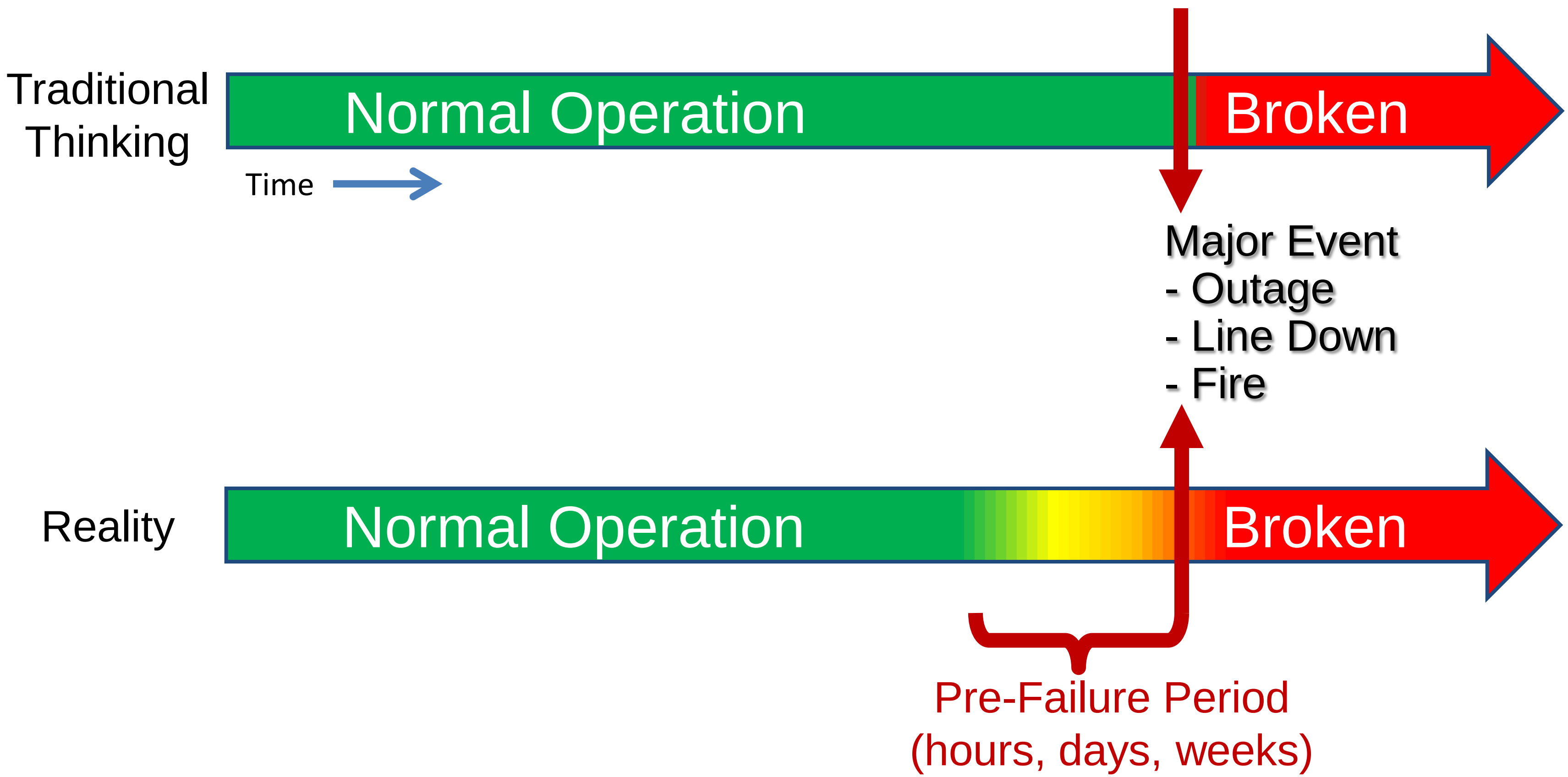
Arcing Cable Faults on Low-Voltage Grid Networks

Industrial Session
67^{th} Annual Conference for Protective Relay Engineers
Texas A&M University, College Station, Texas
Tuesday, 01 April 2014

