Detection of Distribution Circuit Wildfire Ignition Mechanisms Using Substation-only Sensors and Data Analytics

The North American SynchroPhasor Initiative (NASPI) Webinar Series
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Dr. B. Don Russell, P.E., Distinguished Professor, bdrussell@tamu.edu, 979-845-7912
Carl L. Benner, P.E., Research Professor, carl.benner@tamu.edu, 979-676-0499
Dr. Jeffrey A. Wischkaemper, Research Asst. Professor, jeffw@tamu.edu, 979-575-7213
Department of Electrical and Computer Engineering
Texas A&M University, College Station, TX 77843

Wildfire Ignition – A Growing Utility Problem

- Camp Fire (2018): 153,000 acres, 86 deaths
- Cedar Fire (2003): 273,000 acres, 15 deaths
- Witch Fire (2007): 197,000 acres, 6 deaths
- Tubbs Fire (2017): 36,000 acres, 22 deaths
- Bastrop Complex Fire (2011): 34,000 acres, 4 deaths
- Yarnell Hill Fire (2013): 8,000 acres, 19 deaths
- Black Saturday (2009, Australia): 1,100,000 acres, 173 deaths

Utilities and Research Groups Seek New Solutions for Wildfire Prevention

- Increased rigor in power line infrastructure and construction
- Improved wildfire risk modeling and tracking
- Improved weather monitoring
- Physical monitoring including cameras and UAS (drones)
- Public Safety Power Shutoff (PSPS)
  (Electrical circuit conditions currently are not considered for determining PSPS.)
- New techniques in electrical sensing and monitoring
  - e.g., PMUs, RF sensors, DFA, line current sensors, new uses of AMI data, …

Electrical Approaches for Mitigation

- Pre-ignition detection of ignition mechanisms – find and fix (before the failure event)
  - Distribution Fault Anticipation (DFA)
  - Distributed RF sensing (e.g., IND.T)
- Rapid response to failure events – mitigate or prevent ignition (after the failure event)
  - Sensitive earth fault detection (limited to three-wire circuits)
  - Rapid earth fault current limiting (REFCL) (limited to three-wire circuits)
  - PMUs (e.g., broken conductor detection)

Advanced Sensing and Monitoring Architectures

Single-point monitoring/sensing

- Improved conventional protection
- Rapid earth fault current limiting (REFCL)
- Distribution fault anticipation (DFA)

Distributed multi-point monitoring/sensing

- RF sensors
- Line sensors (advanced faulted circuit indicators)
- PMUs

There is a need to benchmark prevention and mitigation methods

- What performance can be achieved by single-point, substation-only methods? This establishes a baseline.
- What incremental benefits can distributed, multi-point architectures add above the baseline?

Areas of consideration

- Which methods can detect the earliest stages of failure mechanisms, before fire ignition?
- Which methods can rapidly respond to a failure event after it occurs?

Baseline Architecture

- Single-point, substation-based sensing
- Conventional CTs/PTs as the sensing input
- Local processing; no massive backhaul of data for centralized processing
- Near real-time processing, event characterization, and reporting to operators to enable decision making

Background: Texas A&M Research Activities

To better understand wildfire ignition mechanisms, the Power System Automation Laboratory at Texas A&M University, in cooperation with multiple utility companies, has conducted a multi-year study to document naturally occurring failures that could ignite wildfires.

- More than 1000 circuit-years of monitoring and data collection
- > 250 circuits at > 15 utilities
- Continuous monitoring
- Sensitive triggering, high-fidelity waveform capture

The study documented ignition-competent failure events including clamps, switches, capacitors, fault-induced conductor slap, vegetation contacts, and downed conductors.

How Do Power Lines Start Fires?

- The study period captured millions of circuit events, including thousands of faults and failures. The following lessons were learned.
  - High-current faults can start fires immediately.
  - Low-current device failures can start fires immediately.
  - Incipient failures, if not corrected, may develop over days or weeks (or even longer!) to start fires.
    - Incipient failures can have low current (e.g., melting clamp).
    - Incipient failures can have high current (e.g., repetitive conductor clash that eventually burns line down).

