21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2015 Grid of the Future Symposium

Automated Fault Location

T. LAUGHNER
Tennessee Valley Authority
USA

SUMMARY

Grid modernization marketing has elevated customer expectations of power quality and reliability. At the same time, Grid modernization technology has facilitated the installation of new metering to provide better situational awareness and faster response time when faults occur. With the installation of new meters, new tools have been developed to sift through the massive quantities of data being recorded in order to readily identify and call attention to actionable information.

This paper shares case studies where data collection systems were in place, but there were no automated tools to call attention to issues which resulted in equipment failure. Then the paper describes the tools deployed in order to automatically perform fault location and analysis. Finally, the paper makes some assertions about how the platform could be used for asset and incipient failure detection.

KEYWORDS

power quality
analytics
fault location

tllaughner@tva.gov

Customer's expectations of power quality and reliability have evolved over the past few years. This evolution has occurred for a variety of reasons which can be distilled into two broad areas: marketing and technology. New power technologies like distributed generation, community energy storage, electric vehicles, and even lighting have made customers more aware of the options available to generate and use power within their homes and businesses. Meanwhile, government grants and utility investment in smart meters and grid modernization efforts have also made customers aware of the role of electric infrastructure. All of this has served to increase expectations on the utility.

On the utility side, there has been significant investment not only in smart metering, but in asset health monitoring. Utilities have made these investments to reduce operational and capital expenditures by extending the life of the assets in service and extending maintenance intervals through equipment health monitoring. The result of this investment is copious amounts of data being generated. So much data is being generated and collected that analysing it manually is impossible.

To realize the benefits of the utility investment, new analytical tools are needed turning mere data into readily actionable information. For example, a single digital fault recorder (DFR) may only generate 3 Megabytes (MB) of data per day. However, a fleet of 250 DFRs generated aver 750 MB per day. Similarly, a single power quality meter or smart revenue meter may also generate 3 MB per day. Consider a fleet of 1000 power quality monitors or a fleet of one million smart meters and quickly realize that the quantity of data rapidly jumps to something that needs to be measured in Gigabytes or even Terabytes!

However, existing utility data systems are not designed to process this quantity of data. The result is missed opportunity and worse equipment misoperation and worse still catastrophic equipment failure. Consider the following avoidable events: capacitor bank switch failure, PT failure, and seven line operations on the same line over a 3 year period.

In September of 2012, a capacitor bank switch was opened to take a 161kV Cap Bank offline. As can be seen in Figure 1 below, about six cycles after the open command fails to open the B-phase switch, the breaker protecting the cap bank opens removing the cap bank from service. Upon investigation of the waveform captured by a nearby power quality monitor, it was determined that low SF-6 gas in the B-phase switch was the cause. The conclusion was later confirmed by field inspection.

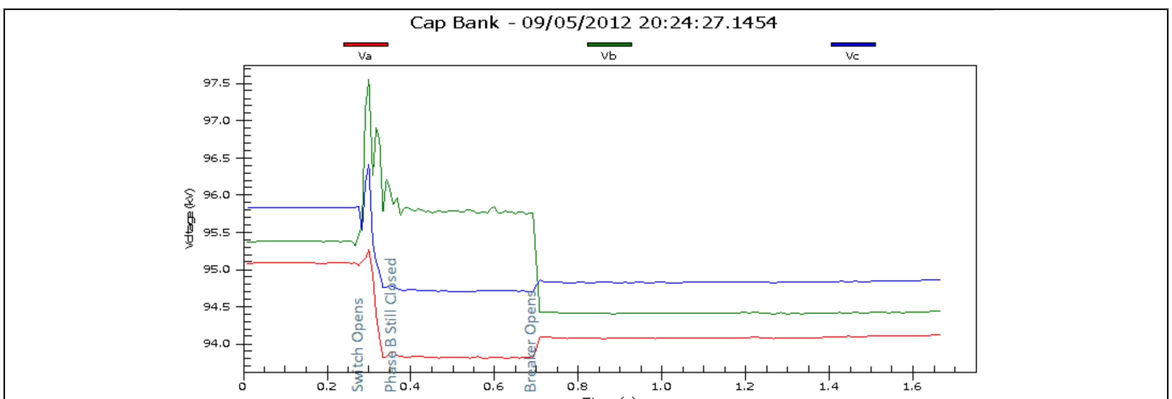


Figure 1

In January of 2013, a 161kV main bus VT failed. Upon investigation of data captured by a nearby power quality monitor, personnel noticed that the VT had been arcing for nearly two full weeks prior to the catastrophic failure. Figure 2 shows the waveform data captured by the PQ monitor just moments before the event. Figure 3 shows the waveform data captured by the PQ monitor two weeks before. The only difference is how frequently the waveform is perturbed.