Carl L. Benner, PE, FIEEE
Senior Research Engineer
Department of Electrical and Computer Engineering
Texas A&M University
979-845-6224, carl.benner@tamu.edu

Electrical Feeder Operational Paradigms



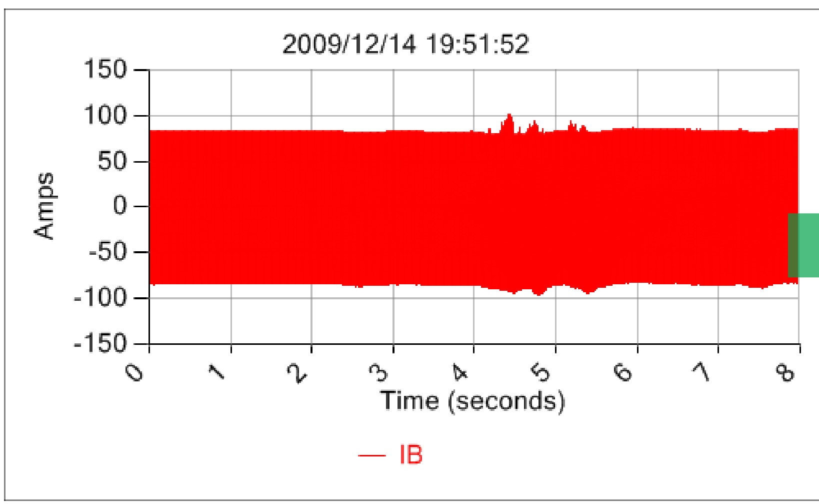
Detecting pre-failures makes it possible to take action before major events occur.

Fundamental Principles of Waveform Analytics

- Feeder-level electrical waveforms represent feeder activity.
- Sophisticated waveform analytics, applied to waveforms of sufficient fidelity, can detect failures, pre-failures, and other feeder events.
  - PQ meters and relays have the same inputs (i.e., CTs and PTs) but do not record data of sufficient fidelity to support some currently developed functions.

Measured Example

- Graph shows current during “normal” feeder operations.
- Analytics report this specifically as a failing clamp. Failing clamps can degrade service quality, drop hot metal particles, and in extreme cases burn down lines.
- Conventional technologies do not detect pre-failures such as this one.



On-Line Waveform Analytics

Scope of R&D Efforts

- Multiple EPRI projects since late 1990’s targeted distribution feeders (initially). The resulting technology became known as Distribution Fault Anticipation, or simply DFA.
- Broadened scope is exploring application to transmission lines (115 kV) and low-voltage grid networks (120/208V).
  - The hardware platform implemented for distribution application has been used for data gathering on transmission and low-voltage.
  - Waveform characteristics and detection algorithms differ but fundamental data and processing concepts remain the same.
- Distinct waveform variations can detect failures and pre-failures of many components, including cables.
  - Primary (15 kV class) URD
  - Secondary service cables (120/240V; detectable at substation)
  - Low-voltage grid network cables (120/208V; detectable at substation and at nodes on low-voltage grid itself)

