USING SMART GRID SENSORS AND ADVANCED SOFTWARE APPLICATIONS AS AN ASSET MANAGEMENT TOOL AT HYDRO OTTAWA

Daniel SABIN
Electrotek Concepts – USA
dsabin@electrotek.com

Gary MACLEOD
Current Power Services – Canada
garymacleod@currentpower.ca

Mark WOJDAN
Hydro Ottawa - Canada
markwojdan@hydroottawa.com

ABSTRACT

In 2014, Hydro Ottawa began a pilot project to use power quality monitors to locate faults on distribution feeders supplied by medium voltage (MV) systems. Fault measurements captured by the meters are downloaded automatically, integrated into a relational database, and processed for reactance calculations. The reactance calculations are combined with detailed distribution circuit models and geographic information system data to build estimated fault location tables and web-based map displays. The systems are integrated on the company intranet and used in real-time by numerous groups within Hydro Ottawa including power quality engineers, control room operators, field operations, and distribution planning. The algorithm used for waveform processing can distinguish between single-phase faults, multi-phase faults, subcycle faults, and feeder energizing magnetizing inrush. This paper will present an overview of some of the parameters and practices for finding faults at Hydro Ottawa.

INTRODUCTION

Hydro Ottawa is the third largest distribution company in Ontario, Canada. It distributes electricity to customers in the city of Ottawa and the Village of Casselman. Its customer class is primarily residential and commercial with very little industrial load.

Table 1: Statistics for Hydro Ottawa Distribution System

Number of Customers	315000
Population Base	900000
Service Area	1104 sq. km
System Peak (Summer)	1500 MW
Annual Energy	7,850 GW-hr
Distribution Substations	84
Total Number of Distribution Transformers	34900
Total Number of poles	48700
Total Number of manholes	3000

Over the past few years, Hydro Ottawa has invested in smart grid devices, including automated reclosers, automated pad-mounted sectionalizers, automated switches, SCADA fault circuit indicators, smart residential metering, and integrated revenue and power quality monitors

The automatic fault location system (AFLS) on the distribution system of the Hydro Ottawa was first put into use during 2014. It incorporates many of these power quality monitors, database applications, up-to-date circuit models, and geographic information system (GIS) databases in order to provide automatic fault identification and fault location estimation. The AFLS has become a valuable tool for quickly and accurately identifying the location of faults on Hydro Ottawa's MV distribution system.

The AFLS uses measurements recorded at medium voltage (MV) stations. These measurements are downloaded automatically and incorporated into a relational database. Calculations on these measurements estimate the reactance from the station to the fault. The calculations are based on phasor measurements derived from the voltage and current samples and calibration constants based on previous fault data and known locations. The result of these calculations is an estimated "reactance to fault," or XTF. The XTF values are compared with line models that estimate the positive-sequence and zero-sequence reactance between station and line structures. The estimated locations can be viewed via the corporate intranet and can be displayed geographically using maps derived from a GIS database. The calculated fault locations are typically available on the Hydro Ottawa intranet within ten minutes after a line fault.

POWER QUALITY MONITORING AT HYDRO OTTAWA

Installation of monitors for recording power quality measurements at Hydro Ottawa began in 2002. Monitoring began at a small number of interconnection points with the transmission system owned by Hydro One. Monitors were installed to record long-term statistics on voltage sags and harmonic distortion at key distribution substations.

At present, the power quality system at Hydro Ottawa consists of more than 125 monitoring locations including all 8.3 kV, 13.2 kV, and 27.6 kV substation busses. The power quality monitors are installed on the secondary side of the substation transformer and monitor the bus voltage and current. A majority of data is downloaded from the monitors using broadband communications (Ethernet) via the corporate network. However, a substation number of substations are still downloaded by telephone modem. Figure 1 illustrates the installation of the PQ monitors at the substation. The power quality monitors are accessible to other computers in Hydro Ottawa via fibre optic wide area network connections. The monitors record mostly line-to-ground voltages.

