USING VOLTAGE SAG MEASUREMENTS FOR ADVANCED FAULT LOCATION AND CONDITION BASED MAINTENANCE

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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. Hydro-Québec (HQ) named this system MILES for Maintenance and Investigation of LIneS. The technique used was presented in previous CIRED publications in 2007 and 2011 as the Voltage Drop-based Fault Location (VDFL) technique. So far, the MILES system has shown a very good potential for permanent and temporary-fault location on overhead radial distribution system and has been deployed on 40 feeders located mainly at HQ and also at two other Canadian utilities.

INTRODUCTION

Distribution networks are aging and necessitate more maintenance, which is for the most part of the corrective nature. We also observe an increase of extreme climatic phenomena, which continues to test these fragile networks. In other parts, the available manpower is often being rationalised in order to lower the costs of operation. In this context, the utilities are having difficulties to maintain the quality of service at an adequate level. The frequency of outages is increasing and the continuity indices such as the SAIDI and the CAIDI, used by the controllers (incentives), are difficult to maintain in the prescribed limits.

The document [1] shows that the utilisation of the FDIR function (Fault Detection Isolation and service Restoration) of the DMS systems reduce the impact of an outage on the SAIDI and the CAIDI, as a majority of the clients are restored automatically without any human intervention. The patrol time of the feeder is reduced and the time to isolate the outage is eliminated. However, this technology has minor impact on operation costs, as these correspond essentially to the time required to repair the network and the frequency of the outages stays unchanged. We also note in [1] that the time for patrolling the feeder to find the location of the problem represents around 6 to 15 % of the total time of an outage. In this context, the use of fault location technologies to reduce the patrol time has only little impact on the time required to fix the outage as well as the associated costs.

Some technologies are proposed such as [2] to find incipient problems on the network and avoid outages. They are based on the localisation of non-persistent faults (NPFs) that represent from 50 to 80% of all the faults [3]. In this case, a fault is defined by a failure of the electrical insulation that causes the operation of a protection device. At HQ, vegetation contacts are the principal cause of NPFs. Galloping conductors, detached or loose conductors and defective insulators are also among the causes of NPFs. Those problems are considered as weak points on the network that can cause outages, which are often repetitive and difficult to locate. Lightning, animals and birds also produce NPFs, but they cannot be considered as weak points. However, the momentary interruptions caused by contact of animals and birds can represent a problem and to know their locations can, in certain cases, be useful to limit the zone of installation for the required mitigation equipment.

The localisation of NPFs represents a major challenge. In principle, during an outage, the network protection that is closest to the fault opens. This is detected by client calls or by alarms that are generated and transmitted by remote controlled network devices. The AMI meters can also be used in the localisation process. The patrol zone is therefore limited and the rapid localisation of the problem is possible. Unfortunately, this fault location mechanism is generally unavailable if no sustained outage is reported. Without this information, the zone to patrol is too large and dispersed, which renders the search of NPFs difficult to justify avoiding sustained outages.

MAINTENANCE AND INVESTIGATION OF LINES – MILES PROJECT

To alleviate this problem and reduce the patrol zone, we propose in this project to used distributed voltage measurements on the distribution network to localise the faults (US 8,269,503). This advanced fault location technique uses voltage triangulation [4] to limit the number of fault locations and an advanced fuzzy logic algorithm to identify the cause of faults.

Measurements Used and Deployment

In 2016, HQ deployed measurement devices on 28 distribution feeders and four more in early 2017. Five previous MILES feeders were still in service, which brings the total to 37 feeders to this date at HQ. Additionally, two feeders in Newfoundland and one in Alberta were equipped in collaboration with other utilities and also with an external partner. The deployment shows that an average of 4 measurement devices are required per feeder.

Figure 1 - Measurement Installation

The device selected for the project saves and transmits the voltage sag waveforms by using LTE cellular communication (4G). The Figure 1 shows a measurement point with a device installed at a three-phase transformer bank. Single phase measurements are also used for the MILES project. The measurement device is attached magnetically on one of the transformers and the measure is made on the low voltage. No service interruption is required during the installation procedure. The analysis of the fault location requires the primary voltage value. This voltage is calculated using the load current measurements and voltage measurements as well as the impedance of the transformer.

