ACCURATE FAULT-LOCATION TECHNIQUE BASED ON DISTRIBUTED POWER-QUALITY MEASUREMENTS

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ABSTRACT

Fault location has been practiced on transmission systems for many years. Some distribution utilities are now using current waveforms from centralized power-quality monitors to measure the impedance and thus locate faults. This paper presents the results of a Voltage Drop-based Fault Location (VDFL) technique using remote power-quality measurement devices. This technique was developed in the course of a project initiated in 2001 as a first step toward a more elaborate preventive and predictive maintenance system. 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 is now operational.

INTRODUCTION

Experts in the early 2000s proposed that power-quality (PQ) measurements could predict the imminent failure of equipment and serve as the basis of a predictive maintenance approach. They named this approach 'Power Quality Predictive Maintenance' (PQPM). Applications of PQPM to the distribution system have been implemented by some utilities but, because of the low cost of distribution network equipment and their long feeders with many laterals that were not adequate for such applications, it is the transmission companies that mainly benefited. Nowadays, however, programs such as Automatic Meter Reading (AMR) using power-quality monitoring have created new opportunities.

In 2001, Hydro-Québec launched a study to assess the potential of PQPM on its own distribution network. The project team rapidly concluded that efficient and economically sound maintenance practice required that imminent equipment failures be detected and located with accuracy. Based on this conclusion, the diversity of equipment failure types and associated power-quality measurements was narrowed down considerably, as confirmed by comparable initiatives among research communities and distribution utilities. For instance, voltage drops (dips and interruptions) are often associated with an intermittent line fault caused by contact with a tree, a defective insulator, a galloping line or a broken conductor joint. Since such faults generally have a degenerative behavior with time, they are good candidates for predictive maintenance.

A so-called Voltage Drop-based Fault Location (VDFL) technique was developed which uses the voltage waveforms provided by remote devices on the distribution network. This technique is similar to those described in the IEEE guide [1] based on the line apparent impedance but it has innovative differences. Applied in a distribution environment, today's fault location techniques are more or less limited in accuracy by multiple unknown parameters such as the fault impedance, the line complexity, the unbalanced loads and the non-feasibility of building an accurate line model. The VDFL technique overcomes these problems by using multipoint voltage measurement rather than the one- or two-end voltage and current measurement techniques used for transmission lines. Moreover, the use of several power-quality analyzers provides plenty of information on distribution system performance such as voltage unbalance, steady-state voltage level and voltage harmonic content, which can be useful for line maintenance and overall system performance.

The technique was initially tested in 2003 when seven power-quality analyzers were deployed along a distribution feeder over 100 km long including laterals. The results showed that the fault distance calculations were accurate and confirmed the VDFL capacity to considerably reduce the number of potential fault locations. The results also revealed that the technique can evaluate fault characteristics such as the fault-current level, arcing-voltage level and fault duration, which could all be used for identifying the fault origin (direct contact, tree contact, insulator failure…).

So far, seven distribution feeders have been monitored with this technique and the automated specialized software package MILE (Maintenance Intelligente de Lignes Électriques or Intelligent Maintenance for Electrical Lines) was developed as a result of the experiments. The study shows that the deployment of four monitoring devices usually suffices to accurately locate faults on most of Hydro-Québec's overhead distribution feeders.

OVERVIEW OF VDFL TECHNIQUE

The technique can be summarized by the following points: remote measurement of the voltage drop, automated grouping of independent measurements, contextual modeling of the distribution line and assessment of the fault distance by an original algorithm. The main idea is based on obvious voltage drop phenomena along the line caused by a fault current. Figure 1 schematizes the overall fault-location process.

