Detection of Incipient Equipment-Failure Signatures

Presentation to the
66th Annual Conference for Protective Relay Engineers
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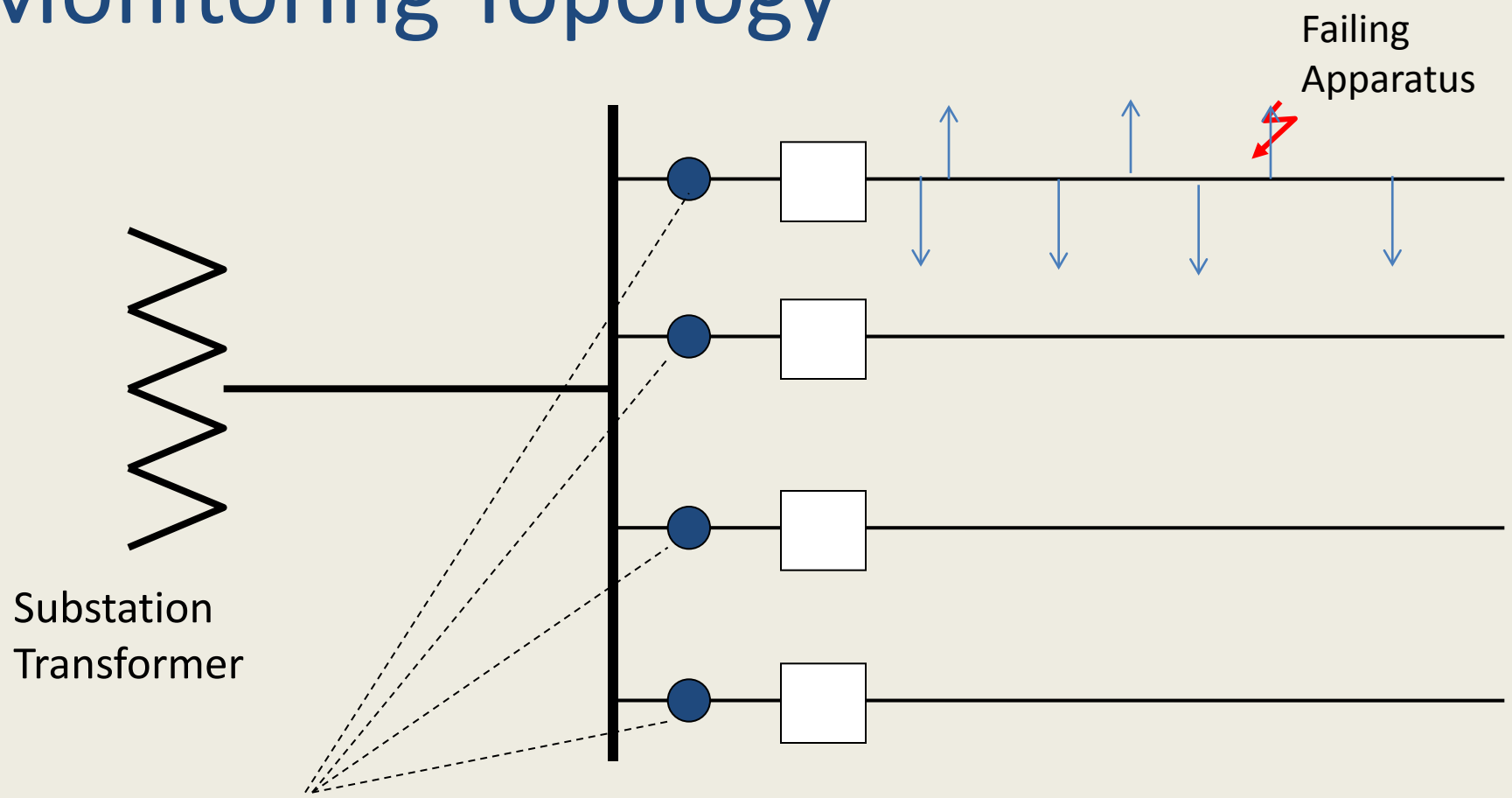
Premise and Background

- Electrical waveforms represent feeder activity.
- Waveforms can be analyzed to improve situational intelligence, including detection of failing apparatus.
- With more than ten years of field data from dozens of feeders, Texas A&M's library includes waveform signatures for:
  * Capacitor failures
  * Slapping conductors
  * Generic arcing
  * Recloser operations (including hydraulics)
  * Failing switches/clamps
  * Primary and secondary cable failures
  * Recurrent faults (incipient failures)
- Because of time limitations, examples provided in this presentation focus on cable failures.

