Failures of Line Capacitors: Selected Case Studies

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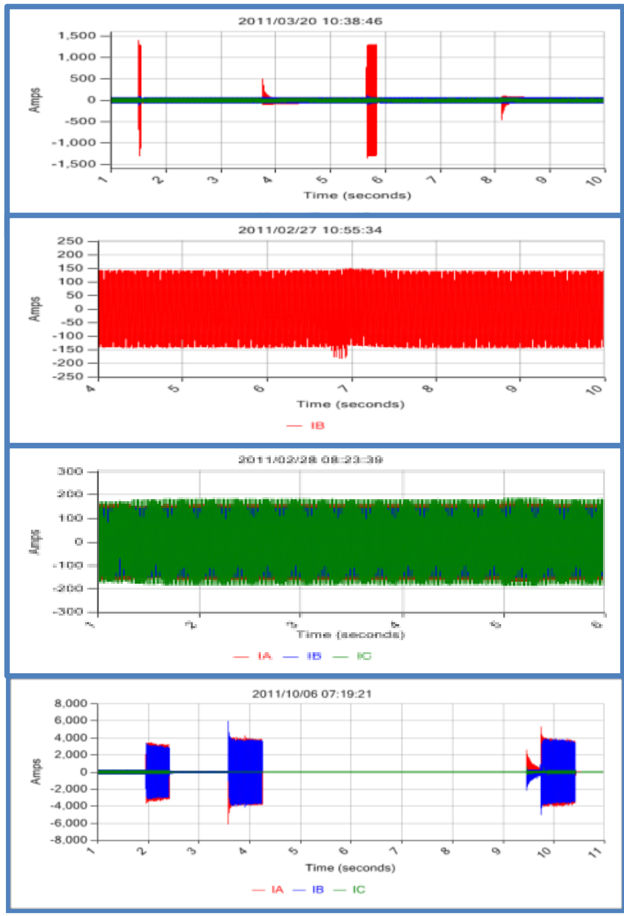
Distribution Fault Anticipation

- Distribution Fault Anticipation (DFA) is a system of waveform analytics developed at Texas A&M University over the past 15 years.
- DFA uses sophisticated waveform recording devices, installed at substations on a one-per-feeder basis connected to standard CTs and PTs to monitor the health and status of distribution circuits and line apparatus.
- DFA technology has been demonstrated on over 150 distribution feeders at 20 utility companies.

Distribution Fault Anticipation – Block Diagram

Inputs: Substation CT and PT Waveforms



Waveform Analytics

On-Line Signal Processing and Pattern Recognition Analytics

(Performed by DFA 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 applied to high-fidelity substation waveforms report on hydraulic line reclosers, switched line capacitors, apparatus failures, etc, without requiring communications to line devices.

Documented Failures

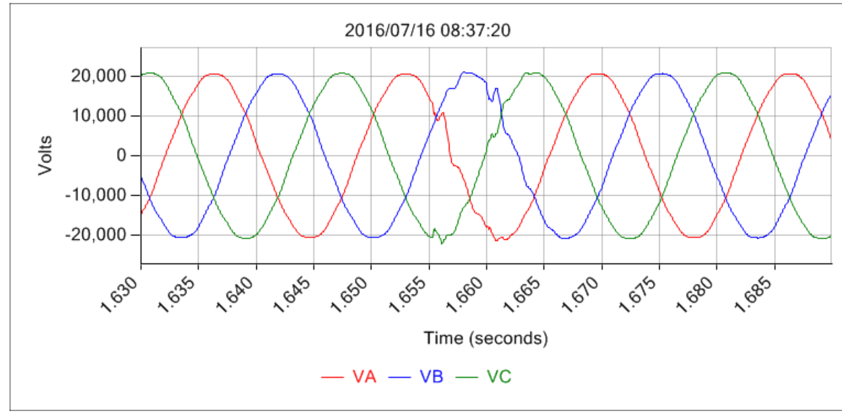
- Voltage regulator failure
- LTC controller maloperation
- Repetitive overcurrent faults
- Lightning arrestor failures
- Switch and clamp failures
- Cable failures
  - Main substation cable
  - URD primary cables
  - URD secondary cables
  - Overhead secondary cables
- Tree/vegetation contacts
  - Contacts with primary
  - Contacts with secondary services
- Pole-top xfmr bushing failure
- Pole-top xfmr winding failure
- URD padmount xfmr failure
- Bus capacitor bushing failure
- Capacitor problems
  - Controller maloperation
  - Failed capacitor cans
  - Blown fuses
  - Switch restrike
  - Switch sticking
  - Switch burn-ups
  - Switch bounce
  - Pack failure