How Do Power Lines Start Fires?

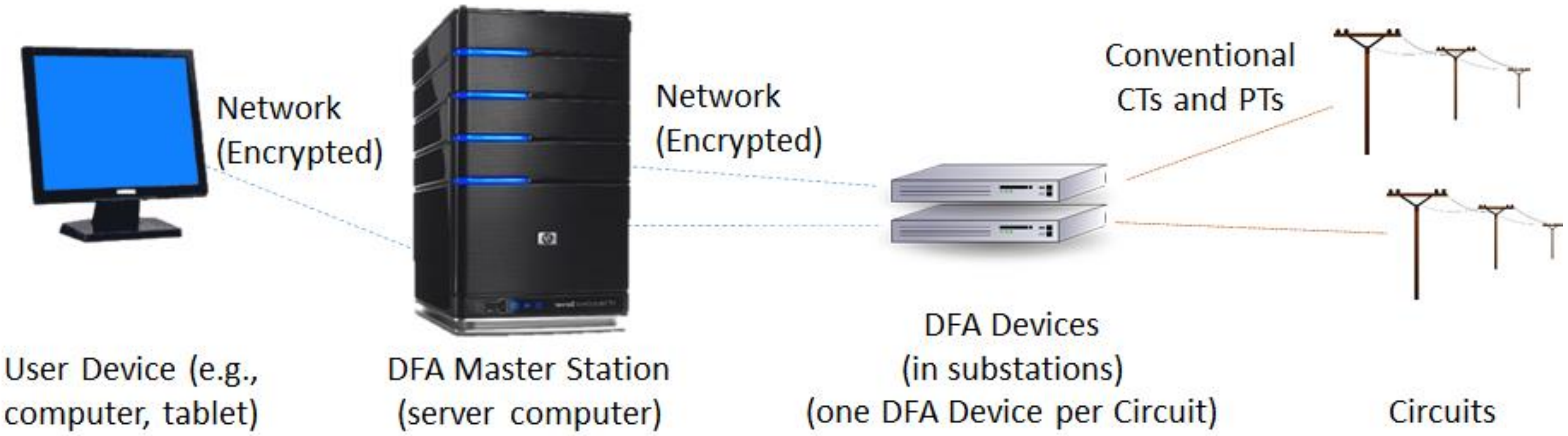
Downed Conductors

Vegetation

Clashing Conductors

Failing Apparatus

Architecture of DFA System (Baseline)

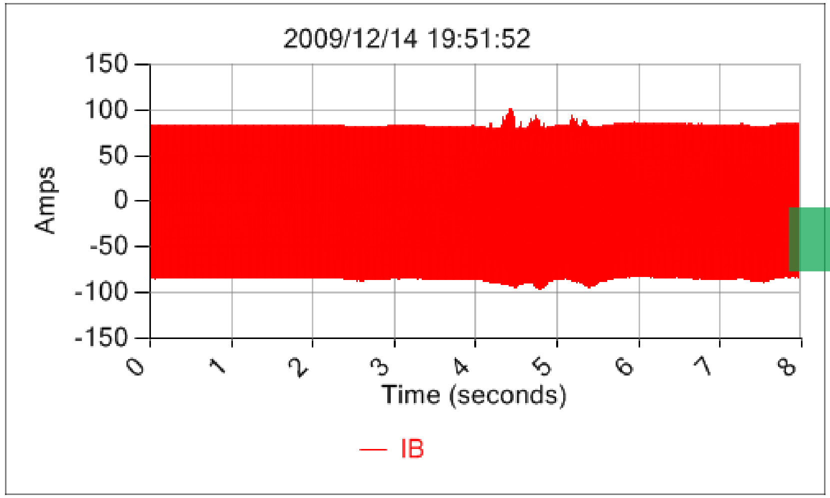


<u>Notes</u>

- Each DFA device monitors one circuit. Each device runs real-time event-recognition algorithms on waveforms and sends reports via network to a central server computer for access by operators and other users (distributed processing).
- Each DFA device synchronizes its time via Internet (NTP) and generally is +/- 1 second.
- Each DFA device samples currents and voltages continuously at 256 samples/cycle with 18+ bits of range/accuracy, to capture harmonics and transients that enable detection of low- and high-current faults and other events.
- The event-recognition algorithms analyze single-point (substation) waveform data for a single circuit.
- <u>Terminology</u>: Texas A&M's use of the term "waveform" is equivalent to NASPI's use of the term "point on wave."

