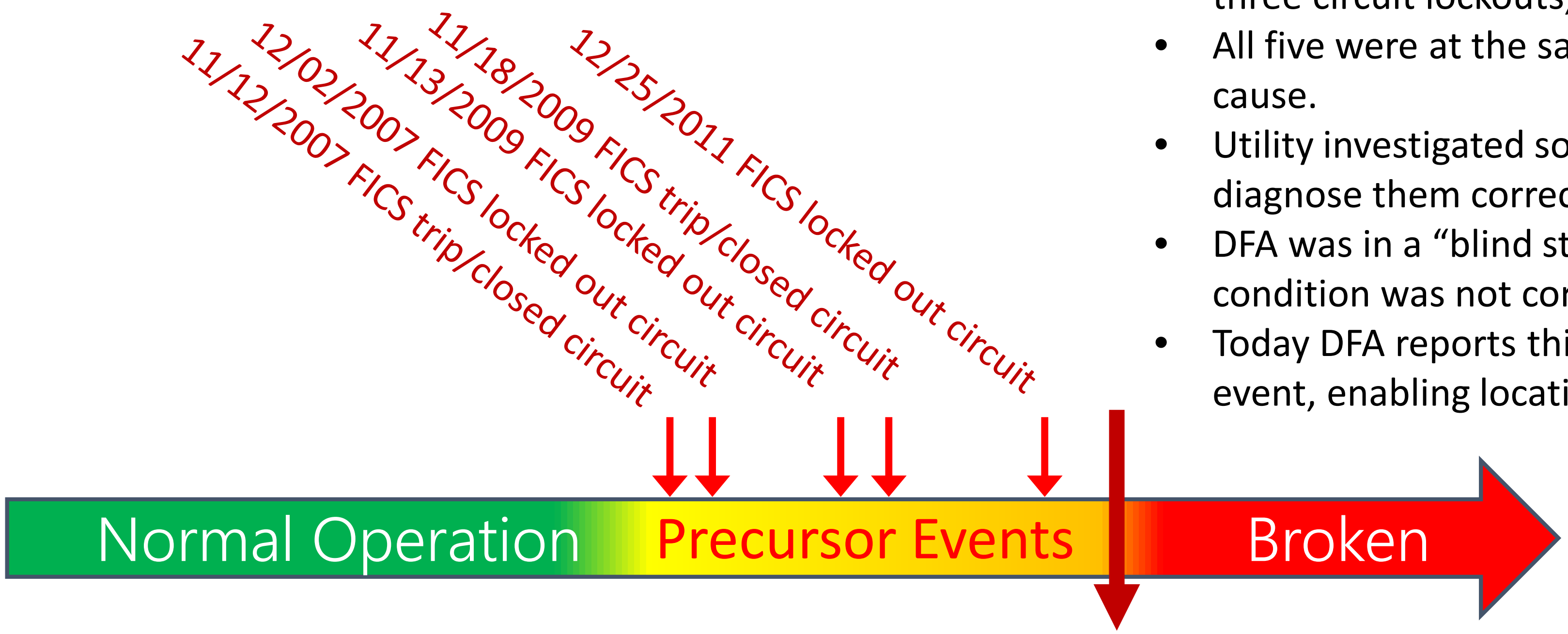
Conventional response starts after outage or other consequential event.

Smart grid response still starts after outage or other consequential event.

