

Customers Monitoring

Some customers are supported by point PQ monitoring in order to perform an accurate characterization of the PQ supplied and help identify improvement actions. Examples of these customers are sensitive industries and LV micro-generators. Typically, a portable class A PQ recorder is installed for monitoring during a month.

PQ Data Collection and Processing

For systematic monitoring campaigns in substations and customers monitoring, data are collected locally every month, and inserted in an SQL database. For continuous monitoring, the data are collected and stored automatically in the SQL database by scheduled actions. After each quarter, PQ data of the systematic campaigns are processed in order to issue PQ overview reports to the Portuguese regulator. These reports are performed using a dedicated web based application (QWebReport). All PQ data are also submitted to analysis in order to support operation and maintenance.

PQ MONITORING RESULTS

PQ monitoring results from the HV/MV and MV/LV substations analyzed in the systematic campaigns during the quadriennium 2006-2009 are briefly presented.

HV/MV Substations

During the quadriennium, all the HV/MV substations were analyzed. In the Table 1 are presented PQ results (continuous phenomena) from the 539 MV busbars, in a total of 5819 monitoring weeks. These results are about the percentage of weeks in accordance to the NP EN 50160.

Table 1.

	Voltage variations	Long term flicker	Voltage unbalance	Power frequency	Harmonics*
In accordance	100%	97%	100%	100%	99%

* Excluding isolated recordings of 15th harmonic due to public lighting control.

The most part of flicker severity “not in accordance”, both in HV/MV and MV/LV substations, is associated to the occurrence of voltage dips.

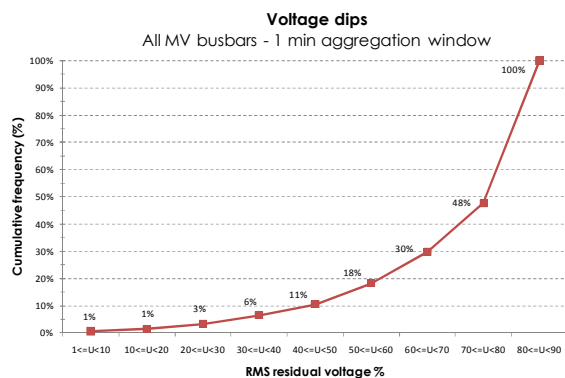


Figure 2. Voltage dips overview – Cumulative frequency.

In the Figure 2 is shown an overview of the voltage dips recorded in the same MV busbars. The voltage dips characterization was performed as defined in the Annex IV of the Portuguese QoS Regulation Code.

MV/LV Substations

During the quadriennium, at least 2 MV/LV substations per municipality were analyzed. In the Table 2 are presented PQ results (continuous phenomena) from the 580 LV busbars, in a total of 5792 monitoring weeks. These results are about the percentage of weeks in accordance to the NP EN 50160.

Table 2.

	Voltage variations	Long term flicker	Voltage unbalance	Power frequency	Harmonics
In accordance	89%	93%	100%	100%	98%

IMPROVEMENT ACTIONS

Distribution Network

Voltage Variations

The main PQ parameter “not in accordance” was voltage variations monitored at LV busbar of MV/LV substations. For the most part, there are situations associated to slight exceeded 110% of nominal value, in a short time. In some cases, situations were identified with origin in voltage regulation in upstream HV/MV substation or proximity of MV distributed generation.

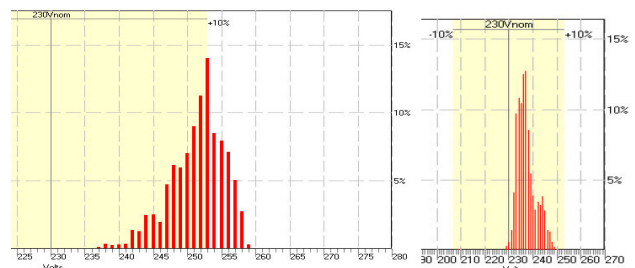


Figure 3. rms voltage values, before and after to decrease one point from tap changers.

Finally, some changes were performed on MV/LV transformer tap changers. For the case study presented in Figure 3, one notices that there were some recorded values slightly above the standard threshold.

After network analysis, the strategy to correct the rms voltage values was to decrease one point from tap changers, as shown in the same Figure. In sequence of the analysis, in some neighbouring MV/LV transformers the same change was made.

