INTEGRATION OF FAULT LOCATION IN A SMART GRID OPERATING SYSTEM

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ABSTRACT

The paper describes the advantages and constrains of integrating of a fault location functionality to the system that is used by a dispatch center to operate a Smart Grid in the electricity distribution sector.

An electricity distribution grid contains a large number of power lines and equipments distributed over a wide area that might be the size of an entire country (see Figure 1). A great number of these equipment are power protection equipment capable of detecting power faults as they occur, protecting consumers and the grid itself from the consequences of these faults. When a fault is detected in a remote location, such as a power line, it is necessary to dispatch repair teams to the field to locate the place where the fault occurred. If it occurs on rough ground (i.e. forests or mountains) or during bad weather (i.e. storms or hurricanes), the most common situation, this job gets significantly harder. We are able to detect a fault occurrence but we are not able to easily locate where it physically occurred.
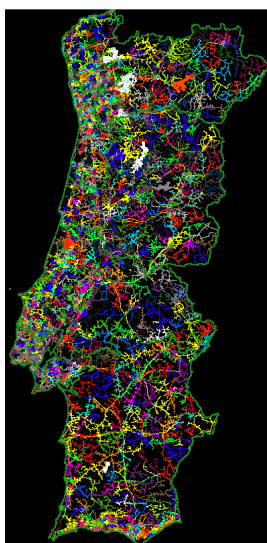
Figure 1 - Portuguese electricity distribution grid

In a smart grid the electricity distribution grid is managed through a communications network that enables
remote monitoring and control of power equipments through the use of a grid operating system (SCADA). EDP Distribuição (EDP Group), Portugal controls more than 400 primary substations, 1100 secondary substations (out of 60000) and 3000 circuit breakers in overhead medium voltage (MV) lines. All equipments are connected to a core infrastructure where the SCADA system is hosted and from where it is able to send and receive information from remotely distributed equipments, including fault detection data.

The solution implement a fault location functionality for EDP Distribuição's SCADA system that uses the collected data in order to calculate the possible location of a power fault and to calculate also the affected MV and high voltage (HV) branches of the electricity distribution grid. As soon as a fault is reported to the SCADA it is displayed in real time on the substation one-line diagram. From here a mouse click on the fault symbol will open the schematic or geographical diagram showing the fault location.

With this solution, the dispatchers are able to position repair teams on the field with increased efficiency, decreasing fault repair times and improving the working conditions of SCADA operators and fault repair teams.

INTRODUCTION

The new fault location functionality that is described in this paper is integrated in the GENESys SCADA system developed by EFACEC for EDP Distribuição (EDP Group), Portugal. At a first stage it will work only in the medium voltage (MV) level of the electricity distribution grid. In the medium term it is planned to work also in the high voltage (HV) level.

MV grid protection devices report the fault by sending the calculated values of fault resistance and reactance to the SCADA system where these are processed by the fault location algorithm to estimate the fault location.

The same algorithm was implemented in another system in the context of a pilot project with the objective of determining the best manner of grasping its full potential as described in [1].

A new GENESys application – the Fault Manager – was developed to handle fault visualization and management. With this, fault locations can be consulted by dispatchers

through the GENESys graphical user interface (GUI) in one-line, schematic and geographical diagrams or through the Fault Manager window.

In the following sections, we start by describing the fault location algorithm. Then, we discuss implementation constrains that can impact its performance. We present the Fault Manager application. We review advantages of the fault location functionality for dispatchers. Finally, we draw some conclusions and we discuss further work.

ALGORITHM

The fault location algorithm execution gives two results:

1. Minimum and maximum distances between the protection device and the probable fault location;

2. List of equipment located in the probable fault area with a percentage to the last terminal included in that area (a value of 100% means that the whole equipment is included).

Whenever there is a change in the resistance and reactace values reported by a protection device, these new SCADA values are sent to the system thereby creating a "fault" with the received characteristics:

- device where the measure was taken,
- resistance and reactance values and
- measurement timestamp.