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

Distribution Circuit Operating Paradigms

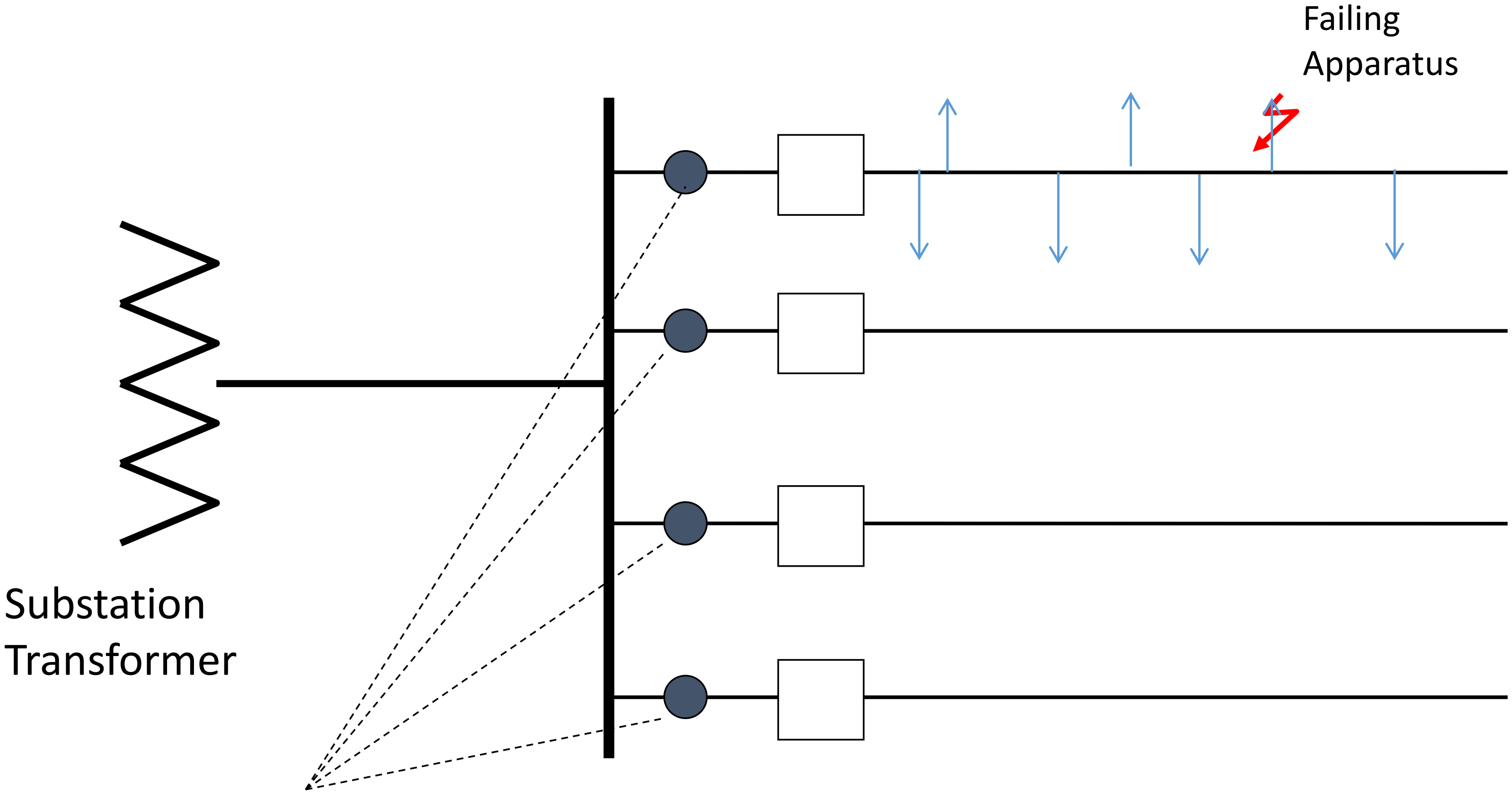
Actual Example



- Five FICS events caused two trip/close operations and three circuit lockouts, over a period of four years.
- All five were at the same location and had the same cause.
- Utility investigated some of the events but did not diagnose them correctly with conventional approaches.
- DFA was in a “blind study” mode during first events, so condition was not corrected.
- Today DFA reports this specific condition, after first event, enabling location and repair.

Repetitive FICS at the same location causes cumulative damage and eventually breaks conductors, causing safety hazards, in addition to power quality and reliability problems.

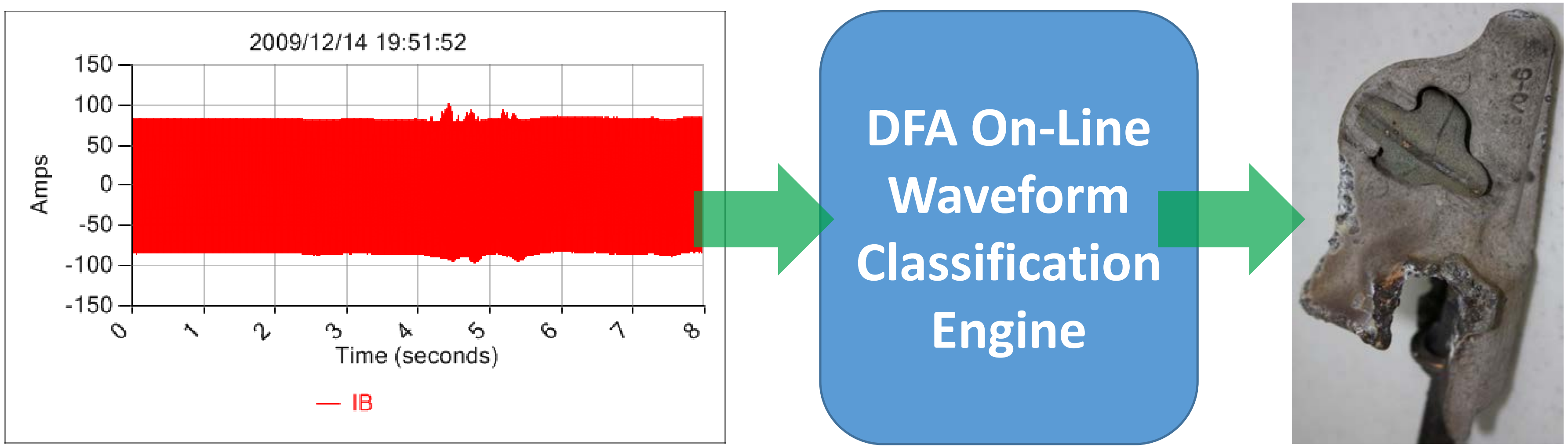
DFA Monitoring Topology



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.

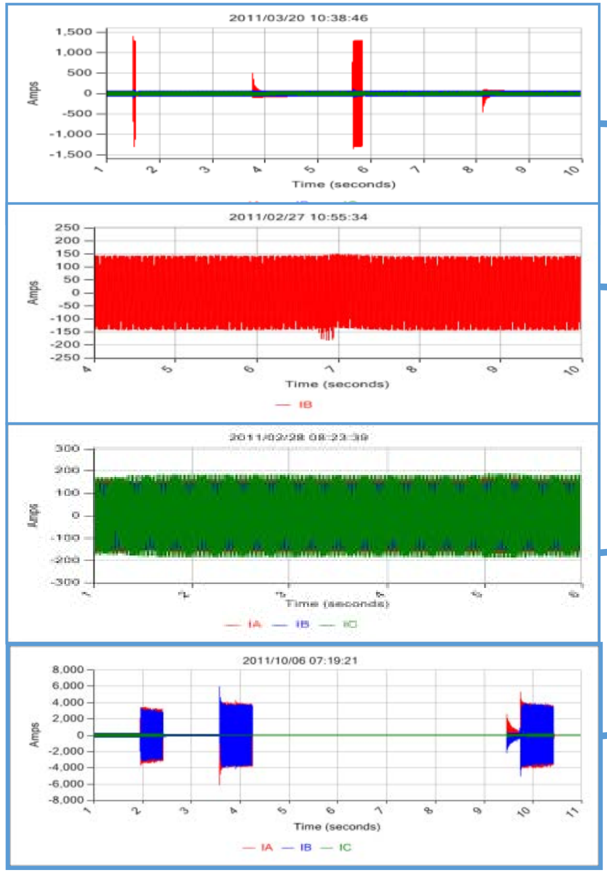
DFA Principle: Waveforms Contain Useful Information

- Graph shows line current during "normal" operations.
- DFA reports this specifically as a failing clamp (which can persist for <u>weeks</u>, degrade service quality, and even burn down a line).
- Conventional technologies do not detect such conditions until customers experience outages, flicker, or other trouble.