Flicker

The second case study is about the voltage flicker recorded in two MV busbars of a HV/MV substation. The substation topology is characterized by two transformers, one busbar for each transformer.

As shown in the Figure 4, the values of voltage flicker in busbar #2 significantly exceeded the limits defined in NP EN 50160.

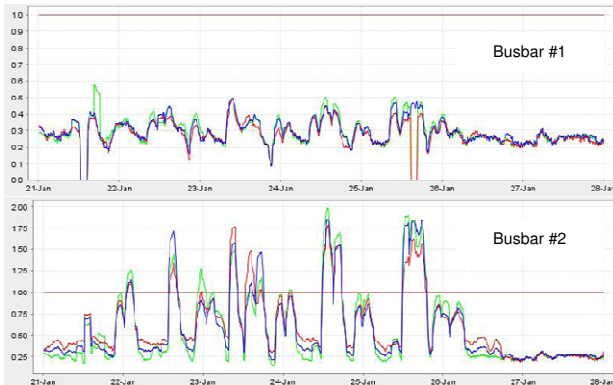


Figure 4. Voltage flicker (P_{st}) in busbars #1 and #2 (worst week) and the permissible limit.

In MV busbar #2 some customers were identified as potentially PQ polluters, including foundry (arc furnace), metal processing, recycling of scrap and stone industries.

The flicker level decreases with the increasing network short-circuit power. Therefore, a strategy to mitigate the voltage flicker, immediately and without any investment, was changing the busbar topology, namely, connecting the MV busbars. However, the advantages and disadvantages of this reconfiguration have been carefully studied.

This way we achieved an increase of 58% in short-circuit power in both MV busbars and approximately 16% in a foundry industry.

An additional monitoring in the HV/MV substation validated the procedures in order to mitigate voltage flicker throughout network, to regulatory values.

Harmonics

As a result of these systematic campaigns, EDP D has identified some problems in the distribution network, which deserve careful attention, namely those related to the 5th voltage harmonics levels at particular points along the MV and LV grids.

Resonance Harmonic:

The resonant harmonic h_r , based on fundamental frequency impedances, is defined as follows [1]:

$$h_r = \sqrt{\frac{MVA_{SC}}{Mvar_{cap}}} \quad (1)$$

where h_r = resonance harmonic
 MVA_{SC} = system short-circuit MVA
 $Mvar_{cap}$ = Mvar rating of capacitor bank

The resonant harmonic for the MV busbars of all HV/MV substations is calculated from the equation (1).

When the resonant harmonic is approximately close to the 5th harmonic voltage, studies are developed to prevent high voltage distortion based on the identification of potential resonance conditions in most probable network configurations.

In order to deal with the identified problems, to understand their main causes and, as much as possible, to foresee their solution, EDP D has been developing harmonic power-flow analysis models as well as harmonic state estimation models. These have been integrated into DPlan, an analysis and optimization program which evaluates and foresees future trends on harmonics phenomena in the grid, as well as their impact in PQ [2].

Once the non-linear loads have been estimated and the network has been characterized (for the selected frequencies), it is possible to simulate the harmonic behaviour of the system under topology and parameters changes. For example, it is possible to simulate the effect of switching-on capacitor banks, changing tap positions of transformers, connecting busbars and/or reconfiguring the HV or the MV network.

In a case study, the filter function “Harmonic voltage distortion” from a MV network was applied. It was concluded that the increase in the 5th harmonic in MV busbar #1 happens when the capacitor bank (CB) 1, connected to busbar #1, is switched on and the CB 2, connected to busbar #2, is switched off, coinciding still higher values of 5th harmonic with the periods in which the load is lower (off-peak hours). For another busbar, the conclusion is similar.

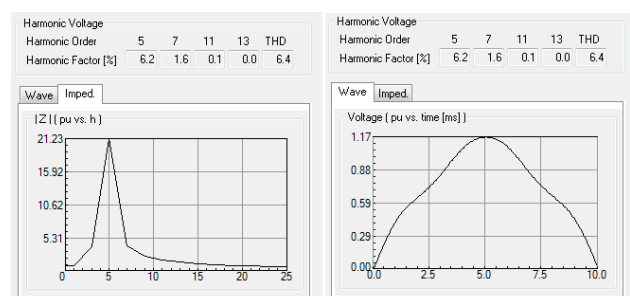


Figure 5. Harmonic voltage results in MV busbar #1.