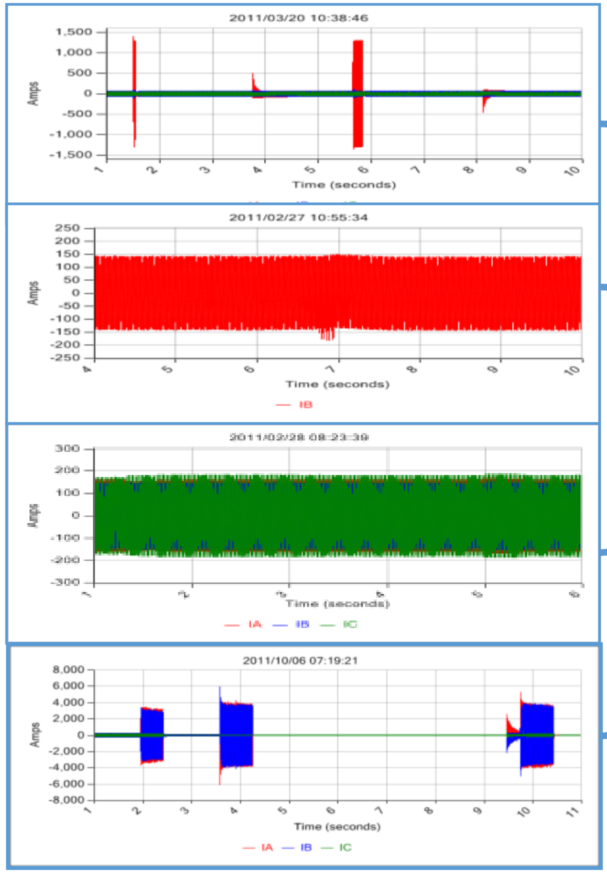
Principle: Waveforms Contain Useful Information

- This graph shows line current recorded at substation during routine operations, with current modulated by a failing clamp signature.
- Conventional technologies do not detect such conditions, which can persist for weeks before catastrophic failure (e.g., broken conductor).



Behind-the-Scenes Architecture

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.

Illustrative Case Studies

- Two illustrative case studies follow – one a low-current event and one a high-current event.
- Case studies come from installations on real utility circuits, during routine operations. Nothing is staged or simulated.
- The monitoring system connects to conventional CTs and PTs at substations, so recordings contain load current in addition to the current caused by the event of interest.
- The monitoring system records 256 samples/cycle, but this presentation shows RMS to convey the “big picture.”
- The point of using these case studies in today’s webinar is to provide examples of what can be done with <u>baseline</u> single-point sensing.

Recent Example of Low-Amplitude Incipient Arcing

(series arcing)

The DFA system detects series arcing. This case study is based on an example from last week and helps illustrate several important points about series arcing:

- Series arcing produces a "hot spot" in a current-carrying device and represents a competent ignition mechanism.
  - Direct ignition, for example by dropped particles or "candling" cutouts
  - Indirect cause of ignition, for example by melting conductors and other hardware, resulting in broken conductors
- Series arcing can persist, intermittently, for hours to weeks, providing opportunity to find and fix at least some cases, <u>if you know it is happening</u>.
- The electrical activity is too small to be picked up by conventional means (relays, PQ meters, …).
- Series arcing primarily affects current, with little effect on voltage.
- Much of the electrical activity is harmonic/transient current, with little activity at the fundamental frequency.