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)

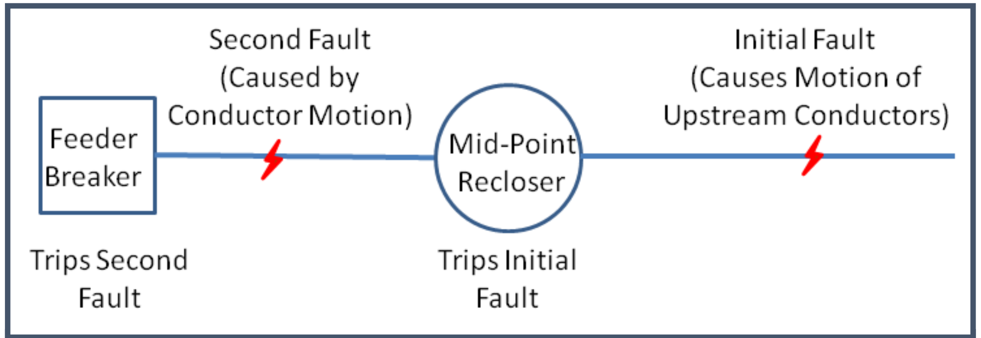
<u>DFA Device software technologies</u>

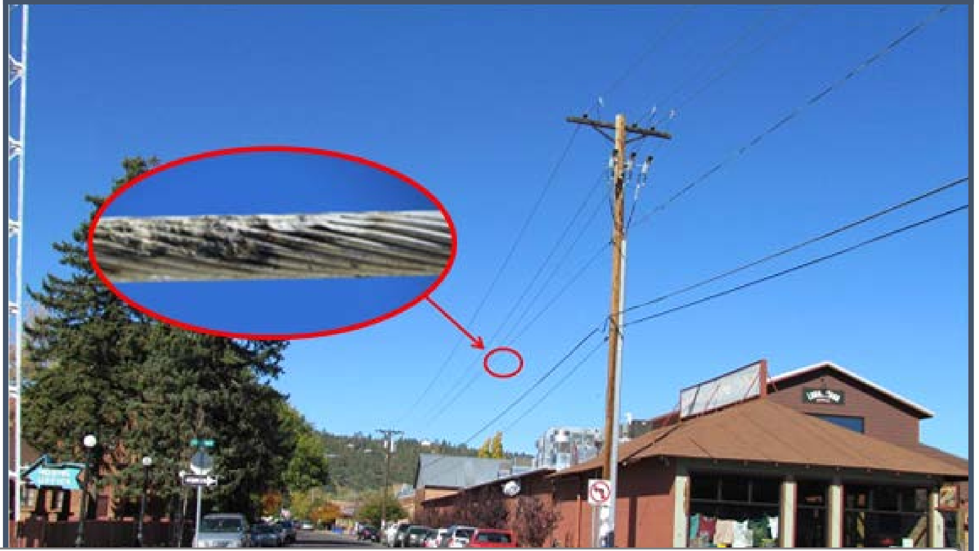
- Multi-rate polyphase filter banks for phase drift compensation
- Fuzzy expert system for classification
- Fuzzy dynamic time warping for shape recognition
- Hierarchical agglomerative clustering for recurrent faults
- Finite state machine for fault SOE identification
- Shape-based and event-specific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

Circuit Lockout (4,000 Customers)

- Fault-induced conductor slap (FICS) locked out 4,000-customer circuit.
- 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 FICS as the cause and provided location parameters.
- FICS <u>recurs</u> in susceptible spans. Knowing that FICS has occurred avoids future circuit trips, system stresses, and outages.





Improved reliability; improved safety; reduced manpower; reduced system damage.

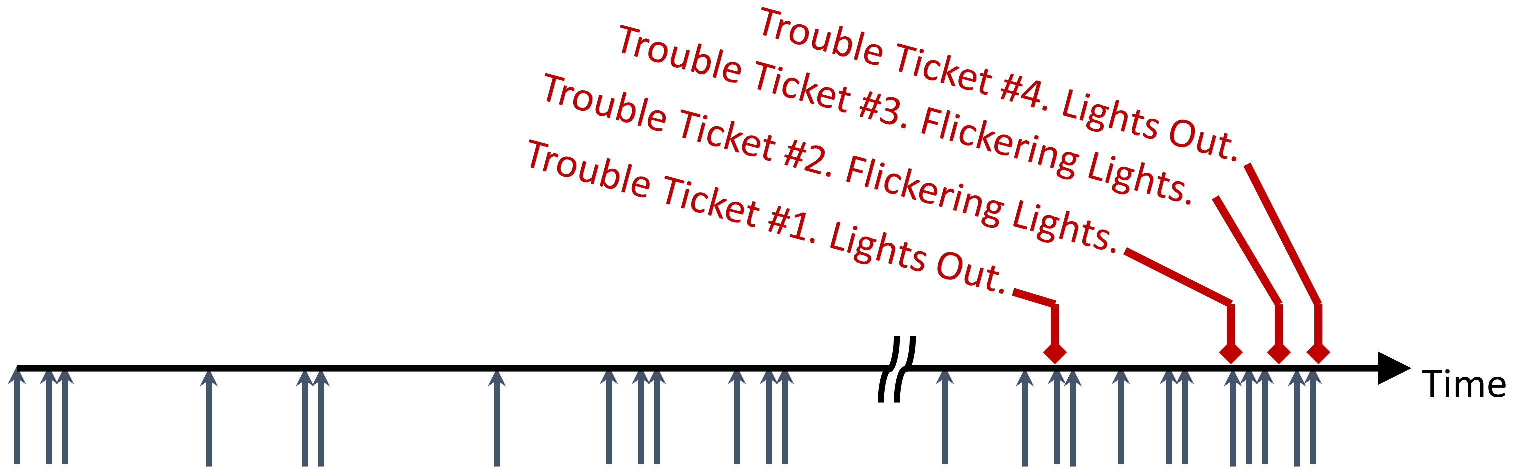
Repeated Vegetation-Caused Circuit Trips

- Momentary substation breaker operations occurred during storms three weeks apart.
- DFA provided utility's only notice that the two incidents were the same fault. (This is the key.)
- DFA also provided information to locate branches pushing phases together.
- Note progressive conductor damage (broken strands) in photo.
- Targeted trimming prevented additional momentary operations, circuit lockouts, line damage, and potential burn-down.