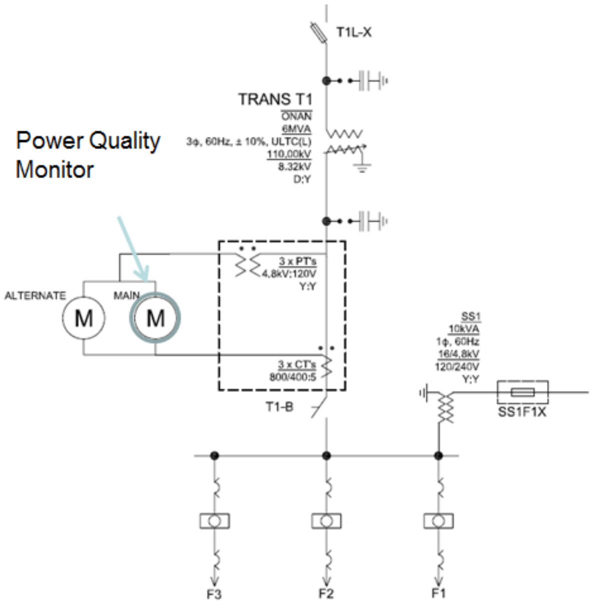

Figure 1: Typical Metering Single-line Drawing for PQ Monitoring at Hydro Ottawa

FAULT IDENTIFICATION AND LOCATION PROCESS

Fault Measurements

Measurements are recorded on the distribution busses using power quality monitors installed on the secondary of 115kV/8.3 kV, 115kV/27.6 kV, or 115kV/8.6 kV transformers. At Hydro Ottawa, each substation usually has four busses, and each bus supplies usually four feeders. The current from each transformer is monitored by a single Schneider Electric® ION® power quality and revenue meter.

Figure 3 represents a fault measured on a Hydro Ottawa distribution feeder. The fault begins as a single-phase fault but evolves into a two-phase fault. The measurement was recorded upstream from the fault. cycles.

Measurements by the power quality monitors are triggered using high and low rms voltage thresholds. When a voltage sag (less than 90% of nominal) or voltage swell (more than 110% of nominal) is detected, it will trigger voltage and current waveform samples and rms samples to be recorded. RMS voltage and current values and estimated reactance values to the fault are computed from the waveforms. The Hydro Ottawa power quality monitors are configured to record voltage and current waveform samples at a rate of 128 points per 60 Hz cycle with typically five cycles of pre-trigger and many cycles of post-trigger data.

The power quality monitors communicate with a server via a broadband Ethernet connection. This allows the fault measurements to be downloaded from the monitors to the corporate network typically within one minute. See Figure 2.

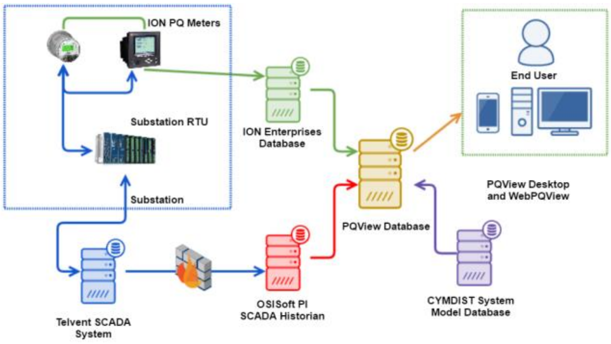

Figure 2: Power Quality Monitoring System at Hydro Ottawa

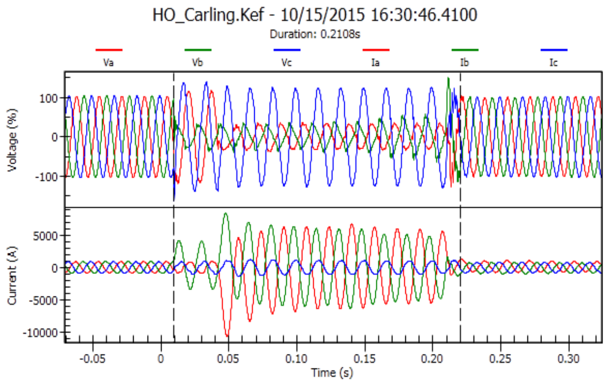

Figure 3: Example of a fault on a Hydro Ottawa distribution feeder. The fault begins as single-phase but evolves into two phases