Monitoring Topology



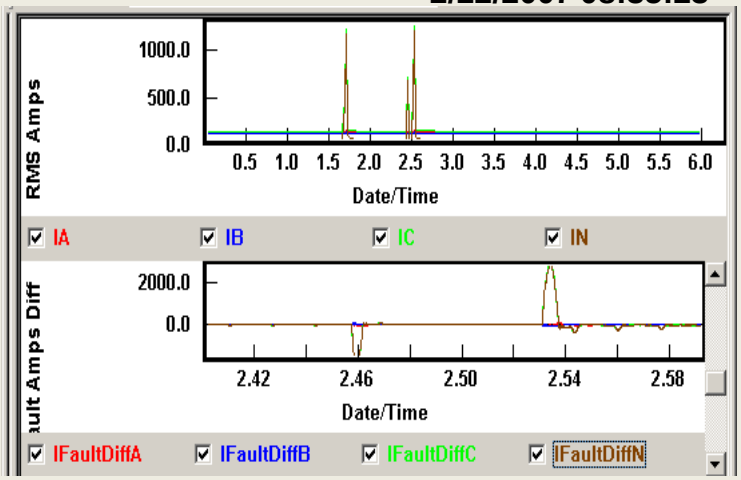
One monitor per feeder. Each monitor measures bus voltages and feeder currents.

Example 1: Primary URD Failure

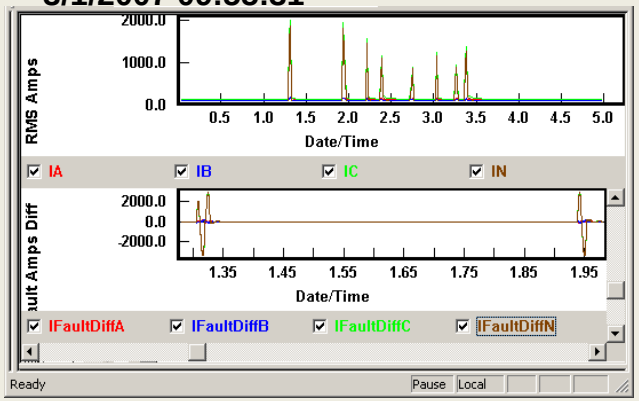
(With Precursors)

- 2/22/2007: Precursor to URD cable failure
- Additional precursors one week later
  - 3/1/2007 09:55 and 10:02
- Cable fault and outage 3/1/2007 10:56
- Primary cable faults can produce detectable precursors for weeks prior to outage.
- Location can be challenging, particularly where a feeder has multiple URD loops.