Improved reliability; reduced system damage; fair-weather repairs; improved safety.

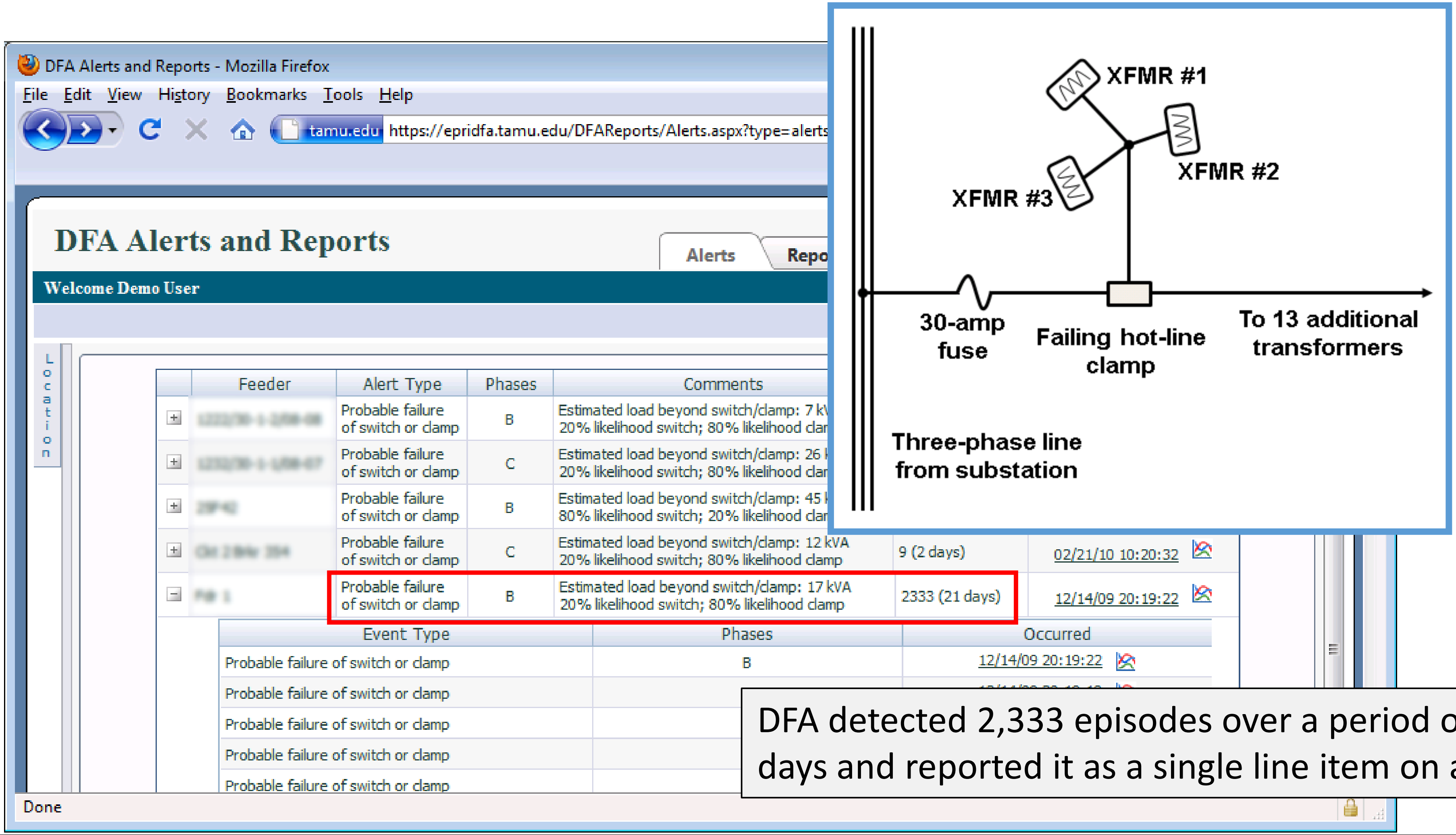
Operational Inefficiency Using Conventional Practices

- DFA detected incipient failure of a single clamp repeatedly for three weeks.
- At the end of the three-week period, a group of customers experienced trouble four times over a period of 40 hours, necessitating four crew trips.
- DFA was operating in “blind study” mode. Utility crews responded using conventional processes and had difficulty identifying the root cause.
- **Result**: A single failing clamp “cost” four trouble tickets, four truck rolls, and two transformer replacements, all on overtime and mostly unnecessary.