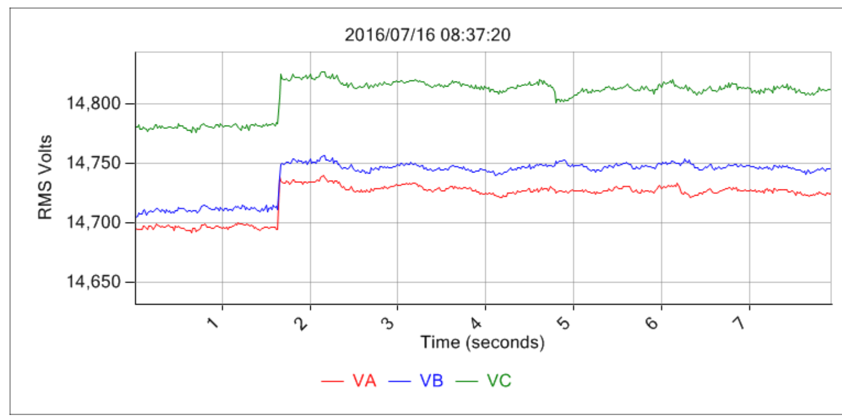
Why Capacitors?

- Given the fact that DFA detects a wide variety of failures, why focus on capacitors?
  - Capacitors are common on distribution systems and fail relatively often.
  - Capacitor failures can cause other devices on the same circuit or other circuits to fail.
  - Capacitor failures demonstrate important lessons for design of waveform analytics systems.

Case Study 1: Capacitor Controller Failure

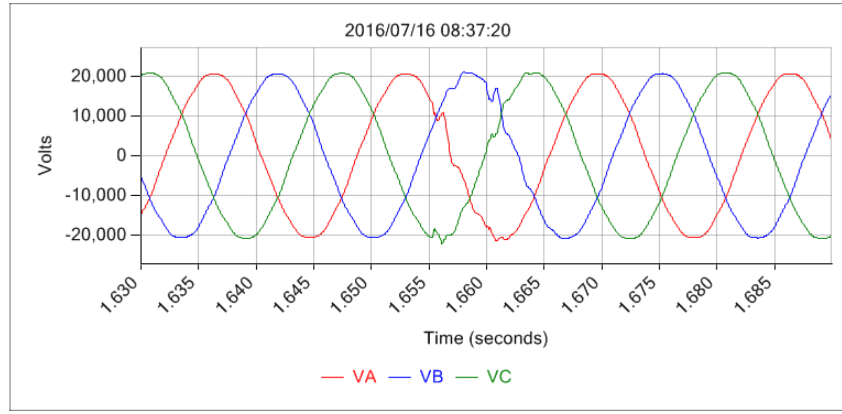
- “Normal” capacitor switching operations are characterized by distinct waveform phenomena:
  - A high frequency voltage transient
  - A step change in voltage, visible at the bus

