EDP'S EXPERIENCE IN OPTIMIZING IN-SERVICE PROTECTION SYSTEM UNITS

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ABSTRACT

Distribution System Operators are increasingly urged by their stakeholders to provide a better and higher quality of service, while minimizing CAPEX and OPEX.

With this in mind, EDPD Distribuição (EDPD) developed a programme to optimize its current protection asset base that spans along several generations and technologies, and, consequently, with different levels of protection functions. This programme consisted of an exhaustive revision of all Medium Voltage (MV) protections function settings that comprised a total of 484 substations and switching stations, and over 5100 feeders within the entire mainland Portugal distribution grid. The main goals were to ensure protection relays coordination, guarantee sensitivity for electrically distant short-circuits and minimize voltage dips duration.

At first, EDP's Protection and Automation Department used DPlan to conduct systematic short-circuit and protection studies. In order to optimize this process, and reducing man-hours needed, EDPD and AmberTREE worked together to develop improvements within the short-circuit and reporting modules.

With the newly optimized protection settings, EDPD advanced towards in-field confirmation and implementation, resulting in more than 6600 protection function changes, preventing 190 potential coordination failures and reducing the voltage dips duration in 1197 MV feeders. The actual study results' impact on grid operation are now under an assessment stage with an in-house tool that correlates SCADA and voltage quality monitoring system data.

With this work, EDPD expects to improve significantly quality of service and reduce Customer complaints regarding voltage dips and short interruptions by using the existing asset base, while keeping the costs low.

INTRODUCTION

Today's Distribution System Operators (DSO) need to address increasingly demanding requirements by their stakeholders. Providing a better and higher quality of service, improving the relationship with customers and shareholders, while reducing operational and investment costs, but not forgetting the importance of "prosumers" on the network operation. These are important matters that need to be addressed skillfully. Additionally, Utilities have a protection unit asset base that spans along several generations and technologies, with older electromechanical and static units providing less protection function flexibility than the more recent digital ones.

Taking these questions into consideration, EDPD carried out an exhaustive revision programme of all its MV Protections Functions during the past two years, which comprised a total of 484 substations and switching stations, and over 5100 feeders within the entire mainland Portugal distribution grid. The main goals were clear: provide a better and higher quality of service, by reducing the duration of voltage dips, the number of short interruptions and preventing potential unintended interruptions in the public service power grid.

To achieve the proposed results, a multidisciplinary team, with experts from different areas, was needed. EDPD conducted systematic short-circuit and protection studies using DPlan. AmberTREE developed critical improvements to the short-circuit and reporting modules of DPlan – its proprietary software system for power distribution analysis, operation and investment planning – in order to deepen the scope and optimize the aforementioned studies. EDPD's field crews performed the necessary in-field confirmation and implementation of the protection settings.

COMPUTATIONAL SIMULATIONS

The optimization of all MV Protection Functions of the entire continental part of Portugal was based on a set of computational simulations brainstormed and conducted by EDPD. The main goals were to ensure protection relays coordination, sensitivity for electrically distant short-circuits and minimizing voltage dip duration. Such studies resulted in the following tasks:

- Validation of Protection Functions operational times by performing phase-to-phase and earth faults simulations over the entire extension of MV Feeders in order to ensure longitudinal coordination between

Power Transformers, Feeders and MV Power Stations relays and Reclosers.

- Validation of Earth Current Protection Functions by applying earth faults simulations on MV Substations busbars in order to ensure transversal coordination between parallel feeders.
- Performing electrically distant phase-to-phase and earth faults simulations in order to ensure that Feeder's Protection Functions operate for short-circuits along the entire extension of the grid.
- Conducting three-phase and phase-to-phase faults simulations over the entire extension of MV Feeders in order to adjust Protection Functions response (time and intensity) in accordance to IEC 61000-3-11 voltage characteristics (Figure 1). A breaker response time of about 100ms were considered as the worst case scenario for this matter.

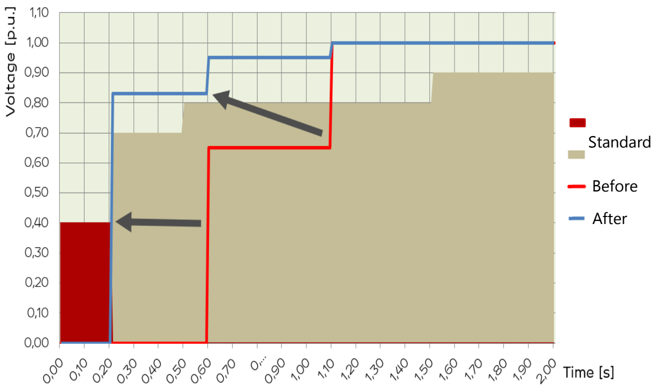

Figure 1 – Protection Functions adjustments in accordance to IEC 61000-3-11 voltage characteristics.

