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# Analysis of Power Quality Disturbances in Industry in the Centre Region of Portugal

Licínio Moreira<sup>1,2</sup>, Sérgio Leitão<sup>2</sup>, Zita Vale<sup>3,4</sup>, João Galvão<sup>1,5</sup>, Pedro Marques<sup>1</sup>

<sup>1</sup> School of Technology and Management, Polytechnic Institute of Leiria,  
P-2411-901 Leiria, Portugal.

<sup>2</sup> UTAD-ECT Science and Technology School, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal.

<sup>3</sup> Department of Electrical Engineering, Polytechnic Institute of Porto (ISEP/IPP),  
Porto, Portugal .

<sup>4</sup> GECAD (Knowledge Engineering and Decision Support Research Group),  
Porto, Portugal.

<sup>5</sup> INESC Coimbra - Institute for Systems Engineering and Computers at Coimbra,  
Coimbra, Portugal.

licinio.moreira, jrgalvao, marques{ @ipleiria.pt}, [sleitao@utad.pt](mailto:sleitao@utad.pt), zav@dee.isep.ipp.pt

**Abstract.** Power quality issues have taken a more prominent role in power systems over the last years. These issues are of major concern for energy customers, primarily for customers with a widespread use of electronic devices in their manufacturing processes. Even though the quality of service is increasing, customers are becoming more demanding of the energy provider. This research aims to provide some industrial managers the technical support in deciding of investments in the mitigation of power quality disturbances, such as the use of less sensitive devices or the use of interface devices (UPS, DVR ...) In order to recommend an appropriate solution, the problem is characterized. The technical and economic influences of the PQ disturbances in the manufacturing processes are assessed resorting to power quality audits in the customer facilities. This research covered a significant number of facilities in several industrial activities.

**Keywords:** Power Quality, Audit, Voltage Sag, Voltage Swell, Interruption, Wiring.

## 1 Introduction

Power quality (PQ) problems are inevitability, even in state-of-the-art power networks. The current worldwide economic competitiveness requires the organizations to be stricter in delivery times, following the just-in-time production model, and the profit margins tend to become smaller. Thus, any interference in production may lead to failure in delivery, sometimes implying large economic (direct and indirect) losses [1], [2] and [3].

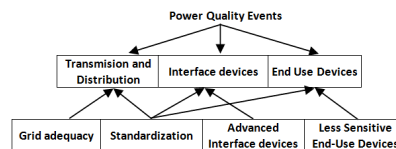
The constant modernization of the manufacturing processes is based on the widespread use of electronic equipment. These electronic devices have an increased sensitiveness to PQ disturbances and, at the same time are responsible for PQ degradation [4]. Several studies have been conducted to evaluate the costs of PQ problems for consumers. The assessment of an accurate value is nearly impossible; so all these studies are based on estimates. But all the studies point to losses valued in thousands of million Euros per year [5], [6] and [7]. In addition, the relevant studies point to the fact of investment made to minimize these disturbances is rather insignificant compared to the losses.

This research is centred in power quality audits conducted in several industrial facilities, such as plastic, moulds, wood, metallic construction and drywall manufacturing [8] and [9] in the centre of Portugal. Also some data from the quality of service reports issued by Portuguese energy regulator is used. The data is used to estimate losses (occurred and expected) and evaluate the economical feasibility of the use of mitigation techniques, including the use of uninterruptible power supplies (UPS), dynamic voltage restorers (DVR). The frequent contact with facility managers is used to encourage the option for devices that are less sensitive to short-duration PQ disturbances. Often, the PQ audits also deliver information used to the acting in the energy efficiency field

## 2 Contribution to the Collective Awareness Systems

This work aims the rising of collective awareness on the mitigation of the problems arising from faulty power quality. Everyone in the electricity sector, from the generation to the consumption can and should be participative for the minimization of losses. The mission of the energy sector operators (generation, transmission and distribution) is to fulfil the requirements of the electricity consumers. The customers have become more aware and demand low-cost electricity of high reliability and quality, where the priorities are different for different customers. They are certainly no longer willing to accept their position as merely one parameter in a global optimisation [1].