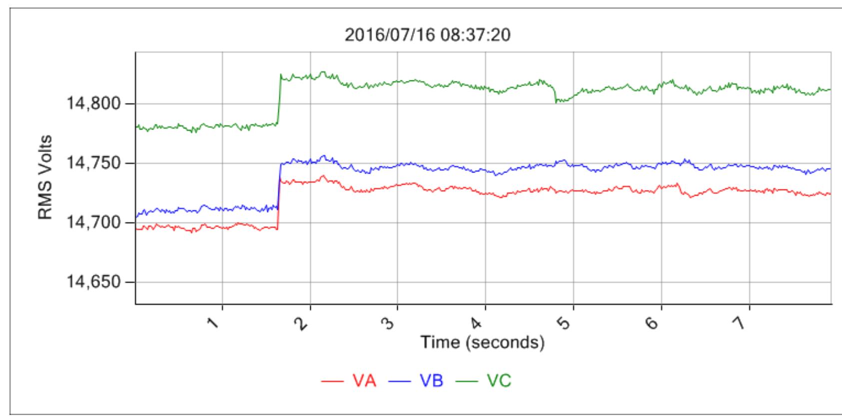




Case Study 1: Capacitor Controller Failure

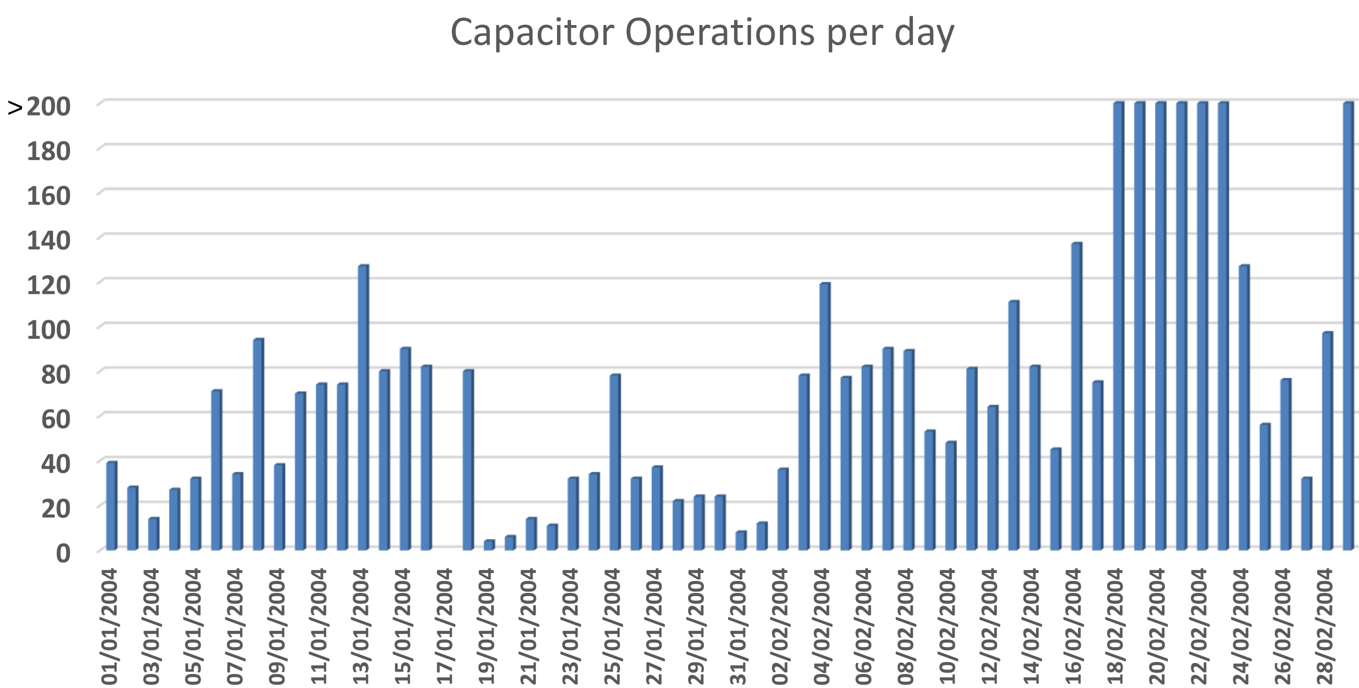
- Capacitor switching is generally controlled based on time of day, temperature, and / or voltage.
- Line capacitors typically switch ON and OFF one, or perhaps two times per day.