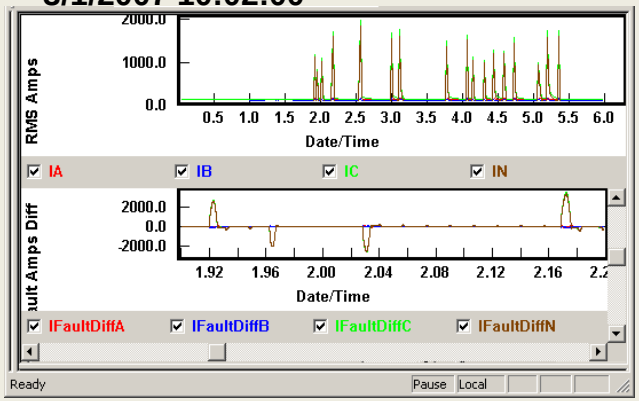
2/22/2007 08:35:23



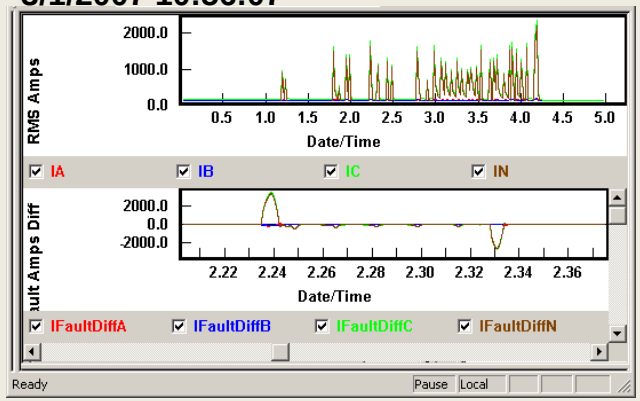
3/1/2007 09:55:31



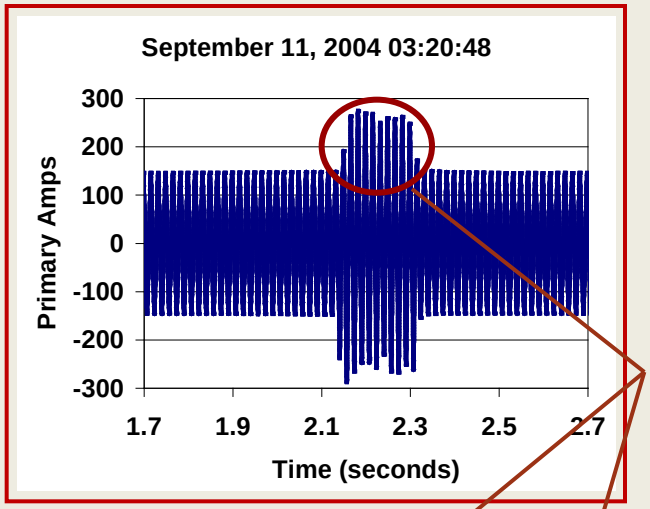
3/1/2007 10:02:00

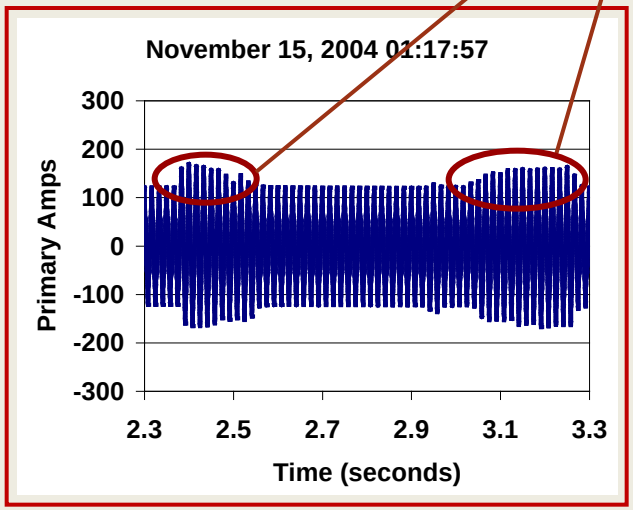


3/1/2007 10:56:07



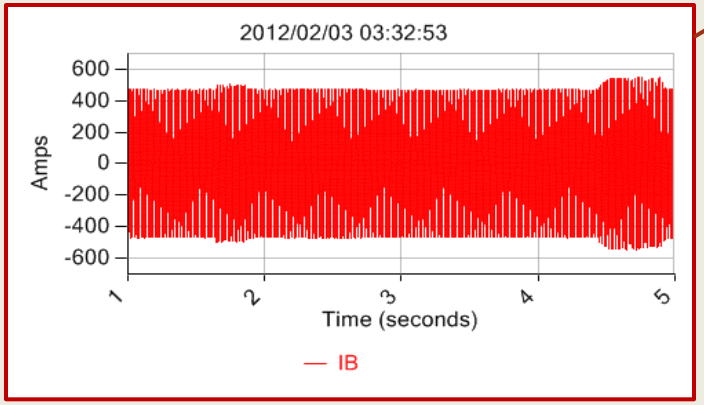
Example 2: Primary Waveforms for Failing Secondary Cable





- Silo thinking: Secondary activity cannot be "seen" in primary measurements.
- These graphs represent phase current, measured from substation CTs, with steady-state load of approximately 100Arms.
- The graphs show temporary "surges" of current superimposed on the load current.
- Similar electrical activity was recorded dozens of times over a period of three months.
- At the time, researchers did not know what this signature represented, so the condition remained uncorrected. The cause eventually was determined to be arcing on secondary service cables.
- Note: 50A x 60:1 xfmr ratio = 3kA secondary! Some episodes tripped xfmr breaker but many did not. Breaker held when reset by crew.