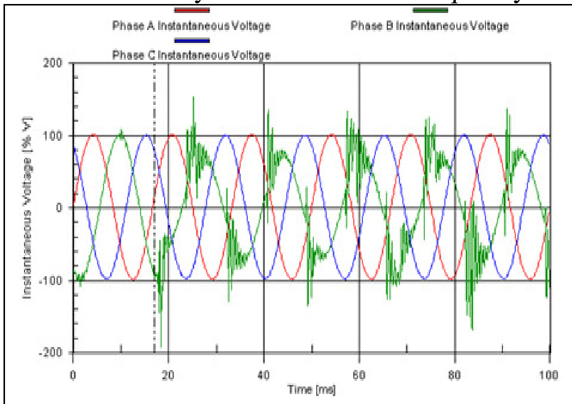


Figure 2 - Waveform Just Before The Failure

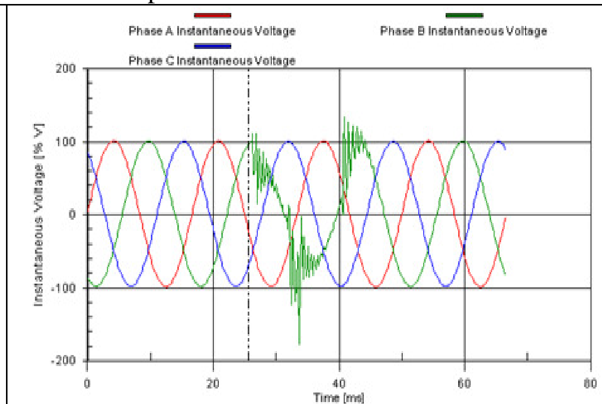


Figure 3- Waveform Two Weeks Before

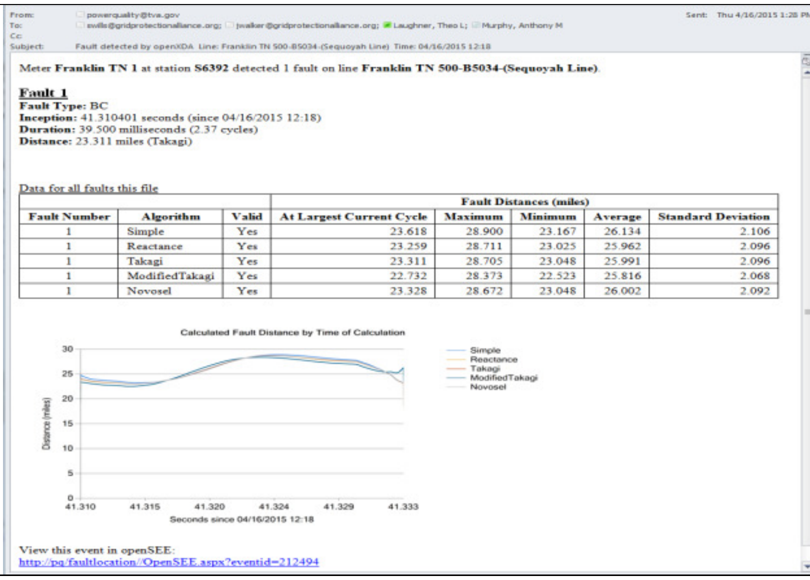
In the previous two examples, the failures were found and the root causes identified. In the next example, a transmission line had breakers operate seven times over a three year period. The faults had all been classified as unknown events. These types of events are particularly disturbing to utilities because if a root cause is not identified future events may occur.

A transmission line first operated in January of 2010. Subsequent faults occurred in February of 2010, August of 2010, February of 2011, July of 2011, and April of 2013. As staff considered the historical events additional information came to light. All but one of the events were on the C-Phase conductor. All of the events were in the early morning hours. All but one of the events had a calculated fault location within a seven structure section of the line. Ground patrols identified two damaged insulators within the calculated location. The insulators were damaged in such a way that aerial patrol could not observe the damage.

In all three cases, there was data to support field staff. However, no one was looking at the data! These events demonstrate the need for analytical tools to distil information from the data collected and alert relevant personnel so that action can be taken before catastrophic or unnecessary repeat failures occur.