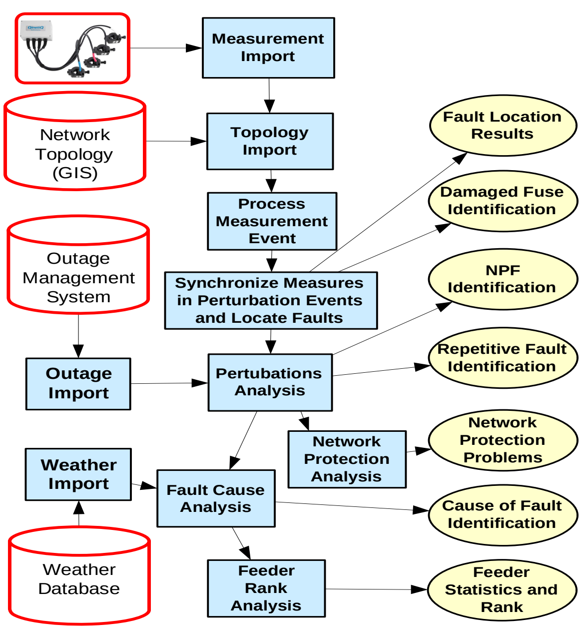

Figure 2 - MILES Process Analysis, Data Requirements and Results

MILES Analysis Processes

The Figure 2 shows the processes and the data involved in the analysis of the NPFs by the MILES system. This modular architecture permits updates to the system in function of the requirements. When multiple voltage sag measurements from different feeders arrive almost simultaneously in a short period of time, MILES automatically duplicate some processes to increase the number of NPFs that can be analysed simultaneously. The number of simultaneous calculations is limited by that of the virtual machines dedicated to the MILES system. During a fault, the measurements, the network topology, the weather and the outage data can be available at different moments. The analysis processes described in Figure 2 were developed to manage the previously mention asynchronous data.

VDFL Fault Location Algorithm

The VDFL technique is explained here with an example depicted by the Figure 3. This figure shows a feeder with four measurement locations identified at points 1, 2, 3 and 4 with the fault location at F. The substation is designated by S. The fault provokes a high current that is a function of the impedance between the source and the fault, as well as the type of fault. The current produces a voltage drop on the conductor along the path S-1-A-B-C-F. The residual voltage at F corresponds to the arc voltage of the fault.

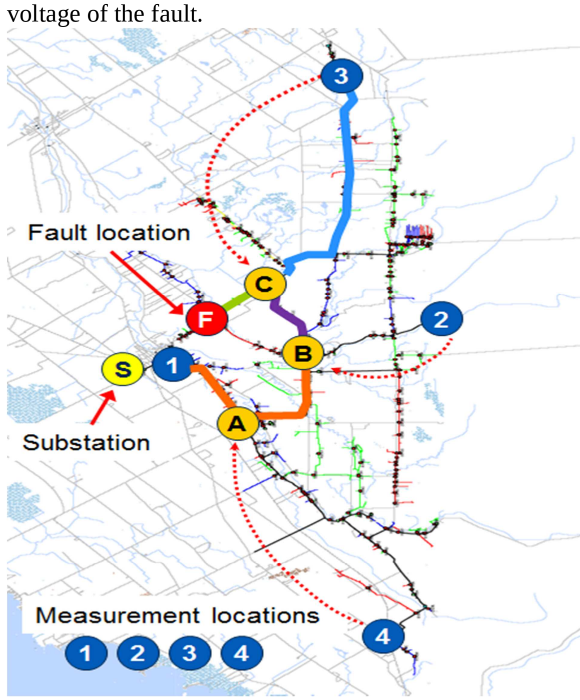

Figure 3 - VDFL Fault Location Technique

The first step of the analysis consists to determine what measurement has seen the biggest voltage variation, which corresponds here to the measurement at point 3. The algorithm determines then that the fault had taken place on the portion of the network between S and 3 or in an attached lateral that does not possess a measurement device. The algorithm attaches the other measurements on this axis S-3 by their point of common coupling. The measurement 1 is directly on this path. The point of common coupling of the measurements 2 and 4 with the path of the fault are identified by B and A. We consider that the points 2 and 4 have seen the fault as if they were at the locations B and A respectively. An algorithm is then applied to reduce the topology used for the fault location calculations. This reduced topology is evaluated in function of the voltage drop measured by the four measurements. Then, the three best measurements are conserved for the calculation of the fault location.