Case Study 1: Capacitor Controller Failure

- In 2004, a capacitor controller on a DFA monitored feeder began switching excessively, logging over 4,000 operations in a period of two months.



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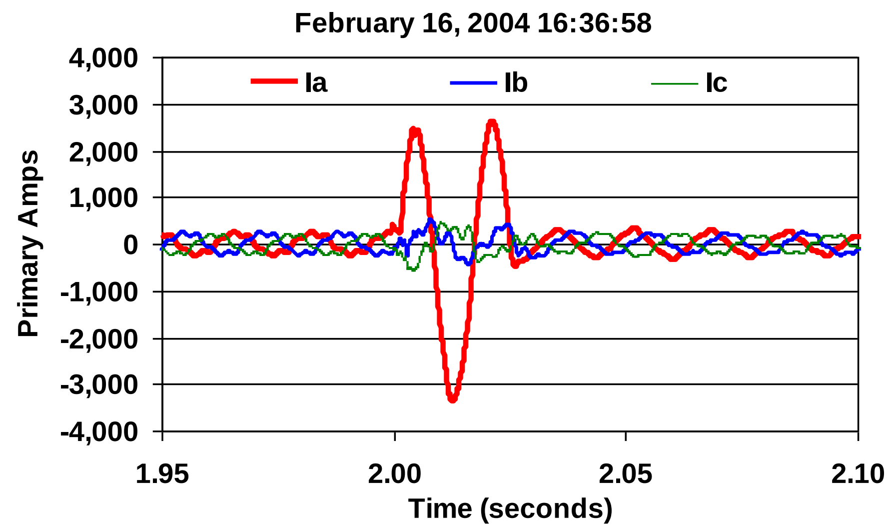
Case Study 1: Capacitor Controller Failure

- TAMU informed the utility company of the excessive operations, but because DFA was a "research" project, the utility allowed the capacitor to continue to failure.
- Initially, each individual switching event could be considered "normal" if viewed in isolation (i.e. none of the individual events *by themselves* suggested anything was amiss – they were identical to a "healthy," "normal" capacitor switching event).
- Taken together, however, it was clear even from the first day that a capacitor controller was failing (i.e. four "normal" operations in one day are truly normal – forty "normal" operations in one day are *not* normal).

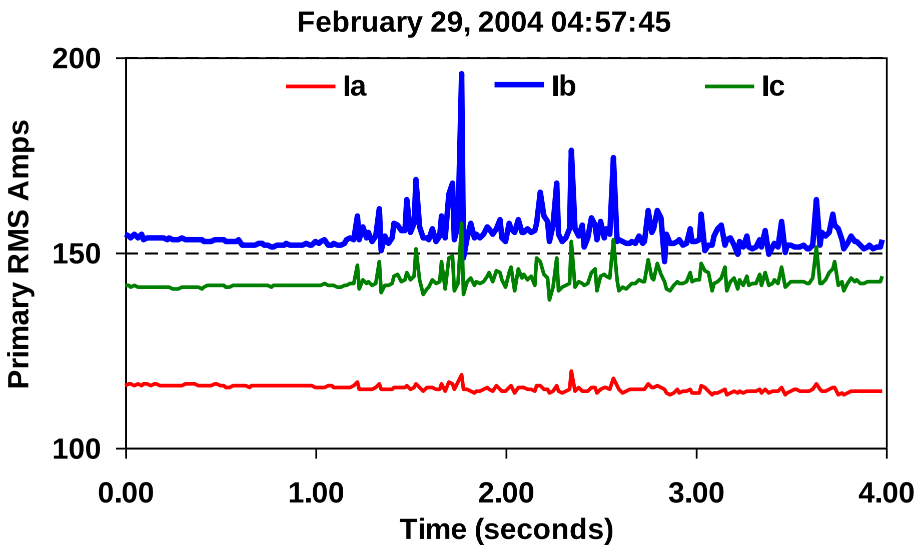
Case Study 1: Capacitor Controller Failure

- After several weeks of excessive switching, one phase of the capacitor bank failed in a short-circuit, resulting in a fuse operation. The other two phases continued switching "normally," resulting in dozens of unbalanced capacitor switching operations each day.
- After two months and thousands of switching operations, the switch on one of the two remaining phases degraded to the point where it failed to make a good connection, resulting in inter-contact arcing.



