Distribution Fault Anticipation (DFA) Technology

Automatic Circuit Health Diagnostics and Failure Analysis

Presentation by Texas A&M Engineering

Friday, 21 April 2017

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Distribution circuits are receiving increased attention: DERs, energy storage, micro-grids…

How do you know your circuit is healthy?

Is your circuit strong or in a failure mode?

DFA Technology Background

- Power System Automation Laboratory
  - Department of Electrical and Computer Engineering, Texas A&M University
  - Started waveform analytics research in 1978
  - Developed first commercial, HiZ arcing fault detector
- Distribution Fault Anticipation (DFA) technology R&D
  - DFA research sponsored by EPRI, starting in 1997
  - More than $10M invested by EPRI, the state of Texas, and utilities
  - Heavy involvement of 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
    - Result: Largest existing database of electrical data from naturally occurring failure and misoperations events
  - Developed sophisticated suite of algorithms (a/k/a on-line waveform classification engine) for automatically identifying failures and other events

Distribution Reliability

- 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 for customers.
- 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 the next 20-30 years.

Distribution Operations – Current Status

- Distribution circuits consist of thousands of components (transformers, connectors, insulators, switches, …).
- Components run until failure and then are repaired or replaced.
- Most components last for decades. Periodic inspections and other preventative maintenance activities are resource-intensive and rarely cost-effective.
- Distribution topology is complex (as compared to transmission).
- A utility company does not know when a failure is imminent. Personnel lack awareness, or visibility.
- Consequences: Interruptions, outages, explosions, fires, safety hazards, PQ problems, …

What if one device seamlessly provided operators and field personnel integrated circuit information this is partially provided today by systems such as SCADA, IEDs, power quality monitors, capacitor monitors, certain RTUs, monitored ACRs, etc.?

What if operators had “on demand” access to circuit history and data for all switching and protective device operations, abnormal transients and momentary events?

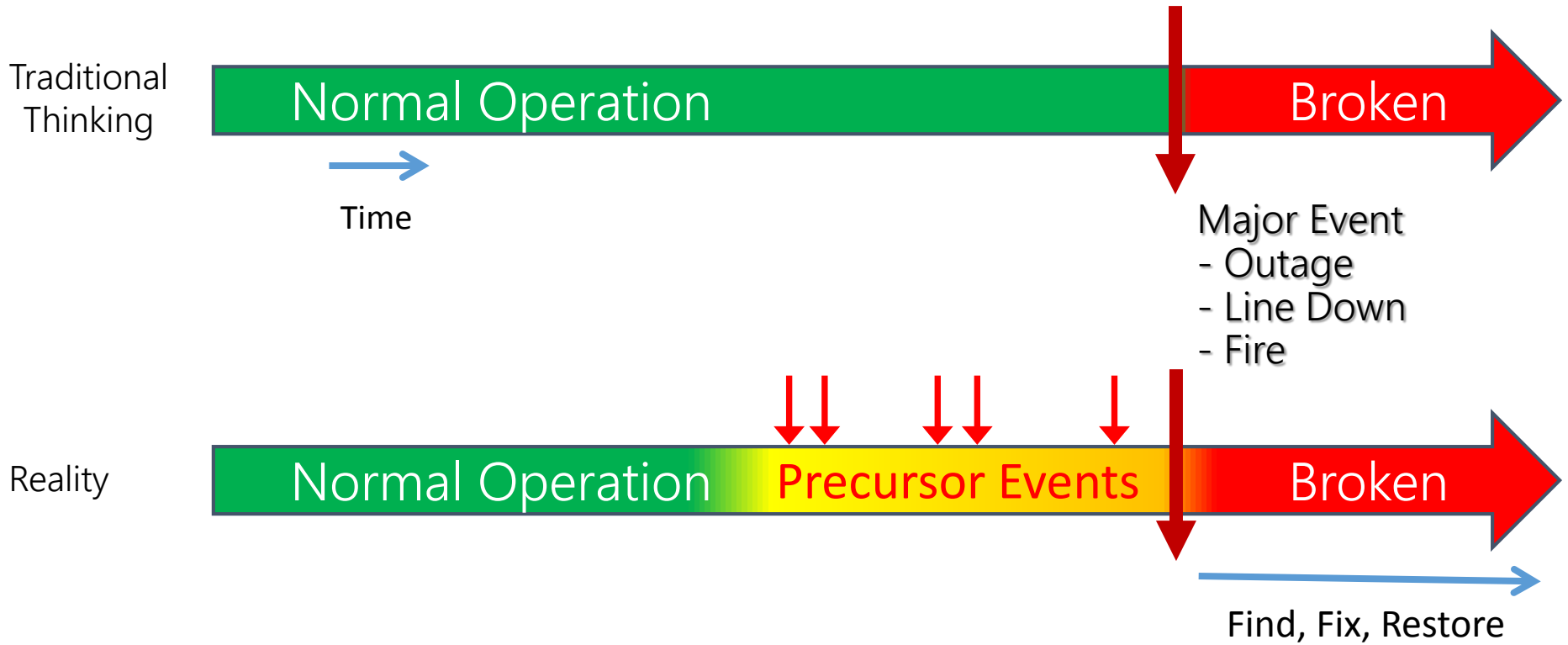
Scenario:
An industrial facility operator calls and says, “We have experienced process interruptions twice today.”
(No utility protective devices have operated.)