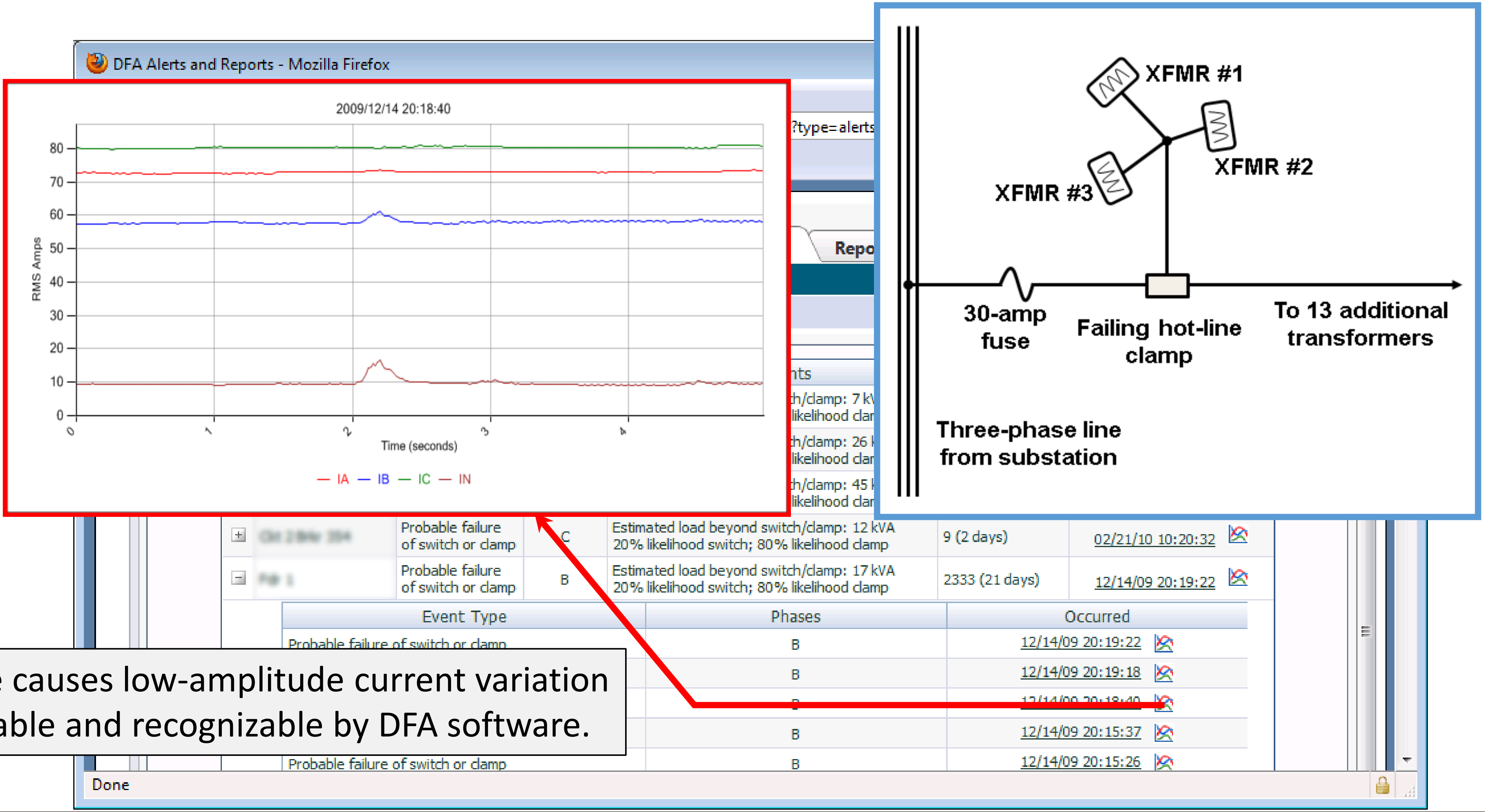
Failing-Clamp Detections by DFA (2,333 Episodes over 21-Day Period)

Operational Improvement Using DFA



DFA detected 2,333 episodes over a period of 21 days and reported it as a single line item on a report.

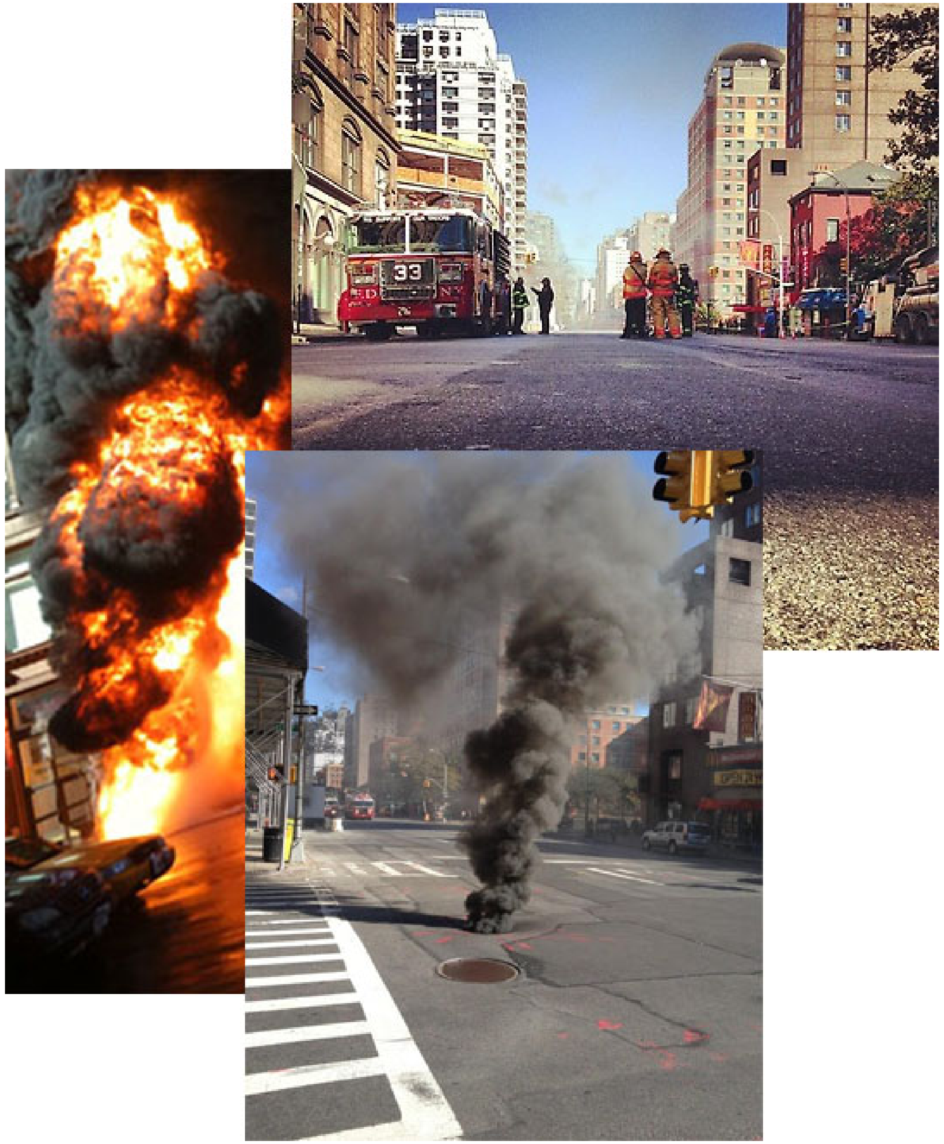
Operational Improvement Using DFA



Clamp failure causes low-amplitude current variation but is detectable and recognizable by DFA software.