Case Study 1: Capacitor Controller Failure

- Recall that each time a capacitor switches ON, it results in a large voltage transient, which in turn creates a significant voltage transient.
- Electrically, contact arcing is similar to the switch operating many times a second, resulting in many high frequency transients in a short period of time.
- These transients create significant voltage distortion, creating serious power quality problems, and damaging other line apparatus.



Total customer complaints: 0!

Case Study 1: Capacitor Controller Failure

- After several days of inter-contact arcing, the switch failed in an open-circuit state, at which point the utility company investigated and documented failures.
- After two months of excessive switching, voltage transients caused by the malfunctioning capacitor controller resulted in the failure of:
  - The capacitor bank it was responsible for controlling
  - Another capacitor bank on the same feeder
  - A third capacitor bank on an adjacent feeder.

Case Study 1: Capacitor Controller Failure

- Lessons:
  - Don’t ignore “normal” events!
    - Shortly after this event, DFA detected 22 capacitor operations in a single day at a different utility.
    - Prompt response by the utility company in the second case avoided the escalation seen in the first case.
    - Each individual operation was “normal” but the 22 taken together were a failure!

Case Study 1: Capacitor Controller Failure

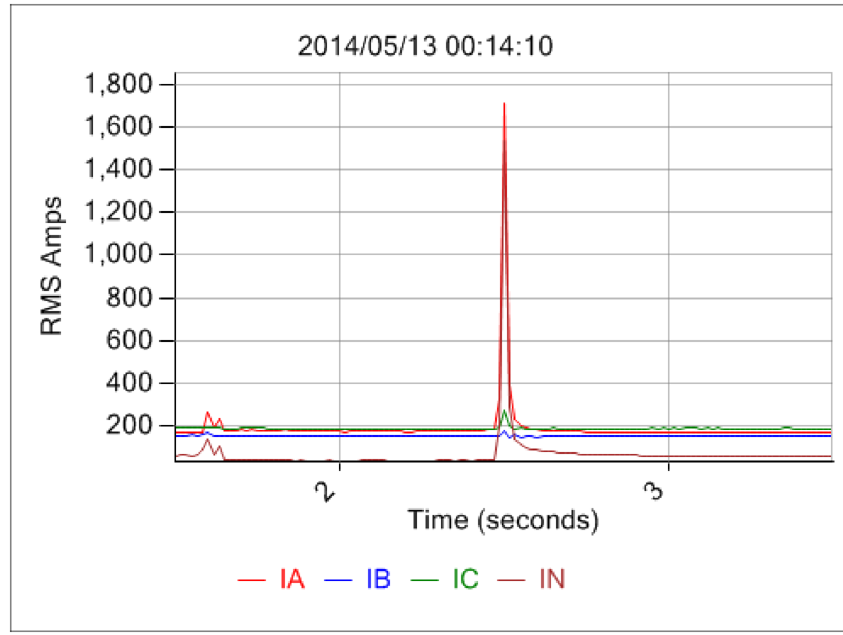
- Lessons:
  - Don’t ignore “normal” events!
  - Capacitor failures can cause other equipment to fail (including equipment on other circuits!).
    - Voltage transients affect all customers on the *bus*.
    - In this case, the failing capacitor controller caused the failure of three separate capacitor banks, including one on an adjacent feeder.
    - This is *not* an isolated incident. DFA has documented multiple examples of sympathetic equipment failure caused by capacitor misoperations.

Case Study 2: Vacuum Switch Failure

- On 11 May 2014, a DFA device detected a capacitor OFF switching operation with severe restrike.
- Capacitor restrike is a condition that occurs when a bank switches OFF, caused by a breakdown in the dielectric integrity of the switch, which allows current flow to resume momentarily.
- The following day, the capacitor switched OFF without incident.