What does the utility operator do?

With DFA, you can:

- Open the DFA archived circuit history.
- Study full event history and sequence, waveforms and diagnostics for low and higher current circuit events and operations.
- Do this while on the phone with the customer.

Distribution Circuit Operating Paradigms



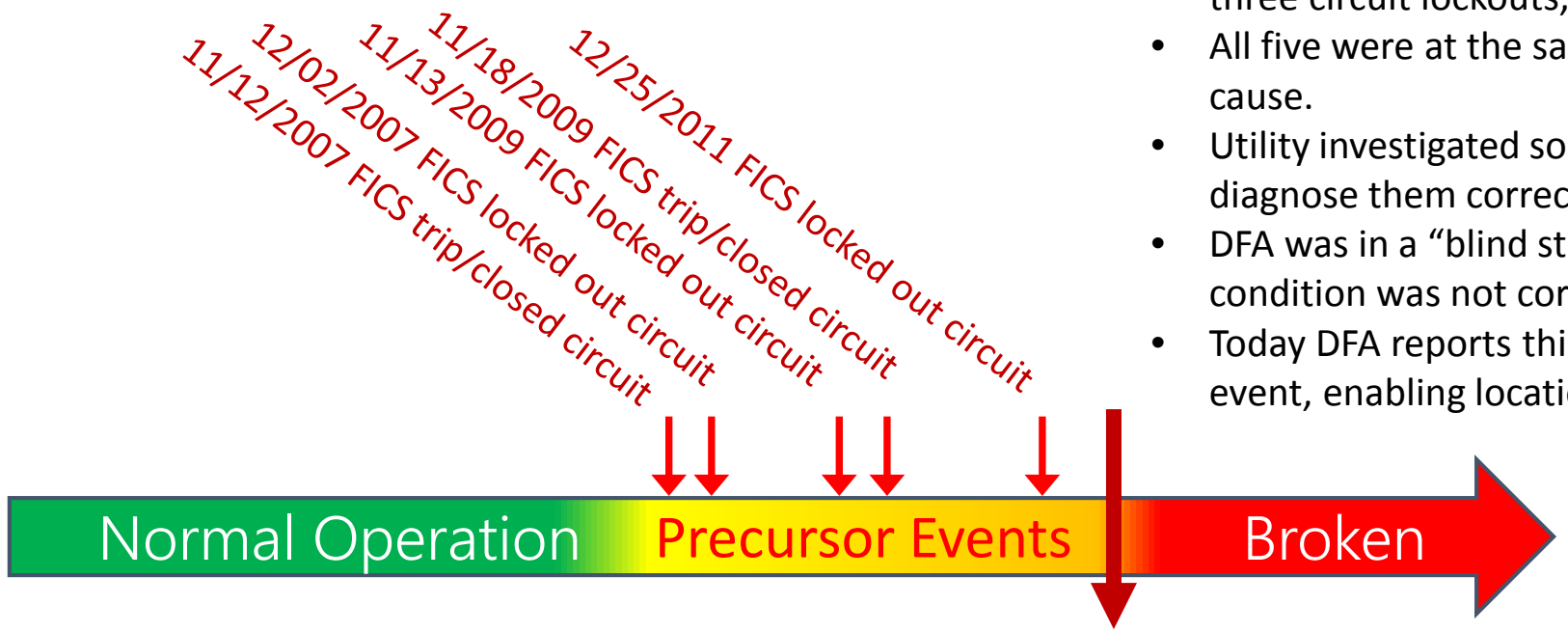
Conventional response starts after outage or other consequential event.