Circuit Models

The distribution circuit models are stored in Eaton®/Cooper Industries CYMDIST databases, which are extracted from Hydro Ottawa GIS database. These models provide the geospatial coordinates for the nodes that comprise the line segments of distribution feeders in a Lambert conformal conic projection system. These coordinates are converted to the WGS 84 coordinate system so the maps can be displayed in standard GIS software systems as overlays on maps and aerial imagery. The circuit models include conductor types used in different line sections that include positive-sequence and zero-sequence impedance characteristics. The number of phases for each line segment is also stored, as well as whether the line section is underground or overhead. The cumulative impedance to each underground and overhead structure is stored in a relational database. An example model is displayed in Figure 4.

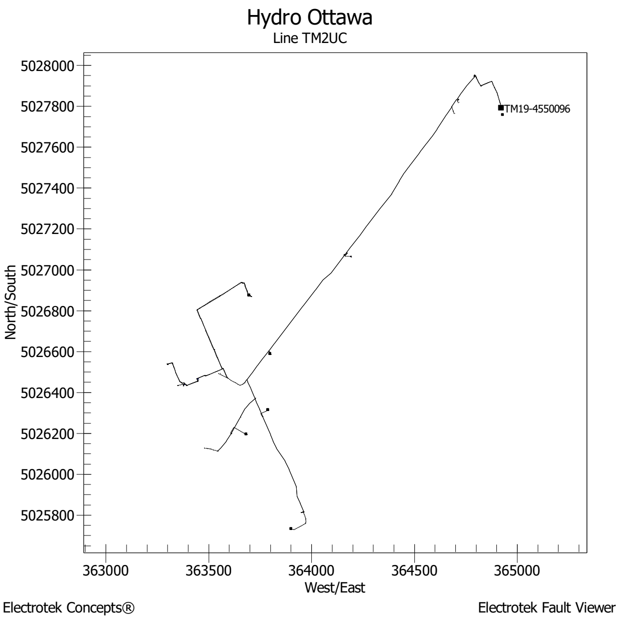

Figure 4: Typical Distribution Line Showing Both Underground and Overhead Line Sections

Data Integration

Once downloaded from the substation, data from the power quality monitors is integrated automatically into PQView®, which employs a relational database for data storage [4]. The waveforms from the power quality monitors are stored in a proprietary database format provided by the monitor vendor.

The fault measurements are incorporated into the relational database usually within a few minutes of a fault occurrence. Once in the database, the measurements can be queried and analysed directly using workstation computer applications or indirectly via intranet web applications.

A single measurement may be classified as more than one type of fault. This means that the AFLS is able to identify single-phase faults that evolve into multi-phase faults. As another example, the system is able to identify the start and end of each stage of a fault that begins as a transformer energizing transient but degrades into a fault condition.

