FAULT LOCATION IN PORTUGUESE MV NETWORKS

Miguel LOURO
EDP Distribuição – Portugal
miguel.louro@edp.pt

Mário LEMOS
EDP Distribuição – Portugal
mario.lemos@edp.pt

Luís MARCELINO FERREIRA
IST - Portugal
lmf@ist.utl.pt

Pedro CARVALHO
IST - Portugal
pcarvalho@ist.utl.pt

Fernando CARVALHO
IOA – Portugal
fernando@ioa.pt

ABSTRACT

Today's challenges faced by electrical utilities are always related, directly or indirectly, with improving the quality of the service while maintaining, or decreasing, costs (both operational and investment costs). From the analysis of the client interruptions it is possible to conclude that the majority of the interruptions are caused by faults in the Medium Voltage (MV) network. The process of handling faults in this voltage level has several stages: fault location; maximum power restoration to clients; fault repair.

Nowadays, MV protection units usually have incorporated a "fault location" module for no extra cost. Recognizing the interest of estimating fault location from protection units' data, EDP has been involved in a pilot project to ascertain the best manner of grasping its full potential.

The pilot project's results showed the potential for a decrease in interruption time between 12% and 76% and a reduction of the number of network incidents.

INTRODUCTION

With the objective of improving the Quality of Service EDP deployed a fault location pilot project using the information of the protection units.

Nowadays, MV protection units usually have incorporated a "fault location" module for no extra cost. This is a well established function for transmission networks; however, distribution networks have some differences that must be taken into consideration. The main factor is that distribution networks are radial and constituted by many branches which may have different impedances. So, it is not possible to use a distance to fault in kilometres information as it is common practice in higher voltage levels. An option is to use the fault impedance data, which is available in the protection units, and determine the likely area of fault location in a central software application.

The pilot project lasted from Jan. 2010 to the end of Nov. 2010. The actual faults that occurred during the project are presented. The fault location's performance is assessed in terms of distance error between the actual location and the protection unit calculations. Some recommendations are made for those who which to endeavour in a similar project.

FAULT LOCATION SYSTEM DESCRIPTION

Besides their main functions modern protection units can also perform other tasks (ex.: control functions). One of these tasks is commonly named "fault location". It consists of an analysis performed on recorded fault data, by the protection unit, with the objective of determining the fault's electrical impedance.

By comparing the fault impedance with the network impedance it is possible to locate the fault. In HV networks each line has a protection unit and it is possible for the protection to compare the line's impedance (which is one of the protection unit's settings) with the fault impedance and transmit the fault's location in kilometres. However, in MV networks that is not possible because, despite being radial, there are many ramifications with different electrical characteristics. So, the option, in our case, was to perform the fault impedance comparison not in the protection unit but in the Control Centre using DPlan software.

The fault location system operation is shown in Figure 1. The protection unit detects the fault, records the voltage and current time values and trips the circuit breaker. Afterwards it performs a "fault location" calculation and sends the fault impedance data to the SCADA system. The SCADA then sends it to the DPlan software which determines the fault's possible location.
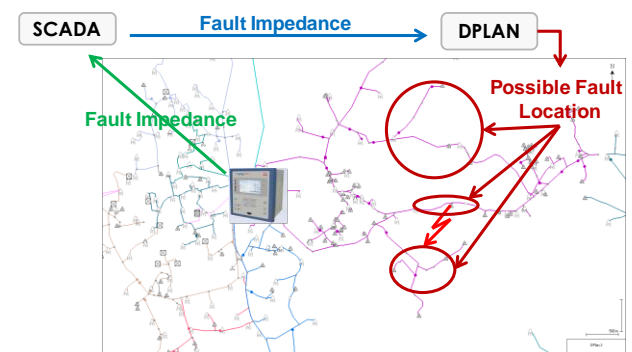

Fig.1 – Fault location system operation

FAULT LOCATION USING DPLAN

The software DPlan has been used for almost a decade in Portugal for power system planning at a Distribution level. Therefore it is a very stable and tested platform.
It can determine the possible faulty branch with the fault impedance from the protection units very quickly.
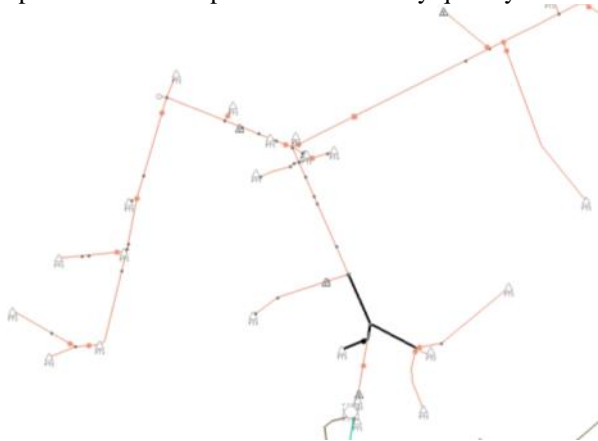

Fig.2 – Fault location example using DPlan (possible faulty branches in black)

Because DPlan currently does not yet have access to the SCADA system data for cyber security reasons the process of inserting fault impedance data remained manual during the pilot project.