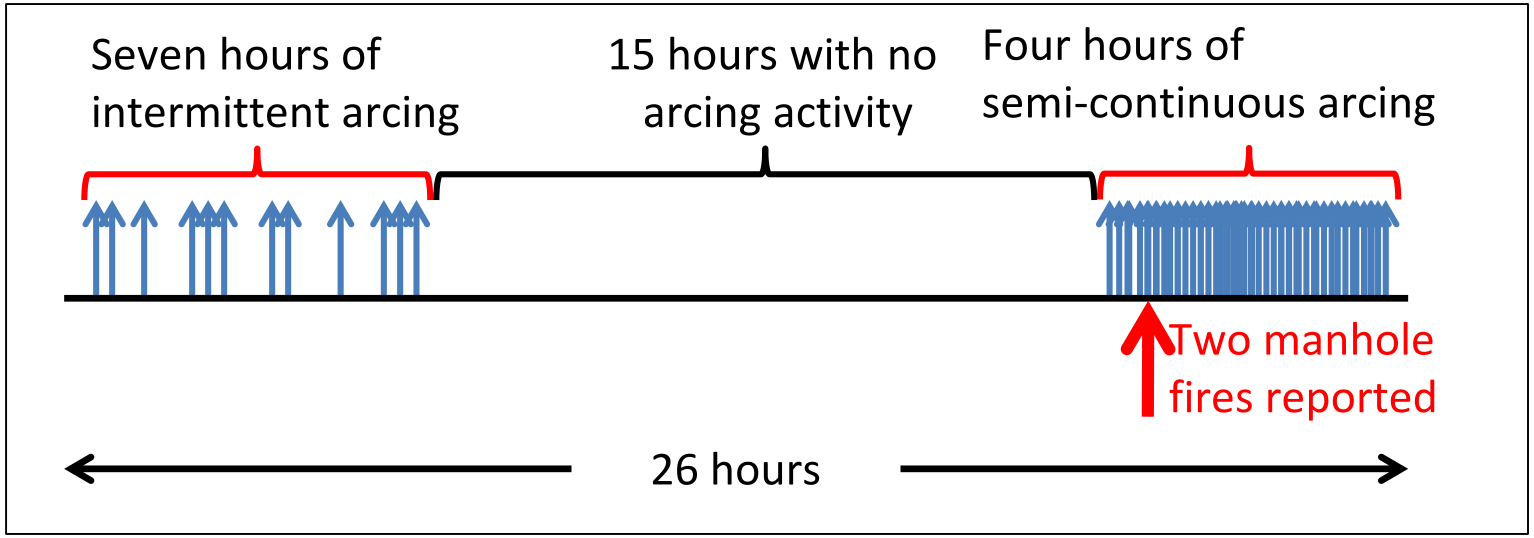
Low-Voltage Network Arcing

- Arcing on low-voltage networks has been a known problem for decades.
- Arc heat degrades cable insulation, producing explosive gasses that can cause smoke, fires, and explosions.
- In addition, carbon monoxide and other noxious gasses can enter buildings and force evacuations.
- Secondary arcing faults can damage primary cables, leading to primary-feeder damage and outages.
- Arcing and other single-point failures can persist indefinitely without notice.