Today’s Presentation

Low-Voltage Grid Networks

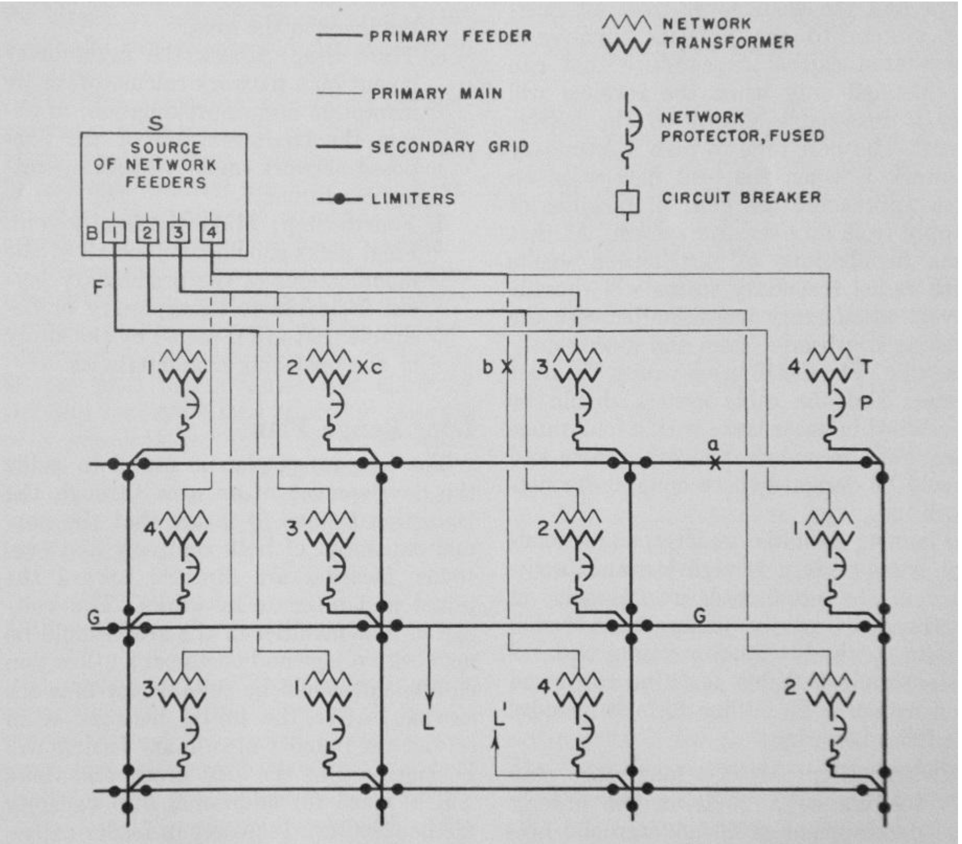


Fig. 5-1—One-line diagram of a secondary network.
5-1

- Provide highly reliable power to dense urban areas.
- Consist of multiple primary feeders (e.g. 13kV) serving an interconnected mesh of secondary (120V or 480V) cables.
- Can tolerate the loss of any cable, transformer, or primary feeder with no loss of service to customers.

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.
- Because of the grid network's highly redundant topology, arcing and other single-point failures can persist without notice until reported by the public or by the fire department.

