Power Quality problems in the mould industry

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Abstract. The main goal of this work is the characterization of the power quality (PQ) in the mould industry in the centre region of Portugal and the effects of the PQ disturbances in their production processes and their worldwide competitiveness.

First a panorama of the mould industry in Portugal is described pointing key figures of the sector, some history and present needs. Then the classification of voltage dips registered in some points of the transmission and distribution networks in Portugal is studied and presented, allowing to compare with measured values during monitoring campaigns and to help to characterize the expected scenario in terms of dip occurrence.

Finally, the key results of a monitoring campaign in a mould industry unit are presented and analyzed.

Keywords: Power quality, economical impacts, mould industry, voltage dips, harmonic distortion.

1. Introduction

The evolution of the worldwide economy led to an increasing competitiveness, and some factors that were considered irrelevant in the past are now of most importance today. With the decrease of the profit margins, any incident disturbing production may imply huge losses, sometimes difficult to regain.

The constant modernization of manufacturing processes is based on the widespread of electronic equipment. These electronic equipments have an increased sensitiveness to power quality (PQ) disturbances and, at the same time are responsible for PQ degradation.

A. The mould industry in Portugal

One example of the use of advanced manufacturing processes is the mould industry. Most companies now make use of CAD/CAM/CAE[1] techniques. From the mould production planning to the final product, the whole process is highly technological. The core of the mould manufacturing process is based on CNC (Computer Numerically Controlled) machines and other sensitive equipments, such as electroerosion equipments.

Some disturbances in a CNC machine can lead to the loss of materials, damage in the tools and some hours or even days of lost work. Along with these direct costs, some indirect costs, such as the inability to satisfy the delivery dates to the client may compromise the company's competitiveness.

A cluster of this industry is based in the centre of Portugal, mainly in the Marinha Grande-Leiria area, which comprises some hundreds (about 535) of small and medium companies, employing about 8350 workers. The total production of this sector represented a total of 373 million euros, 91% of which for exportation [1]. The main target markets for the Portuguese moulds are within European Union (about 80%). Exportations for United States and Canada demonstrated a continuous decrease trend since 1993. This trend can be explained by the manufacturing relocation.

The most important industry served by Portuguese moulds is the automotive sector. In 2008, it took in about 72% of total production. In 1991, the automotive sector represented only 14% of the total production. Other important clients are the domestic appliances, houseware and packaging industry.

Facing the current menace of the Asian mould making industry with lower production costs, Portuguese mould industry must seek the minimization of production losses. A way to reduce production costs may be the reduction of the losses related to power quality issues. This loss of competitiveness to Asian industry, along with a predictable shortage of orders from the automotive sector, may lead to the closing of several companies and guide many workers to unemployment.

[1] Computer aided Design / Computer Aided Manufacturing / Computer Aided Engineering.

B. Economical impacts of power quality problems

Several studies have been made 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. Some of these studies are presented below.

i. Business Week (1991). PQ costs were estimated on 26,000 million USD per year in the United States;
ii. EPRI (1994): This study pointed 400,000 million USD per year for PQ costs in the United States;
iii. US Department of Energy (1995): PQ costs were estimated on 150,000 million USD per year for United States;
iv. E Source (2001): A study comprising continuous process industries, financial services and food processing in the United States, estimated the average annual costs of PQ problems on 60,000 to 80,000 USD per installation;
v. PQ costs in EU (2001): Overall PQ costs in industry and commerce, in European Union (15 countries), are estimated in 10,000 million EUR per year [2];
vi. PQ costs in EU-25 (2007):150,000 million EUR are wasted due to inadequate power quality management [3].

The estimates of the various studies differ a lot, but all point to a common factor: the PQ costs are enormous. All these studies also indicate that the investment made to minimize these costs is rather insignificant.

Table I – Typical costs of momentary interruptions (1 minute) for different types of industrial and services facilities [4].

	Cost (USD/kW demand)	
	Maximum	**Minimum**
Industrial		
Automobile manufacturing	5.0	7.5
Rubber and plastics	3.0	4.5
Textile	2.0	4.0
Paper	1.5	2.5
Printing (newspapers)	1.0	2.0
Petrochemical	3.0	5.0
Metal fabrication	2.0	4.0
Glass	4.0	6.0
Mining	2.0	4.0
Food processing	3.0	5.0
Pharmaceutical	5.0	50.0
Electronics	8.0	12.0
Semiconductor manufacturing	20.0	60.0
Services		
Communication, information processing	1.0	10.0
Hospitals, banks, civil services	2.0	3.0
Restaurants, bars, hotels	0.5	1.0
Commercial shops	0.1	0.5

An interruption is the PQ problem with the most perceivable impact on facilities. Table I summarizes the typical costs of momentary interruptions (1 minute) for different types of consumers. These values were assessed for situations in which there were no major investments in technologies to achieve ride-through capabilities to deal with with the interruption. These values are based on published studies and individual studies and were compiled by *Electrotek Concepts* [4].