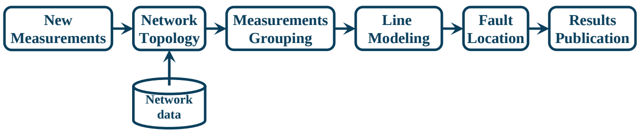

Fig. 1 Overall fault-location process

The technique requires at least three remote voltage-drop monitoring devices, known as remote monitoring units or RMUs, to be deployed at selected sites on the distribution feeder, usually on the customer side. A 4-kHz, 8-bit A/D device can deliver an acceptable performance. Since there is no need to keep the device's internal clock up to date very exactly (a few seconds of accuracy is enough), low-cost equipment can be used. A standard AMR is currently used in the prototype. When a fault occurs, the resulting voltage drop is recorded by some RMUs and the measurements are transmitted to the database where they are saved.

The present network topology is imported from the network database server and is associated with the corresponding measurements. It should be noted that, in some cases, the database may not be up to date so the ensuing analysis would produce line models that conflict with the voltage drop levels given by the RMU. Nonetheless, the fault location can be calculated by applying a few hypotheses to the current network topology. There is some potential here for developing an erroneous-topology detection tool.

The measurements are initially sorted into sets of measurements which, considering the real-time stamp error interval of each RMU, are likely to coincide. This approach does not guarantee that all grouped measurements correspond to the same electrical disturbance. Even, if the RMUs were perfectly synchronized in time (e.g. by GPS), there would still be a possibility that two phenomena occur at almost the same moment and the corresponding measured voltage-drop waveforms would overlap. For this reason, the various sets of measurements are thoroughly analyzed using voltage-drop waveform characteristics in order to improve the initial grouping.

A simplified line model is created for each set of measurements and previously associated topology, in consideration of the measured voltage drop levels.

For each such line model, an iterative computing method finds the best fault locations using several synchronizations, approximations and error corrections. Some computational burden is required for this method, depending largely on the complexity of the feeder topology. The more laterals the feeder has, the more complicated the calculation will be and more potential locations would be found. However, in any case, this method drastically reduces the number of possible locations compared to any method based on centralized measurements.

Finally, analysis of the overall results determines the best set of fault locations to be presented on the user interface and sent to the control centre or used by maintenance technical staff to analyze the system performance.

MILE SYSTEM PROTOTYPE

The following figure represents the overall system prototype as tested. It is composed of a Line Monitoring System (LMS) - currently deployed on two distribution feeders (BOL212 and MAN234), a server of the MILE application software and some workstations with the MILE graphical user interface (GUI). Readers should also note the access to other Hydro-Québec applications which provides auxiliary information such as line architecture, outage information and weather conditions.

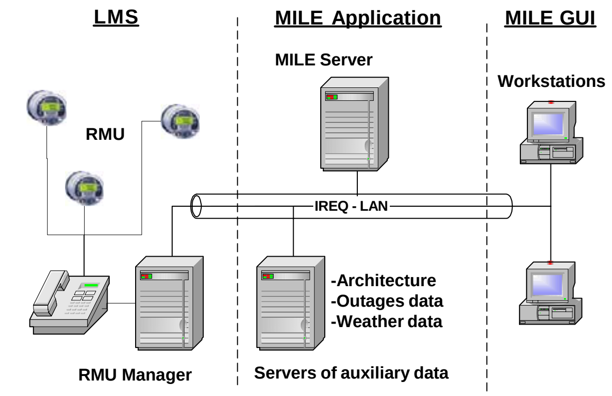

Fig. 2 - MILE System Prototype

Line Monitoring System (LMS)

The LMS comprises ten RMUs installed on two distribution feeders, which are controlled by a measurement devices manager (see Fig. 2).

The RMU comprises a meter with PQ capability, an optical insulator, a modem, a voice/fax/modem call processor and a backup power source. The revenue meter used for the RMU is equipped with three voltage and four current input channels. The voltage (120/208 V) and the current (up to 5 A) applied to it came from PT and CT secondaries.

Three different types of installation, one mobile, two fixed, were designed to meet the particular requirements imposed by the location of the RMU. They are illustrated in the following figures. The indoor fixed units are mounted in revenue meter cabinets and the outdoor ones in mounted cabinets on distribution poles.