IMPEDANCE BASED FAULT LOCATION ALGORITHM ERRORS

Load Current Compensation

During a fault the feeder is still providing current to the loads. Therefore, the current flowing from the feeder has two main components: fault current and load current. Because fault location algorithms calculate fault impedances, the presence of the load current can lead to large errors. This is especially true for phase-to-ground faults in systems where the neutral impedance limits the maximum fault current to values near the feeder nominal current. In Portugal the neutral current is usually limited to 300A for substations serving a mainly overhead network.
Fortunately there are algorithms that can compensate the load current and perform a more accurate fault impedance calculation (most notably the algorithm in [1]). However, these algorithms need information about the load in the instants before the fault. If the fault appears just after a circuit breaker closure (consider a previous opening due to a fast reclosing) there is no information about load current and the fault location is less precise.
In the case of several automatic, or manual, reclosures the most precise information is the first one, which is the one that is most likely to have load compensation.

Measurement errors

As with any other measurement the fault impedance is also affected by errors. These errors affect the resistive (R) and reactance (X) part of the impedance.
The error region is shown in Figure 3. For further information on this topic the reader is recommended to refer to [2].
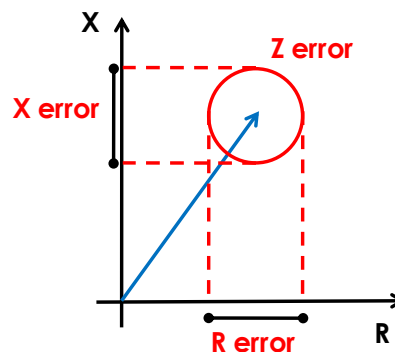

Fig.3 – Impedance measurement errors

The fault location estimation is usually done through the fault reactance. Using the R value is less precise because of the fault resistive nature, the resistance of which is unknown.
A value of 10% was used for the overall fault impedance measurement error for the fault location project. For further information about this topic please refer to [3].

PREPARATION TASKS

Protection unit testing

Before installing the system in the field several tests were performed to the protection units. These consisted on injecting currents and voltages, obtained by simulating various fault types and fault resistances, in the protection relays and accessing their response.
Some of the relays tested selected phase-to-ground fault loops [4], instead of phase-to-phase loops, to perform the fault impedance calculation while in the presence of phase-phase-ground faults. This can lead to a less precise location because the fault resistance to ground is usually larger than between phases.
Several protection unit configuration issues were also detected and resolved during the testing stage.

SCADA and Substation Automation System interfaces

SCADA systems have limitations on the type of information that can be sent to them.
Fault location information results from the analysis performed at the protection unit level after a fault event. However, the final product of the analysis are two numerical values (R and X) that have to be with high precision (a 3 decimal representation was chosen for this pilot project).
After careful consideration of the available options it was

decided that the fault location information should be communicated to the SCADA system as a measured value similar to a voltage or a current. The fault location report was performed by variation in value, instead of a time controlled refreshing.

Considering the typical number of feeders in a substation the number of measured values to be transmitted is significant. To reduce the workload associated with the pilot project another criteria for the substation selection was the presence of a substation automation system (using IEC 60870-5-104 or IEC 61850). Wiring at the project's substations was kept at a minimum.

IMPLEMENTATION STAGE

In order to minimize the cost associated with this pilot project only four new substations were chosen to participate. The cost of configuring the fault location system fell under the overall substation configuration. Due to the previous testing of protection units and relative ease of sending information to the SCADA system the implementation stage was straightforward.

The selected substations network is mainly overhead.

DPlan software was also installed in the MV Control Centre and basic training was given to the users.

RESULTS

During the pilot project 13 faults were detected by the field crews in the network served by the four substations from Jan. to end of Nov. 2010.

The results of the new fault location strategy are shown in Table 1.

Table 1 – Pilot project fault location results

Fault	Fault location	Description
1	successful	Broken conductors due to fallen tree
2	successful	Bird contact
3	successful	Broken conductors
4	successful	Damaged distribution transformer
5	successful	Broken conductors due to fallen tree
6	successful	Tree contact
7	successful	Broken conductors due to fallen tree
8	successful	Broken conductors
9	successful	Tree contact
10	successful	Tree contact
11	successful	Broken conductors
12	successful	Tree contact
13	unsuccessful	Damaged surge arrestor

There were 12 correct fault locations and 1 incorrect location.