The impedance curve depicted in the Figure 5 shows the resonance behaviour for the 5th harmonic.

The harmonic distortion problem was being caused by resonance created by the substation capacitor banks in the MV busbar. This resonance was magnifying the 5th harmonic component in the currents from all the customers on this system, causing high voltage distortion levels.

Optimizing the schedule of both CB, also associated to the management of reactive power in the network, reduces the 5th harmonic voltage to regulatory values.

Events

EDP D has been working on the reduction of the fault incidence on overhead networks in order to decrease the number and duration of voltage dips and short interruptions. Therefore, some actions have been considered, like preventive and predictive maintenance strategies, adjustment of the insulation level to the specific local conditions of the network and implementation of new overhead technologies, such as covered conductors.

At the operation level, some actions have been also considered, like optimization of the protection systems, supply of sensitive customers by shorter circuits, from busbars with lower fault incidence or higher voltage levels, and increasing HV network robustness.

Sensitive Customers

Potentially sensitive customers are invited by EDP D to report PQ disturbances during the systematic monitoring campaigns. Mostly, they report production disturbances facing to voltage dips. The sensitivity is variable, but an important number of them are sensitive to voltage dips of short magnitude and/or short duration. Continuous processes supported by PLC, ASD and other electronic devices are very sensitive to voltage dips and long downtime periods can be experienced. There are typical difficulties to adopt immunization solutions and re-engineering strategies to improve the process reliability at the customer level.

Based on the available information, root causes and effects of reported disturbances are analyzed. This allows to check the sensitivity of customers, as well as to launch the research for improving actions at distribution network and customers levels.

With the technical support of EDP D, the following improvement actions are some examples of successful cases: immunization of glass production machines; installation of static and dynamic UPS in moulds, dairy and ceramics industries; immunization of fan systems driven by ASD in cement and chemical industries; optimization of the distribution network and immunization of command and control systems in the chemical industry; consultancy in the adoption of several immunization solutions in the automotive components industry; implementation of alternative supplying circuits with fast transfer switches.

MAIN CHALLENGES

In terms of PQ, the challenges are mainly related to the customer sensitivity to voltage dips, increasing penetration of Micro-Generation (MG), trends of regulation to request higher PQ levels, as well as management of large amounts of monitoring devices and PQ data.

Since 2007, there has been a noticeable increase of MG in Portugal, leading to an installed base of around 10000 MG units in the end of 2010. This amounts to around 30 MW of installed MG power. This increasing number of micro-

generators injecting power in the LV grid is bound to cause a significant impact on the main grid PQ parameters. EDP D has performed some monitoring studies including a few MG units and the MV/LV substations to which they are attached, relating the results to their location and the types of load they feed. The first conclusions point to non-degradation of the grid operating conditions within the current legal power limitations, in the vicinity of MV/LV substations (~200 meters) but, however, some parameters may change with different conditions. Given the interest they raised, these studies will be continued with monitoring campaigns of larger dimension, in duration, scope and periodicity.

On the other hand, in order to implement continuous PQ monitoring at the distribution network scale, some developments are expected in the solutions available to PQ data transfer, storage and management. An important requirement is the adoption of standards, like PQDIF format, to integrate data from devices provided by several vendors.

CONCLUSIONS

Despite the current challenges, it has been possible to develop a comprehensive PQ monitoring program, including several monitoring weeks in more than one thousand MV and LV busbars. Furthermore, it is expected an increasing of the measuring points with recent developments in the EDP's PQ Monitoring Platform, namely with the continuous monitoring strategy in HV/MV substations. Based on the PQ monitoring results, EDP D has been adopting several measures aiming to develop its actions in the distribution network, such as, mitigation of harmonic distortion, mainly the 5th harmonic, attenuation of flicker induced by industrial loads, reduction of faults in overhead networks in order to decrease the incidence of voltage dips and short interruptions, as well as adjustment of voltage levels in some LV busbars. The PQ monitoring campaigns are also giving support to sensitive customers who wish to adopt immunization solutions and improve their production reliability.

Power Quality is becoming an important reference factor to distribution network operators concerning its contribution to the global QoS.

Acknowledgments

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- [2] C. Santos et al., 2009, "Voltage distortion in large-scale MV and HV distribution networks: harmonic analysis and simulation", 20th International Conference on Electricity Distribution - CIREC.