Failures of Line Capacitors: Selected Case Studies

Jeffrey Wischkaemper, Ph.D.
Texas A&M University
IEEE PES General Meeting
Boston, MA USA
18 July 2016
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.
Inputs: Substation CT and PT Waveforms

Waveform Analytics

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.
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 arrester 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 \textit{a priori} whether an event that looks “normal” at the time will later become \textit{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.