2016 PES GM Panel Session

Electrical Signatures of Power Equipment Failures

Power Quality Data Analytics WG

Power Quality Subcommittee

July 2016

- There is a widespread use of disturbance monitoring tools
- Disturbance data has been used to determine the health conditions of T&D equipment
- The objective of this panel session is to share experiences on detecting and analyzing various electrical signatures related to equipment failures
- The ultimate goal of this and other efforts is to create innovative condition monitoring applications based on power quality data analytics.

Presentations and Panelists

Electrical Signature Analytics for Equipment Condition Monitoring

By Wilsun Xu; University of Alberta

Signatures of Arcing and Incipient Faults from Underground Power Distribution Cables

By Tom Cooke; EPRI-US

Incipient Faults in Distribution Systems: Experiences, Use Cases, and Case Studies

By Mirrasoul Mousavi; ABB

Progressive Failure Signatures of Selected Line Apparatus

By Carl Benner (Jeff Wischkaemper) Texas A&M University

Electric Signature Analytics for Equipment Condition Monitoring

Wilsun Xu
University of Alberta
July 2016

Outline of presentation

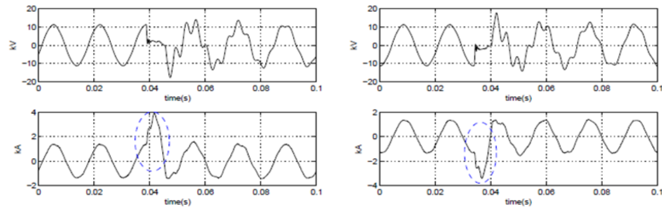
1. **Motivation**
2. **Feasibility and trends in power system monitoring**
3. **Power quality versus condition monitoring**
4. **Where to start?**
5. **Summary**

1. Motivation

- The wide availability of waveform monitors has enabled the collection of equipment failure waveforms
- People have noticed that some of the waveforms contain unique signatures specific to a particular type of equipment or failure conditions
- These signatures can be used and have been used to monitor the "health condition" of equipment
- It represents a new form of "situation awareness" for power systems

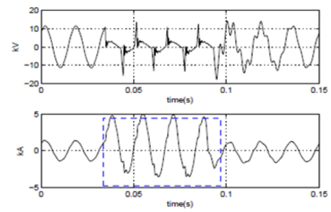
1. Motivation

Electric signatures two days before a permanent cable failure



(a) Self-Clearing Fault on 2008-11-12 at 19:40 (b) Self-Clearing Fault on 2008-11-12 at 21:11

Actual failure

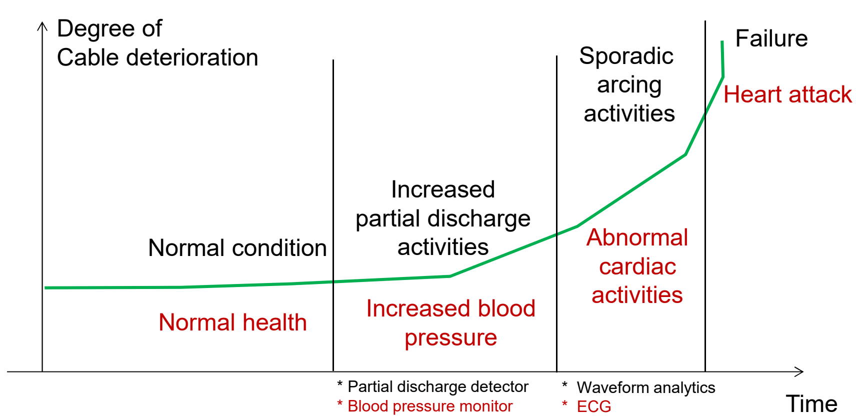


(c) Permanent Fault on 2008-11-14 at 15:51

1. Motivation

Medical analogy

Methods for cable health check and their analogies to human health check



1. Motivation

Signature-based condition monitoring was a difficult work in the past

- Failure signatures were not well understood
- Automatic signature capturing was therefore not possible
- Traditional (PQ and other) monitors have gaps in data recording
- As a result, the data is not adequate to capture failure signatures
- In summary, signature based monitoring was not possible in the past

What have changed?

2. Feasibility and trend

Three trends in power system monitoring are enabling this new form of situation awareness for power systems:

- **Gapless recording: It makes possible to perform high fidelity off-line analysis, leading to the collection of failure signatures**
- **GPS synchronized recording: It brings opportunities to isolate and compare signatures from multiple terminals of equipment**
- **Large scale waveform-based monitoring: Signature capturing is no longer a niche activity. Large scale waveform type of data collection and analysis are becoming reality**

With experiences and time, automatic signature capture will become possible in the future.