Manhole "Smoker" Caused by Arcing in Low-Voltage Grid Network

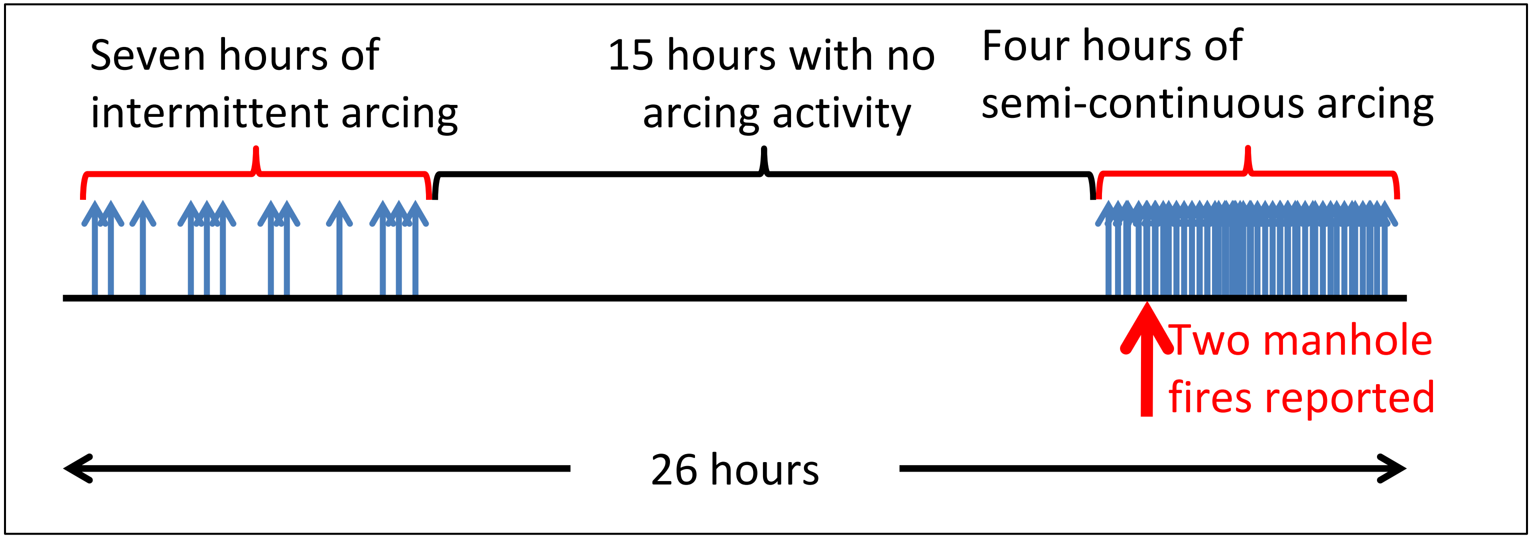
Characterization Project

- *1950: "… arcs are not sustained [on 120/208V grid networks]."*
Electrical Transmission and Distribution Reference Book, Westinghouse, 1950.
- *2001: "… clearing of arcing faults [on a low-voltage network] … is an industry problem that currently has no available solution."*
"Assessment of the Underground Distribution System of the Potomac Electric Power Company," Washington DC, Appendix A, p. 87, Stone and Webster Consultants, 2001.
- Texas A&M and ConEdison instrumented a single grid network to characterize naturally occurring arcing faults.
  - Sensitive, high-fidelity, high-capacity, Internet-connected recorders
  - Two years, 24x7 monitoring, fully automated data retrieval
  - Recorders directly on 30 low-voltage (120/208V) grid network nodes
  - Recorder on one of 26 primary feeders (13.2 kV) serving that network
- Thousands of arcing events were recorded and analyzed.

General Findings

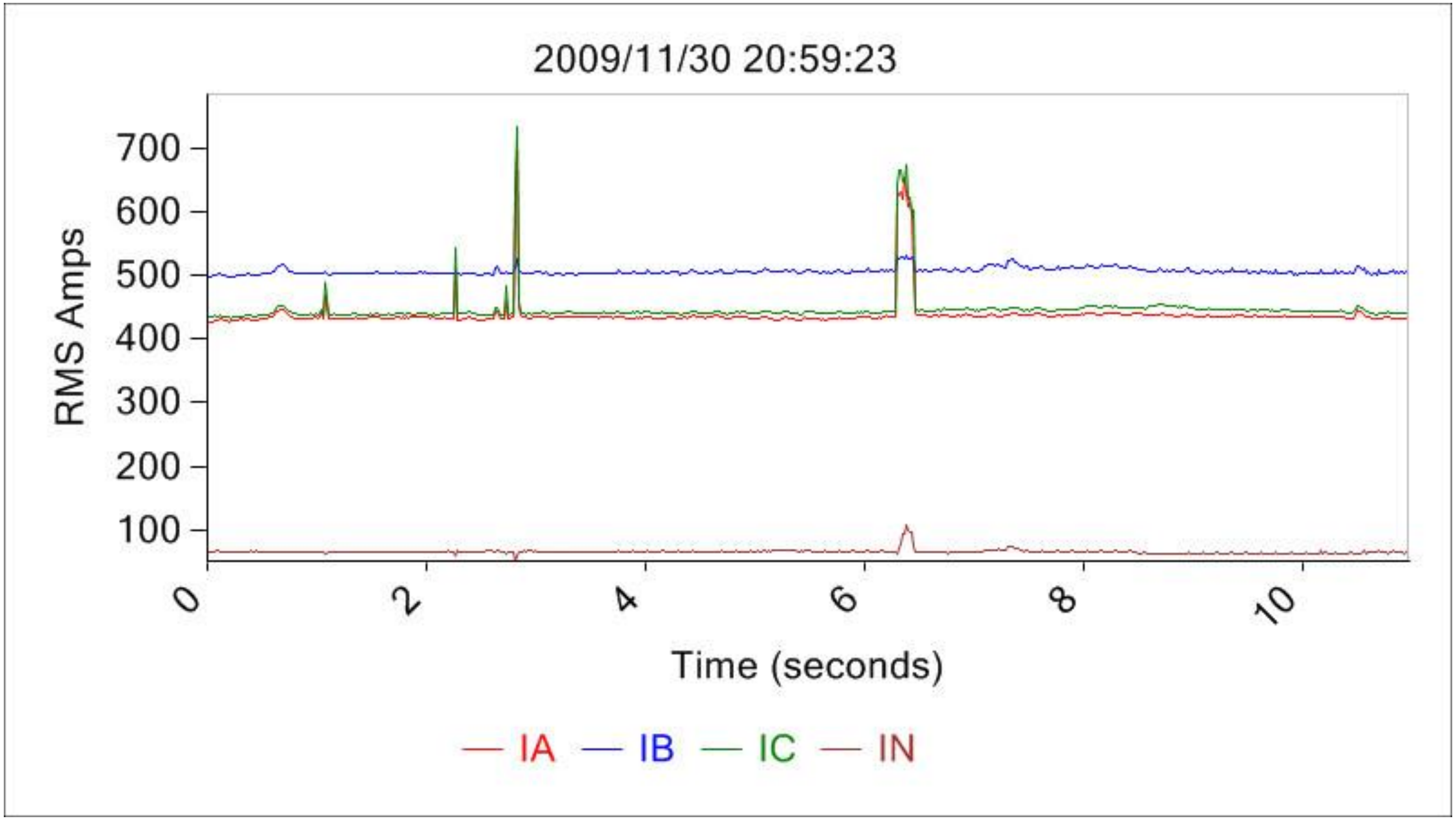
- Results generated new understanding about the behavior of low-voltage grid network arcing, discovering that it:
  - occurs more frequently than previously believed;
  - can persist for long periods (e.g. hours) without self-clearing;
  - can recur multiple times over a period of days or weeks;
  - can be detected at secondary grid network nodes and also on primary feeders that serve the network.