Mobile Indoor Fixed Outdoor Fixed

Fig. 3 - RMU unit configurations

When a voltage drop is detected, an alarm is triggered and the RMU communicates with the RMU manager via modem using a 1-800 phone number. The original idea was to share the customer phone line, which would have required a call processor. However, the communication reliability became questionable when the customer was using equipment such as a fax, a burglar alarm system or switchboards, all of which meant renting dial-up phone lines.

MILE Application

The VDFL technique requires significant software support and heavy use of a database. It is implemented as MILE application software, which is based on asynchronous processing and a relational database management system. The technique consists of a sequence of tasks (Fig. 1), each processed by an independent service application (daemon). This approach significantly simplifies system maintenance and is very suitable for applying a computer cluster architecture in order to improve overall performance. Tests were performed with four simultaneously running computers and the result shows a significant acceleration of the fault location process.

MILE Interface

Tools have been developed to allow extensive fault-position analysis and present additional useful information. A first

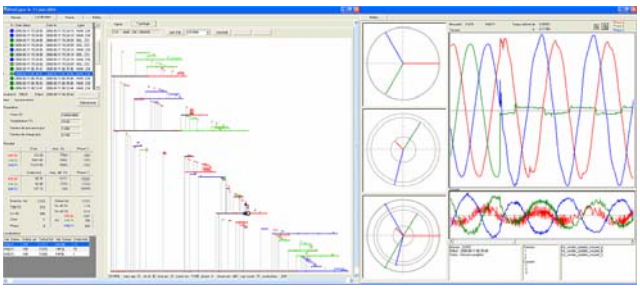

Fig. 4 MILE user interface panel

overview of the results is presented in a calendar form, which illustrates, on a daily basis, the most significant informations. The number of recorded measurements, the number of faults and the number of power outages detected by the control center can be easily and quickly seen on the calendar. The voltage and current waveforms, corresponding to the voltage drop even, can be consulted. The fault locations and reported outage position can be seen in the grid topology, which is presented in Fig. 4.

RESULTS

Seven distribution feeders were monitored from 2002 to 2006 using this method. Feeders LAW231 and CAS239, equipped with Hydro-Québec's PQ analyzers Mini-AQO, were used for development purposes. The regular pilot project is based on feeders BOL212 and MAN234, which have been monitored for the last two years. The goal of the pilot project is an extensive performance analysis of the system. The three feeders HTD236, DBC238 and BLU239 were analyzed in order to detect particular problems identified by field maintenance personnel. The pilot project gives the following class of result:

(A) All voltage drop events grouped by date

This class is a result of the first step of measurement grouping. It contains:

- located faults,
- disturbances originating on the transmission side or on another distribution line on the same transformer,
- disturbances having insufficient data to be properly analyzed,
- groups of measurements of what were in fact independent events but which almost coincided,
- local disturbances on the secondary of the distribution transformer,
- other, so far unexplained, events.

Only the measurement groups leading to coherent location are analyzed in depth in this project, leaving the remainder for future use.

(B) Recognized disturbances with coherently computed locations.

Recognized disturbances with coherently computed locations (subset of previous class) are the main subject of this project. They are analyzed in order to locate the fault, decipher its causes, inform maintenance staff, etc.

(C) Fault location confirmed by maintenance staff

Faults are confirmed by maintenance staff if they are located in situ and unambiguously related to the calculated faults. They are used as feedback and are very important for the system because some parameters can be adjusted in order to improve the accuracy of future fault location. The following table presents the occurrence of each class of event

Class	MAN	BOL
A	626	637
B	31	43
C	8	7

At the present time, the most important class of results for this project is disturbances not confirmed by maintenance staff (class B above, excluding class C). These are disturbances representing phenomena that are located but remain unexplained, which constitute the building blocks of predictive maintenance.