Reactance Estimation

For SLG faults, the XTF is estimated using (1), where V_f is the magnitude of the voltage measured on the phase showing a voltage sag, N_T is the number of transformers in service during the fault, I_0 is the magnitude of the zero-sequence current, and Θ is the phase angle between V_f and I_0.

$$XTF = \frac{V_f}{N_T k_1 I_0} \sin\theta \qquad (1)$$

The constant k_1 is a calibration factor that is determined using previous faults recorded at the bus in the recent past. The historical faults must have occurred when the network was in the same configuration as the fault that occurs in the present in order for the k_1 factor to be useful. Practical use of the fault location at Hydro Ottawa indicates that the actual distance in reactive ohms for historical faults can be used to determine a value of k_1 that will estimate the reactance to fault for future events. The k_1 constant can be computed at the bus level for all lines supplied by a station, or can be computed for each line. The line-level k_1 constants are typically more accurate than the bus-level constants. This approach to SLG fault location using positive-sequence reactance only was first described in [5]. It is also summarized as a case study in IEEE C37.114 [1].

For multi-phase faults, a more traditional method is used for fault location. The approach described in IEEE C37.114 for single-ended impedance-based measurements has been applied successfully to the Hydro Ottawa distribution faults. This method requires computation of phase-to-phase voltage and current phasors before the fault and during the fault.

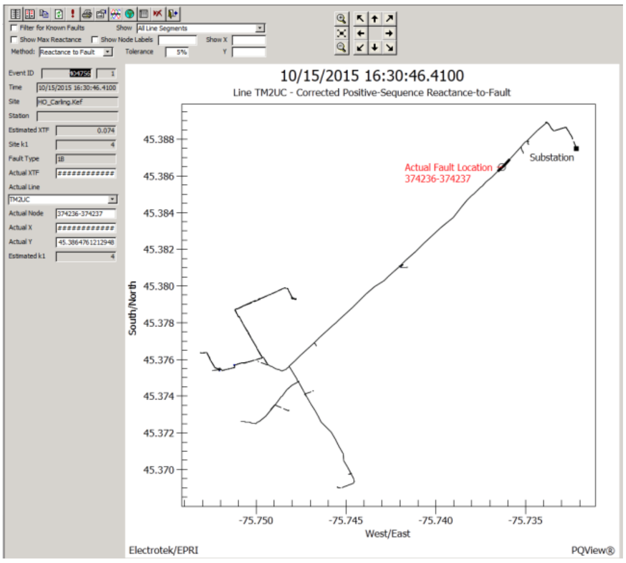

Figure 5: Example One-Line Diagram Showing Estimated Fault Locations and Actual Location with Coordinates for SLG Fault in Figure 3

Fault Location Visualization

There are multiple applications available for displaying estimates of fault location. Figure 5 presents an example one-line diagram showing the estimated fault locations as circles and the actual fault location with a callout annotation line. This estimate is for the SLG fault displayed in Figure 3. Multiple estimated locations are possible whenever a line has laterals. This one-line is visible via desktop computer programs or within a web page display. Figure 6 presents the same one-line diagram, but overlaid on an aerial map available from Google® Earth.

On the Hydro Ottawa intranet, several applications provide system operators and engineering staff with estimated fault locations. In Figure 8, an example of a one-line diagram from another intranet web application is shown for the feeder with an estimated fault location. This map display was drawn using the ESRI® ArcGIS® API for Silverlight®. The lightning bolt icons represent the estimated (green) and actual (red) location of the fault. This application can also display the locations on satellite imagery.

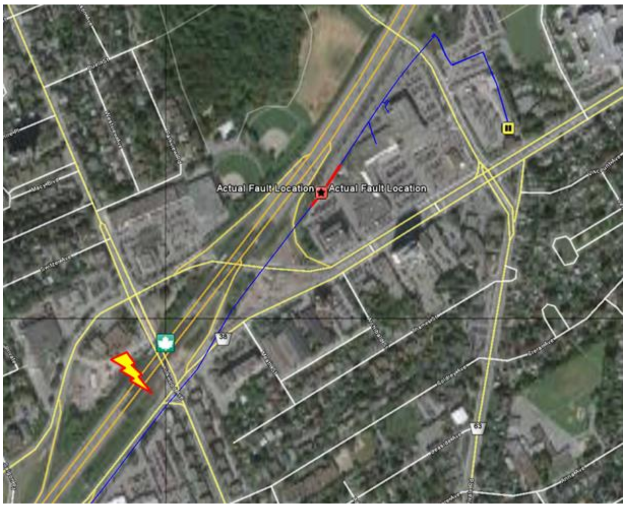

Figure 6: Example One-Line Diagram Showing Estimated Fault Locations and Actual Location Displayed with Aerial Map Data for SLG Fault Shown in Figure 3