Network Arcing Fault Example #1



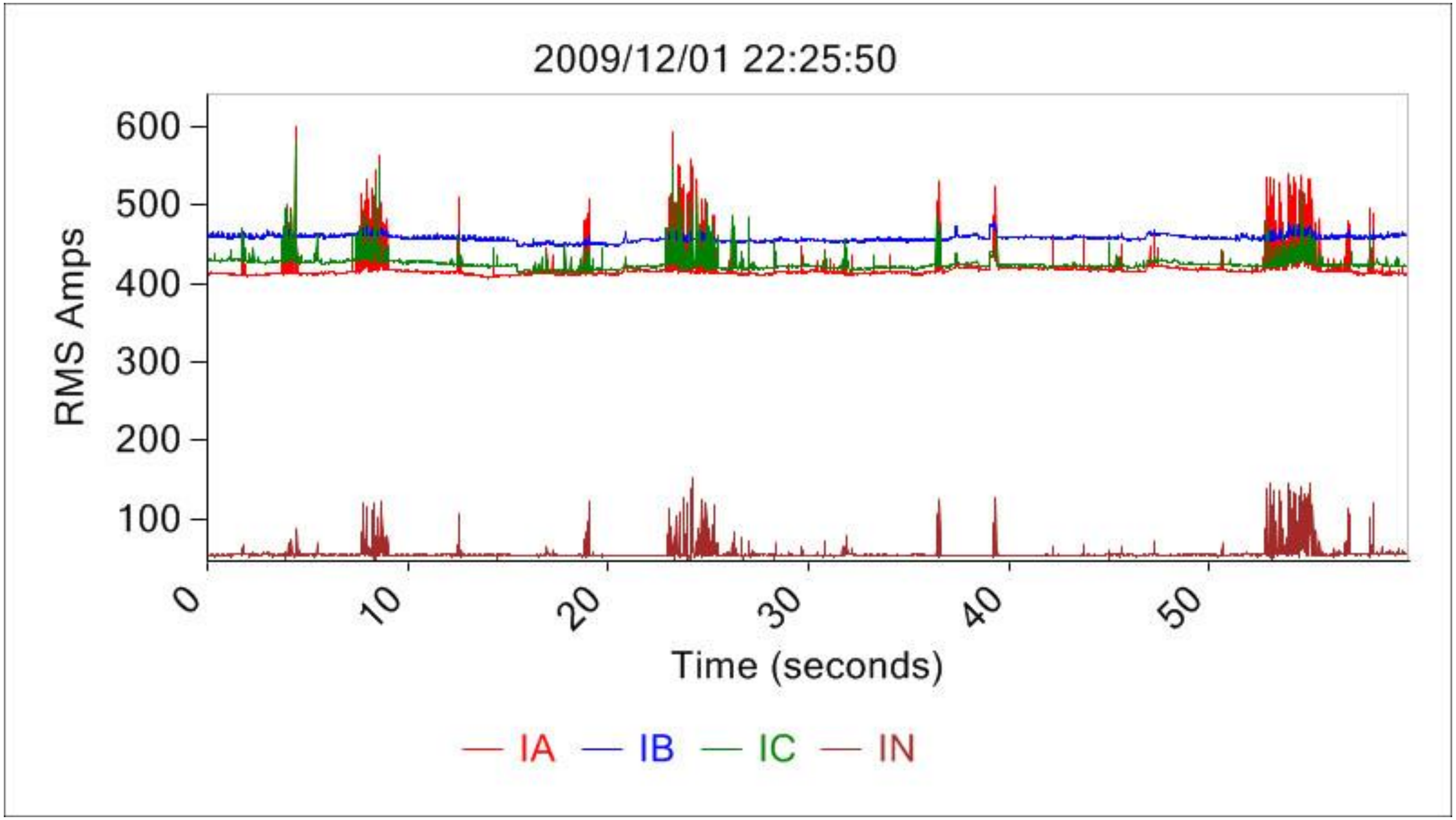
- Research instrumentation recorded substantial arcing for seven hours, followed by fifteen hours of quiescence.
- Substantial arcing resumed fifteen hours later, and FDNY reported two manhole fires shortly thereafter.
- The utility had *no conventional notice* of the problem prior to the FDNY report.