2. Power Quality in Portuguese T&D Networks

Every year, Portuguese energy services regulator (ERSE) publishes a report on the technical and commercial quality of the service provided in electricity transmission and distribution (T&D) activities. This information must be sent to the regulator by all licensed operators and is then gathered and evaluated by the regulator [5].

Fig. 1 shows the classification of voltage sags measured in interconnection points of transmission network. These are annual values for 2007, measured and averaged over seven different sites (two sites with voltage level of 150 kV and the other five with 60 kV) [6]. The average number of dips in each site is of 67 per year.

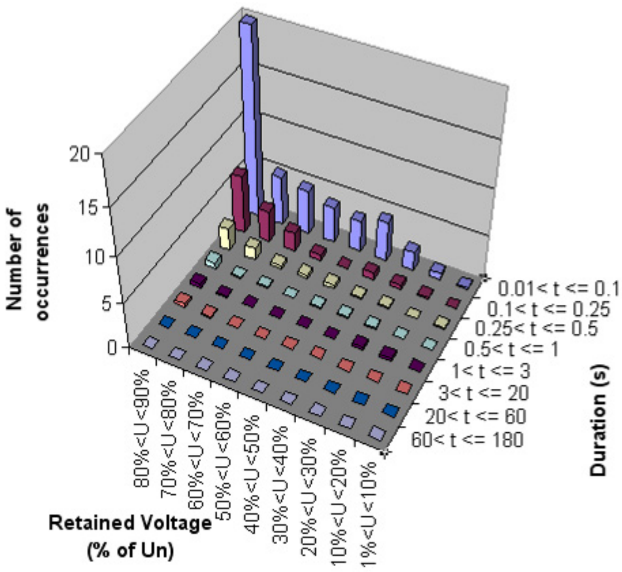

Fig. 1 – Annual average voltage sag, and its classification, registered at interconnection points (seven sites) between transmission and distribution networks, during 2007.

The distribution network operator also provides some data for voltage quality parameters. Until 2006, they provided only the number of events, but in 2007 they have provided the number of PQ events and their classification. One can see in Table II the classification of voltage dips based on data provided by Portuguese distribution network operator (EDP) [6]. This classification is done according to the standard IEC 6100-2-8 [7]. These values were registered in electrical substations feeders with voltage level of 30 kV. No annual monitoring was done on the same substation. The average duration of monitoring was of 79 days. The annual value of dips results of a weighted average of the occurrences registered in the 35 monitored feeders. The average number of dips in each 30 kV feeder is of 826 per year. This classification is graphically represented in Fig. 2.

Table II – Annual average number and classification of voltage dip events in 30 kV buses of electrical in substations of the distribution network in 2007.

Voltage (% of U_{ref})	Number of events / Duration (seconds)							% of total events
	$0.01 < t \leq 0.1$	$0.1 < t \leq 0.5$	$0.5 < t \leq 1$	$1 < t \leq 3$	$3 < t \leq 20$	$20 < t \leq 60$	$60 < t \leq 180$	
80%<U<90%	394,6	127,4	33,7	6,3	0,0	0,0	0,0	68,0
70%<U<80%	56,2	40,1	18,1	3,0	0,0	0,0	0,0	14,2
60%<U<70%	19,9	24,5	11,4	5,7	0,0	0,0	0,0	7,4
50%<U<60%	13,4	15,9	4,5	1,7	0,0	0,0	0,0	4,3
40%<U<50%	3,9	11,1	3,8	1,6	0,0	0,0	0,0	2,5
30%<U<40%	2,4	6,7	0,9	1,4	0,0	0,0	0,0	1,4
20%<U<30%	0,2	4,2	0,5	0,1	0,0	0,0	0,0	0,6
10%<U<20%	0,4	6,3	0,7	0,7	0,0	0,0	0,0	1,0
1%<U<10%	0,3	3,5	0,7	0,1	0,0	0,0	0,0	0,6
% of total events	59,5	29,0	9,0	2,5	0,0	0,0	0,0	Total events: 826