Recent Example of Low-Amplitude Incipient Arcing

(series arcing)

Expand	Substation	Circuit	Event Type	Phases	Comments	Count	Last Occurred	Graph
−	[illegible]	[illegible]	Probable failure of switch or clamp	B	Estimated kVA capacity beyond switch/clamp: 47 kVA 80% likelihood switch; 20% likelihood clamp	244 transients (3 hours)	2020-08-11 11:51:23 CDT	

Export Show 10 entries Search:

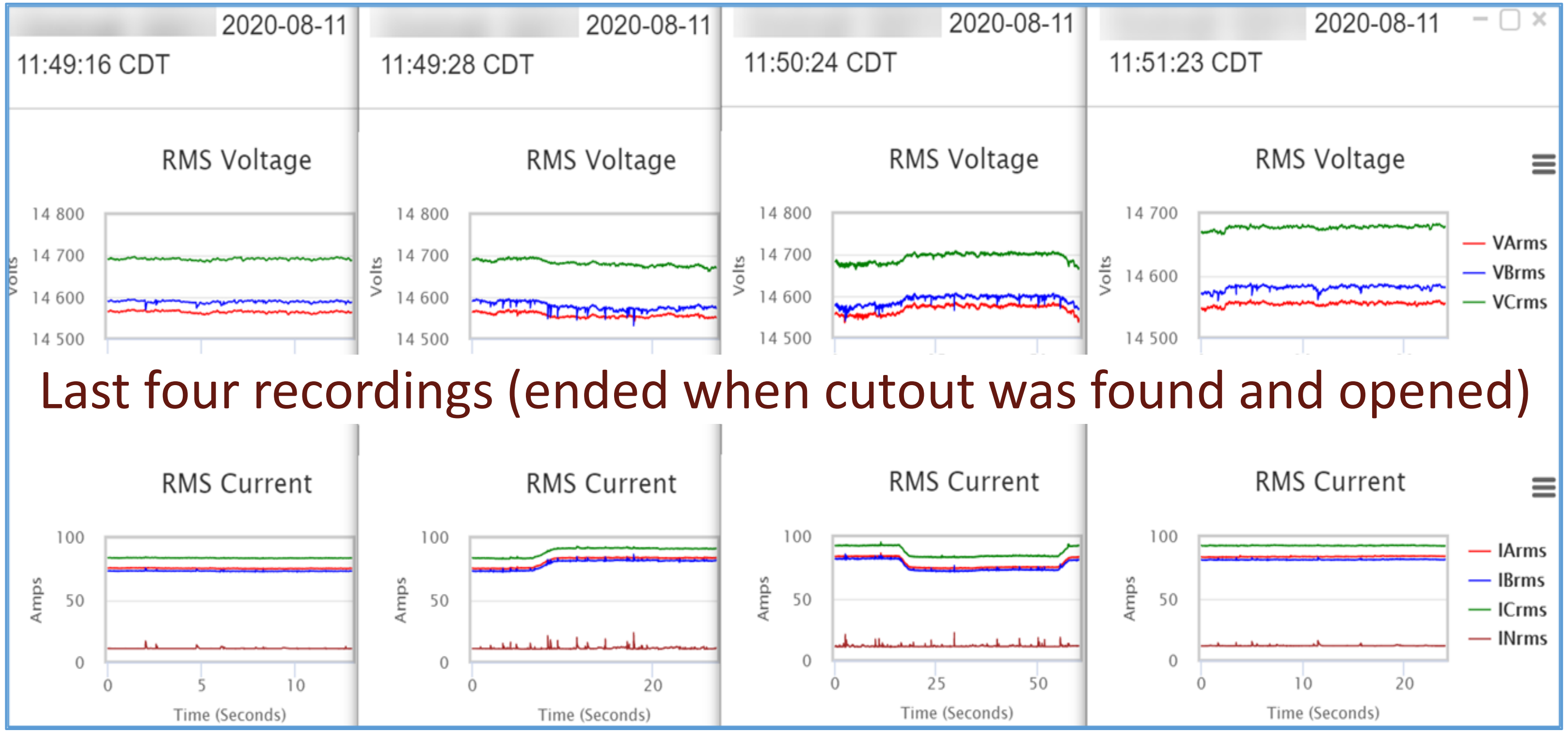
Event Type	Phases	Transients	Last Occurred	Graph
Probable failure of switch or clamp	B	5	2020-08-11 11:51:23 CDT	
Probable failure of switch or clamp	B	5	2020-08-11 11:50:24 CDT	
Probable failure of switch or clamp	B	4	2020-08-11 11:49:28 CDT	
Probable failure of switch or clamp	B	3	2020-08-11 11:49:16 CDT	
Probable failure of switch or clamp	B	7	2020-08-11 11:47:16 CDT	
Probable failure of switch or clamp	B	6	2020-08-11 11:45:42 CDT	
Probable failure of switch or clamp	B	3	2020-08-11 11:42:29 CDT	
Probable failure of switch or clamp	B	2	2020-08-11 11:37:03 CDT	
Probable failure of switch or clamp	B	1	2020-08-11 11:34:25 CDT	