Fault Identification

Each measurement downloaded by the remote power quality monitors is analysed by a power quality database management and analysis software system for voltage characteristics and zero-sequence current characteristics that indicate a single-phase fault has occurred. Other line-line voltage characteristics are examined that indicate that a two-phase or three-phase fault has occurred. Harmonic content and event duration are used to identify events as magnetizing inrush events. Zero-sequence and negative-sequence current content is used to search for other overcurrent events that are not faults but otherwise noteworthy for automatic notification.

Indication with Fault Circuit Indicators

As part of its grid modernization, Hydro Ottawa has been installing fault circuit indicator (FCI) that are polled via its SCADA system. The status of each FCI is stored in the historian system, which is maintained in a historian system provided by OSIsoft® PI System® Server. As each fault measurement is imported into the AFLS database, a query on the historian system is made to determine if any FCIs have changed status. Figure 7 shows an example where a single phase fault was recorded without an interruption of feeder. However, two FCI sensors captured the fault.

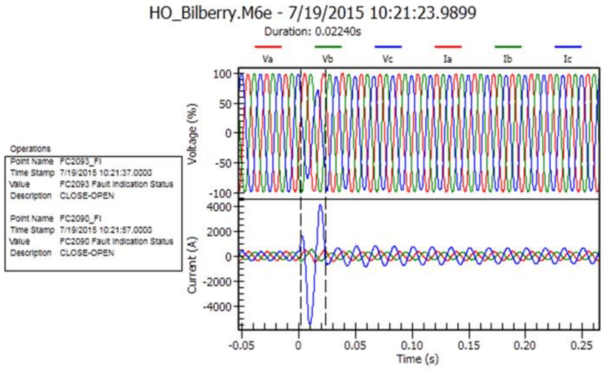

Figure 7: Single-Phase Fault with Correlations to Two Fault Circuit Indicator (FCI) Sensors via SCADA

In this example, the electric system operators were able to use the estimated location of the fault, along with FCI sensors that showed a fault compared with FCI sensors that did not show a fault. This analysis allowed the system operators to compare data with mapping to predict fault location. A repair crew found a dead bird and flashed insulators. The insulators were changed and a future outage was prevented.

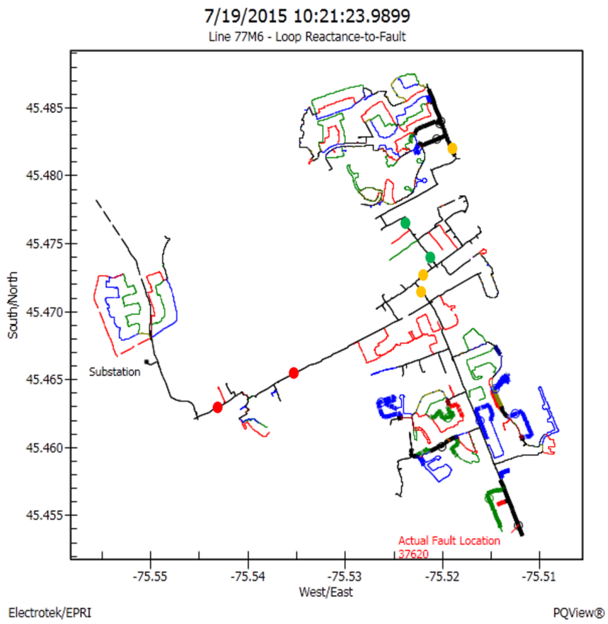

Figure 8: One-Line Diagram for the Fault in Figure 7 Showing Status of Fault Circuit Indicators