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



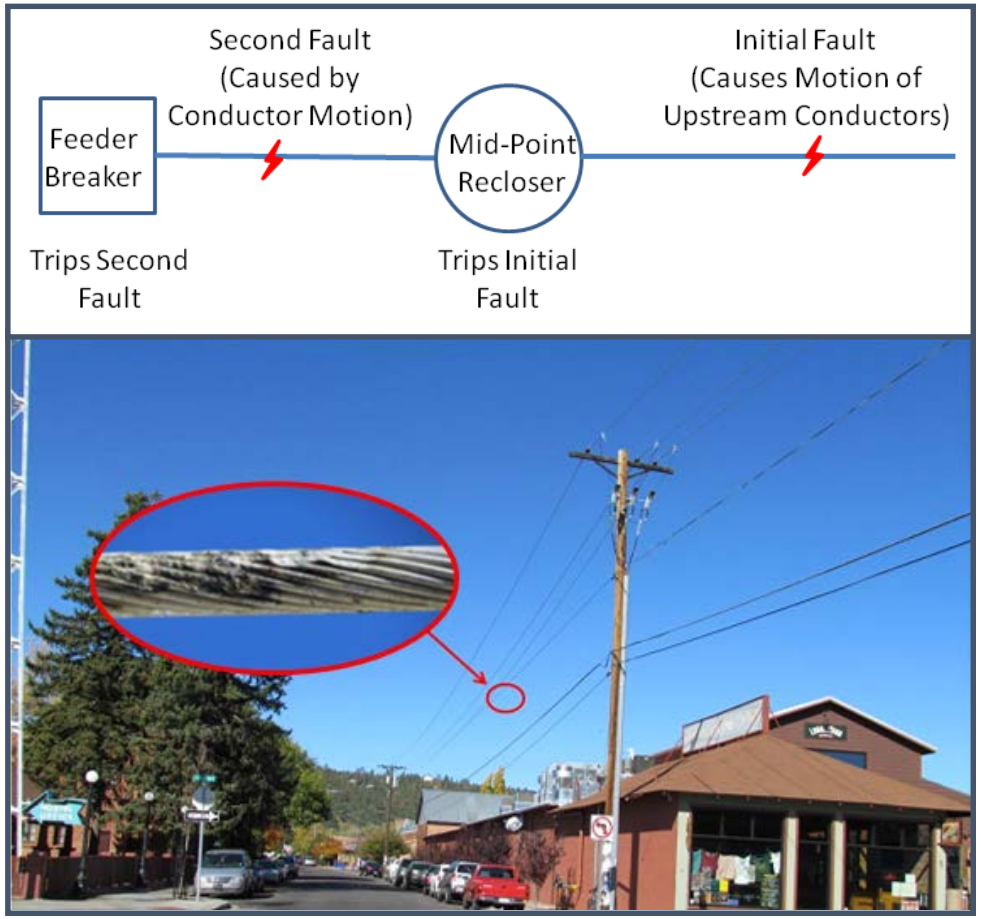
- Five FICS events caused two trip/close operations and three circuit lockouts, over a period of four years.
- All five were at the same location and had the same cause.
- Utility investigated some of the events but did not diagnose them correctly with conventional approaches.
- DFA was in a “blind study” 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.

Use Case Summary

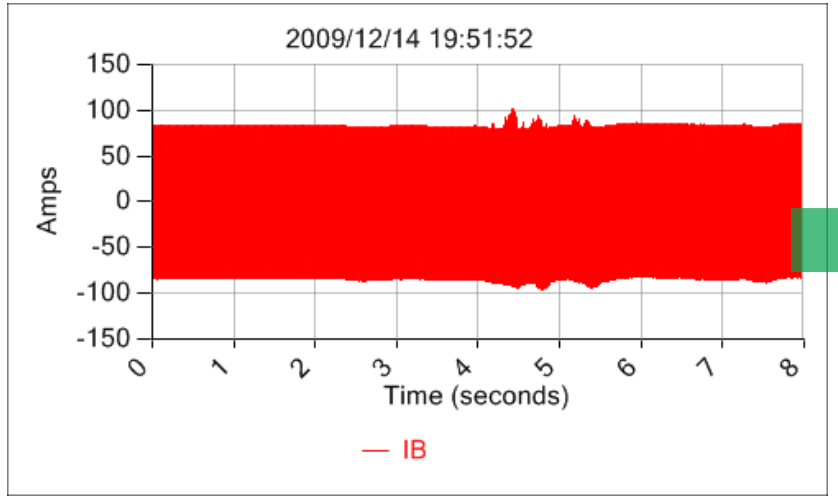
Circuit Lockout (4,000 Customers)

- Fault-induced conductor slap (FICS) locked out a 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 recurs in susceptible spans. Knowing that FICS has occurred avoids future circuit trips, system stresses, and outages.



DFA Principle: Waveforms Contain Useful Information

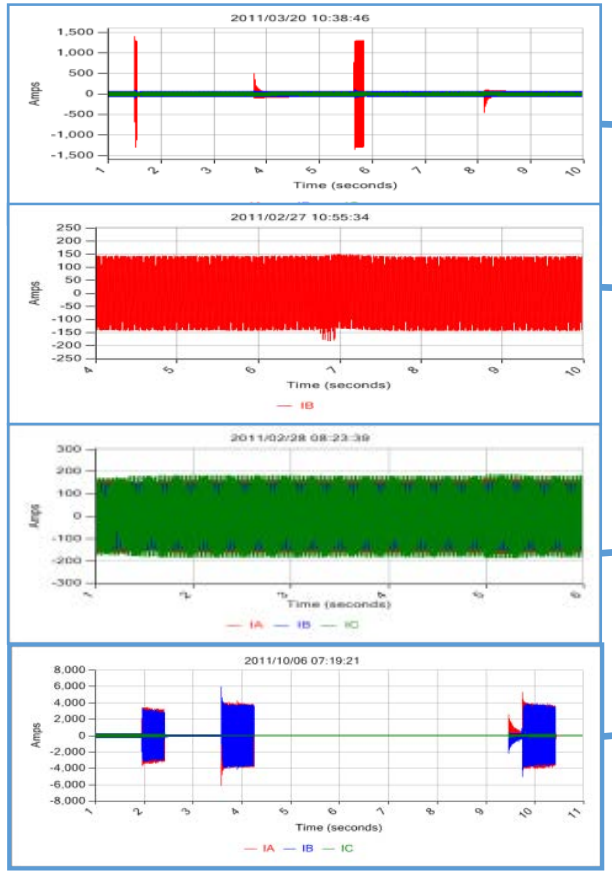
- Graph shows line current during “normal” operations.
- DFA reports this specifically as a failing clamp (which can persist for weeks, degrade service quality, and even burn down a line).
- Conventional technologies do not detect such conditions.



