Study Committee B3

Substations & Electrical Installations

10208

Substation-based Waveform Analytics Monitoring System for Improved Circuit Awareness

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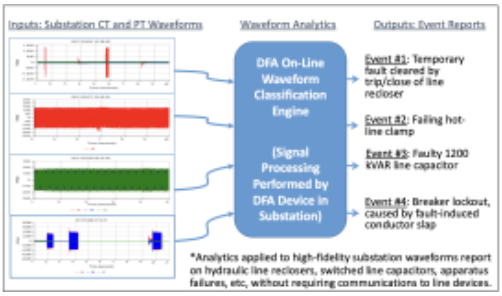
Motivation

- Distribution systems are often operated in a "run to failure" mode.
- Many apparatus failures produce distinct electrical signatures that can be detected from substations.
- Advanced waveform analytics provides the possibility for utilities to detect, locate, and repair failing apparatus before catastrophic failure occurs.

Method/Approach

- Researchers developed a sophisticated suite of algorithms (Distribution Fault Anticipation) which automatically classifies waveform inputs.
- DFA uses an expert-fuzzy system based developed from real-world failure mechanisms to detect many classes of normal and abnormal power system events.



Objects of investigation

- DFA has been deployed on over 500 circuits at multiple voltage levels, ranging from 120/208V secondary networks to 115kV class transmission.
- The majority of DFA installations have been on US (radial) 4-wire 15kV and 25kV class systems.
- DFA has also been deployed on US (radial) and EU-style 3-wire distribution systems at 11kV, 22kV and 33kV class voltage levels.
- The initial scope of DFA centered primarily around detecting faults and failures but expanded to include situational awareness more broadly.
- Some "normal" events may signal unhealthy circuit behavior when viewed in a broader context – e.g., a capacitor that switches on "normally" 50 times in a single day.
- DFA aims to provide operators with all relevant electrical activity on a given circuit, without requiring personnel to be experts in waveform recognition.

Experimental setup & test results

- Instrumented over 500 distribution circuits in 5 countries
- Currently 1,900 circuit years of exposure; the largest known database of naturally occurring faults and failures of distribution apparatus
- Early work focused on capturing waveform transients and correlating specific signatures to failure modes in collaboration with utility companies.
- As the project scaled, automated data analysis and triaging events became necessary.
- DFA has been deployed at multiple utility companies and is used to find and repair failing apparatus before catastrophic failures occur.

Discussion

- DFA has recorded and analyzed millions of normal and abnormal power system transients, including tens of thousands of faults.
- DFA is in operational use at multiple utility companies, and often provides them the only notice of an incipient condition.
- Ongoing DFA research is focused on integration of DFA into utility business-as-usual practices.
- DFA is currently leveraged by multiple utilities for wildfire risk mitigation, as it provides early warning of conditions which pose credible ignition risk.

Conclusion

- Many apparatus faults and failures can be detected well in advance of an outage or other catastrophic failure.
- When incipient failures can be detected and located, utilities can repair the underlying condition rather than allowing it to progress to final failure.
- Early repair of incipient conditions
  1. Improves system reliability
  2. Improves public safety
  3. Often lowers overall costs for utility companies
- Sensitive waveform monitoring combined with advanced analytics and signal processing enables true condition-based maintenance while providing utilities new levels of situational awareness and circuit health assessment.

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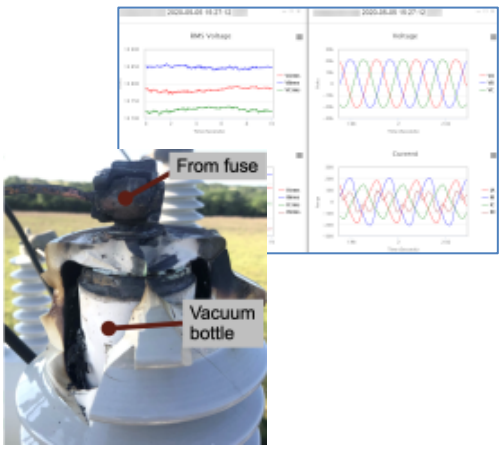
Case Study 1: Repetitive fault

- During normal system operations, a circuit experienced two unusual faults with similar characteristics 6 days apart.
- DFA automatically clustered the two faults together and emailed the utility notifying them of a potential problem.
- No other system notified the utility of an issue.
- The automatically-generated DFA report can be seen in the figure to the right.
- Based on characteristics of the second fault waveform, the utility began their search at a midpoint recloser.
- The responding crew found a dead squirrel on top of the recloser. After removing the squirrel, no further faults were observed.

Case Study 2: Capacitor Arcing

- One morning, DFA observed a line capacitor switch off "normally".
- Two seconds after the switching operation, Phase B began conducting again, but with arcing.
- Waveforms from the failure can be seen in the graphs at right. The waveforms are notable for how little activity is visible without sophisticated processing.
- DFA immediately and reliably detected the presence of capacitor arcing, and emailed utility operators notifying them of an issue.
- Based on the DFA report, the utility dispatched a crew the same day.
- The responding crew found the damaged switch shown in the image to the right. Repairs were made the same day.
- The utility had no other notice of the problem.



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Case Study 3: Substation Switch

- Early one morning DFA detected substantial series arcing on a 25kV distribution circuit.
- Unlike shunt arcing where there is an unintended current flow to ground, series arcing occurs when there is interference with an intended current flow.
- DFA provided the only notification of the event.
- The failure occurred in a very rural area but was still located by crews in approximately an hour and a half based on information provided from the DFA report.
- The utility considered the situation serious enough that they brought in an overtime crew (on the weekend) to repair the problem the same day.
- The detection and repair turned out to be fortunate, as a major storm passed through the area the following day.
- Faults and / or moisture from the storm would likely have failed the switch, resulting in an outage for 2,000 customers and possible damage to the substation.

Conclusion

Waveform analytics have the potential to transform how utilities operate their systems, but requires:

1. Sensitive triggering, an order of magnitude more sensitive than most current PQ monitors or relays.
   If the data is not recorded, it cannot be analyzed or operationalized.
2. Access to the data in near-real time.
   If the data is not analyzed and communicated before the failure, it cannot be operationalized.
3. Automated analysis.
   If manual analysis is required, the system will quickly become unscalable. Unanalyzed data is not useful.
4. Outputs that do not require specialized knowledge.
   The system should not require users to have extensive training in waveform analysis to extract meaningful value.