Real experience using power quality data to improve power distribution reliability

by Lance A. Irwin

Executive summary

Reliability has always been the central focus of network operators. However, today they must also focus on sustainability and efficiency. Maintaining the balance between quality, reliability and efficiency requires new tools for the network operator. This paper describes a system that utilizes various methods for monitoring and reporting power quality information to help utilities maintain the balance of quality, reliability, and efficiency. Examples of real-world uses are given as well as quantified benefits where available

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Summary

Abstract

Reliability has always been the central focus of network operators. However, today they must also focus on sustainability and efficiency. The ever increasing use of intermittent renewable energy sources and the need to reconfigure the network based on efficiency seem to counter the quality of supply standards set forth by regulators. Maintaining the balance between quality, reliability and efficiency requires new tools for the network operator. This paper describes a system that utilizes various methods for monitoring and reporting power quality information to help utilities maintain the balance of quality, reliability, and efficiency. Examples of real-world uses are given as well as quantified benefits where available.

Index Terms—Fault location, power distribution reliability, power system monitoring, power system transients

Introduction

Depending on the region of the world and the regulation in place, the utility may have to meet a specified reliability target with penalties for exceeding this target or they may simply impose their own target as a way to measure performance toward customer satisfaction goals. The most common methods of measuring electrical network reliability deal with the total number of outages and the duration of those outages over a specified time. Again, depending on regulatory or internal concerns, utilities may choose to implement more detailed measures at the customer level, on specific values, or segment outages into categories.

The most common indices are System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI). These indices deal in terms of the system level averages and are good benchmarking indices for the industry. Utilities have found further need to define more granular indices to help in the management of their networks and decisions for reliability based capital expenditures. Some examples of other indices include Customer Average Interruption Duration Index (CAIDI), Momentary Average Interruption Frequency Index (MAIFI), and Customer Experiencing Multiple Sustained and Momentary Interruptions ($CEMSMI_n$)[1].

All of the indices give a baseline for performance and give utilities a method for targeting improvements. The targeting efforts must focus on preventing faults from occurring which impacts SAIFI or locating and repairing faults faster which targets SAIDI. Power Quality information has historically been used to for post-mortem analysis to determine root causes of problems and to mitigate the future occurrences or impact of those problems and thus has targeted SAIFI. In recent years, power quality information has been used to locate faults to help speed the restoration and improve SAIDI. New research and demonstrations are proving that power quality information can be used to detect the signatures of failing equipment and alarm the network operator in time to prevent a fault from ever occurring which will improve not only SAIFI but other indices like MAIFI and $CEMSMI_n$.

[1] IEEE Guide for Electric Power Distribution Reliability Indices, IEEE Standard 1366-2003, Dec. 2003.

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Fault analysis

Power quality information is used in fault analysis to help improve reliability.
The data is either used before faults occur, say in an asset management role or after a fault occurs. Pre-fault and post-fault analyses are both effective ways of using power quality information to impact the reliability of a distribution network.

Post-Fault Analysis

Many methods are used and much research has been done to try to detect and isolate faults to restore service more quickly. Protective relay schemes in substations, deployment of faulted circuit indicators along medium voltage feeders, and more recently Fault Location, Isolation, and Service Restoration (FLISR) schemes which automate the network switching are all attempts by network operators to reduce SAIDI by deploying hardware, software, and communications. Using waveforms and symmetrical components analysis on hardware to locate faults is difficult and inaccurate on complex distribution networks. Better location accuracy requires the addition of a communications network and software algorithms. The Electric Power Research Institute in the US has worked with several utilities to study the capabilities of reactance based location techniques and voltage drop techniques. The studies show that each method has merits and drawbacks but it is clear that combining hardware, software, and communications to take power quality data and turn it into actionable information for reducing outage durations is possible[2].

Pre-Fault Analysis

Distribution Fault Anticipation (DFA) projects are underway at universities and in field trials around the world. Work from the US and Korea[3,4] show actual cases of finding bad capacitor controllers, loose connections, failing transformers, mis-aligned switches and more. These efforts show that using Power Quality data to locate problems before they become outages is possible but requires powerful hardware, good communications, and software.

2 M. Tremblay, M. Demers, G. Simard, M. McGranaghan, and J. Kim, «Using waveshape analysis for fault location in distribution systems,» Utility Automation, pp. 40-44, Aug. 2009.

3 C. Wallis, "Distribution fault anticipation for distributed applications," presented at the EEI TD&M Conference, Savannah, Georgia, USA, 2008.