On the other hand, the customers should take action, being proactive in the search for solutions that minimize the costs arising from PQ disturbances (mainly the ones with short duration) that are an inevitable. Standardization (both on supply and demand sides) plays an important role defining PQ parameters that are acceptable for the satisfaction of electricity consumers, but also defining standards for end-use equipments tolerance and interface devices. Fig. 1 resumes the actuation levels and strategies that could lead to a decrease in the magnitude of PQ events.



**Fig. 1.** Different levels of the electricity sector and actuation strategies.

### 3 Data Collected from Distribution Network Operator

Every year, the operators of the transmission and distribution (T&D) networks are obliged to prepare and submit to the energy sector regulator reports stating the technical and commercial quality of the service provided. The technical quality of service is related to the analysis of the continuity of service, through the number and duration of supply interruptions, and the quality of the voltage wave (evaluation of its frequency values, amplitude, harmonic distortion, imbalance and others) [10].

To estimate the average annual number of voltage sags in each industrial facility, the values found in the quality of service report for medium voltage (MV) buses with permanent monitoring can be helpful, combined with the data collected in PQ audits. Table 1 shows the registered events categorized by time and amplitude.

**Table 1.** Average number of voltage sags in MV buses of the distribution network in 2012.

Retained Voltage (% U <sub>c</sub> )	Number / Duration (seconds)						% of events
	[0.01;0.1]	[0.1;0.25]	[0.25;0.5]	[0.5;1]	[1<;3]	[3;20]	
80%<U<90%	26.10	11.59	3.30	5.85	2.08	0.16	53.6
70%<U<80%	6.38	5.49	1.99	2.10	1.19	0.05	18.8
60%<U<70%	3.74	2.27	1.78	1.24	0.94	0.14	11.1
50%<U<60%	0.64	1.53	1.72	0.78	0.59	0.03	5.8
40%<U<50%	0.33	0.81	1.05	0.33	0.78		3.6
30%<U<40%	0.36	0.89	0.75	0.48	0.30		3.0
20%<U<30%	0.08	0.30	0.72	0.36	0.11	0.08	1.8
10%<U<20%	0.11	0.22	0.78	0.25			1.5
1%<U<10%	0.03	0.11	0.22	0.19	0.11		0.7
% of events	41.3	25.4	13.5	12.7	6.7	0.5	

The total number of sags recorded was 3843 over 42 buses. This results in an average of 91.5 sags per bus per year in 2012. This record is 15% lower than the one recorded in 2011. The shadowed cells on Table 1 represent the events that are under the lower limits of the ITIC curve, and are therefore likely to cause malfunction on electronic devices, such as computer numerical control (CNC) machines, widely used in manufacturing processes. The fraction of the occurrences under the ITIC curve is 18.8%, representing approximately 17 sags per year that can cause equipment malfunction.

This national average value is very similar to the value recorded in the substations located in the Leiria area, validated by the records of the distribution network operator and the data collected in the PQ audits conducted in this research.

### 4 Power Quality Audits

The referred several audits were performed using two Hioki Power Quality Analysers 3196. The PQ analysers were installed in low voltage buses with settings that are in accordance with EN 50160. These devices allow the continuous monitoring

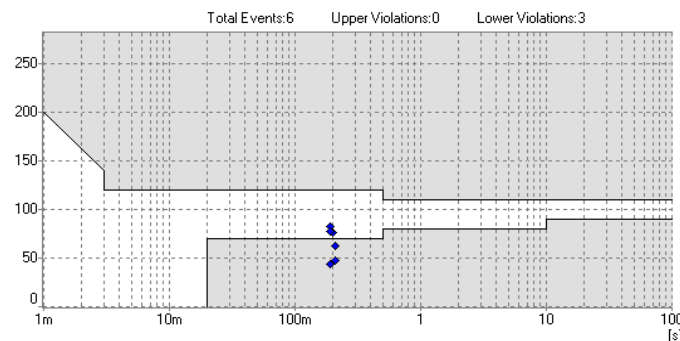
of electrical parameters and the recording of averaged values and the recording of transient phenomena, such as interruptions, voltage sags, swells and other.