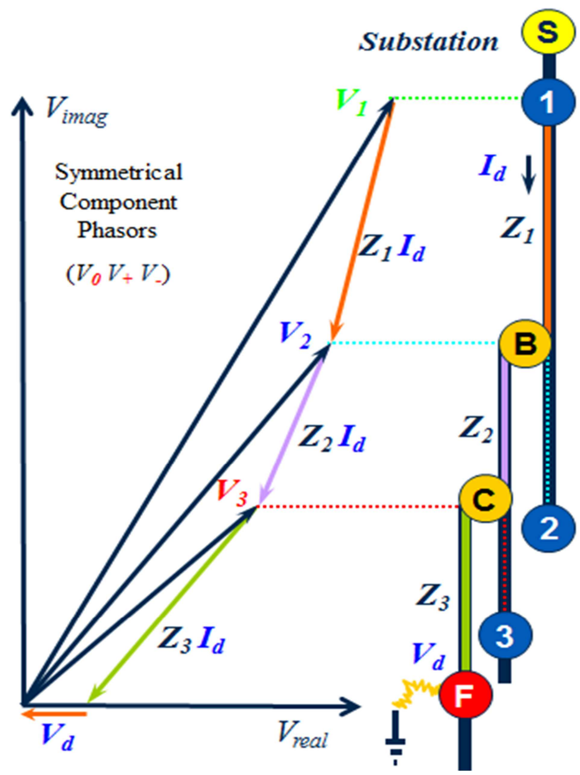

Figure 4 - VDFL Algorithm

The Figure 4 demonstrates the VDFL technique applied to the voltage phasors calculated for the fault of the example of Figure 3 . Only the measurements 1, 2 and 3, considered as the best ones for the fault location calculation, are kept. The measurement 2 was considered in the calculations as if it was placed at the location B. We do not yet know the location of the measurement 3 with respect to the fault path. It will be determined by triangulation in the VDFL technique.

The VDFL technique can be summarised by the following steps:

1. Calculation of the fault current ***Id*** using ***(V1-V2)/Z1***; ***Id*** is the unbalanced fault current ***Id0***, ***Id+***, ***Id-.***
2. We evaluate the location where ***V1-Id*(Z1+Z2) = V3*** (triangulation)
3. Depending on the phase angle of ***V3***, we determine if the fault is in the axis 1-3 or in a lateral branch. If the angle is null, then the fault is on the axis 1-3 at the position identified by ***Z1+Z2*** and ***V3*** corresponds to the arc voltage. If not, it is in a lateral branch.
4. If the fault is on a lateral branch, we search for all the laterals in proximity to the position identified by ***Z1+Z2***.
5. For each lateral branch identified, we re-evaluate the fault current ***Id*** using ***(V1-V3)/(Z1+Zb)*** where ***Zb*** is the impedance between the lateral branch and the position B.
6. We find the fault location ***Z3*** that is identified by the point where the phase angle of the voltage evaluated by ***V3-Id*Z3*** is null, therefore in phase with ***Id***; the amplitude of the voltage evaluated at this location corresponds to the arc voltage of the fault.

The VDFL technique gives only one possible fault location for the above example. If substation measurement and an impedance fault location technique were used instead for the case presented before, we would have obtained six possible fault locations. The Figure 5 shows these possible fault locations identified by F and the star symbols.

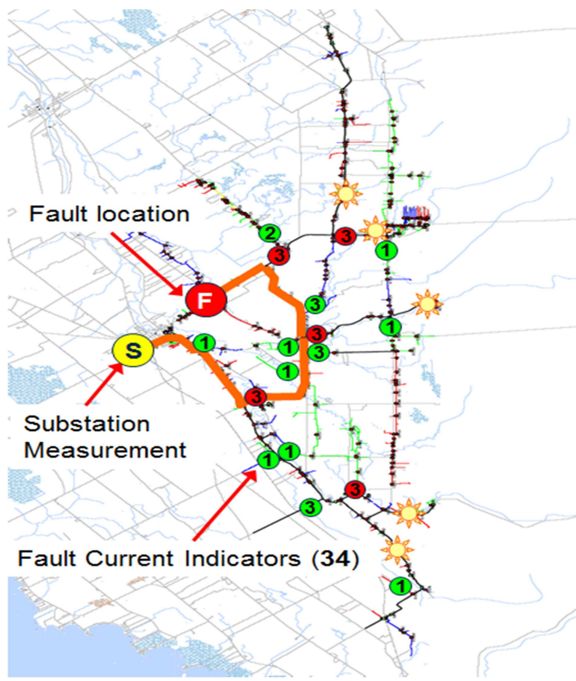

Figure 5 - Impedance Based Fault Location Technique

To isolate the true fault location F, it would have been necessary to add 15 remote controlled fault indicators in addition to the voltage and current measurements at the substation. To obtain the same performances as the

VDFL technique for all the possible fault positions on the feeder, 34 fault indicators would be required. This example shows the advantage of the VDFL technique in localising a NPF comparatively to a conventional technique.