In addition to the historical performance of the asset, there are other key pieces of information that would be useful to integrate with an analysis tool. Weather, for example, would provide additional context about the operating conditions of the equipment. System configuration (i.e. breaker status, line configuration, system topology, etc.) might also play an important role in identifying where the issue occurred or the extent to which an event would impact the system.

OpenXDA and the Open PQ Dashboard were developed to address the data to information gap. OpenXDA is an open source, eXtensible Disturbance Analytics platform. The vision for the platform is to provide a suite of tools to automatically analyze data. The platform can serve as a broker between many third party developed modules that will enable customized reporting on a variety of application types. Initial testing of the platform was conducted by encoding several fault location algorithms into the tool. OpenXDA reads the data and generates a report informing the report recipient as to the location of a fault on a power line as shown in figure 4, below.



From: powerquality@tva.gov
To: swills@gridprotectionalliance.org; jwalker@gridprotectionalliance.org; Laughner, Theo L; Murphy, Anthony M
Cc:
Subject: Fault detected by openXDA Line: Franklin TN 500-B5034-(Sequoyah Line) Time: 04/16/2015 12:18
Sent: Thu 4/16/2015 1:28 PM

Meter **Franklin TN 1** at station **S6392** detected 1 fault on line **Franklin TN 500-B5034-(Sequoyah Line)**.

Fault 1
Fault Type: BC
Inception: 41.310401 seconds (since 04/16/2015 12:18)
Duration: 39.500 milliseconds (2.37 cycles)
Distance: 23.311 miles (Takagi)

Data for all faults this file

			Fault Distances (miles)				
Fault Number	**Algorithm**	**Valid**	**At Largest Current Cycle**	**Maximum**	**Minimum**	**Average**	**Standard Deviation**
1	Simple	Yes	23.618	28.900	23.167	26.134	2.106
1	Reactance	Yes	23.259	28.711	23.025	25.962	2.096
1	Takagi	Yes	23.311	28.705	23.048	25.991	2.096
1	ModifiedTakagi	Yes	22.732	28.373	22.523	25.816	2.068
1	Novosel	Yes	23.328	28.672	23.048	26.002	2.092

View this event in openSEE:
http://pq/faultlocation//OpenSEE.aspx?eventid=212494

Figure 4 - Fault Location Email

In addition to reporting the location of a fault, OpenXDA stores data in a database which is then read by the Open PQ Dashboard. The Open PQ Dashboard is also an open source tool that provides a way to visualize where there are issues on the system. In addition, the dashboard generates a heat map which reflects how widespread the issue may be in a geographic context as can be seen in figure 5, below.

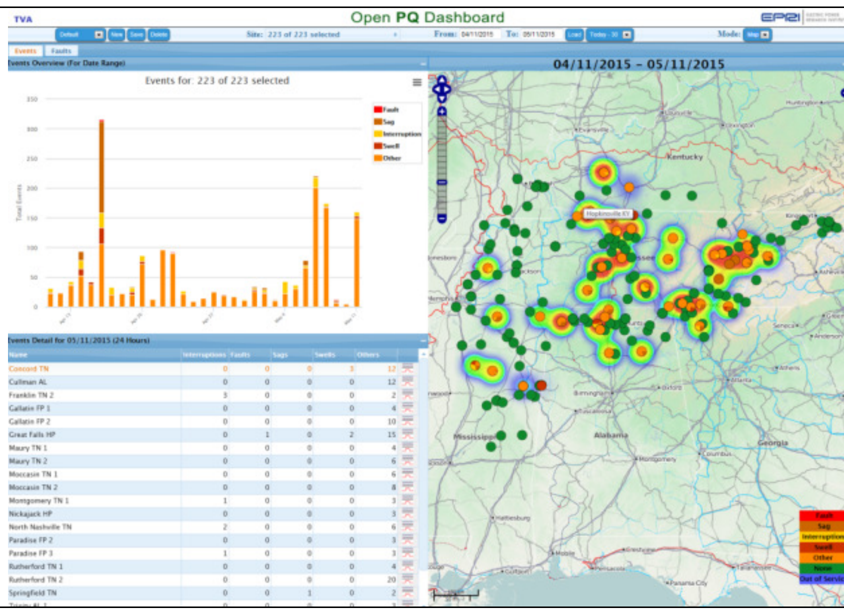


Figure 5 - PQ Dashboard Display

In conclusion, automated analytical tools are essential for the modern grid. There are too many devices collecting too much data to be evaluated manually. Customers expect high reliability and quality from utility infrastructure. Automation and visualization platforms bring the promise of reduced downtime and increased power quality.