Nearly all data collected was compliant with the norm. The only exception was registered on the 19<sup>th</sup> of January, 2013, when a gale occurred in Portugal, leading to the destruction of several power distribution network infrastructures, causing service interruptions that lasted for several days in some areas of the centre of Portugal. One can conclude that the values required by the norm are easily fulfilled (excluding acts of god) by the distribution operator, since the norm only applies to average voltage values of 10 minutes. Nevertheless, even when the quality of service complies with the norm, some disturbances which are detected are responsible for equipment malfunction and the disruption of manufacturing processes [11].

#### 4.1 Voltage Sags

The voltage sags and swells recorded during a monitoring campaign in a metallic construction site, with several CNC machines (one week period) are represented in Fig. 2. These events are plotted in the ITIC curve, which defines the expected tolerance of electronic equipment to voltage variation events. Events plotted in the upper shaded area (swells) are dangerous for the equipment, susceptible of causing damages to it, while the events plotted in the lower shaded area may cause malfunction of the devices, but shouldn't be destructive. Any event in the non shaded area shouldn't interfere with normal function of the device.

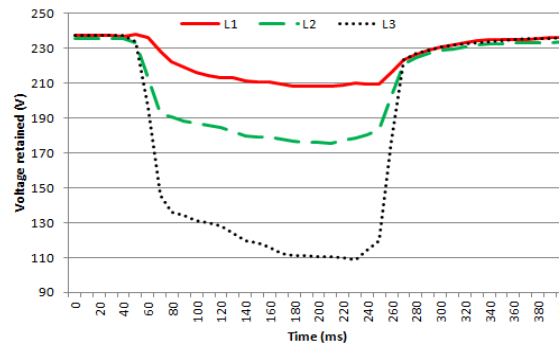
The plot shows the occurrence of six voltage sags, with three of them under the tolerance limits defined in the ITIC curve.



**Fig. 2.** Voltage sags and swells recorded over a week period (from the 14<sup>th</sup> to the 21<sup>st</sup> of March, 2013) and plotted over the ITIC curve.

The average voltage values with 10 ms sampling time during a voltage sag is represented in Fig. 3. The voltage retained is 109 V and the duration is 201 ms.

The events recorded by the energy analyser were compared with the record of manufacturing process disturbances. The sag represented in Fig. 3 is responsible for a CNC machine malfunction causing the delay of the piece production of several hours. The CNC needed to be reprogrammed before continuing the piece machining.



**Fig. 3.** Voltage sag recorded on the 18<sup>th</sup> of March, 2013.

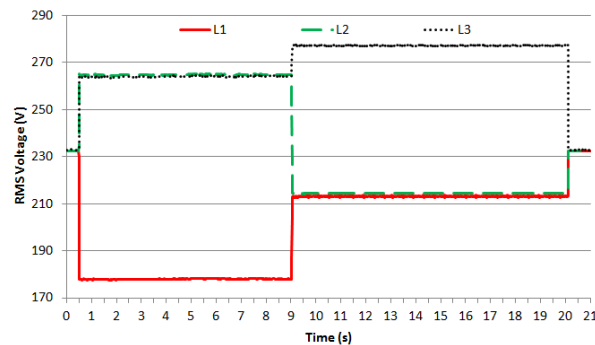
In some cases reported by facility managers, some malfunctions due to voltage sags or micro-interruptions cause damages to tools and / or machined piece. This can happen if the tool is performing a high speed operation and becomes uncontrolled due to the power failure in the controller.

#### 4.2 Voltage Swells

Voltage swells are also transient phenomena susceptible of causing damage. These occur less frequently, but in some severe cases are more likely to cause direct damages on electrical equipment.

During the monitoring campaigns made, no damage could be directly related to the occurrence of a voltage swell, but it is widely known that voltage swells contribute to the lifetime shortening of electrical devices.

In Fig. 4, the most severe voltage swell (both in amplitude and duration) is plotted. In phase L3, the voltage reached 277.7 V (20.7% over rated voltage) and the duration was of about 20 seconds.



**Fig. 4.** Voltage swell recorded on the 15<sup>th</sup> of February, 2013.

### 4.3 Wiring

The selection of proper wiring and protective devices is imperative for the operation of an electrical installation and the proper functioning of end use devices. Also, an incorrect installation, from the placement of the components to the correct tightening, can lead to the occurrence of problems.