DFA On-Line Waveform Classification Engine

Waveform-Based Analytics – 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

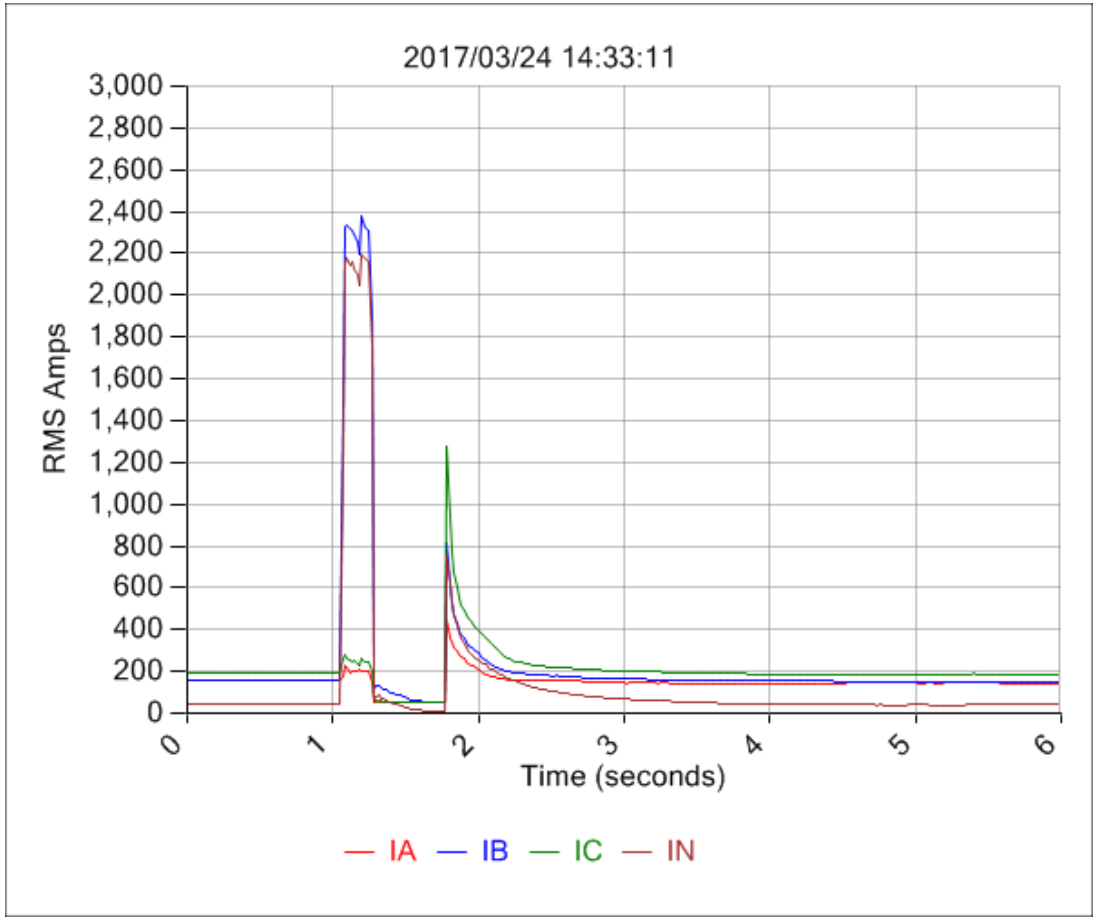
The DFA on-line waveform classification engine uses sophisticated software to analyze waveforms and thereby identify circuit events.

Distribution Operations – Paradigm Shift

DFA technology represents a paradigm shift in distribution operations and requires a change in mindset, not just technology.