4 I.K Moonjong Jang, H.J. Song, H.J. Lee, J.Y. Kim, "Current practice and prospect of the distribution automation system of Korea," presented at the Gridwise Architecture Council Forum, Denver, Colorado, USA, 2009.

A real-world example system

Jacksonville Electric Authority (JEA) operates generation, transmission, and distribution assets to serve more than 360,000 customers in the city of Jacksonville, Florida, USA and surrounding areas. Known in the North American power industry as a leader in adopting technology to provide reliable and low cost energy to it's customers, JEA has been utilizing smart grid technologies like advanced metering infrastructure, computer automated work force management, and active outage notification and management to improve system performance and personnel response time in an effort to mitigate outage times to improve key performance indicators such as SAIDI and CAIDI.

The Power Quality System

JEA decided to install a wide area power quality monitoring solution to ensure they were delivering the clean power required for a twenty-first century economy. Initially, the system was limited to monitoring equipment and data collection software. JEA quickly became aware that manually pouring through thousands of records generated by the power quality monitors was not efficient. Useful information was lost among the forest of waveforms and alarms. JEA decided to enhance the PQ monitoring system by installing a reporting tool that could roll up data based on known events, summarize Fig. 1. Wide area power quality monitoring system architecture statistics, and provide a dashboard view for multiple users based on a specific area of interest. An architecture for the system is shown in Fig. 1.

Hardware

At the writing of this paper, the hardware in the system consisted IEC 61000-4-30 Class A compliant power quality monitors located at interties between generation and transmission, transmission and distribution, and on large industrial sites. The monitors are ION7650 or ION8600 devices provided by Schneider Electric. Revenue data is also utilized for billing and SCADA purposes. The breakdown of total monitors is as follows: 17 Generation; 73 Transmission and Distribution; 92 Industrial.