Network Arcing Fault Example #1 (cont'd)



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

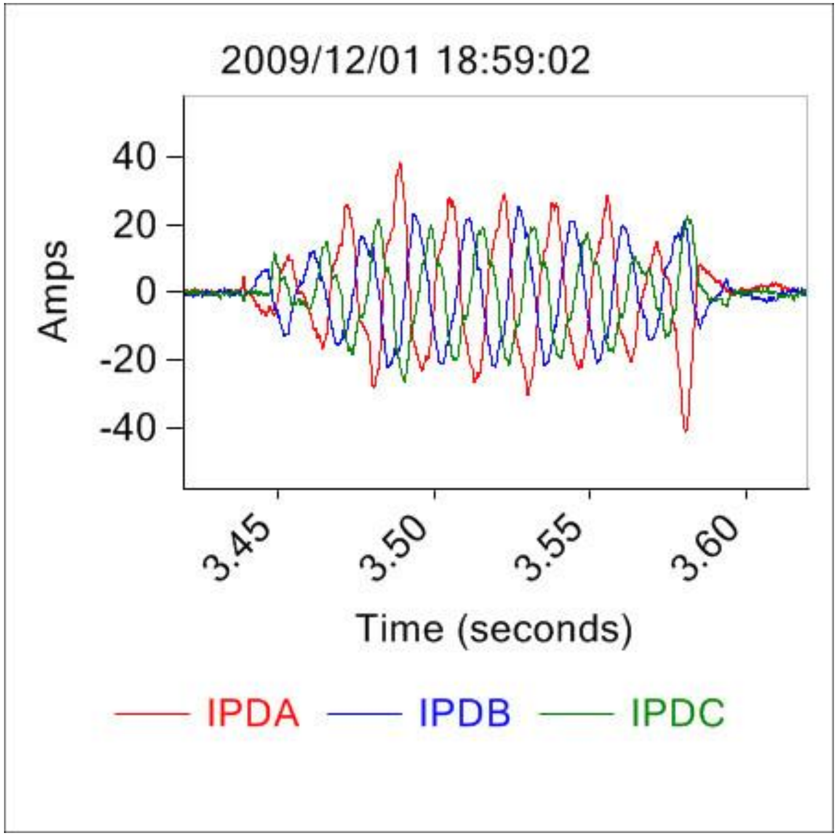
Network Arcing Fault Example #1 (cont'd)