This information is also sent to the Fault Manager which estimates the fault location by using the following information:

- fault impedance value,
- distance calculation error,
- grid topology and
- equipment (line) impedances.

In a first step, fault impedance is calculated through Equation 1.

$$Z_{fault} = \sqrt{R_{fault}^2 + X_{fault}^2}$$

Equation 1 – Fault impedance calculation

Then, maximum and minimum values for the distance between the protection device and the probable fault location are calculated based on the reactance value affected by an error through Equation 2 and Equation 3.

$$X_{max} = X_{fault} + error . Z_{fault}$$

Equation 2 – Maximum distance calculation

$$X_{min} = min(0, X_{fault} - error . Z_{fault})$$

Equation 3 – Minimum distance calculation

The error value is configured to be 10% by default ([1]). Although it cannot be altered directly by a user, it is possible to change it through a configuration file.

The algorithm assumes that the measured fault impedance is the same as the grid impedance in the path between that location and the fault location, minus the error. Therefore, it searches and identifies all paths ahead of the device that have an X value between X_{min} and X_{max} as possible fault locations. Paths with transformers in the middle are not considered. The identified area is added to the fault's characteristics.

The grid topology considered in the search must be the topology presented by the grid right before the fault occurred. Therefore, to exclude changes associated with the fault occurrence, the algorithm considers a time frame around the instant when the fault measurements were received. The start and the end of the time frame must correspond to stable states of the system before and after the fault has occurred respectively. The algorithm "travels back in time" to obtain the right topology and associated automatisms' states.

Currently, the fault time frame is configured to four minutes which is considered an acceptable time according to dispatchers' experience. This value can also be altered in a configuration file.

Probable fault locations are calculated and ready to be shown soon after the end of the time frame.

CONSTRAINS

It is only possible to use the fault location functionality in areas of the network where the primary substations are equipped with devices that are capable and configured to obtain and send fault measurements to the SCADA system. Currently, not all primary-substations possess this capability and an effort is being made to progressively change this situation.

Moreover, the algorithms' reliability is dependent on the correct characterization of grid equipment (e.g. if a situation occurs where the impedance of a line proves to be wrong, the algorithm may give a bad result that may complicate the work of dispatchers and repair teams).

FAULT MANAGER

In the Fault Manager a fault can have one of three states with different durations:

1. calculating – four minutes (corresponding to the considered fault time frame) or until manual reposition;

2. active – four hours (average time foreseen to resolve an anomaly);

3. inactive – indefinitely.

The indicated times can be altered in a configuration file.

The dispatcher is warned of the occurrence of a fault when the fault symbol – a blinking light bulb – is shown in schematic and one-line diagrams near the corresponding circuit breaker. The light bulb changes colors depending on the state of the "fault":

1. red – calculating (see Figure 2);

2. yellow – active (see Figure 3 and Figure 4).

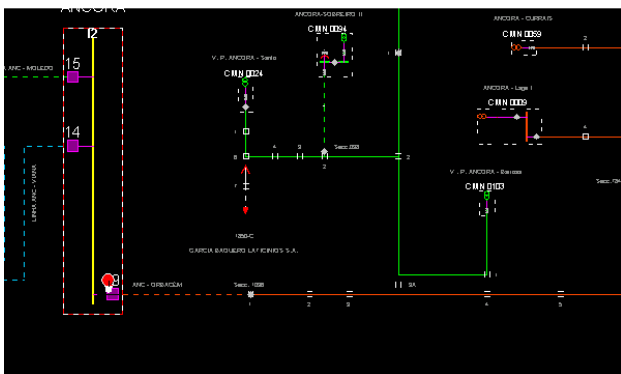When the "fault" becomes inactive automatically or manually, the symbol disappears.