2. Feasibility and trend **Evolution of power system monitoring**

- 60Hz magnitude data (SCADA Network)
  For load flow, state estimation & other applications
- 60Hz magnitude & phase data (PMU network - WAMS);
  Some applications have been identified
- Interval E, P, V & I data (Smart Meter - AMI Network);
  For billing purpose and demand monitoring
- Waveform data (PQ network and relays);
  The most detailed data that can be collected
  For PQ monitoring and, in the future, for power quality data analytics including signature based equipment condition monitoring

2. Feasibility and trend **An application example**

Power quality versus condition monitoring

Type of Applications	Power Quality (Current Practice)	Condition Monitoring (Future Practice)
Illustrative problem	A customer complains repeated trips of its variable frequency drives	A utility company needs to determine if an aging underground cable needs to be replaced
Solution steps	1) A power quality monitor is used to record disturbances experienced by the customer 2) The data are then analyzed to find the cause of the drive trips	1) A power quality monitor is used to record voltage and current responses of the cable during its operation 2) The data are then analyzed to check if the cable exhibits abnormal V & I responses such as partial discharges. The frequency & severity of abnormal responses may be compared with those collected from various cables
Outcomes	Methods to mitigate the PQ problem are recommended	Decision on if the cable needs to be replaced is made
Nature of monitoring	Diagnostic monitoring	Preventive monitoring
Medical analogy	Find the causes and damages of a heart attack after it has occurred	Determine if a patient has the risk of heart attack

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3. Learning from the development of PQ monitoring

It is useful to study and compare the evolvement of power quality monitoring with what we want to do here

- **Power quality is concerned with the impact of electrical disturbances on equipment**
- **Condition monitoring is concerned with the health condition of (utility) equipment**
- **Both use similar type of electrical data to derive information**

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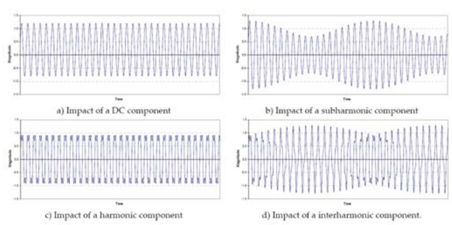
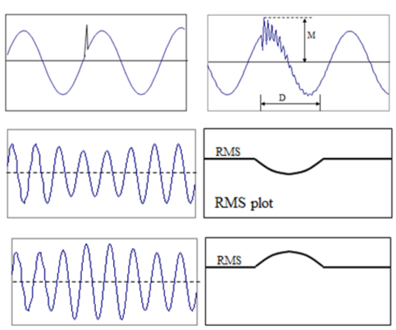
3. Learning from the development of PQ monitoring

Power quality disturbances:

More concerned with voltages

Waveform Distortions



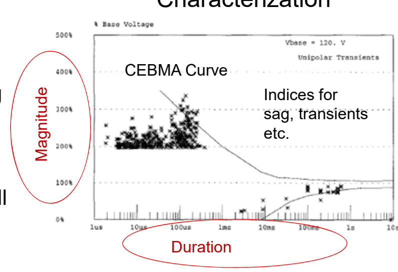


Transients

Sag

Swell

Characterization



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3. Learning from the development of PQ monitoring

Main characteristics of equipment failure/abnormal signatures

- Protection schemes often do not respond
- Abnormal current responses are more visible
- Diverse time scale: from sub-cycle waveform change to RMS value change
- Complexity in characterization: various change patterns
- Challenge in detection

3. Learning from the development of PQ monitoring

Comparing PQ concerns with condition monitoring concerns

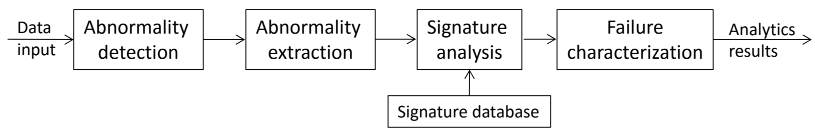
Issues	Power quality	Condition monitoring (PQ data analytics)
Focus	Severity of disturbance	Similarity of signatures
Main variable	Voltage waveform	Current waveform
Time scale	3 known scales: (transients, short-term variation, long-term variation)	From sub-cycle transients to multiple cycle RMS values
Disturbance pattern	Common patterns are already known (magnitude ~ duration)	Limited knowledge
Method to detect	Well established	To be developed

↑ "Obvious", everyone can understand

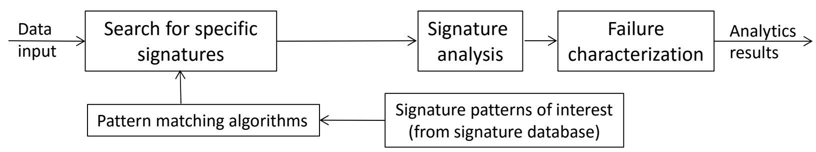
↑ A daunting task?