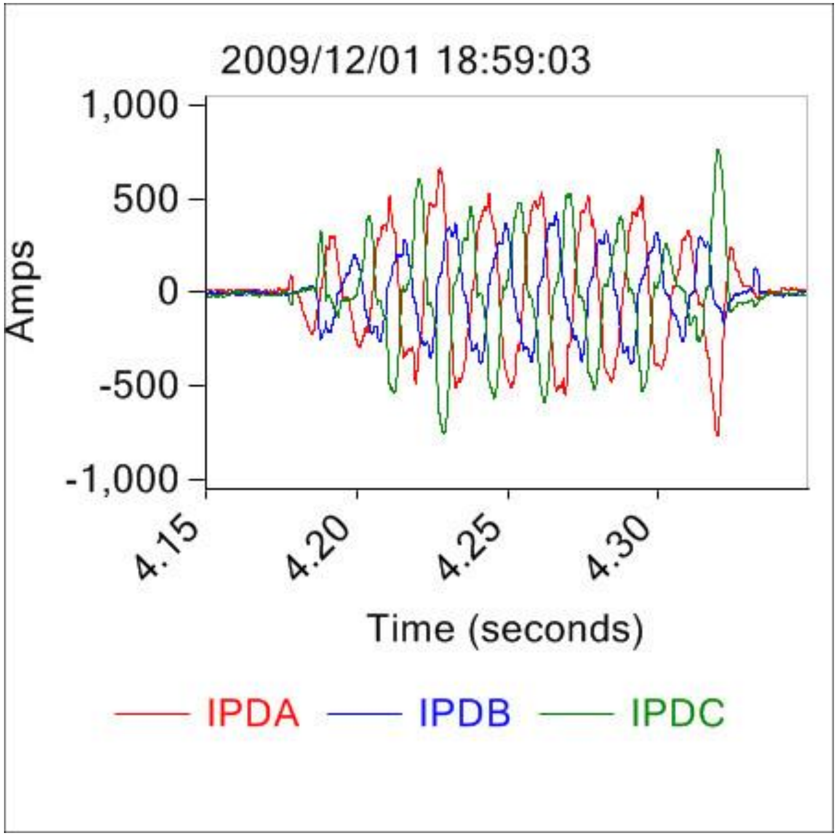
Sixty seconds of RMS current at a network node, showing semi-continuous arcing (representative of four-hour period on second evening)

Network Arcing Fault Example #1 (cont'd)

Primary feeder measurements



Secondary network node measurements



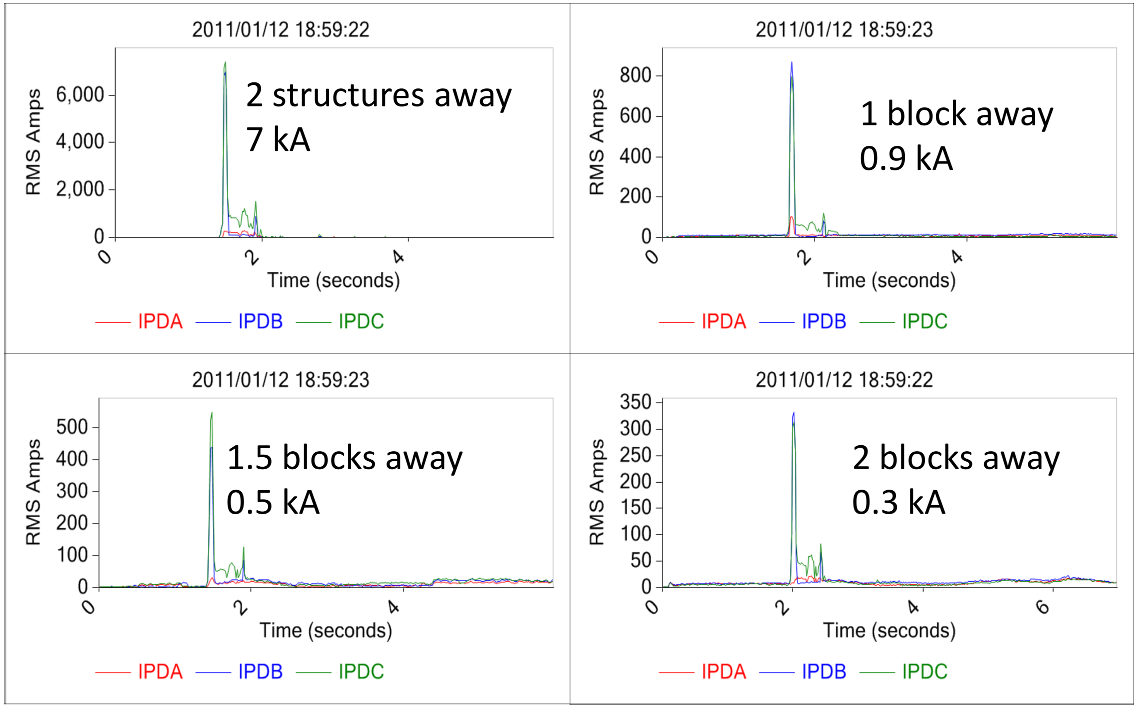
Note: graphs have been digitally processed to remove steady-state load current, with the resulting waveforms representing *only* arcing fault current