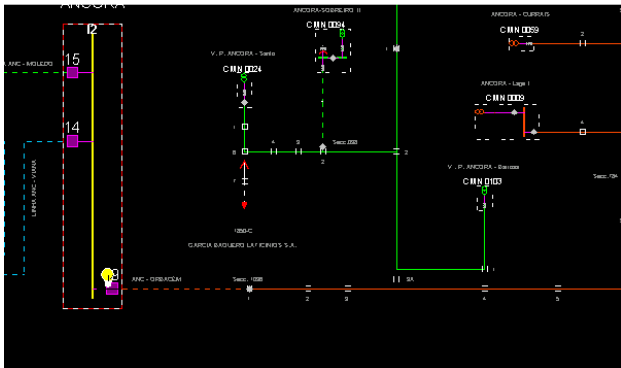**Figure 2 –** Red light bulb in schematic diagram

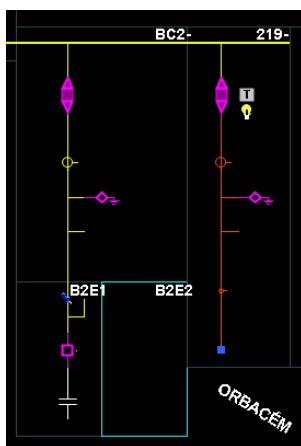**Figure 3 –** Yellow light bulb in schematics diagram

Figure 4 – Yellow light bulb in one-line diagram

A mouse click on the yellow light bulb allows to the dispatcher the possibility to:

- see the fault location area in schematic and geographical diagrams (see Figure 5 and Figure 6, respectively);

- access to all the fault location information (e.g. resistance, reactance and calculated distance);

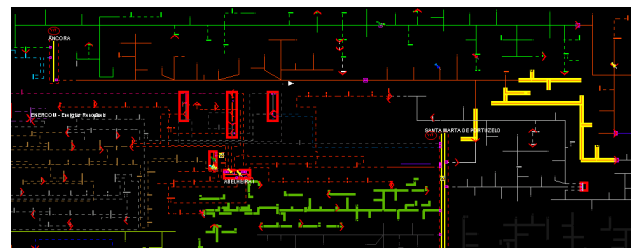- open the Fault Manager window (see Figure 7 and Figure 8).

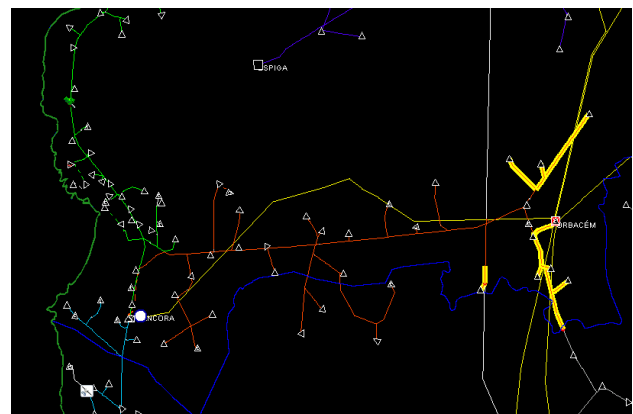**Figure 5 –** Fault location represented in yellow in schematic diagram

Figure 6 – Fault location represented in yellow in geographical diagram

A fault location area is shown in the diagrams by highlighting equipments (i.e. lines) that are included in that area with a thicker yellow line. Fault visualization is a static functionality. It only shows the result of the algorithm execution; it is not dynamically updated.

The Fault Manager presents two types of tabs. The first type is the fault details tab, which shows information such as:

- Fault measurements (e.g. resistance, reactance);

- List of equipment located in the probable fault area with a percentage to the last terminal included in that area (a value of 1 means that the whole equipment is included).

It also allows the dispatcher to further characterize the fault. He can confirm that an equipment is really inside