To support the aforementioned simulations DPlan – Distribution Planning software (developed and distributed by AmberTREE) was used. This tool constitutes EDPD Distribuição's corporate software for integrated analysis and optimization of power distribution network.

Before performing computational simulations, the preparatory work of loading all the 484 MV substations and switching stations with the corresponding MV distribution grid to DPlan needed to be done.

The entire MV distribution grid and all the related equipment, were automatically extracted from EDPD Geographic Information System (GIS) and loaded in DPlan (Figure 2). The newly imported data was then carefully validated considering network topology, short-circuit power values and power equipment technical data - including Power Transformer, Neutral Earthing, Voltage Transformers and Feeder's Current Transformers. Afterwards, the Protection Functions from a total of 5120 feeders based on EDP's Protection database were loaded to DPlan. Depending on Protection Unit generation and technology, each MV feeder bay unit may contain up to 6 phase-to-phase and earth current protection functions. In total, it is estimated that more than 20.000 MV protections functions were loaded to DPlan's Protection module. The computational simulation work followed.

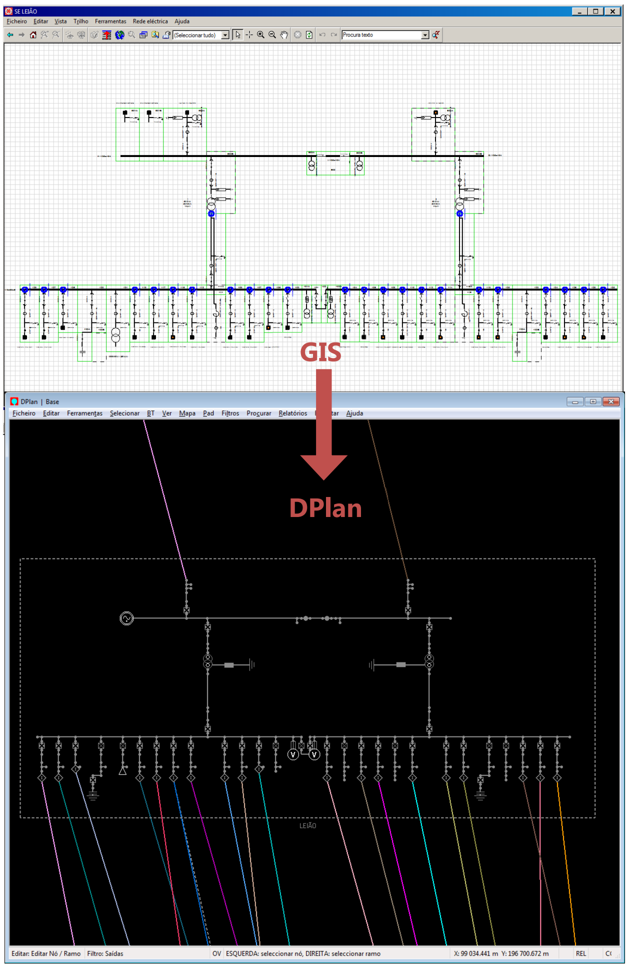

Figure 2 – HV/MV Substation (SE Leião) automatic extraction from GIS to DPlan.

Critical Improvements

In order to optimize the described simulation processes, EDPD and AmberTREE worked together to develop a set of critical improvements to the short-circuit and reporting modules of DPlan. On the one hand, Protection Functions adjustments in accordance to IEC 61000-3-11 voltage characteristics entail a large amount of short-circuit simulations. In other hand, realizing which node represents the most electrically distant one of each feeder is not an easy process. If manually conducted, those simulations would greatly increase man-hours, and thus time and cost. Consequently, the developments on DPlan focused primarily on automating and systematizing the necessary large-scale short-circuit simulations along the entire extension of all 5120 analysed feeders.

Fully automated Three-phase, phase-to-phase and earth faults simulations were performed along the entire extension of every distribution feeder, that is, on each one of DPlan's nodes. Resulting Substations busbar voltages and currents were automatically reported to specific excel tables, allowing to process the data, and achieve the proposed goals of this work. Figure 3 illustrates an example of fully-automated systematic short-circuits throughout an underground MV feeder and the related fault voltages and current values.