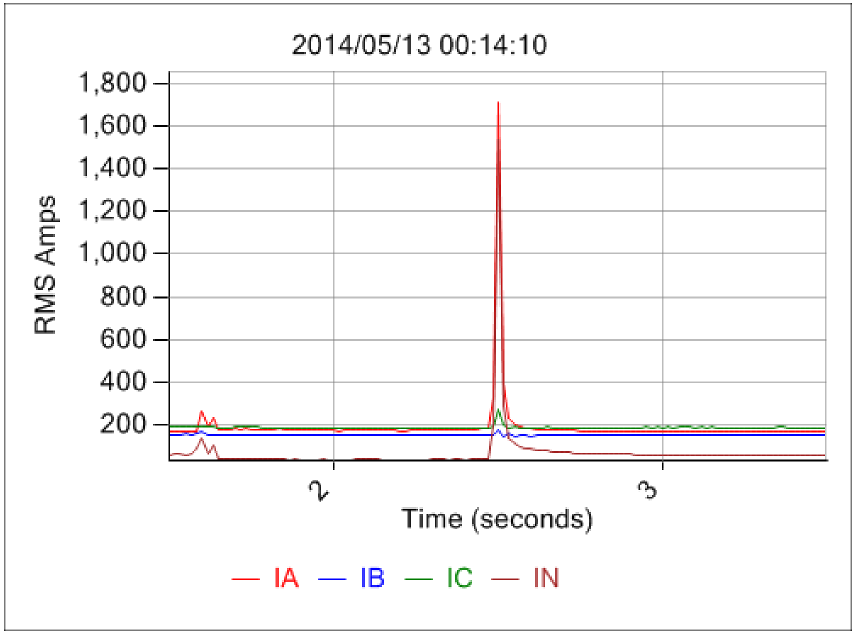
Case Study 2: Vacuum Switch Failure

- On 13 May 2014, the capacitor experienced severe restrike again, which this time escalated into an overcurrent fault, shown in the graph on the right.
- After being informed of the event, the utility serviced the capacitor, and found a blown fuse and blown lightning arrestor.



Case Study 2: Vacuum Switch Failure

- Surprisingly, when the line crew performed a high potential test on the switch, it passed.
- The event began when a capacitor switch failed to open cleanly, which caused high frequency transients, which caused a lightning arrestor to go into conduction and a fuse operation.



Case Study 2: Vacuum Switch Failure

- Lessons:
  - Waveform analytics often provide the first (and sometimes only!) notification of incipient problems.
    - In this case, the utility uses a sophisticated capacitor switching system, which would (and did) detect the next, unbalanced, switching event - but it does not (and cannot) detect abnormal switching events like a switch bounce or restrike.
    - Notification must be timely! The failure could have happened on *any* restrike. Prompt action was necessary.

Case Study 2: Vacuum Switch Failure

- Lessons:
  - Waveform analytics often provide the first (and sometimes only!) notification of incipient problems.
  - Waveform records often provide a more complete picture than field investigation alone.
    - Because the switch passed its initial hi-pot test, it is likely that absent DFA information, the utility would have simply returned the switch to service, which would create further problems.

Conclusions

- Labels like “normal” and “abnormal” are contextual.
  - You cannot know *a priori* whether an event that looks “normal” at the time will later become *important* – and thus you cannot ignore it.
  - The “normal” event you just ignored (and didn’t save) may become “abnormal” five minutes from now.
- Reporting possible incipient events needs to be automated, prompt, and actionable.
  - You can’t wait for a customer complaint to assign an engineer to analyze data from the past two weeks hoping they will discover a problem.

Conclusions

- Waveform recordings of incipient failures have limited value *after* the failure occurs.
  - Forensic analysis *after the failure* ("I have waveforms from three weeks ago that would have let me avoid the problem... if I had looked at them…") is much easier than predictive analysis *before the failure happens* ("This waveform from five minutes ago indicates that ______ may be about to fail…").
- Systems that require humans to classify waveforms or analyze data will not scale beyond "research" projects.