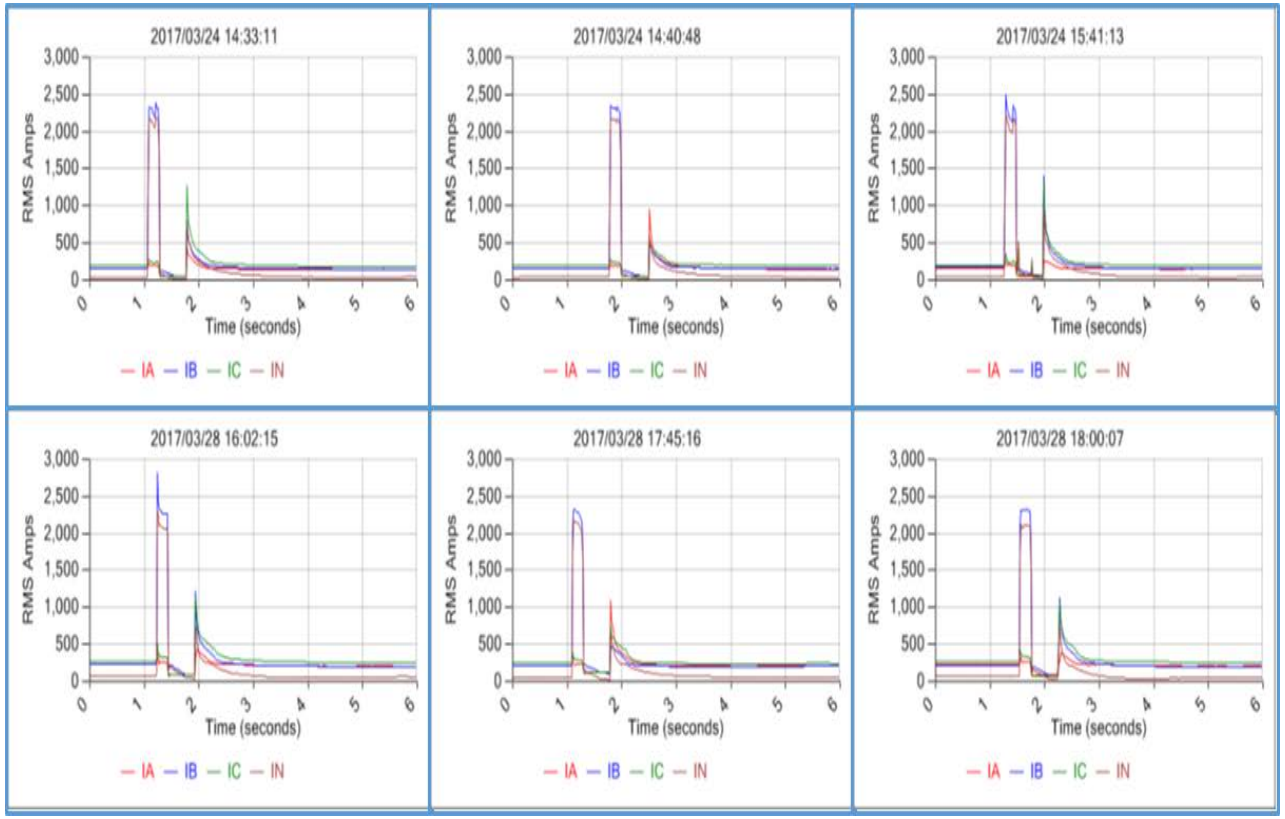
- Proactive, not reactive
- Predictive
- Diagnostic
- Situational awareness
- Visibility
- Actionable recommendations
- Operator knowledge (not more data!)

What Would You Do?