Finally, the following figure provides statistics on the accuracy of fault location for a total of 26 confirmed fault locations for four monitored feeders LAW231, CAS239, BOL212 and MAN234. The bar chart represents the occurrence of absolute errors in meters.

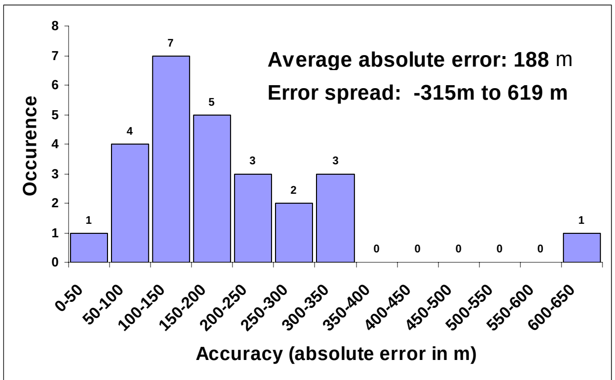

Fig. 5 – Statistics on fault location accuracy

The average absolute error is 188 m. The absolute error for all cases is less than 332 m except for one, which is 619 m. The ratio between these values and the average distance to end of line, namely 23 km, of the four tested lines gives an average error of 0.8% or 2.7% in the worst case.

This error value reflects not only the accuracy of the numerical assessment but also errors in the database and inaccuracies in the actual distance evaluation. The latter is usually provided by maintenance staff in terms of the pole span, being 50 m on average and reaching a maximum of 90 m for Hydro-Québec feeders.

PREDICTIVE MAINTENANCE

The following example illustrates the potential of the MILE system to detect an incipient equipment failure. The distribution feeder in Fig. 6 is 253 km long including laterals and is located in a rural area southwest of Montreal (Québec) where it feeds 2074 customers. In summer 2006, an investigation was initiated when customers complained about multiple fugitive faults. Analysis of data from circuit breaker controllers and line patrols did not solve the problem. Power-quality recorders were therefore deployed to catch the voltage waveforms affected by the phenomenon and to analyze these with MILE. On August 18, a fault was measured and two possible locations were calculated. A 1.3-kV fault amplitude was also deduced by the VDFL algorithm, indicating possible contact with a tree or a defective insulator.

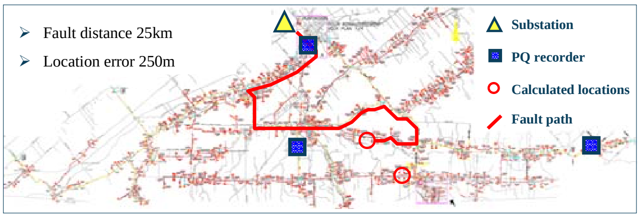

Fig. 6 - Incipient insulator failure in line HTD236

Site inspection of the calculated location revealed a pole with traces of burning (see Fig. 7), which was caused by a faulty insulator. The latter was replaced and the problem solved. Study of the current-fault amplitude and duration shows that an upstream fuse had probably melted and was partially damaged. It was presumed that this fuse would not withstand the next winter load rise and it too was replaced in order to prevent any further power outage.

Fig. 7- Faulty insulator

The team continues to develop dedicated tools for predictive maintenance using information from this project. Information such as weather conditions, lightning strike positions and outage information in the MILE system will provide a useful indication of maintenance needs in the distribution system.

CONCLUSION

So far, the VDFL technique has shown a very good potential for locating faults on the distribution grid and also for detecting incipient equipment failure or necessary tree trimming, which are major keys to predictive maintenance. Moreover, in 2007, five new feeders will be selected and instrumented in order to validate low-cost equipment and communication systems. In this next project phase, a larger number of personnel will be involved in use of the MILE system and the gathered feedback and comments should be helpful for the orientation of future development work.

REFERENCES

[1] C37.114 – IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines, *IEEE Power Engineering Society, 2005*