PREVENTION OF STATION EQUIPMENT FAILURES

Hydro Ottawa has experienced five load tapchanger failures in the past six years. The power quality monitors have been successful in recording the waveform and rms events at the time of the failure. Figure 9 shows the voltage and current waveforms during a tapchanger transformer failure. Figure 10 shows a timeline of rms voltage dip events during the same series of failures. Figure 11 shows a trend of short-term flicker perception (Pst) recorded as a tapchanger failure began.

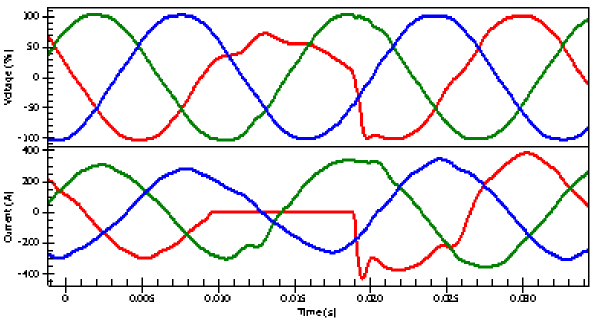

Figure 9: Example of Voltage and Current Waveforms during Tapchanger Failure

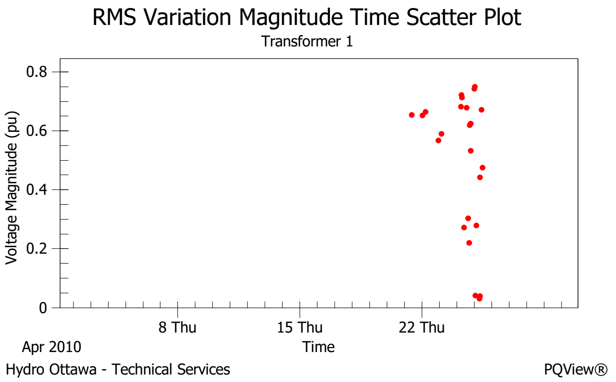

Figure 10: RMS Voltage Variation Timeline during Tapchanger Failure

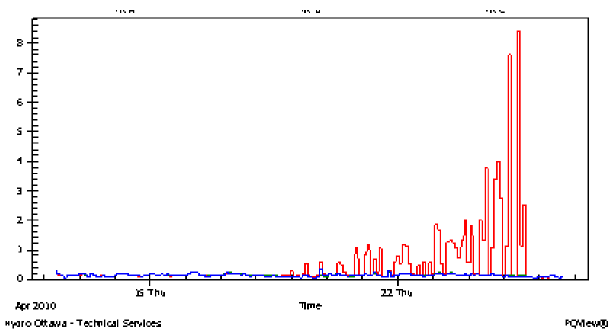

Figure 11: Trend of Short-Term Flicker Perception (Pst) during Tapchanger Failure

By monitoring on unusual waveform events, voltage dip events, and changes in flicker perception, Hydro Ottawa has found it possible to find numerous tapchanger problem as they begin and before catastrophic failure.

CONCLUSION

The core development of the AFLS at Hydro Ottawa was begun in 2014. However, minor revisions have been completed since then. Regular usage by the system operators, operations engineers and others started in 2016. The AFLS has proven dependable and has resulted in improved asset availability. The system has proven to be of great benefit to the company especially for underground faults in busy city streets. As system operators and operations engineering get more familiar and comfortable with the AFLS system, the company can expect significant benefits. These benefits include a reduction in time to find and repair faults and therefore a reduction in O&M expenses, as well as reduced outage duration and therefore reducing CAIDI.

Plans for future enhancements to this system include microprocessor relay integration, integration with the outage management system (OMS), and automated reporting for IEC and IEEE standards compliance.

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