<u>Last week's event</u>

- The DFA system reported low-level series arcing repeatedly over a period of 3-1/4 hours.
- Based on DFA-recorded electrical data, the utility targeted a patrol that located an arcing fused cutout.
- At no time did the utility receive notice from any source (SCADA, meters, customer calls) other than the DFA system.

Recent Example of Low-Amplitude Incipient Arcing

(series arcing)



Takeaways

- Incipient failures (e.g., series arcing) that can cause ignition can draw minimal current (a few primary amps) and have almost no effect on voltage, especially at the fundamental frequency, so changes in phasors may be imperceptible.
- Single-point (substation) sensing, using conventional CTs and PTs, enables detection of series arcing.
- Location can be challenging. After series arcing is known on a circuit, AMI sometimes can be used to target patrols.

Other Examples of Series Arcing

Eroded hotline clamp

Conductor burn-through at clamp

Substation blade switch

Each of these photos shows an example of series arcing.

* Each example had low current magnitude.
* Each went undetected by conventional means.
* Each has direct and indirect ignition potential.

Conductor Burndown Resulting from Repeated Vegetation Intrusion

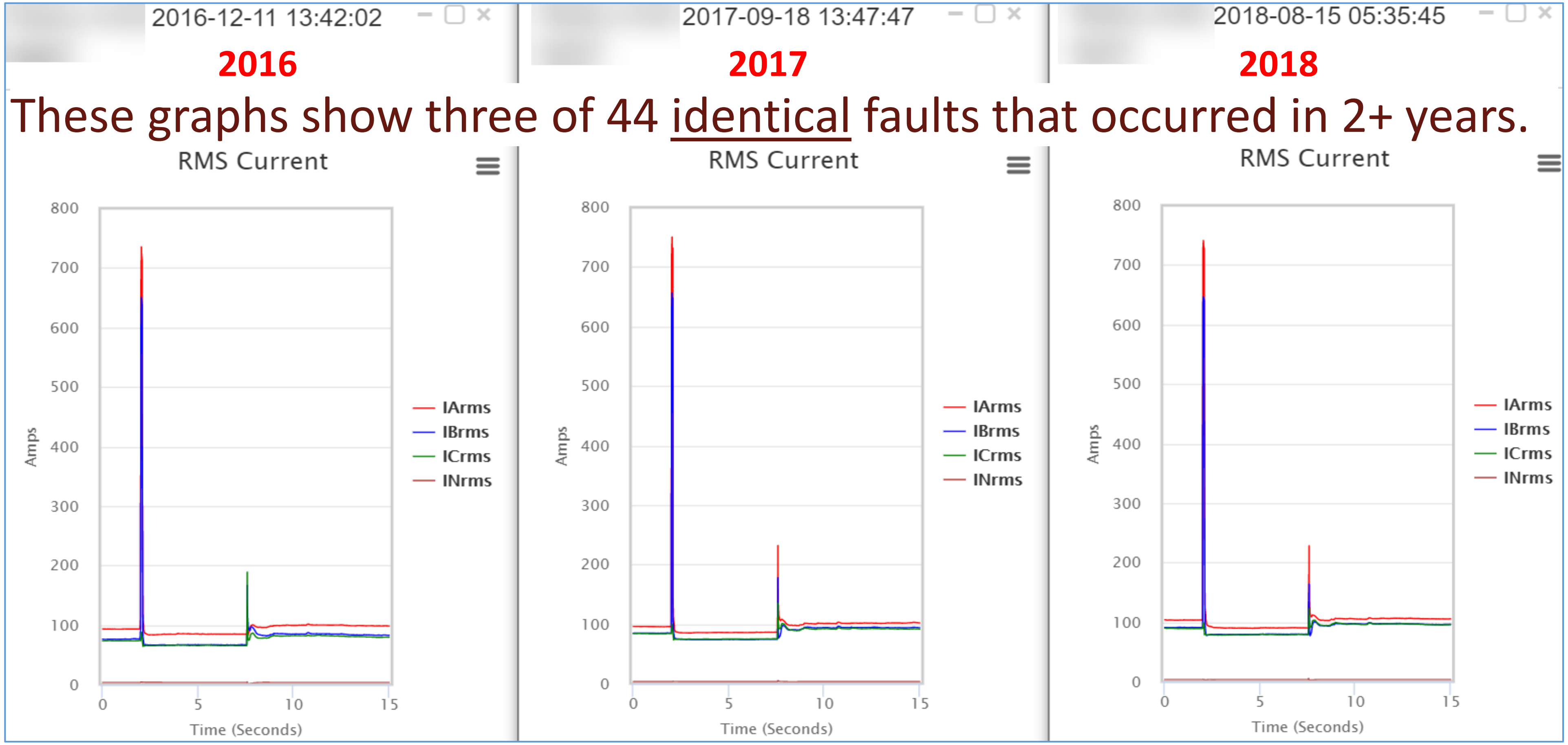
- This case study occurred during the subject utility's "blind study" period for the DFA monitoring system.
- The utility operated as if the DFA monitoring system were not present.
  - They did not make DFA reports available to operators or otherwise respond to those reports.
  - They used their other systems (e.g., SCADA, communicating ACRs, customer calls) as usual and responded as usual to those systems. They did not withhold normal response actions.
- The "blind study" provided an opportunity to assess additional value achievable with intelligent monitoring.
- The subject utility is in the AUS/NZ region.

