PQ MONITORING WITH SMART METERS FOR CONDITION BASED MAINTENANCE ON DISTRIBUTION SYSTEMS

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ABSTRACT

This paper presents the results of a condition based maintenance system using a new fault location technique based on voltage dip measurements. This fault location technique was presented in a previous CIRED publication as the Voltage Drop-based Fault Location (VDFL) technique in 2007. So far, it has shown a very good potential for permanent and temporary-fault location on an overhead radial distribution system. A fully automated prototype of the condition based maintenance system is now operational on seven distribution feeders and it has given promising results for improving reliability. As an example, HTD 236 was one of the worst performing feeders before installing the system and now shows a significant reduction in the number of outages and in the SAIDI index.

INTRODUCTION

Outages caused by vegetation and equipment failure are largely responsible for the poor quality of service on distribution networks. Some of them could be prevented by increasing the frequency of line patrols, intensifying vegetation control programs or substantial investments in equipment replacement programs. However, these solutions require significant annual recurring investments that are difficult to justify by utilities.

For distribution systems, detailed monitoring of individual equipment for predictive or conditional maintenance purposes is not feasible. However, the power outage caused by the failure of one device can have a significant impact given the number of customers affected. From the perspective of conditional maintenance, it is possible to consider a distribution line, in its entirety, as being equivalent to a major transmission or production piece of equipment if the monitoring and detection of anomalies on it helps avoid outages. In this context, fault location techniques provide interesting alternatives.

The fault location on distribution networks is used primarily to reduce the response time of the maintenance crews during outages. Certain utilities use substation monitoring data with some success [1] [2] [3] [4]. Others use the location of temporary-faults to detect and locate faulty equipment or vegetation to line contacts, which can avoid in many cases power outages. The DFA system (Distribution Fault Anticipator) [5] is one example. This system was developed jointly by Texas A & M University and EPRI, and also uses substation monitoring data.

The MILE system (Maintenance Intelligente de Lignes Électriques or Intelligent Power Line Maintenance in english) presented in this paper is another example of temporary-faults location for condition based maintenance. This system uses distributed voltage dip measurements (VDFL) [7]. A first stage deployment of this measurement system was realized on two distribution feeders in 2006 and a second deployment on 5 additional feeders was completed in 2008. A web interface was also made available to maintenance personnel in 2008, which has helped to achieve significant gains in reliability.

VDFL FAULT LOCATION TECHNIQUE

The VDFL fault location technique used, in the MILE system, requires several calculation steps. The first two are to calibrate and synchronize the voltage waveforms coming from the monitoring equipment (ME), which are ranked in order according to their voltage drops. The balanced line model is used and every vector (phasor) and calculation are done with the resulting symmetrical components of the three-phase power system. This model gives excellent results with every type of fault. To simplify the explanation of the technique, Figure 1 shows only one of the three dimensions of calculation. The fault current, that is used to calculate the vector voltage drop along the conductors, is calculated with data from ME_1, ME_2 and the impedance of the line Z_1. The intersection between the vector voltage drop and the phasor calculated from the third ME indicates the probable faulty network lateral or tap-off consequently limiting the number of possible fault locations. Afterwards, the fault current is reassessed with data from ME_1, ME_3 and the sum of impedance Z_1 and Z_2 for greater accuracy in subsequent calculations. Considering that the impedance of a fault is purely resistive, fault location is determined by the intersection of the vector voltage drop with the real axis. The residual voltage corresponds to the voltage of the fault at fault location and is specifically used by the MILE system in conjunction with other information to identify the most probable fault type. This technique allows for the determination of the fault location if it is on the load side of at least one ME. Unique phasors triangulation technique, which is now under patent pending (PCT/CA2008/000691), significantly reduces the number of possible fault locations and is more advantageous for locating temporary-faults than any other existing technique.