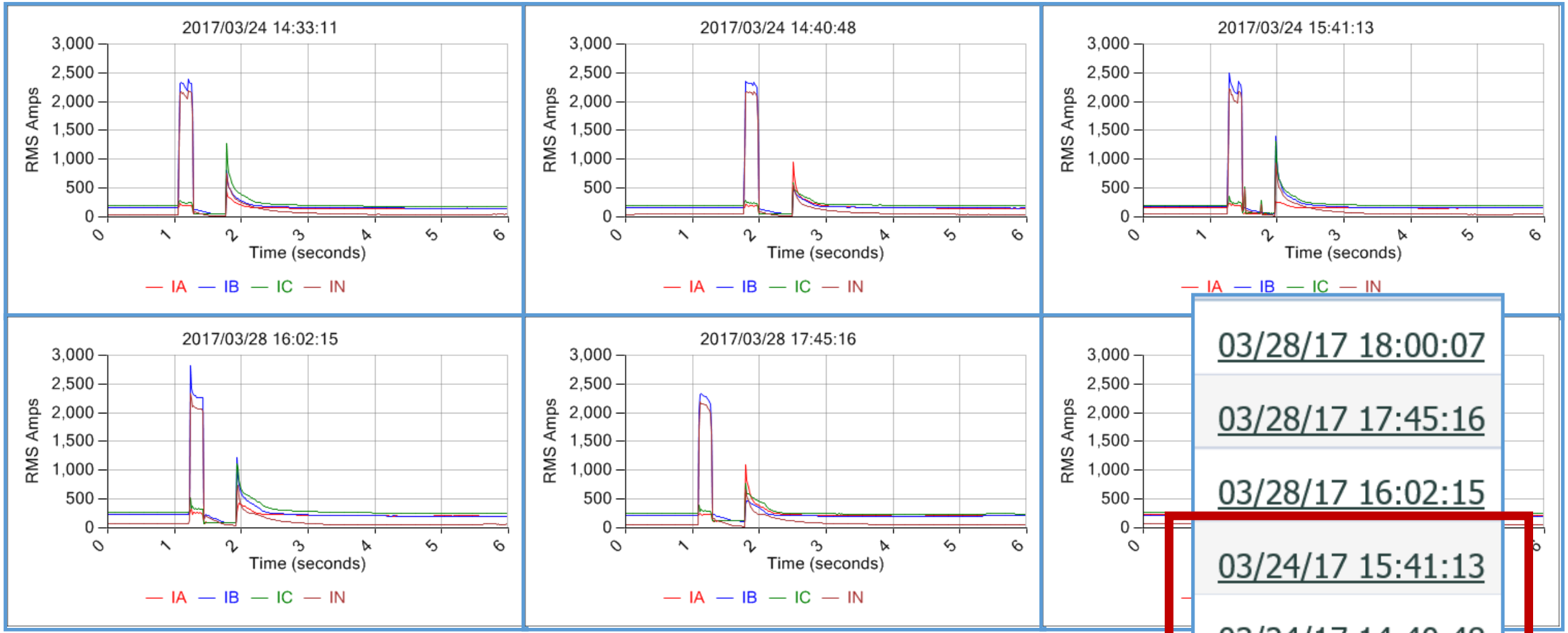


- Assume you know this fault occurred.
  - Downstream recloser trip/closed
  - No substation breaker operation
  - No outage
- What is the significance of this event?
- What would you do in response?

What Would You Do?



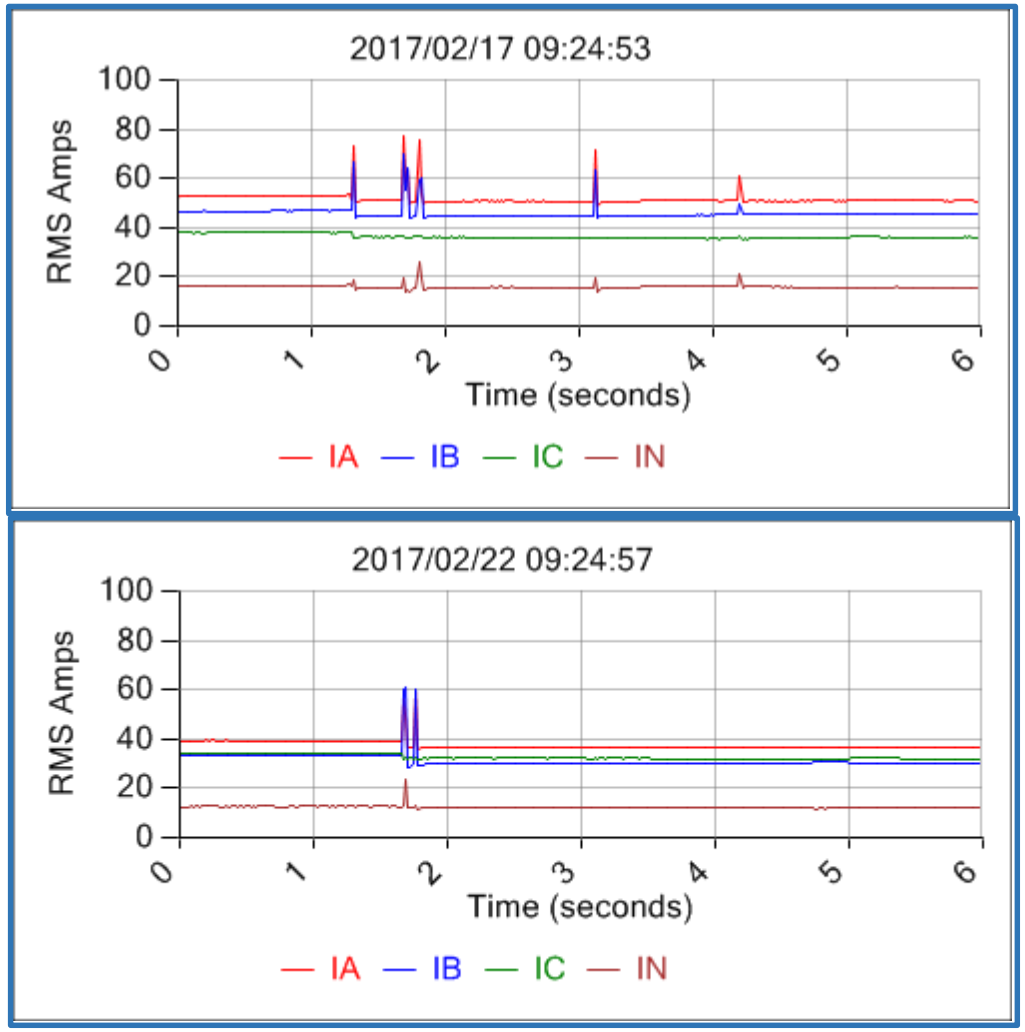
- Now assume six <u>identical</u> faults have occurred in four days.
  - Downstream recloser trip/closed
  - Still no outage
- Now what is the significance of the events?
- Now what would you do in response?