The incorrect location was a peculiar case of a fault that initially started in phase C with a fault current of 70A. After the first automatic reclosure the fault reappeared in phase A with a fault current of 140A. Later, a damaged surge arrestor was found. Probably the first circuit

breaker trip was not due to the damaged surge arrestor but to another fault (which was eliminated by the circuit breaker reclosure). However, because the first fault location indication is usually the most accurate it was used to assess the system's performance. The incorrect fault location results from a rare situation.

The accuracy of the fault locator was also assessed. The results are shown in Figure 4.

By observing Figure 4 it is apparent that the impedance error is below 10% for most cases (there was a case of 10,5%). So, using an error margin of 10% will yield good results for practical cases. The impedance error was determined by comparing the fault impedance with the network impedance in DPlan's database.

Unfortunately when the faults described in Table 1 occurred there were adverse meteorological conditions in several zones and therefore the Control Centre was very busy dealing with several simultaneous faults to devote some attention to the new system. An estimation of gains was performed considering the search and repair times associated with each of the faults shown in Table 1.
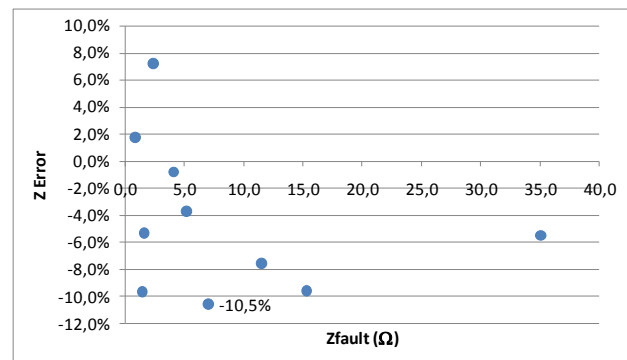
Fig.4 – Fault impedance error vs. total fault impedance

It was determined that the fault location system can lead to a reduction in interruption time from 12% to 76%. The average reduction for the 12 faults was of 40%. Some of the lines served by the pilot project substations go through mountainous terrain with no roads nearby. So finding a fault in these conditions can be very time consuming. Therefore, fault location can contribute very significantly to reduce the total interruption time.

There is still another gain that can be achieved from a fault location system. Some faults begin as non-permanent faults and are typically eliminated by the automatic reclosures. However, after a time, and several reclosures, they become permanent and give rise to interruption time for the costumers. EDP has specialized teams that are in charge of the MV line maintenance and that look for the non-permanent fault locations. The fault location data of automatic reclosures of the monitored substations were made available to the specialized teams. With the data provided the teams found four faults (which were inserted in Table 1. Faults #2, #6, #10 and #12) and thus prevented further occurrences.

LESSONS LEARNED

Protection unit configuration

Special attention should be paid to the protection unit configuration. In the course of the pilot project it was discovered that the fault location information was not being transmitted after a fast reclosure. This was a configuration issue in the protection modules.

It should also be noticed that the fault location information is being communicated in primary values by the protection. Therefore it is essential that the correct CT and VT relation is inserted in the protection unit.

Full automatic system

Due to the low budget and short time of the pilot project it was not possible to establish a secure database link between the SCADA system and DPlan. Therefore several stages of the fault location system remained manual through the pilot project.

It was established that the fault location information is most necessary in periods were there are multiple faults in the network. In those periods the Control Centre are extremely busy dispatching crews and need to get information without manual intervention.

An automatic and easy to use system is necessary to obtain higher gains.

Network Data

The fault location process is based upon the comparison between the fault impedance (calculated in the protection unit) and the network's impedance (computed by DPlan). If the electrical characteristics of the network are not correctly loaded in DPlan's database the comparison is error prone.

Therefore, before engaging in a similar project it is advisable to conduct a quality test to the electrical information of the network's database.

During the course of the pilot project a few erroneous situations were detected and corrected.

CONCLUSION

The usage of the fault location information given by the MV protection units has the potential for a large reduction of interruption time. Our experience shows that gains can range from 12% to 76% per incident. There are also gains by avoiding re-occurring faults, provided that the line maintenance teams are supplied with the fault location information.

A fault location system, as reported here, could be easily implemented because it was built upon existing functions of the protection units and DPlan that is a stable technology, widespread in EDP.

The system's full potential is however dependent on automating the process.

REFERENCES

[1] T. Takagi et al., 1982, "Development of a new fault locator using the one-terminal voltage and current data", *IEEE Transactions on Power Apparatus and Systems,* vol. 101, 2892-2898.

[2] J. Pinto de Sá, 1994, "Stochastic analysis in the time domain of very high speed digital relays – Part1: Theory", *IEE Proc. in Generation, Transmission and Distribution,* vol. 141, 161-168.

[3] J. Pinto de Sá et al., 1997, "A probabilistic approach to setting distance relays in transmission networks", *IEEE Transactions on Power Delivery,* vol. 12, 681-686.

[4] IEEE, 2004, C37.114 *IEEE Guide for Determining Fault Location on AC Transmission and Distribution Lines,* IEEE, New York, USA, 1-36.