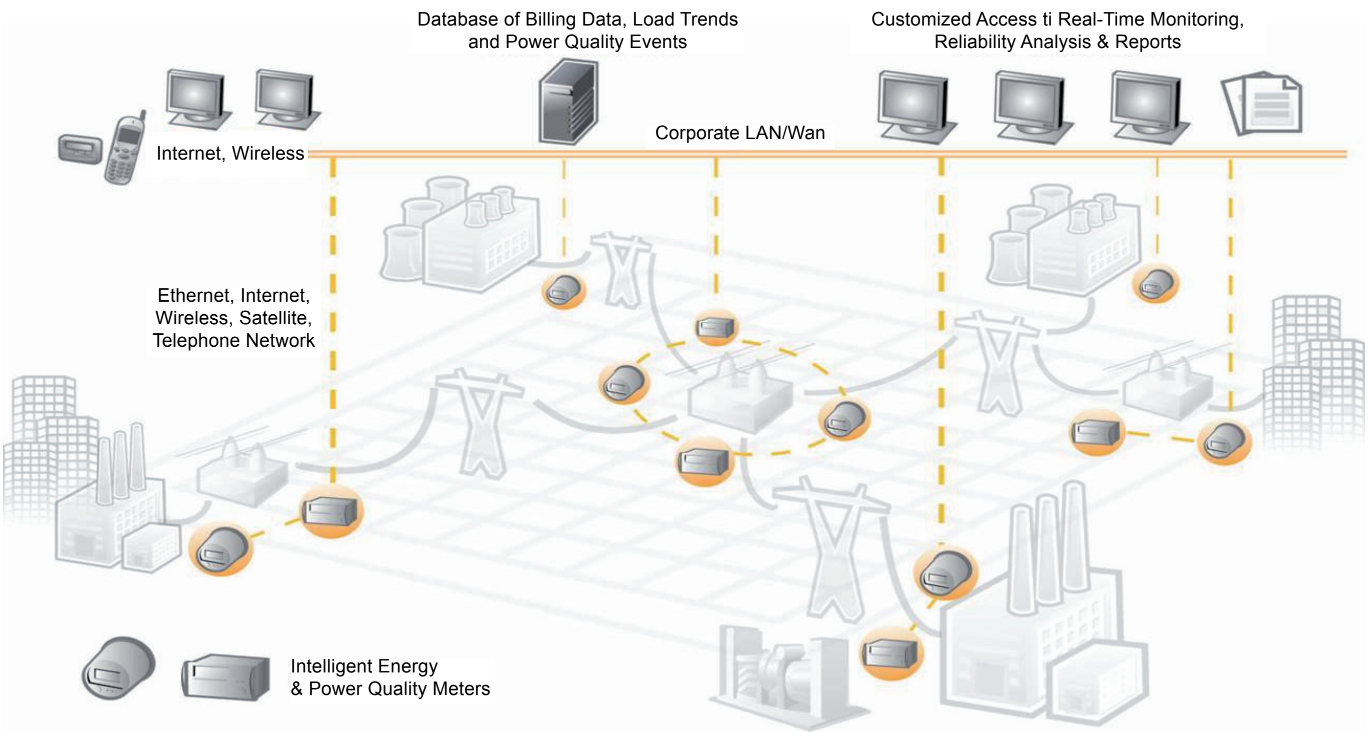

Fig. 1_ Wide area power quality monitiring system architecture

Communications

As with most systems utilized by electric utilities, the PQ system has grown and will grow over time. Availability of communications infrastructure varies with location and time of installation. One requirement for the system was to handle multiple forms of communication seamlessly while allowing for easy upgrade as new technologies were introduced. Today, JEA has devices communicating with software with multiple protocols and through multiple media simultaneously. For example, in the Distribution substation, a device will use DNP3.0 over Ethernet to communicate with SCADA while allowing a MODEM connection to the billing software, a GPRS connection to the Power Quality Analysis software, and serve as a gateway for SCADA to master local devices over a serial connection.

Software

Initially, the system consisted only of data collection software that allowed viewing and analysis of waveforms and data. Reporting existed but the system was dedicated to one vendor. Use of the system was limited to compliance monitoring for quality of supply and post-mortem analysis of problems. As the system grew, the ability of the reliability engineers at JEA to review all of the data and make decisions was restricted. Also, while the value of the system for customer service was meeting the intended ROI, JEA felt there were better uses for the data to make informed asset management decisions BEFORE there was a problem that caused an interruption.

Knowing that further growth of the system was certain, a requirement for the software was to be easily scalable from the current size to many hundreds of devices more.

