INTRODUCTION

This paper discusses a methodology of analysis of the power quality in high voltage and medium voltage EDP's Customers based on the monitoring results of the distribution network substations, more precisely through voltage monitoring of their high voltage and medium voltage busbars. The issues associated to this methodology are explored, namely, its configuration, application, as well as results. There are presented the results of some studies developed according to this methodology, as well as the adopted actions to each case.

POWER QUALITY IMPORTANCE

In the last times, the questions related with the quality of the electricity supply and the consequent influence in the equipment of the Customers’ installations, have earned primordial importance among the factors of decision and the strategies of the electrical companies. The liberalization of the energy markets, the electricity regulation and the increasing motivation to satisfy the Customers thus also demand it.

The Customers, more and more demanding, are also more conscientious of the factors associated to the electricity supply. By this way, if, on the one hand they demand their supplier the optimization of the electricity distribution network in order to minimize the number of voltage disturbances and to reduce the impact in their processes, on the other hand they are demanding the manufacturers of their equipment that these become more immune to Power Quality (PQ) disturbances or even to look for solutions that can immunize their critical equipment to these disturbances.

On the Customers perspective and considering the state of the actual technological development there are basically identified three main susceptibility levels in terms of electricity supplying, as illustrated in the Figure 1.

For any Customer, the long supplying interruptions, although being of reduced incidence, are absolutely intolerable. Furthermore, there are other two susceptibility levels that assume particular importance to some final electricity applications. In applications of large dependence of high technology or in continuous processes, the Customers show a major susceptibility to short interruptions and PQ disturbances. In this scenario, the electric utilities are developing all efforts to reduce the number and the duration of the supplying interruptions. On the other hand, the most susceptible Customers to PQ disturbances should invest in high power quality solutions and adapt immunization strategies.

Although the susceptibility to PQ disturbances be a relatively recent reality, it is expected that the sensitive Customers segment to PQ disturbances will significantly grow, once the basic necessities at the level of short and long interruptions are being satisfied, by electric utilities, and it is also released a massive adoption of sensitive technologies. In this way, the future tendency of operation interruptions of the equipments will be specially associated to PQ disturbances, being the short and long interruptions of marginal importance (Figure 2).

In this context, looking forward the system optimization, the electric utilities have been developing strategies to PQ analysis to satisfy these necessities of the Customers and also to study, simultaneously, the propagation and the influence of the disturbances, both on the side of the network and on the side of the Customer installation.

METHODOLOGY FRAMEWORK

In order to guarantee a good service quality, EDP is trying to collaborate closely with its sensitive Customers. The power system is a “communitarian system” and its power quality depends on all partners.
Beyond the detailed studies of the electric power supply conditions performed in the installations of individual Customers, which report some supply voltage disturbances, EDP is developing a methodology of PQ analysis in High Voltage (HV) and Medium Voltage (MV) Customers based in the results of the monitoring of distribution network substations, more concretely on their HV and MV busbars.

With this approach, there are analysed, simultaneously, several HV and MV Customers with sensitive technologies in their facilities supplied by the same substation, allowing a higher pro-activity to the Customers and a significant reduction of the spent time and necessary resources, comparatively to an individual analysis to each Customer.

The implementation of this methodology studies, simultaneously, the propagation and the influence of the disturbances, both on the side of the network and on the side of the installation of the Customer. Therefore, it allows a higher sight of the implemented measures in the optimization of the electric network and until the possibility to schedule several Customers by a critical index to voltage dips. In a second stage, and in the case whose network reconfiguration is not enough to reduce the production process outages to admissible indices, the analysis may even support the implementation of immunization solutions in critical equipments.

This paper presents the results of some studies developed by EDP in Portugal according to this methodology, as well as the adopted actions to each case. Specifically, they are briefly explained by the following cases:

- Distribution network optimization through closing a HV mesh and splitting MV busbars;
- Protections operation optimization at the level of the MV network;
- Making of decision to inspect and perform maintenance actions in MV overhead power lines;
- Optimization of the Customers processes through adoption of immunization strategies to voltage dips and installation of high power quality technologies to supply sensitive equipment with the best power quality.

Usually, the studies based on this methodology of PQ analysis are developed in four main phases.

**Phase I - Preliminary Analysis**

The first phase is characterized by a preliminary analysis to all selected Customers’ installations and technologies. Through the dialogue with the production and/or maintenance managers it is possible to know the historical of the installations, as well as the technical and operational characteristics of all equipments. This allows a preliminary identification of the critical equipment. After getting this information it is asked the mentioned managers to register, during the monitoring period, the behaviour of the processes and of the critical equipments during the disturbances.

**Phase II - Monitoring**

In the second phase it is installed a Power Quality Analyser (PQA) on HV or MV busbars of the substations. Depending on the configuration of the busbars, it can be useful to install a supplementary PQA.

The Figure 3 shows a simplified scheme of a HV/MV substation and the way how PQA can be connected, through voltage transformers, to obtain the voltages of two MV busbars.

![Figure 3 – Scheme of a HV/MV substation with a PQA](image)

There are being developed equipments that can analyze two different voltage levels simultaneously. These new PQA can be advantageous in this type of methodology.

In order to permanently monitorize all voltage characteristics, during a representative period, the PQA is installed and programmed to record the data in accordance with [1] NP EN 50160 standard and [2] Portuguese Quality of Service regulation.

**Phase III - Comparative Analysis**

After the monitoring period, it is performed a comparative analysis through the correlation of several information - monitoring data, Customers reports, chronological register of protections actuation in substations and outages transmission and distribution databases. This analysis allows to understand and to justify the several Customers labouring outages associated to network disturbances, as well as to characterize the equipments sensitiveness.