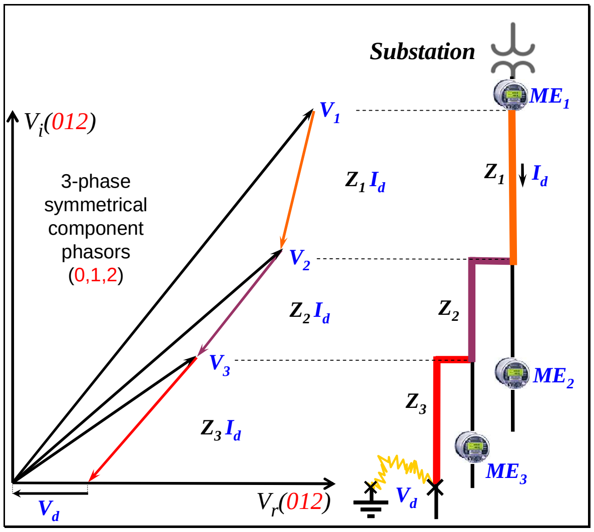

Figure 1 - VDFL technique

In-depth analysis of 63 faults that occurred in 2009 indicates that the median accuracy obtained for this technique is 0.54% and the average is 1%, which corresponds to a mean deviation of ±300m for the feeders analyzed (50% of time it is less than 160m). The following figure shows the statistical distribution accuracy of the VDFL technique. The accuracy is normalized to the feeder's greatest distance from the substation.

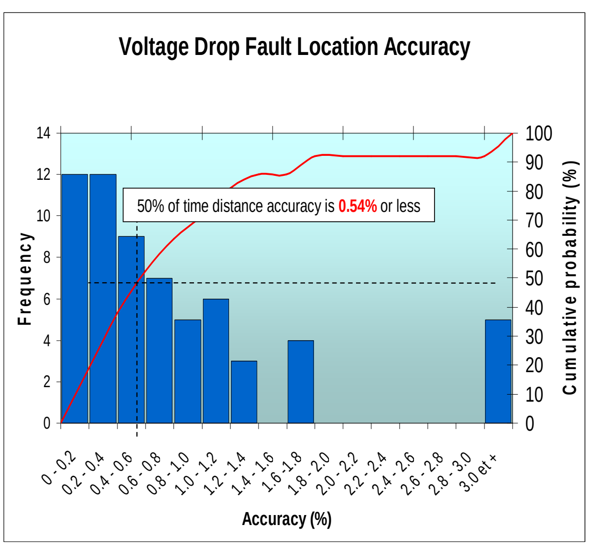

Figure 2 - VDFL accuracy

MILE CONDITION BASED MAINTENANCE SYSTEM

The MILE system is composed of multiple modules, which correspond to automated process and analysis tools that are available to maintenance personnel via a web site. The following figure shows an overview of the MILE system.

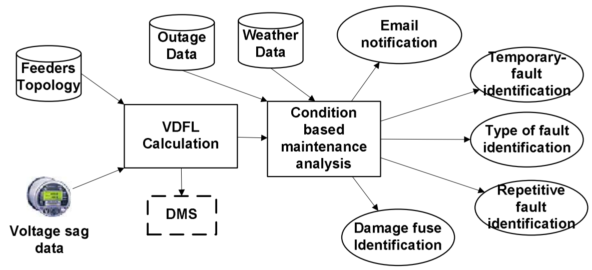

Figure 3 - MILE system overview

The VDFL fault location technique, using voltage dips measurements and network topology, corresponds to the basic module of the system. The coverage of a feeder requires an average of four ME, but the VDFL technique needs only three of them. To analyze all possibilities, we must combine the measurements in trios giving us more results (one for each trio). The MILE system selects the trio that gives the most accurate results, which will then be analyzed by the condition based maintenance module. A notification is also sent by email to maintenance staff including a link to the recorded event allowing for further analysis and corrective actions on feeder if required.