Possible recurrent fault	B	Three-Phase reclose, 2332 Amps	6 (4 days)

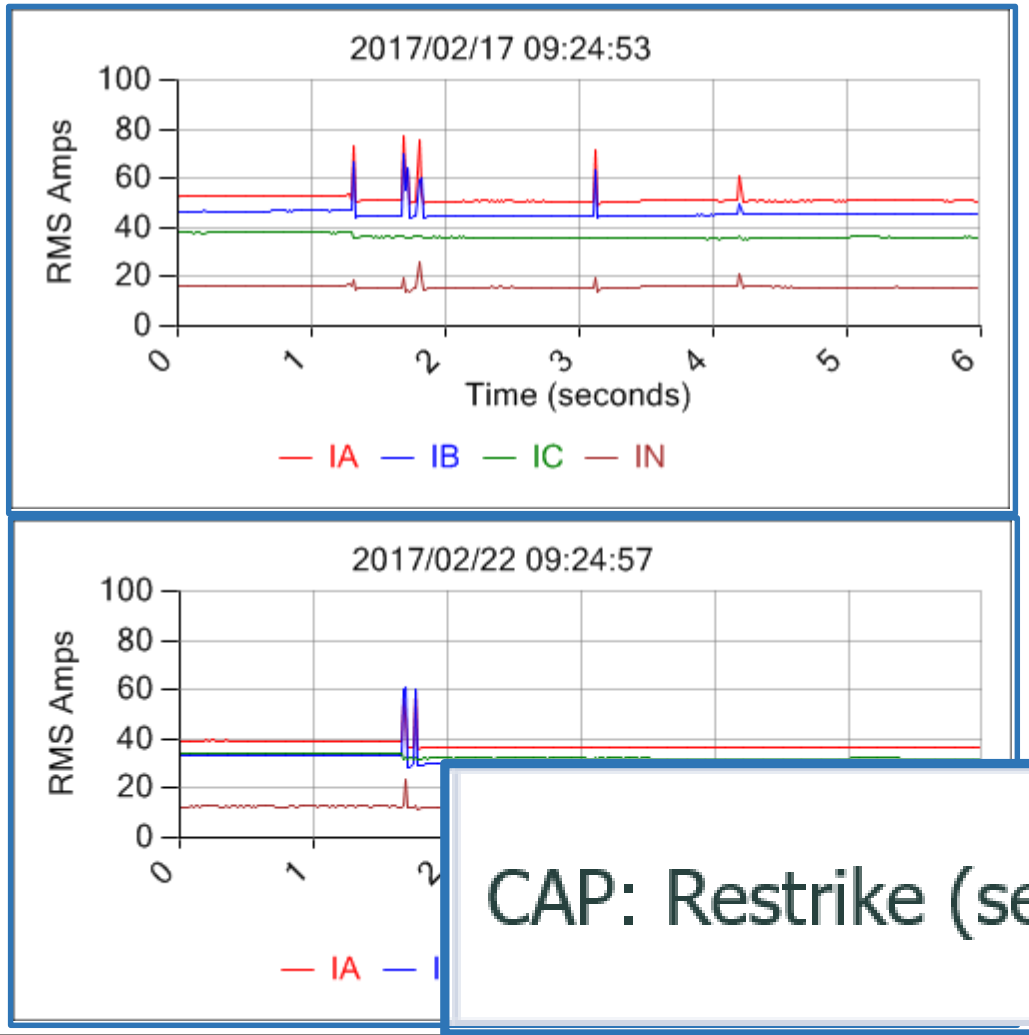
03/28/17 18:00:07
03/28/17 17:45:16
03/28/17 16:02:15
03/24/17 15:41:13
03/24/17 14:40:48
03/24/17 14:33:11

Another “What Would You Do?”



- Assume this activity is happening on one of your circuits.
- You have no way to know it is occurring.
- Even if you did know it was occurring, what does it mean, and what would you do?

Another “What Would You Do?”



- Now assume you know of the events and that you know they are severe restrikes in a 600 kvar capacitor switch.
- Now what is the significance of the events?
- Now what would you do in response?

CAP: Restrike (severe)	B	191	194	190	02/22/17 09:24:57

Distribution Fault Anticipation (DFA) Hardware Device Photos

DFA Device Drawings - August 2015. Subject to change.

Rack-Mount DFA-Plus Device

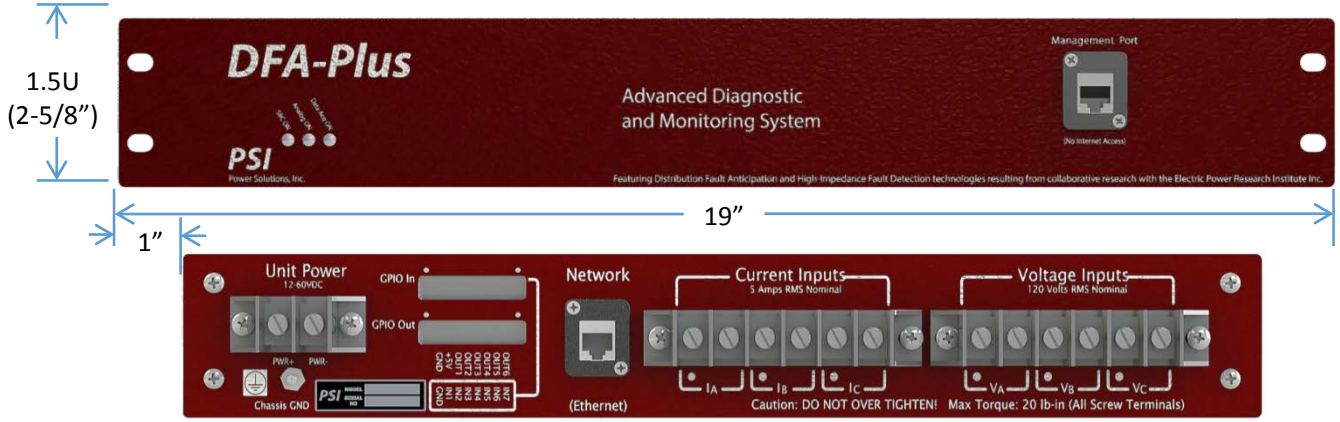
Case depth is 11-3/16". Current, voltage, and unit power terminals on rear add 1" for total depth of 12-3/16".