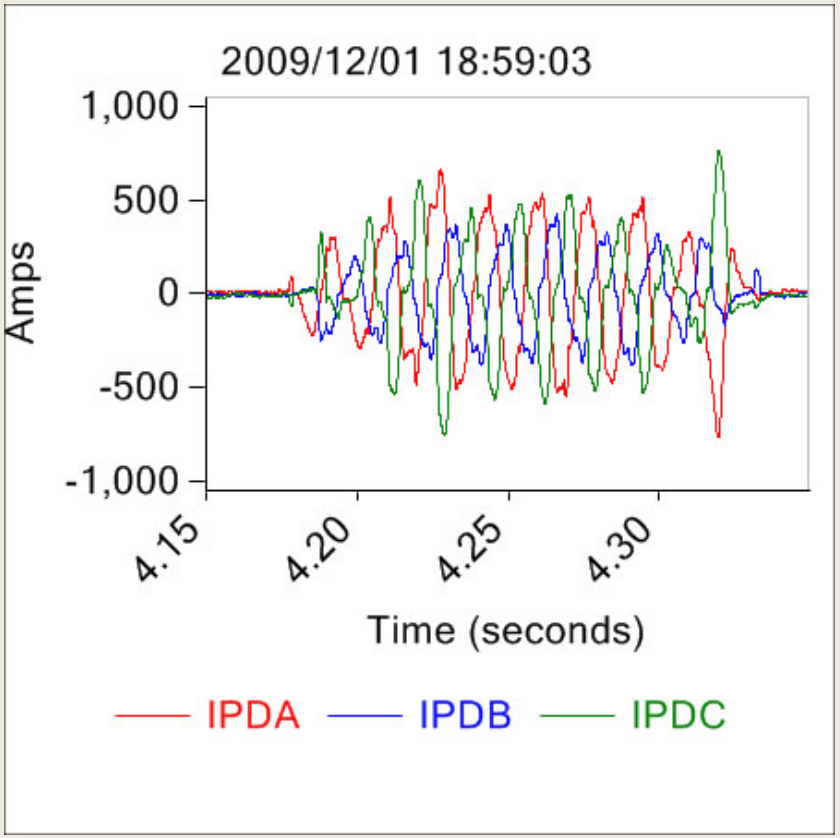
Failed Cables Found in Field



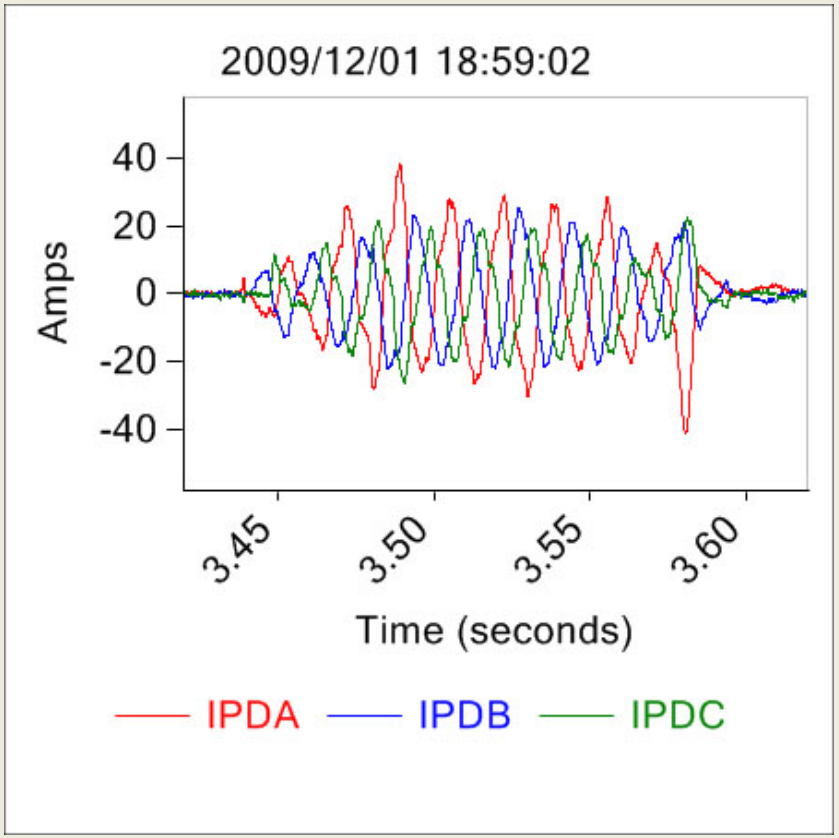
- These cables were excavated after they finally failed.
- In a more recent event, similar cables arced intermittently for 44 minutes and then burned open. Based on the previously identified signature, that failure was diagnosed correctly from substation waveforms.
- Hypothetical: Imagine telling a crew not just that a customer HAS "blinking lights" or "no lights," but also WHY. Waveform analytics can enable better diagnosis and thereby reduce incorrect diagnoses and "no cause found" incidents.