Network Arcing Fault Example #1 (cont’d)

- Substantial arcing activity can and does persist for hours without any conventional report of a problem to the utility.
- Cessation of arcing activity *does not* indicate that the problem is “fixed” – it is likely to return hours, days, or weeks later.
- Many cases which “end up on the news” have precursors that are detectable well in advance of the catastrophic failure.

Network Arcing Fault Example #2

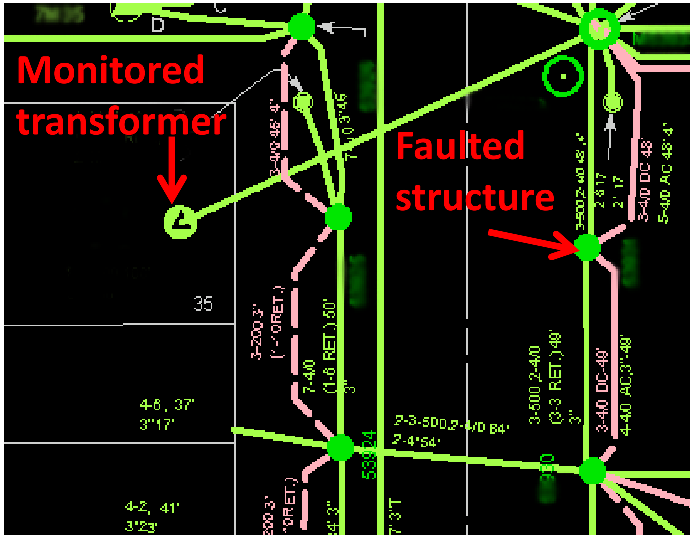
- Network fault current diminishes rapidly with increasing distance to fault.
- Five monitors simultaneously recorded the arcing fault shown here.



The closest monitored transformer sourced more than 7 kA of fault current. The farthest, three blocks away (not shown) sourced less than 0.1 kA.

Network Arcing Fault Example #2 (cont'd)

- Using measurements and utility models, researchers estimated the structure most likely to contain the fault.
- The fault location technique had not been developed when the fault occurred, but four months after the initial fault, utility crews found significant damage in the target structure.



- In the four months between the initial fault and the crew locating it, live, energized cables remained in an incipient state, ready to cause a manhole event.

What We Have Learned?

- Cable failures, including those on low-voltage grid networks, often degrade over time and produce detectable signatures in electrical waveforms.
- When a low-voltage grid network experiences an arcing fault, the utility company's first notice often is smoke, fire, or explosion, often reported by the fire department.
- Arcing is often measureable hours, days, or weeks before a final, catastrophic event.
- Locating incipient arcing is still in the research stage, but has provided early indications of success.

Remaining Questions and Future Work

- How well can we detect and locate secondary grid network arcing faults based solely on measurements on primary feeders?
  - Also, what primary failures and pre-failures could be detected by sensitive monitors placed on primary feeders?
- If monitoring on the secondary, what is the optimal number and placement of monitors to get the best “bang for the buck”?
- How do arcing faults and pre-failures manifest themselves on spot networks and at 277/480V?