**Phase IV - Conclusions and Recommendations**

With the results obtained in phase III it is possible to present conclusions of the fulfilment degree concerning to voltage continuity and quality, of [2] Portuguese Quality of Service regulation and [1] NP EN 50160 standard, to identify the infrastructures of Transmission and Distribution (T&D), which are responsible for incidents, and to appreciate the
sensitiveness degree of the Customers’ installations to voltage disturbances, namely to voltage dips.

These conclusions can lead to recommendations and to the selection of adequate solutions, both to T&D systems and to Customers’ installations.

RESULTS OF THE METHODOLOGY APPLICATION

Case Study 1

As a result of some studies developed previously in a substation, EDP concluded that the main disturbance causes of the sensitive equipments in the Customers’ installations, supplied by that substation, were not the long or short supplying interruptions but the sporadic occurrence of voltage dips. In order to reduce the voltage dips severity there were analysed alternative operation schemes to the HV and MV networks. As a result of these studies there were reconfigured the HV and MV networks, namely:

- Supplying of the substation directly from the transmission network by two HV (60 kV) parallel lines (close the HV mesh);
- Operation of the MV (30 kV) network of the substation with two independent MV busbars, having as an objective to supply the majority of sensitive Customers by one independent MV semi-busbar and the lines with higher faults percentage by the second MV semi-busbar.

With the methodology of analysis described above it was possible to study the improvements to Customers achieved with these reconfigurations.

Considering that power transformers (HV/MV) have a nearly linear behaviour during possible three phase faults in its MV busbar or in its MV lines, the graph of the Figure 4 approaches the amplitude of the expected voltage dips on the HV and MV busbars in the following situations:
1. Unified MV busbar, with three phase fault in a MV line, and radial HV supplying (substation supplied only by one HV line);
2. Independent MV semi-busbar, with three phase fault in a MV line, and closed HV mesh (substation supplied by two parallel HV lines);
3. HV busbar, with radial HV supplying (substation supplied only by one HV line);
4. HV busbar and the other independent MV semi-busbar, with closed HV mesh (substation supplied by two parallel HV lines).

According to this graph, it is possible to realise that the final configuration with independent MV semi-busbars and closed HV mesh (substation supplied by two parallel HV lines) presents the following disadvantage compared to the initial configuration with unified MV busbar and radial HV supplying (substation supplied only by one HV line):
- The Customers supplied by the same independent MV semi-busbar, which supplies a possible fault in a MV line, are exposed to voltage dips with amplitude slightly superior.

On the other hand, the final configuration shows the following advantages compared to the initial configuration:
- The HV network and the Customers supplied by this voltage level are exposed to voltage dips, caused by MV faults, with significantly lower amplitudes.
- The Customers supplied by the independent MV semi-busbar, without any fault, are exposed to voltage dips with very lower amplitudes.

The following graphs show the propagation and attenuation of voltage dips from one independent MV semi-busbar (Figure 5) to the other one (Figure 6). It is verified a strong amplitude attenuation of the voltage dip through the power transformer.
This study includes a large diversity of installations with different industrial and commercial activities. According to this study, the moulds industry, steel treatment industry and glass industry are the most sensitive to voltage dips, by decreasing order of sensitiveness.

Case Study 2

As a result of similar studies in other HV/MV substation it was possible to optimise the feeders protections parameterisation in order to minimize the duration of the voltage dips that reach the MV Customers, supplied by this substation.

Regarding the reports of the Customers in terms of susceptibility of their equipment to voltage dips and supported in this monitoring methodology, it was measured precisely the duration of the voltage dips. After this analysis there were optimised all protections, which were responsible for voltage dips with duration superior to 600 milliseconds, such as the presented in Figure 7.

Case Study 3

Another study performed in a HV/MV substation detected some short interruptions (less than to 3 minutes) in a MT feeder lead to a significant number of production process interruptions of some Customers. This study supported a base of decision to inspect and to perform maintenance actions in the correspondent MV overhead power lines.

Case Study 4

In situations of high sensitiveness to voltage dips, the best solution would be the adoption of local or global immunization strategies to sensitive equipments. In order to supply individually those sensitive equipments, some production processes or even all the installation systems, high power quality technologies can be installed.

In a techno-economic point of view, other effective approach is the immunization of sensitive equipments, through the changing of some components and/or the operation mode, with the collaboration of their respective manufactures.

Based on these two possible approaches and as a result of the studies developed by EDP, there were implemented the following actions in a sensitive Customer:
1. Immunization of the command and control systems of three sensitive moulding machines through a Static Uninterruptible Power Supply (SUPS) of 30 kVA;
2. Parameterisation’s optimization of three variable speed drives that support the ventilation of the above moulding machines. Two of these ventilators have powers of 400 kVA and the other one has power of 160 kVA. In these variable speed drives, was active the undervoltage control function and the recovery of the kinetic energy of the ventilators, during voltage dips, was implemented.

The following graph (Figure 8) shows a voltage dip that normally disturbed these three machines.

CONCLUSIONS

With the development of the analysis strategy presented in this paper, EDP is improving its attendance actions to Customers with high sensitiveness to PQ disturbances.
The implementation of this methodology studies, simultaneously, the propagation and the influence of the PQ disturbances, both on the side of the distribution network and on the side of the several Customers installations supplied by the same substation. Allowing a higher pro-activity to the Customers, this methodology also allows an analysis of the implemented measures in the optimization of the distribution network, as well as supports the implementation of immunizing solutions in Customers’ critical equipment.

Finally, having as basis the results of this methodology, it seems that it is more and more important to endow the substations with permanent PQ monitoring equipments with remote access. This reality would allow an even greater pro-activity, a reduction in the answering time to Customers’ claims and the increasing of the available information.

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REFERENCES