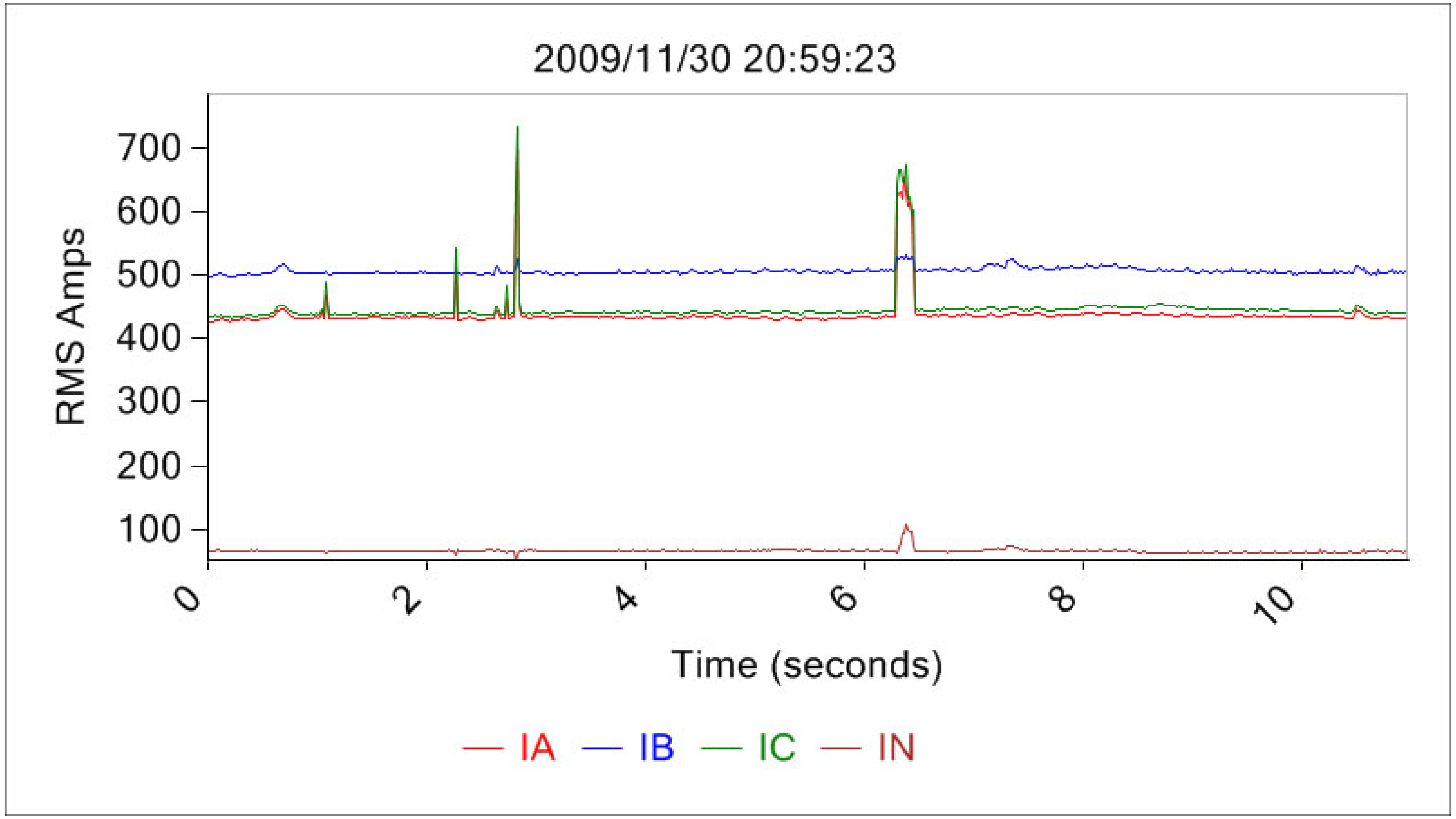
Manhole “Smoker” Caused by Arcing in Low-Voltage Grid Network

Low-Voltage Arcing Fault Example – Timeline



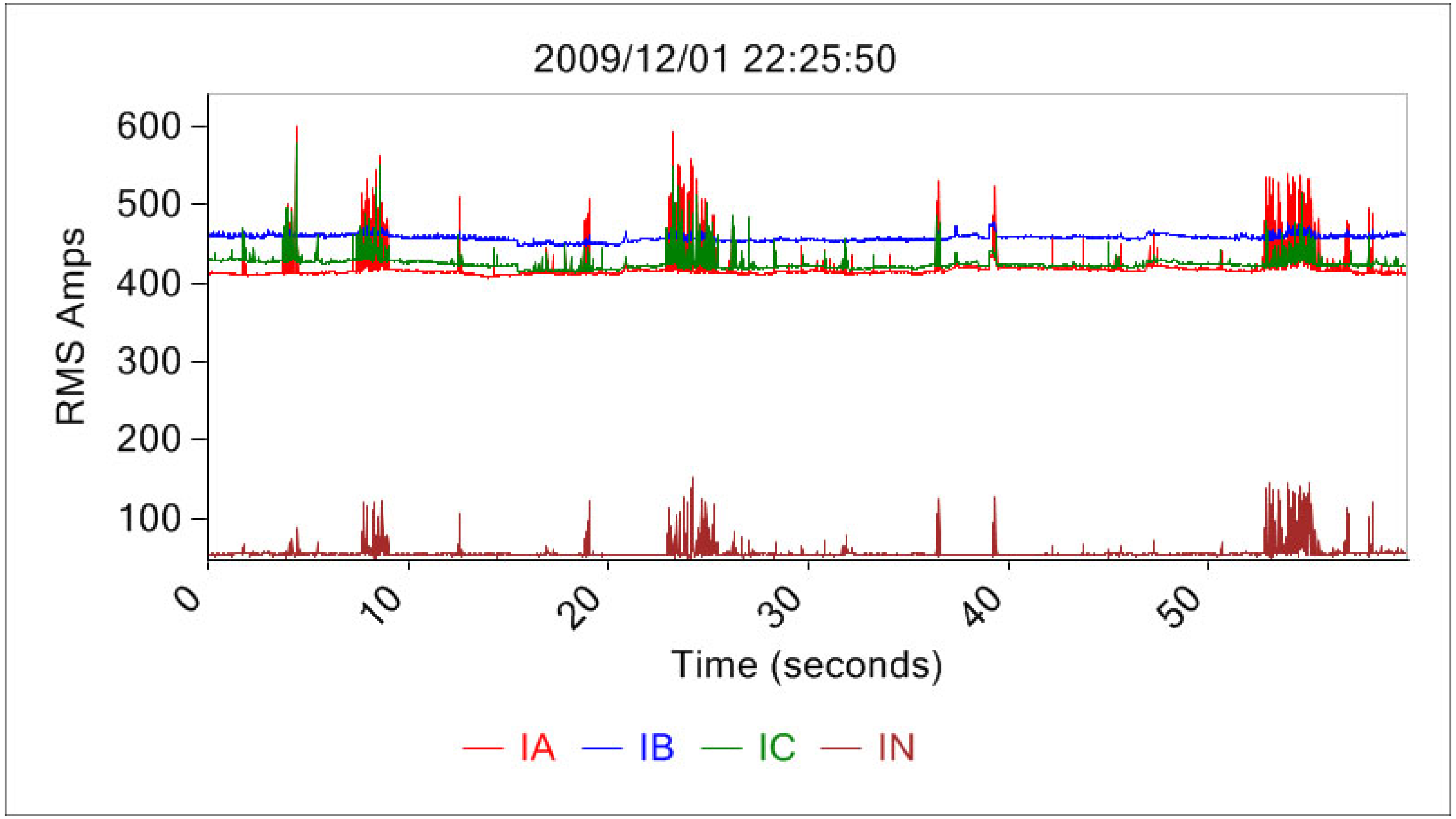
- Research instrumentation recorded substantial arcing for seven hours, followed by fifteen hours of quiescence.
- Substantial arcing resumed fifteen hours later, and FDNY reported two manhole fires shortly thereafter.
- The utility had *no conventional notice* (no visibility) of the problem prior to the FDNY report.