Fault cause recognition and network protection problem analysis

Knowing the location of the fault can, in some cases, be insufficient to resolve the network problem. By example, it would be difficult to find marks left on the conductors caused by galloping. The patrol of a feeder is done generally from a vehicle in motion rendering practically impossible the localisation of such a problem.

The knowledge of the arc voltage produced during a fault, such as that determined by the VDFL technique, permits us to determine the distance between conductors or between the medium voltage and the neutral or ground at the location of the fault. In fact, the amplitude of the arc voltage is proportional to its length in the air. We have an equivalency of approximately 1kV per meter. In the example of galloping conductors, a null voltage between phases will be deduced from the VDFL technique, which permits us to conclude that there was a contact between conductors. When used in conjunction with the weather and other information obtained during the analysis such as the faulted phases, the repetition of the fault, the delay between the repetitions and the duration of the fault, it is possible to identify with sufficient success the cause of the problem.

The MILES system also analyses the behavior of the network protection. The distributed measurements permit us to determine what network protections have acted during the fault and the sequence of their operations. The amplitude and duration of the fault current evaluated are also used in the analysis as well as the sequence of the operations. The analysis is done in two steps. The first step uses the configuration of the topology, the outage information and the voltage variation measurements. It's a simple preliminary analysis, which permits the identification of the potential problems. The second step includes the configuration of the breakers and permits the verification of the correct protection operation with respect to its configuration. This last step was not in function in the MILES system at the moment of writing the publication.

Worst Feeders Ranking and Analysis

A summary table has been developed to classify the performance of the feeders over various time spans, which range from a week to a year. Several indicators have been developed to filter by the fault type, the quantity of events measured, the number of NPF with localisations, and the number of clients possibly interrupted. This synthesis allows the users to prioritise their analysis and maintenance projects on the worst performing feeders.

From this table, the users can select the desired filters and open another interface, which will visually demonstrate the fault localisations determined by the MILES application on a Google maps application. With this knowledge, a user can therefore determine which zone of the feeder would require maintenance work. An example of this is presented in Figure 6. Several vegetation contacts were determined to have caused NPFs at the locations identified with an X and the repetitions of faults are identified by the intensity of the highlighted zones. In this situation, instead of performing vegetation control on the entire feeder, it can be carried out specifically in the identified problematic zones. This will aide to reduce the costs of the intervention and free up time for the employees to perform other tasks.

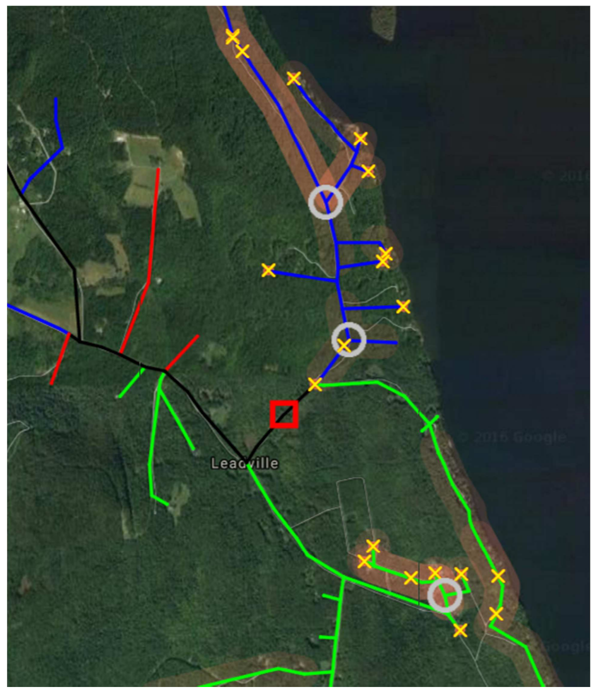

Figure 6 - Highlight of Last Year's Vegetation Problem Locations

USECASE EXAMPLE

In December 2014, multiple repetitive momentary interruptions occurred on a distribution feeder supplying a ski station. The faults happened during the evening at the moment when artificial snow was produced. At each interruption, the night ski lights turn off for a period of 20 minutes, compromising the security of the resort. The holding of an international acrobatic ski competition at this location was also jeopardized. Several patrols of the feeder were carried out without any success. However, certain corrections were brought to the feeder with the hope of fixing the problem, which disappeared at the beginning of January. A defective insulator close to the ski slopes was suspected to be responsible for the problem.

In the scope of the MILES project, three measurement devices were deployed on this feeder in the autumn of 2015 to investigate this problem. On December 26 2015, the problem reappeared. Multiple faults were recorded and analysed.