Conductor Burndown Resulting from Repeated Vegetation Intrusion

Case Study Details

- During certain wind conditions, vegetation pushed conductors together and caused high-current faults. A comms-enabled ACR successfully trip/closed.
- The fault recurred 44 times over a period of 2+ years, causing progressive damage to the conductor and eventually burning it down.
  - This has clear ignition potential.
  - The first several episodes were incipient precursors to the later episodes and burn-down.
- During the multi-year period, the comms-enabled ACRs reported many faults, but not that dozens of them were the same fault.
- By contrast, the DFA monitoring system reported each fault and “clustered” the similar faults as the same fault. If it were not for the “blind study,” it would have been straightforward for the utility to find and fix the problem, thereby avoiding many faults and interruptions and the eventual burn-down. Utilities have responded to DFA recurrent-fault reports many times to find and fix problems without “final failures.”

Conductor Burndown Resulting from Repeated Vegetation Intrusion



These graphs show three of 44 identical faults that occurred in 2+ years.

Key Takeaways Regarding Incipient Failures

- By definition, an incipient failure is one that, if not corrected, will result in a full failure in the future.
- This webinar has outlined two types of incipient failures with direct and indirect ignition potential. There are multiple other types.
- Incipient failures can exhibit low-current (e.g., series arcing) or high-current (e.g., recurrent faults) electrical activity.
- Incipient failures can occur over substantial time periods (hours to months).
- In some cases, a utility can proactively correct the incipient failure and avoid a catastrophic failure in the future…
    - <u>But only if they know the problem exists!</u> (a without-which-nothing condition)

Baseline: Substation-only Monitoring

- Detect low-amplitude and high-amplitude incipient failures and other events.
- Distinguish normal events (e.g., motors, capacitor switching) from abnormal events (e.g., faults, series arcing, shunt arcing).
- Use distributed processing, without massive data backhaul.

<u>For discussion</u>

- What is the incremental advantage of distributed measurements?
    - Improve/simplify location of high-current and low-current events.
- What is the incremental advantage of highly time-synchronized measurements?
    - High-speed broken conductor detection.