Low-Voltage Arcing Fault Example – First Day



Eleven seconds of RMS currents at a network node, first evening

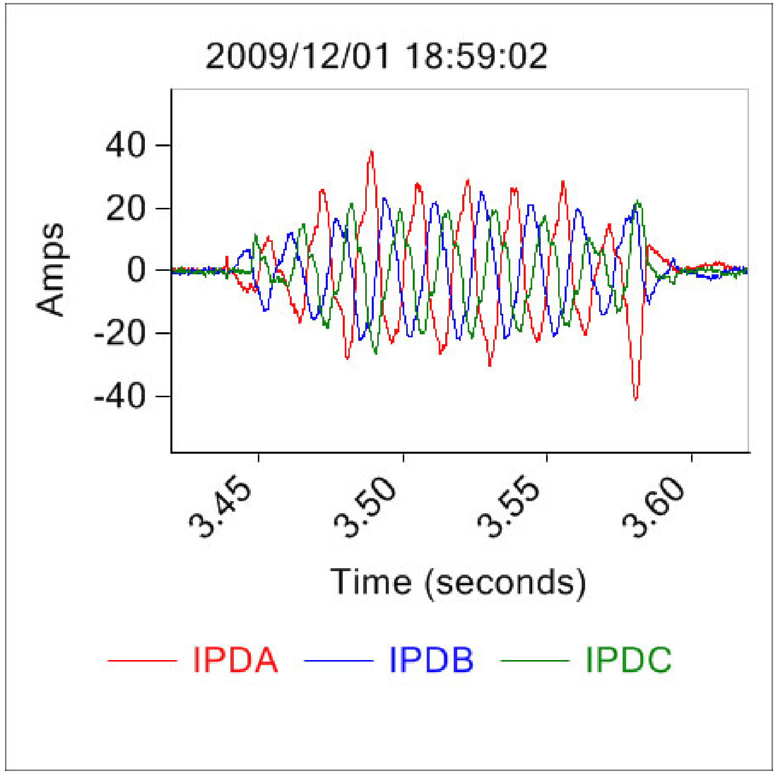
Low-Voltage Arcing Fault Example – Second Day



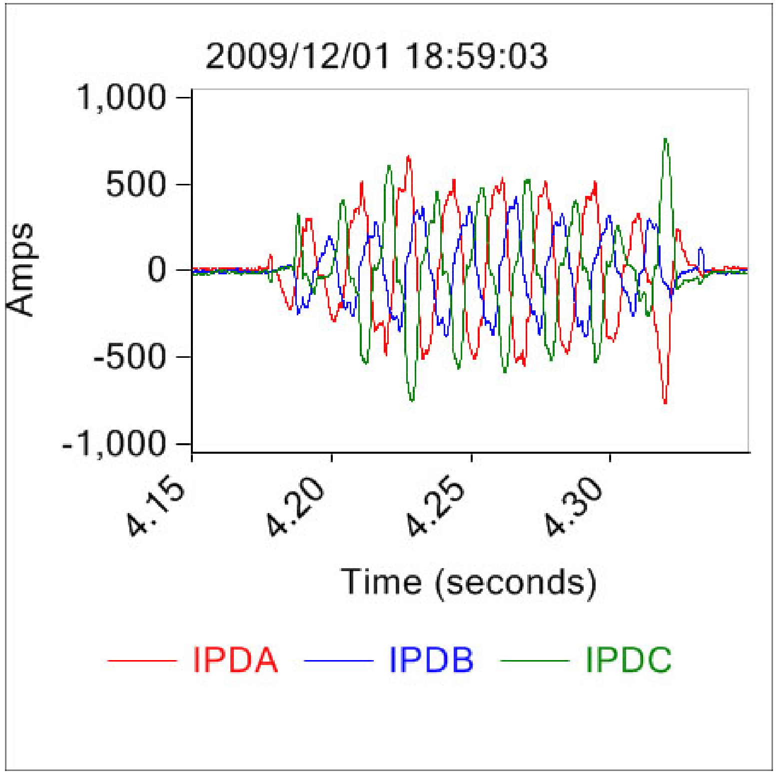
Sixty seconds of RMS current at a network node, showing semi-continuous arcing on second evening

Low-Voltage Arcing Fault Example – Primary and Secondary Measurements of Same Fault

Primary feeder measurements



Secondary network node measurements



Graphs have been digitally processed to remove steady-state load current, with the resulting waveforms representing only fault current.

Network Arcing Fault Example – Conclusions

- Substantial arcing activity can and does persist for hours without any conventional report of a problem to the utility (i.e., no “visibility”).
- Cessation of arcing activity *does not* indicate that the problem is “fixed” – it is likely to return hours, days, or weeks later.
- Many cases that “end up on the news” have precursors that are detectable well in advance of catastrophic failures – but not with conventional technologies.

What Does This Have to Do with Industrial?

- Field research shows numerous examples where utility companies could operate more efficiently, reliably, and safely, if they had better visibility of circuit events and conditions.
- These observations apply to overhead and underground, and to medium voltage and low voltage.
- DFA demonstrates the principle that electrical waveforms contain valuable information about circuit events and health.
- Industrial systems differ in some ways from utility systems, but the aforementioned principle remains.
- On-line waveform classification engine can be adapted to varied systems.

Improved Industrial Plant Reliability and Safety Enabled by Real-Time Distribution Circuit Diagnostics

Presented to the 70th Annual
Conference for Protective Relay Engineers
Texas A&M University, College Station, Texas
06 April 2017

Carl L. Benner, P.E.
Research Assoc. Professor
Texas A&M Engineering
carl.benner@tamu.edu
979-676-0499