Connections to rear of each Device:

* Unit power, battery-backed, 12-60VDC
* (3) Current inputs, 5AAC nominal
* (3) Voltage inputs, 120VAC nominal
* Ethernet/Internet, RJ45 twisted-pair (Network port)

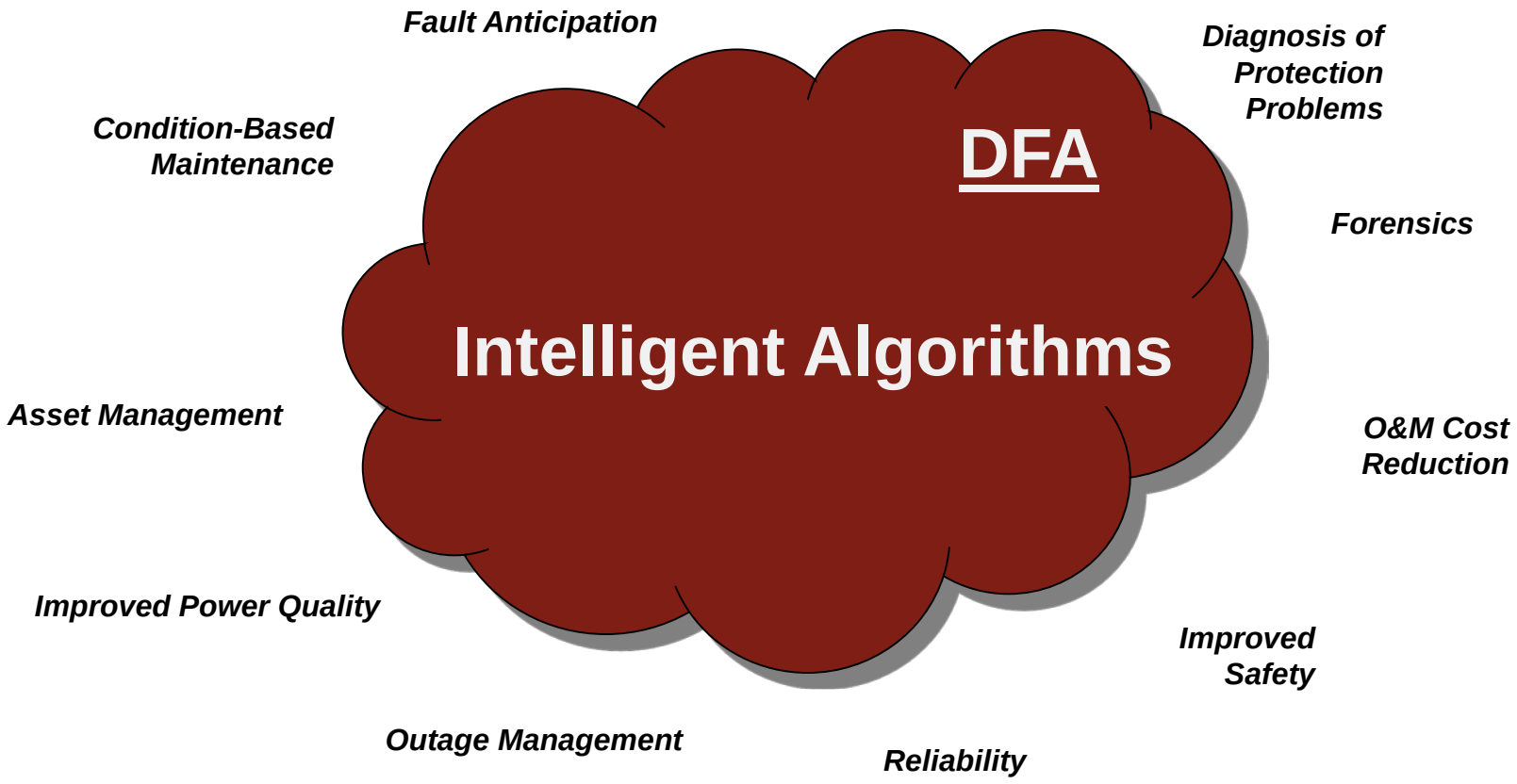
User is responsible for providing unit power, Internet service, CTs, PTs, and all cabling.

The Management Port on the front of the Device is for setup and diagnostic purposes only and is not intended to be connected during normal operation.



Hardware platform by Power Solutions LLC.

Numerous Utility Stakeholders Benefit from DFA Functionality



DFA Technology Enables…

- Visibility
- Situational awareness in real time
- Condition-based maintenance
- Forensic diagnostics
- Outage prevention
- Faster restoration