During the conducted audits, several situations were detected, some before the destruction of equipment, others detected after the equipment failure because of improper tightening.

One example is the destruction of the connector in several ballasts in an industrial facility. The improper connection, combined with the expected heating of the ballast and lamp, led to an overheating and destruction of the terminals of the ballast.

With the use of a thermal camera (Fluke Ti45 Flexcam™), during a normal assessment, a difference of temperature was detected in a set of cables connecting the power transformer (in the customer substation) to the main electrical switchboard. The connection was made using three cables (H1XV-R 1x300 mm<sup>2</sup>) for each phase and for the neutral. The thermal image for each phase is shown in Fig. 5. It is easily found that the current distribution by parallel cables in every phase is unequal.

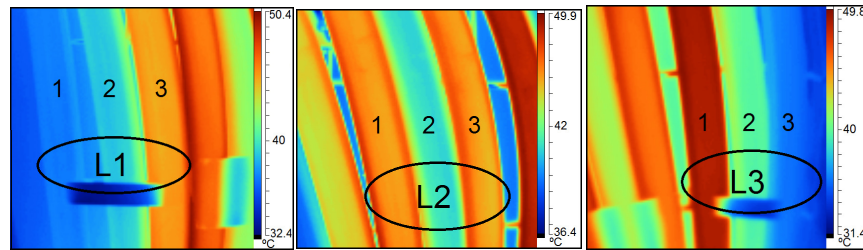


Fig. 5. Thermal imaging of electric cables.

The current in each cable was measured and registered. These values are presented in Table 2, such as the surface temperature of the cables.

**Table 2.** Current and surface temperature in cables between transformer and the main switchboard.

	Phase L1		Phase L2		Phase L3	
	Current	Temp.	Current	Temp.	Current	Temp.
Cable 1	236 A	36 °C	412 A	38 °C	483 A	46 °C
Cable 2	198 A	48 °C	201 A	42 °C	203 A	46 °C
Cable 3	374 A	49 °C	345 A	39 °C	181 A	37 °C
<b>Phase rms current</b>	<b>778 A</b>	-	<b>798 A</b>	-	<b>861 A</b>	-

The values show the expected imbalance of currents, of which the currents in phase L3 stand out. In this phase, the most heavily loaded cable conducts 2.67 times the current of the least loaded cable. One can also easily conclude that the sum of the current in the three cables for each phase is greater than the rms current for the phase.

For example, in phase L2, the algebraic sum of the current in the three cables is 958 A and the rms current is only of 798 A.

Considering that the admissible current of the conductors is of approximately 580 A, no cable is overloaded. Also, the temperature of every cable is within acceptable limits. The problem hasn't reached critical values, because the transformer (with 1600 kVA rated power) is underload, presenting an average load of 650 kVA and a maximum load of about 800 kVA. In the case of a load increase, the cables would suffer a lifetime reduction and, in an extreme event, could trigger a fire.

This imbalance is caused by an incorrect geometric distribution of the cables on the cable tray. The cables are arranged vertically with the sequence shown Fig. 7 (top). This arrangement promotes the increase of mutual inductances in some cables [12] and [13]. It was recommended the change of the arrangement for the one portrayed on Fig. 7 (bottom). The trefoil formation would represent a better solution, but it would be harder to implement, implying the enlargement of holes in a wall and the re-installation (or even replacement) of cable trays.



**Fig. 6.** Present arrangement (top) and proposed re-arrangement (bottom) of cables connecting the transformer and the main switchboard.

## 5 Conclusions

This project has identified several issues related with power quality disturbances that effectively affected production processes, mainly in activity sectors with intensive use of CNC systems, whose methods of quality control are very strict in the manufacturing of steel (in the order of microns). In addition, some issues that could potentially become a problem were detected and solutions were proposed in order to take action anticipating possible damages.

The degradation of power quality can be a trouble resulting in large financial losses. With the increasing competitiveness of world economy, but also with the low financial capability, particularly of most of the Portuguese companies, every investment in power quality improvement must be analysed wisely. The implementation of a monitoring and recording smart system, where the PQ disturbances and their consequences are registered could support the taking of better, informed and sustainability-aware decisions. The linkage of objects, people and knowledge promotes the network effect for the cooperative awareness.



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