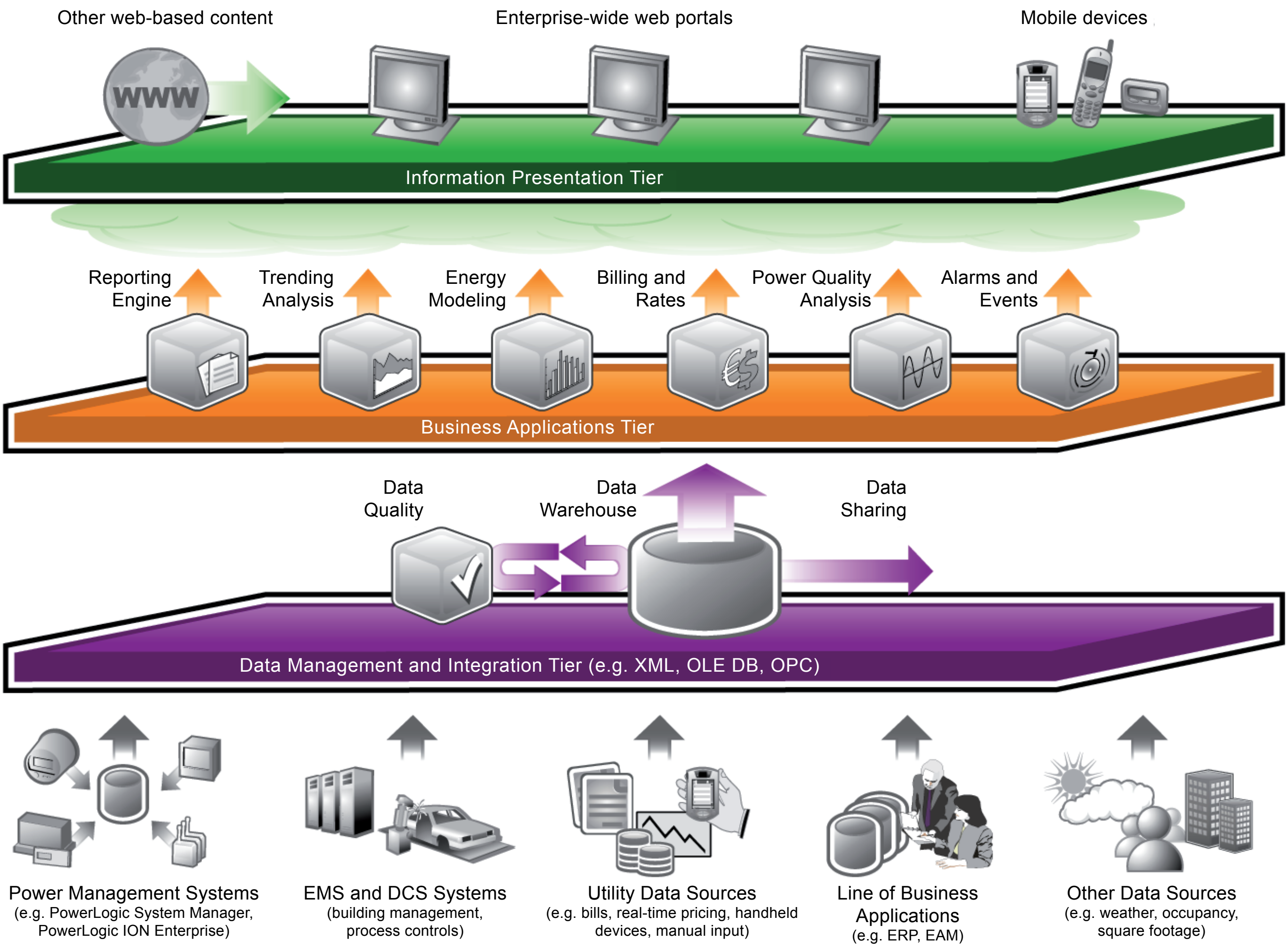

Fig. 2 _ Software architecture of a wide area power quality monitoring system

Also, an “open” platform was required, as JEA wanted to bring data from multiple sources into the system and to not be tied to one hardware vendor, one protocol, or one communication media. Understanding that different stakeholders in the utility needed to see the data in different ways, JEA required that the system allow configurable dashboard views over the web to allow users to see the data in a manner that helped them make decisions. These dashboards should include the ability to see the data in a geographical view, via the web, to run user-defined reports, to classify event data, and to perform analysis.

Simply presenting data is a common feature in many software packages and would not benefit JEA beyond the existing software they were using. The final requirement for the software was to have the system present information based on algorithms used by the JEA engineers. For instance, as the engineers classify events (tree, animal, lightning, etc) the engineers can see over time that more transients are being caused by trees and perhaps the line should be inspected. Another use is breaker timing analysis, the system can monitor the number of cycles for a breaker operation and alarm if the time is slowly increasing. Transformer monitoring is the application we will describe in more detail with a real benefit realized. Fig. 2 shows the software architecture installed at JEA.

Benefit

While reviewing individual records before implementing the new software system, JEA engineers recognized an anomaly that required further investigation to understand. At the Northshore substation, the monitor on Transformer 1 was showing a loss of current on one phase for less than one cycle. The anomaly occurred several time per day. Fig. 3 is an actual view of the waveform.

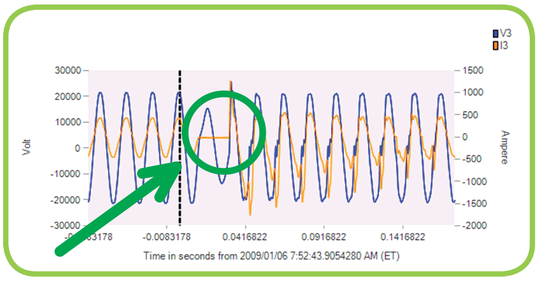

Fig. 3 _ Captured disturbance waveform showing fault on Phase C (flat line) leading to the discovery of melting metal in tap changer

Further analysis showed that the duration of the zero current was increasing over the several days the engineer monitored the situation. A maintenance outage was scheduled and technicians were sent to investigate the cause of the anomaly. When technicians inspected the load tap changer (LTC) on Transformer 1, they discovered a pin that was shearing and causing arcing during the travel of the LTC. Technicians believe the transformer would have been destroyed within two weeks if the arcing had not been detected and corrected.

After installing the new system, JEA configured the software to recognize and report anytime this signature was detected. Since then, 3 other instances have been detected and alarmed automatically leading to the prevention of the failure of 3 more large power transformers. JEA estimates the avoided cost of the transformer damage at four million US dollars.

Conclusion

Many methods are used to measure and verify system reliability and these lead to different approaches to reducing the amount and impact of outages. Technologies are available today to help utilities mitigate the impacts of outages but also to prevent the outages by monitoring their systems and evaluating the data. Systems must be capable of progressive roll out and allow for open communication with multiple devices over multiple media. Flexibility is important, as the communications networks are ever changing and the technology in hardware and the algorithms in software are evolving faster than before. The innovation and adaptability of engineers at utilities will prove to be the key in taking power quality information and using that information to improve system reliability.

Schneider Electric Industries SAS

35, rue Joseph Monier
CS 30323
F- 92506 Rueil Malmaison Cedex

RCS Nanterre 954 503 439
Capital social 896 313 776 €
www.schneider-electric.com

998-4530

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