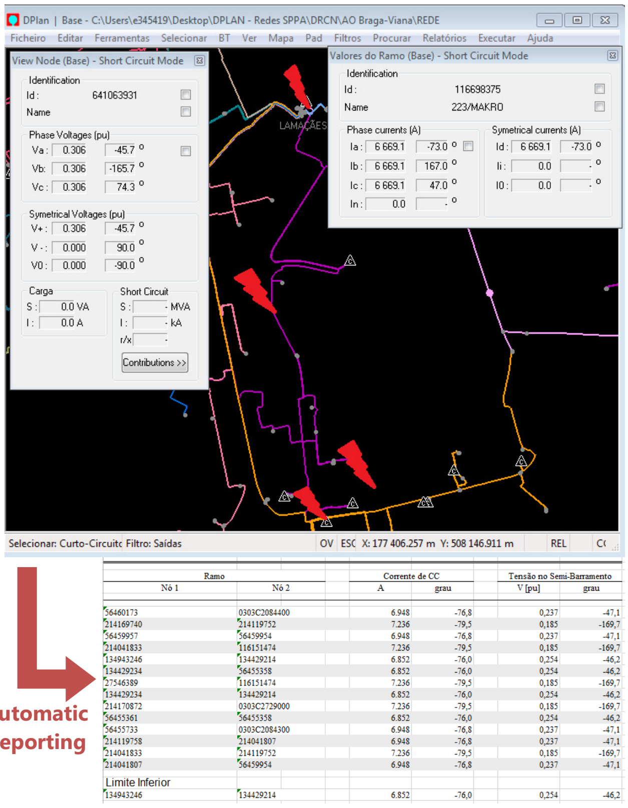

Figure 3 – DPlan automatic short-circuit simulations over the entire extension of MV Feeders with voltage and current reporting.

DPlan proved to be a mission-critical tool for supporting the conducted protection and short-circuit studies and reducing operational costs. It has been estimated that the implemented developments led to savings of about 2 hours per substation/switching station, that is around 120 working days in total.

IMPLEMENTATION

EDPD has long history and therefore several protection practices from the past still remained in the older substations. Hence, the uniformisation of Protection Functions in accordance with Today's EDPD Protection and Automation General Guidelines as a major goal of the present work.

The simulations presented above resulted in a large number of Protection Functions adjustments (see Results), which EDP field crews would implement on site.

The in-field protection adjustments campaign relied only on internal human resources, in parallel with all the remainder activities. Protection functions changes are responsible for nearly 10% of workload of these Departments, thus the difficulty in responding to such campaign in a short time period.

The settings changes were preferably made via remote access in order to reduce operational times and costs. For the remaining cases field crews made the best of other substation interventions as much as possible to make Protection Functions, keeping the focus on minimizing operational costs.

Another important challenge that the field crews had to overcome was the need to perform some acceptance tests to newly implemented Protection Functions of in-service Protections. The tests were conducted in a sample of the total number of cases and all of them were successfully accomplished without comprising the availability and quality of service.

RESULTS

The short-circuit and protection studies described above resulted in a need to change protection settings from 2531 feeders. That is about 50% of all 5120 (Figure 4) feeders within the total of 484 HV/MV and MV/MV substations and MV switching stations of EDPD distribution grid.

In terms of protection functions, that comprised a total of **6622 settings changes** (Figure 4), mostly due to 4 reasons:

- Preventing potential coordination faults;
- Reducing the voltage dips duration in accordance to IEC 61000-3-11;
- Ensuring protection sensitivity for electrically distant short-circuits;
- EDP's Protection and Automation General Guidelines uniformisation;

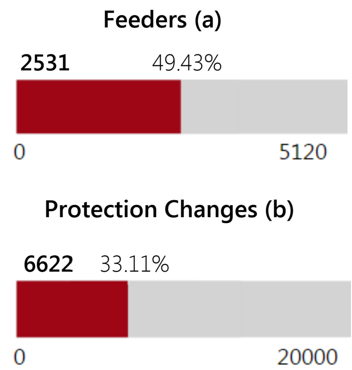

Figure 4 – Feeders with the need for protection adjustments (a) and Overall protection function changes (b).

The conducted studies also resulted in a total of **908 protection functions confirmations** and updates to values listed on EDP's Protection Systems Database, in respect to the actual in-service protection settings. This was also an important result achieved by this work, since it served as an internal audit to protection functions database, contributing to maintain a high data quality.

Considering all the aforementioned results, the overall impacts of the study on the distribution grid were evaluated.