the fault area or remove equipments from the list, thereby changing the estimated area. He can also associate an equipment with the fault origin and provide a motive for the fault occurrence. There can be several detail tabs open at the same time.
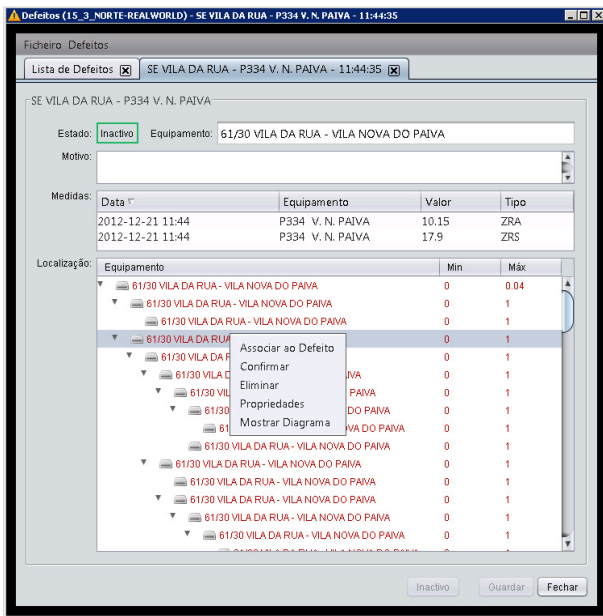

Figure 7 – Fault detail in fault manager window

The second type of tab provides a list of all faults processed by the system with their respective state, characteristics and associated location information. In this list it is possible to highlight fault areas and associated details through a popup that appears when the mouse pointer hovers over a fault.
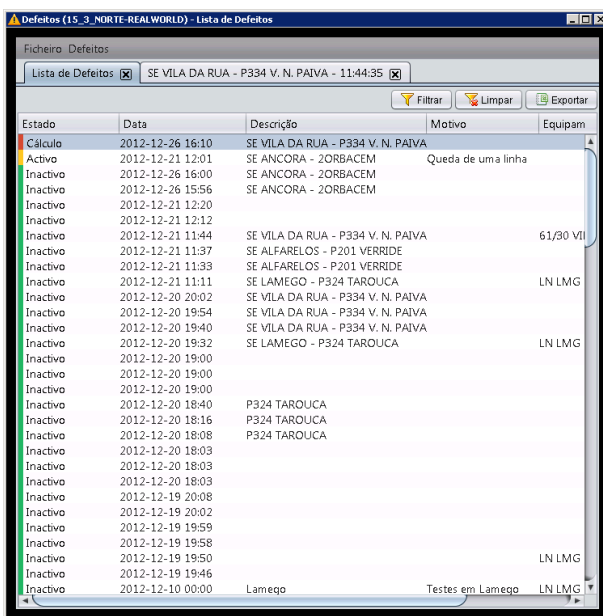

Figure 8 – List of faults in fault manager window

ADVANTAGES

Dispatchers are able to position repair teams on the field with increased efficiency, decreasing fault repair times and contributing to improve dispatching indicators (e.g. decreasing duration of outage times).

The working conditions of fault repair teams should be improved due to a shorter exposure to harsh environments during the repair of anomalies caused by faults.

Clients will also benefit due to shorter outage times when a fault occurs.

CONCLUSIONS AND FURTHER WORK

We have now described how the fault location functionality for GENESys works and how it looks and feels to dispatchers.

The algorithm uses the measured values of resistance and reactance to calculate the maximum and minimum distances where the fault probably occurred. This calculation is constrained by the correct characterization of grid equipment in the system. A bad characterization of equipment can lead to a wrong calculation of fault locations, causing the dispatchers to stop relying on the functionality results. In the long term, information from fault detectors and other devices located in the fault location area will be used to select/ eliminate possible locations.

Dispatchers are warned that a fault occurred with the appearance of a symbol near the circuit breaker at a primary substation that isolates the fault. They are able to see the highlighted fault location in diagrams and associated information in the Fault Manager application.

A set of configuration options including times and colors can be altered in a configuration file. With further testing and dispatchers' feedback it will be possible to adjust these configurations so that the functionality returns better results and becomes more user-friendly.

This functionality improves the work of dispatchers and repair teams to find fault locations on the field. Currently, it is still in testing stage and therefore we can't present data that shows its impact in real fault repairing situations. However, results obtained in [1] indicate potential gains in reduction of interruption time that can range from 12% to 76% per incident.

The functionality will be extended to HV once it is tested and working in the production system for MV.

REFERENCES

[1] Miguel Louro et al., 2011, "Fault Location in Portuguese MV networks", *Cired 2011, paper 0848, Frankfurt.*