Example 3:
Secondary Network Cable Failure

Secondary network measurements

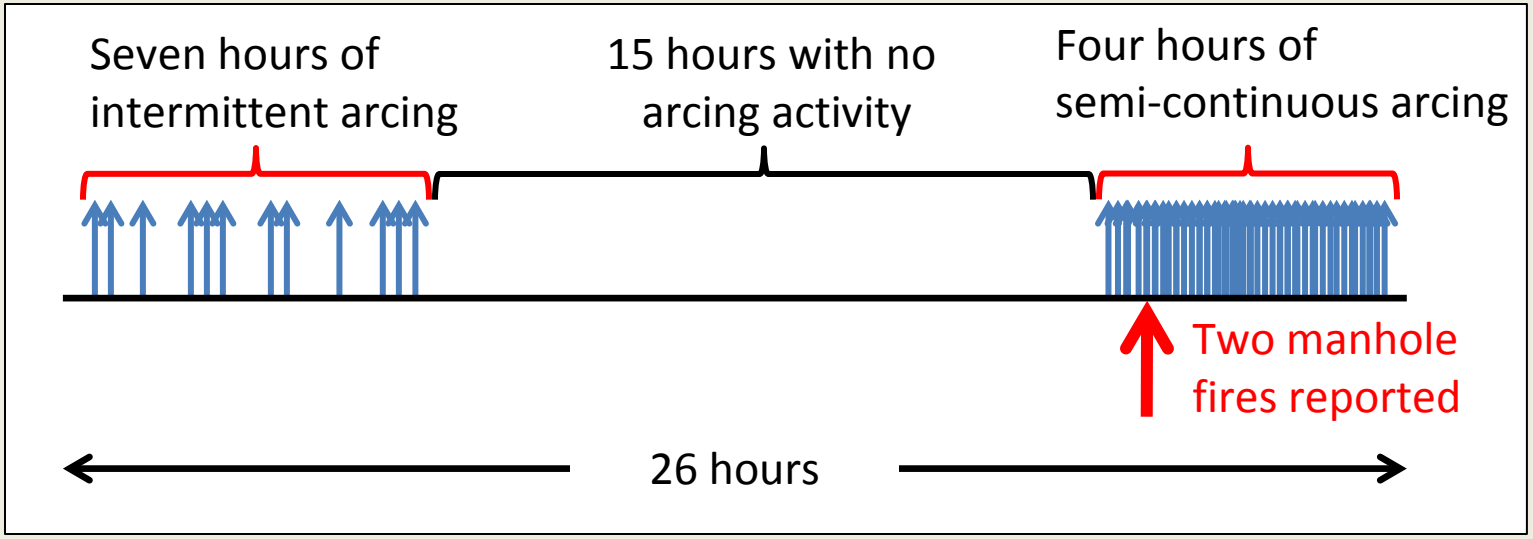


Primary feeder measurements



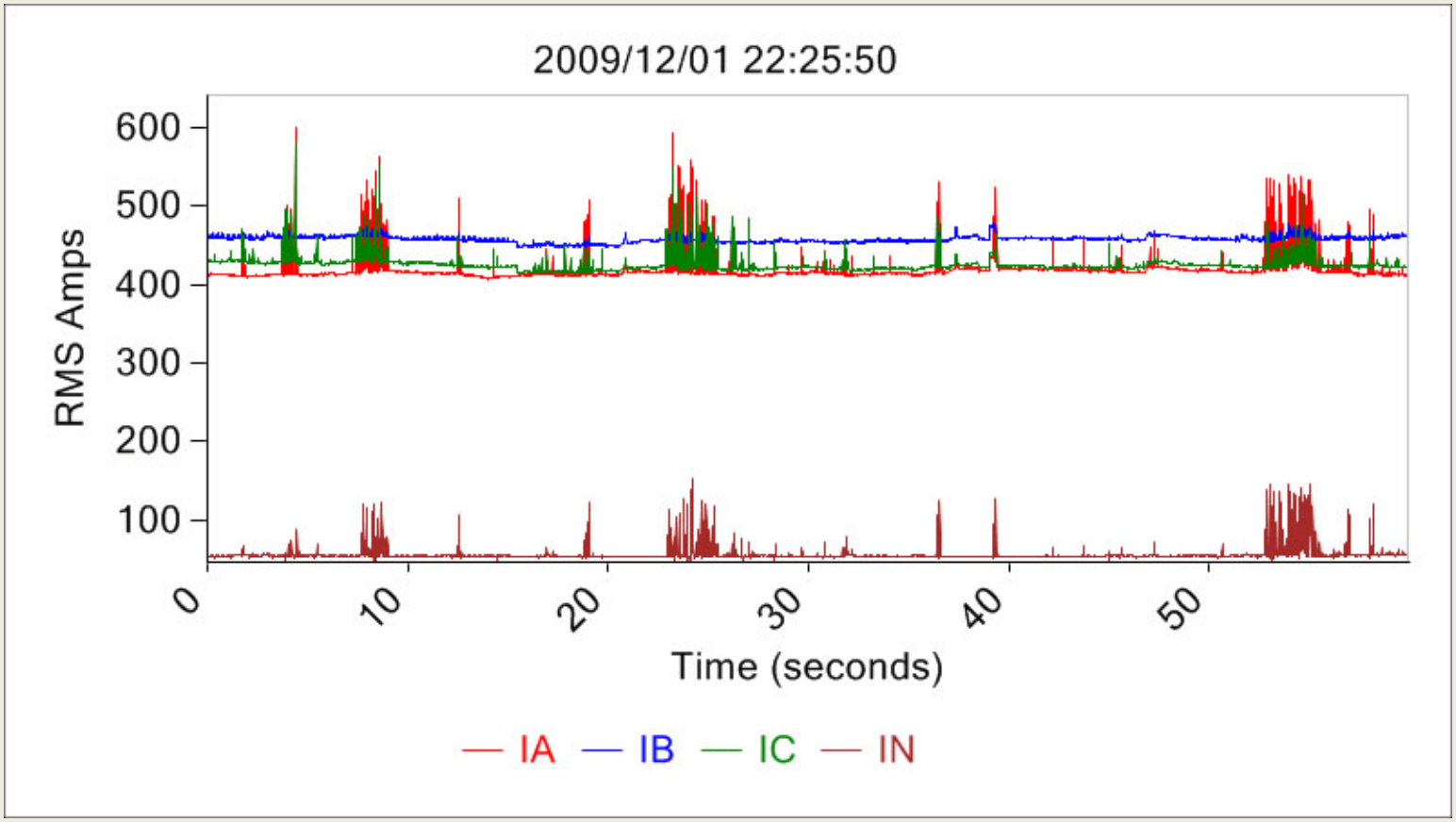
Signals have been processed digitally to remove steady-state load current, with the resulting waveforms representing *only* "event" current.

Secondary Network Cable Failure (cont'd)



- Arcing faults can be highly intermittent. In the case illustrated above, instrumentation recorded arcing intermittently for seven hours, followed by fifteen hours of quiescence.
- Arcing resumed fifteen hours later. Fire department reported two manhole fires shortly thereafter. The fault then took several hours to contain.
- The utility had *no conventional notice* of the problem prior to the fire-department report.

Secondary Network Cable Failure (cont'd)



This 60-second recording of RMS current, as measured on the secondary network, contains 400-500 amps of normal load, plus intermittent bursts of arcing current.