In the first place, all the considered protection functions changes **prevented 190 potential coordination faults**. It might not seem a large number when compared to the whole 5120 analyzed feeders, but these are important numbers considering the importance of this matter for the quality of service. During the past decade EDPD has been making a great effort nationwide to eliminate all possible protection coordination failures. A similar work regarding HV grid had been done previously. The prevented potential coordination faults resulting from this work constitute the nationwide near zero values.

Secondly, all the considered protection functions changes resulted in **reducing the voltage dips duration in accordance to IEC 61000-3-11 in 1197 MV feeders**, out of a total of 1718 that were not previously approximated to standards the curve (Figure 5). This was one of the main goals of the study, since it is a pioneer work on this matter, trying to anticipate future regulation guidelines regarding voltage characteristics conformity.

Considering the aforementioned results, it was not possible to adjust 521 feeders to IEC 61000-3-11, 400 of which due to protection units' limitations - only one protection function level for phase-to-phase and earth faults -, and 121 due to the need of protection coordination with downstream MV/MV substations and switching stations - protection coordination has a priority over voltage dips duration (Figure 5).

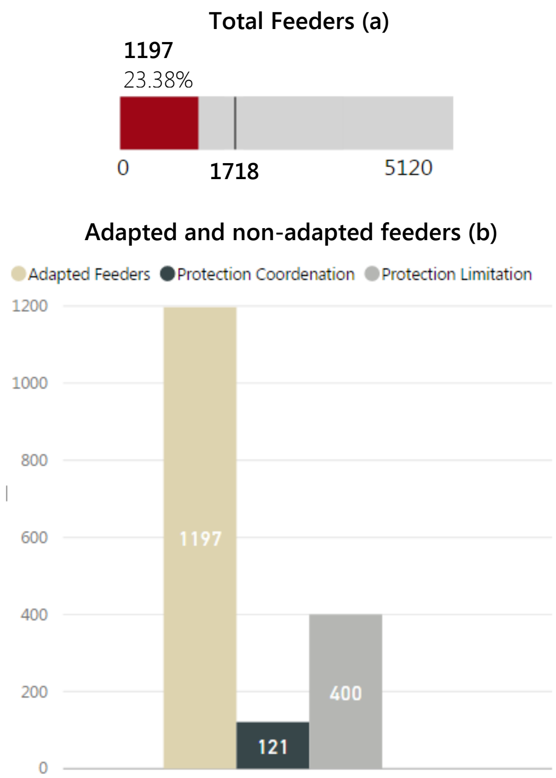

Figure 5 – Voltage dips duration adapted feeders: (a) Total number of feeders; (b) Adapted and non-adapted feeders.

Notwithstanding all the results mentioned in this chapter, it is also important to observe what the actual gains of this work are as it varies with fault location and incidence. Typically, faults in urban distribution grids lead to higher voltage dips than in rural grids, where there is smaller short-circuit power values and lengthier feeders. With this in mind, the results are now under an assessment stage with an in-house tool that correlates and analyzes operational and field data. The voltage quality monitoring system data is correlated with protection functions SCADA events automatic smart analysis - duration and type of each fault. This is an on-going approach that will reveal what are the actual operational gains of this work and in what feeders they occur more frequently.

CONCLUSION

EDP's programme for optimizing the entire MV protection asset base was successfully completed. Protection and short-circuit studies, regarding protection relays coordination, sensitivity for electrically distant short-circuits and minimizing voltage dip duration were conducted using DPlan. To accomplish these studies as efficiently as possible, AmberTREE worked together with EDPD to develop the necessary critical improvements within DPlan software, contributing to minimizing the human effort needed. It has been estimated that the developments led to savings of a total of 120 working days. The study outputs have been fully implemented in all in-service protection units, resulting in more than 6600 protection function changes and around 900 settings confirmations, preventing 190 potential coordination faults and reducing the voltage dips duration in 1197 MV feeders. The results are now under an assessment stage concerning the reliability of protection systems and the respective actual impact on grid operation. An in-house tool that correlates and analyzes SCADA and voltage quality monitoring system data is being used.

EDP's programme for distribution protection optimization addresses increasingly demanding challenges that DSO face by optimizing an ageing asset base, and thus keeping the costs low. With this proactively approach, EDPD expects significant gains in quality of service and reduced Customer complaints regarding voltage dips and short interruptions. In order to boost cost-savings and efficiency even more, plans are under development to make the future revisions of all MV Protections Functions a fully automated process.

REFERENCES

[1] European Standard EN 50160, "Voltage characteristics of electricity supplied by public distribution systems", CENELEC TC 8X, July 2010

[2] International Standard IEC 61000-3-11, "Electromagnetic compatibility (EMC) – Part 3-11", IEC, August 2000