Conditional maintenance is based mainly on the analysis of temporary-faults. A fault is considered temporary by MILE if it is not linked to any outage or is linked to an outage of unknown nature, usually due to vegetation, animal or insulator failure, which are all difficult to locate. By combining available data from various sources such as: the voltage of the fault, the fault duration and the weather conditions (wind, precipitation), it is possible to identify, in many cases, the cause of failure, which help crews in subsequent trouble shooting and corrective procedures. Before dispatching crews, each temporary-fault is weighted in term of urgency by the number of customers that could be affected. This analysis is done automatically by the system. In addition, the annual frequency of same fault occurrence is calculated. Repetitive temporary faults usually indicate that the defect is still present on the network dictating a required maintenance response.

The fault location algorithm estimates the fault current, which helps in identifying a potentially damaged fuse. This is determined by finding the path of the fault current on the feeder topology and identifying the fuses that were highly solicited (between melting and opening). After the fault, these fuses are weakened and proper coordination with other protective devices is lost or could be severely compromised.

A view of the web site is presented in the following figure. It allows maintenance personnel to access analysis tools and raw data like: waveform measurements, weather reports, outages, topologies and fault locations which give an overview of the situation to users without having to access different systems. Several of these results can be viewed in a geo-referenced form by using Google Earth, which is directly accessible through the web interface.

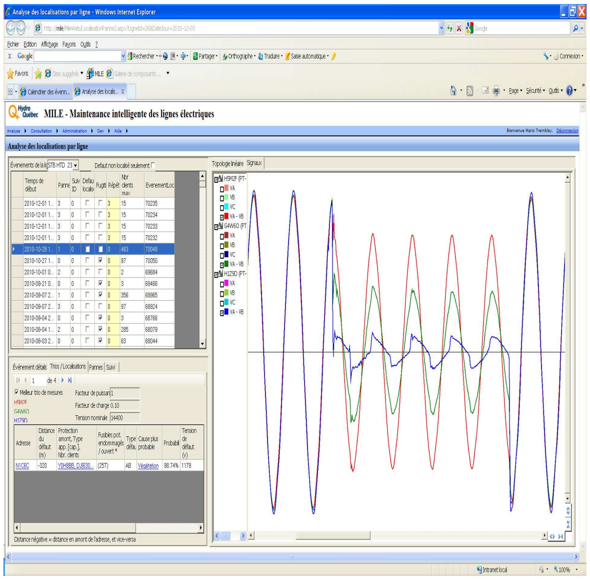

Figure 4 – Web site interface

HTD 236 FEEDER EXPERIENCES AND BENEFITS

With a SAIDI (System Average Interruption Duration Index) exceeding 16.6 hours annually and a total of 180 outages accounting for over 35000 CHI (Client-Hour of Interruption) on average per year (more than 50% of outages being unknown or due to vegetation), the HTD 236 feeder was ranked among the three worst feeders of Hydro-Québec in 2006 and 2007. To help correct this situation, it was decided to equip the HTD 236 feeder with MILE in October 2007. The benefits where quickly felt.

Fast and easy analysis of all events affecting the feeder

Some anomalies causing temporary-faults were corrected before they became outages. As examples, inadequate pole assemblies, damaged insulators and cutouts buried in invasive trees were all identified and corrected (see Figure 5). In some cases, crews restored power to faulty transformers before customer calls were received. Assisting crews in difficult live trouble shooting situations with accurate fault type and locations helps in pin pointing probable faulty equipment to within three spans therefore eliminating all unknown outage causes from the outage database. Knowledge of fault type and location assists operators to safely reclose tripped devices and provide enhanced crew security during work on live feeders in breaker "hold back" situations while minimizing down time.

Figure 5 - Defective equipment found

Accurate protective device selection and coordination

The availability of voltage waveforms underlines the lack of fast curve coordination between series installed breakers (three specifications were modified). Fault voltage values and accurate fault locations give detailed fault characteristics eliminating practically all unknown fault locations and causes justifying the addition or relocation of reclosers and cutouts (one breaker added and one relocated).

Results

The following table illustrates the excellent payback for the use of the MILE system on HTD 236 outage statistics. The number of faults, whose average was 180 for the years 2006 and 2007, fell to 54 in 2010, which represents a reduction of 70%. The SAIDI index was also reduced by 68%. In 2008, this line was the subject of numerous customer complaints. None were logged in 2010.