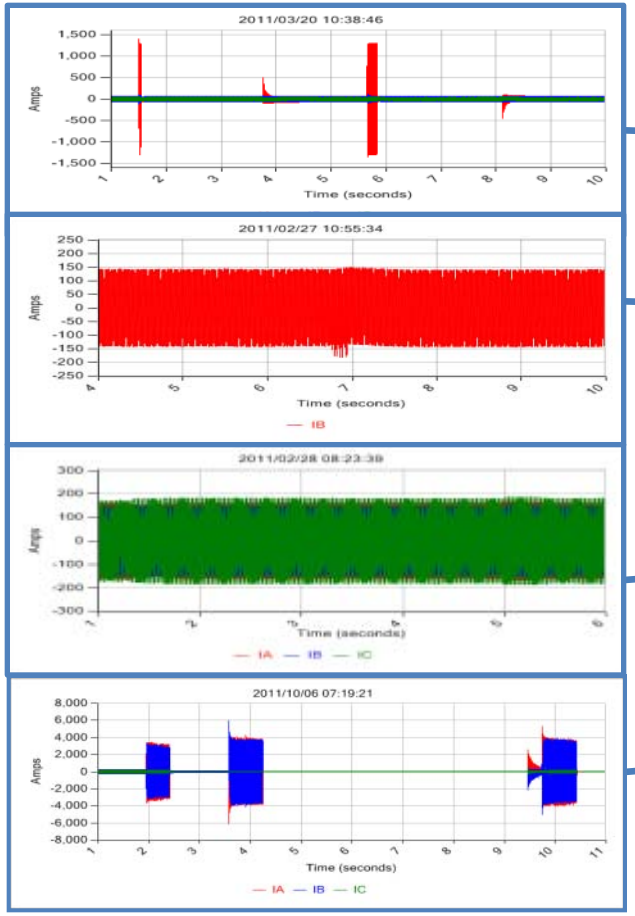
Secondary Network Cable Failure (cont'd)

Observations

- Incipient failures of cables, switches, bushings, arresters, transformers, … often can be detected from substation electrical waveforms, sometimes hours to weeks before causing trouble.
- Early warning can enable avoidance or mitigation of outages and other consequences, but…
- All the waveform data in the world does no good if you can’t analyze it (or have the analysis done for you).

Automated Analysis and Reporting

Inputs: Substation CT and PT Waveforms



Waveform Analytics

On-Line Signal Processing and Pattern Recognition Analytics

(Performed by Device in Substation)

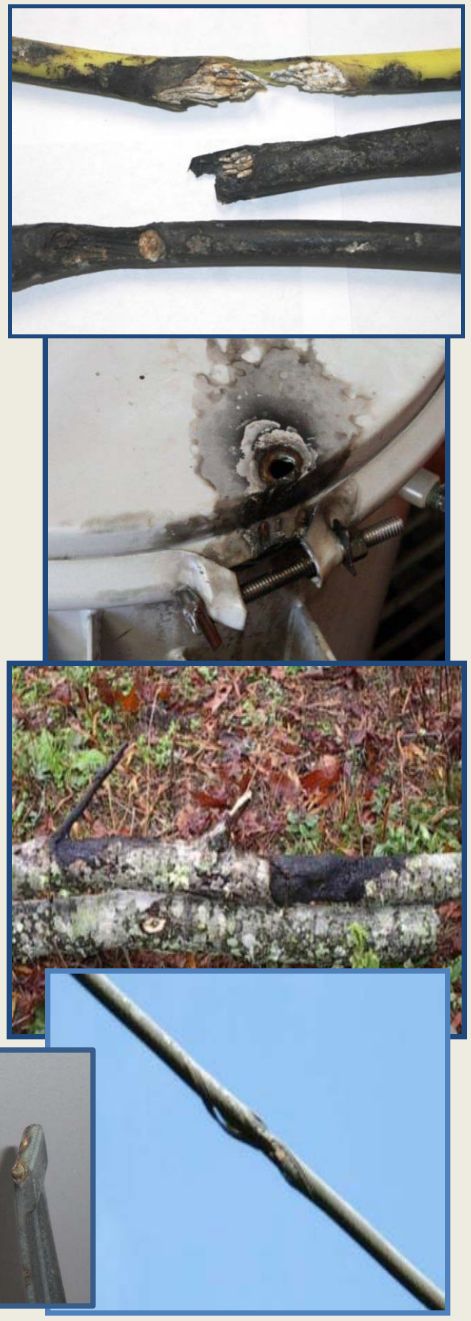
Outputs

- 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 process high-fidelity substation waveforms, to report hydraulic reclosers, switched line capacitors, apparatus failures, etc, without requiring communications to those devices.

Conclusions

- Decade-long research has identified waveform characteristics unique to failure modes of numerous line apparatus (cable failures illustrated in this presentation).
- Using waveform analytics, incipient failures often can be detected before permanent outages occur. These are failures we previously did not even know we had! Now we can avoid some of them and respond better to others.
- *T&D World's* March 2013 edition has a related story by Arizona Public Service and Pickwick Electric Cooperative.



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