4. Where to start?

Two possible paths for signature based condition monitoring:



Path 1 – General purpose condition monitoring scheme



Path 2 – Special purpose condition monitoring scheme

4. Where to start?

Some researches have been conducted in the past for specific equipment or cases
Examples are incipient fault detection and capacitor monitoring

Methods to capture abnormal waveforms or failure signatures

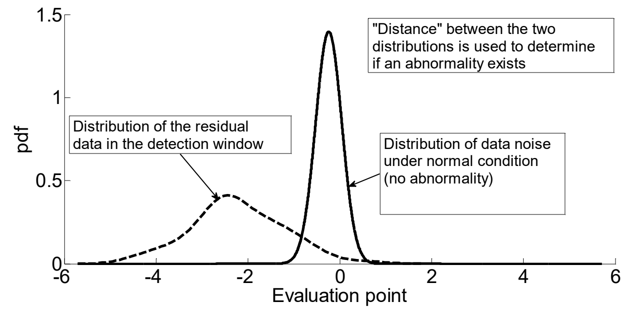
- **Current signal based methods**
- **Voltage signal based methods**
- **Composite Methods**
  - Using both waveform deviations and RMS value deviations
  - Using both voltage and current signals

Empirical approaches were used to formulate methods and establish thresholds

4. Where to start?

An example of more rigorous method under development

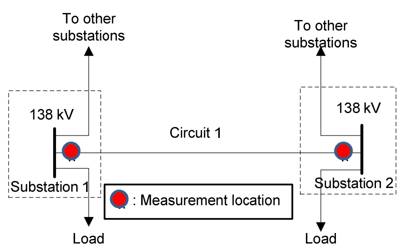
The idea is to detect abnormalities by comparing the statistical “distance” between two distributions

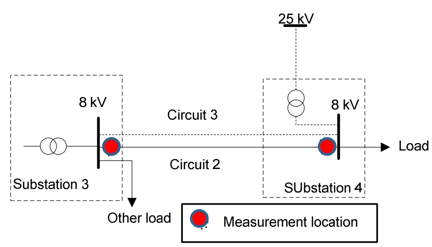


- Mainly target current waveforms
- Automatic threshold based on false-alarm requirement

4. Where to start?

Various methods have been applied to two datasets each containing 5-day gap-less data. The following two figures show the measurement locations of the data.

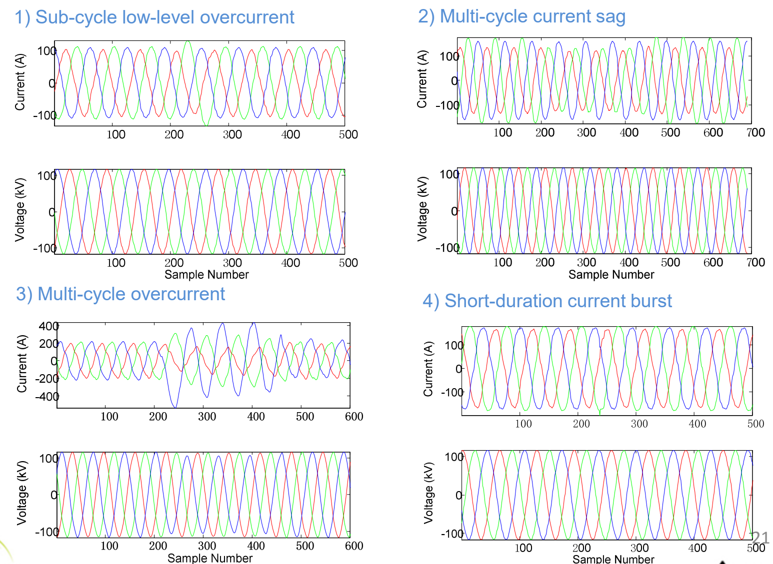




Some of the data are in the website of PQ Data Analytics WG

4. Where to start?

Sample waveform abnormalities detected



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5. Summary

- **It is just a matter of time, signature-based condition monitoring (which may also be called "proactive protection") will be developed by industry and research communities.**
- **In 10 to 15 years, we will notice that the solutions are so "obvious", just like what has happened to power quality.**
- **The trend is with us. Extensive measurement and collection of data is the future. The most detailed data that can be collected for a power system is the waveform type, disturbance data.**
- **The mere availability of such data does not make a power system more efficient or reliable. How to extract useful information from the data and apply it to support power system planning and operation are a new challenge as well as a new opportunity facing our industry.**
- **Signature-based condition monitoring, as one area of PQ data analytics, represents a highly attractive direction to expand situation awareness for power systems**

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IEEE PES Working Group on power quality data analytics

Objective:

To develop use-cases, recommendations and guidelines for extracting information and knowledge from the power quality disturbance data for applications beyond traditional power quality concerns, such as condition monitoring and fault diagnosis.

Scope:

1) Promote and support PQ data analytics research and application activities,
2) Share data and experience on PQ data analytics,
3) Develop guidelines for PQ disturbance analytics including algorithms, tools and monitoring networks.

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