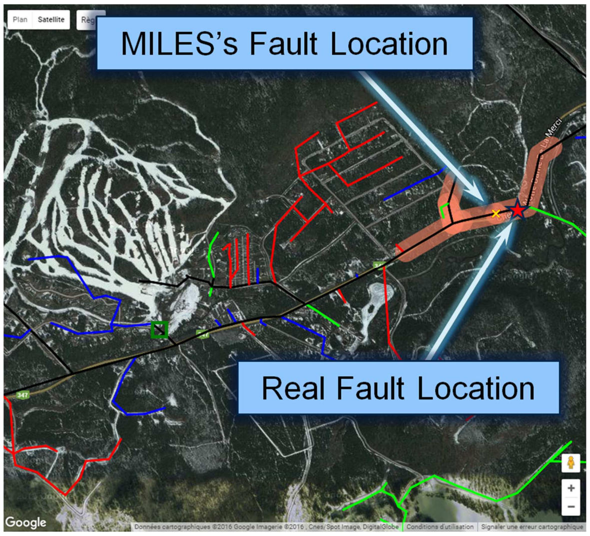

Figure 7 – MILES Fault Location

The Figure 7 shows the fault location given by MILES that determines that it was probably caused by a defective conductor. A team of linesmen discovered the problem at less than 100m from the provided location. The Figure 8 shows a view of the fault location obtained from the Google « Street View » application. The proximity between the conductor and the neutral at this location is clearly visible on this picture.

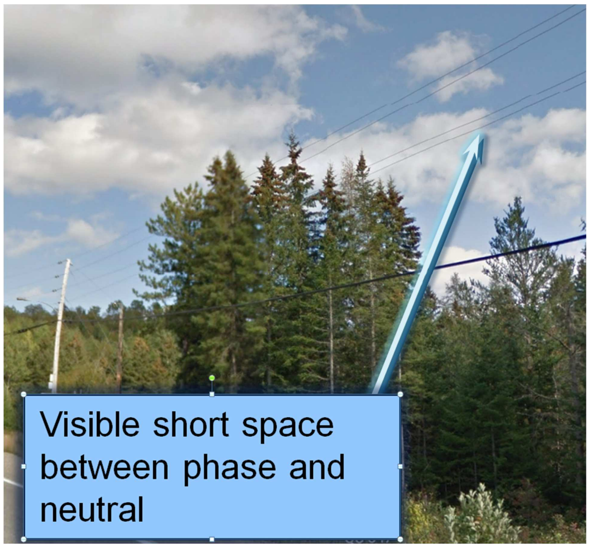

Figure 8 - Street View of the Fault Location

The Christmas and New Year's holiday period corresponds to the maximum load of this feeder. In addition to the production of snow, many tourists invade the region and occupy the hotels and chalets. This period also corresponds to the period where the electric heating is used at its maximum. Consequently, the conductors are heated and expand. At the opposite side, the neutral conductor is shortened due to the low temperature and the balanced load. This caused a contact with the conductor in its close proximity creating the momentary interruptions.

CONCLUSION

The MILES system put in place at HQ shows that the VDFL technique and the tools developed for the conditional maintenance of distribution network are functional and provide good results. In 2017, the gains obtained from the system will be measured. Additional measurement devices will be deployed on other feeders in function of the needs and other types of measurement devices will be tested as well with the objective of finding the ones that are easy to install and more cost effective.

In other news, in 2016, HQ allied itself with external partners for the commercialisation of the MILES system. These partners have negotiated other pilot projects with other Canadian and American utilities in order to test out the MILES solution on their networks. New feeder configurations will thus be tested and MILES adapted consequently. This was the case with the feeder of Alberta where mixed distributed voltage level of 25kV and 8kV were used. Propositions for pilot projects on European and South American networks are also under consideration.

REFERENCES

[1] M S Thomas, J D McDonald, 2015, *Power System SCADA and Smart Grid*, CRC Press, New York, United-States, 233-234.

[2] B. Don Russel, Carl L. Benner, 2010, "Intelligent Systems for Improved Reliability and Failure Diagnosis in Distribution Systems", *IEEE TRANSACTIONS ON SMART GRID*, vol. 1, no. 1, 48-56

[3] T A Short, 2014, Electric Power Distribution Handbook, CRC Press, New York, United-States, 368-373.

[4] M. Tremblay and al, 2011, "PQ Monitoring with Smart Meters for Condition Based Maintenance on Distribution System", Proceedings 21th CIRED