Table 1- HTD 236 outage statistics

Description	2006-2007	2009	2010
# of outages	180	60	54
SAIDI (hrs)	16.6	7.2	5.28
Number of undetermined outage causes per 100 km	2.2	1.94	0.38

DISTRIBUTED PQ MEASUREMENTS OTHER ADVANTAGES

In addition to the direct benefits on feeder outage statistics, here are a few bonus features provided by MILE. Identification and possible correction of all weakened fuses caused by the circulation of severe fault currents. Validation of all outage repairs with MILE data and possible follow up correction in the OMS for diverging cases. Real time validation of the quality of our tree trimming program and it's affect on outage statistics. Interpolation of information contained in voltage waveforms allow direct power quality assessment of all feeder points without local metering equipment installation (see Figure 6).

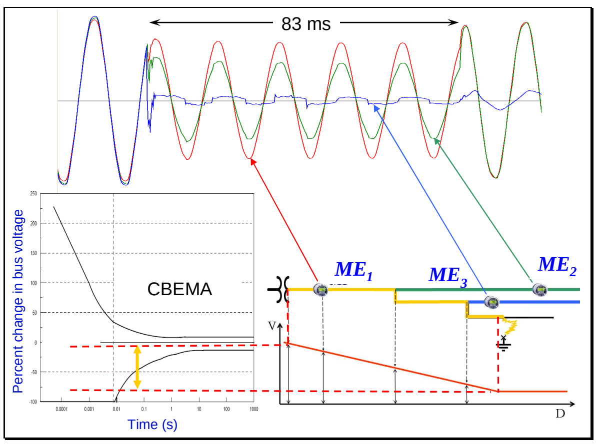

Figure 6 - Available voltage level everywhere on feeder during fault

Over voltage levels measured on healthy phases during phase to ground faults allow for overall assessment of neutral grounding effectiveness (see Figure 7).

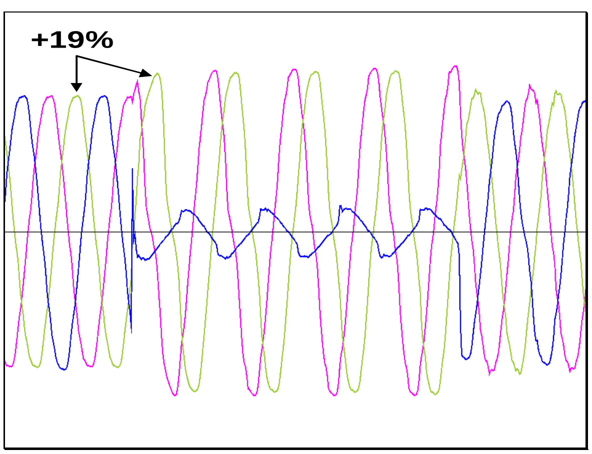

Figure 7 - Measurement of neutral grounding effectiveness

CONCLUSION

Locating intermittent faults, in order to avoid outages, shows a huge potential for reducing the SAIDI reliability index as demonstrated by the MILE system project. The following diagram shows why we should not solely rely on outage location, but on temporary-fault location, in order to avoid outages. Failures prevented and repaired before outages do not count in the total outage statistics.

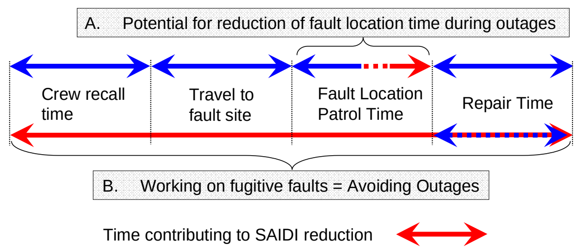

Figure 8 - Conditional maintenance for SAIDI reduction

We are presently studying a MILE implementation phase that would share infrastructure with the smart grid technologies to be put in place simultaneously with the AMI (advance metering infrastructure), the distribution automation infrastructure and the VVC technology (Volt & VAR Control). Further development is expected in 2011.

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