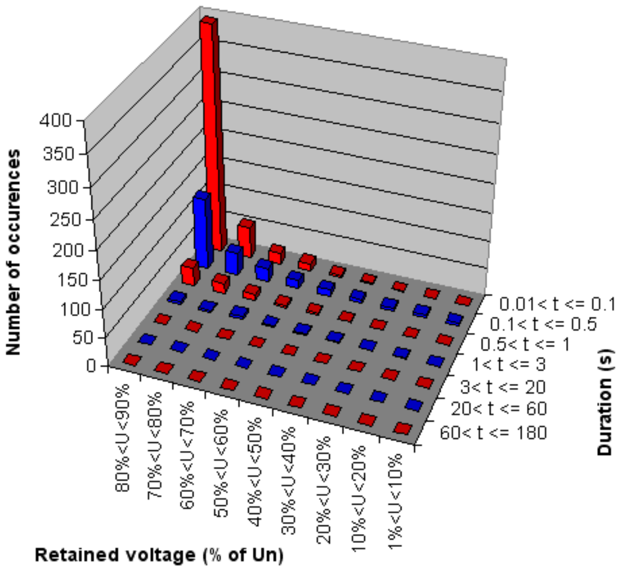

Fig. 2 – Annual average voltage dips registered at several 30 kV bus in electrical substations, registered in 2007.

By analysing the data for the transmission and distribution networks two inferences are easily drawn: The classification of dips is similar, most of the events have a short duration and have low depth. In most cases duration is less than 100 ms and retained is voltage over 80%. The key difference is the total number of events recorded, an average of 67 for transmission network and 826 for distribution network. This is an expected value and is easily explained by the geographical spreading and interconnection level of the distribution network.

3. Monitoring campaign

The monitored unit is located in the centre of Portugal and produces moulds, mainly for plastic injection in automotive industry. This unit is fed by an overhead 30 kV line and an enclosed transformer station. The monitoring was done at the electrical switchboard that feeds the large steel mould making production line, with a demand peak of around 140 kVA.

The monitoring was done using the analyser in Fig. 3 (Hioki Power Quality Analyser 3196). The equipment was connected according to the diagram in Fig. 4. The voltages were monitored on the switchboard bus and the currents were monitored on the cables that connect this board to the transformer station switchboard. The settings of the equipment for the campaign were based on the EN 50160, registering the values with a 10 minute interval and events according to the norm parameters.

Fig. 3 – Hioki Power Quality Analyser 3196 used in monitoring campaign.

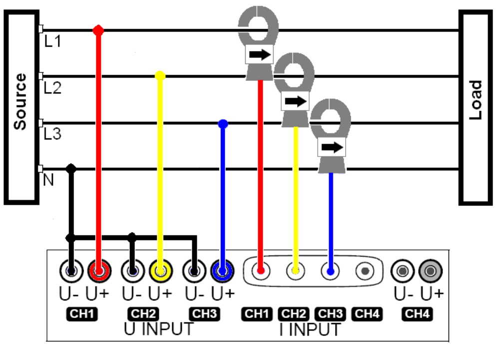

Fig. 4 – Connection diagram of the power quality analyser.

The duration of the campaign was of 8 days in December 2008.

4. Results and discussion of PQ monitoring

In this section results from the PQ measurement campaign in the mould making unit are presented. Several PQ parameters were assessed during monitoring. Some, like frequency, voltage unbalance are not presented or discussed because no relevant disturbances were registered at this level.

All the parameters of the NP EN 50160[2] [8] were met, except for the flicker. Long-term flicker (P_{lt}) exceeded the limit value of 1 in 5.2% in phase 1 and 6.2% of the time in phases 2 and 3. It should be noted that this fact doesn't mean a failure from the electric utility, since the measures were not taken at the point of common coupling (PCC), as the regulations oblige.

A. Voltage level

The voltage at the switchboard bus, for one phase, is presented in Fig. 5. The other phases are not presented since the values are quite similar. The average voltage corresponds to the averaged values of RMS voltage for a 10 minutes period. The maximum and minimum values correspond to the highest and the lowest value of RMS values measured every 200 ms for each 10 minute period.

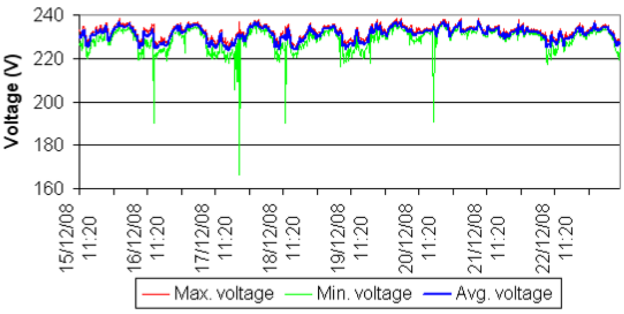

Fig. 5 – Average, maximum and minimum values of voltage in phase 1.

The average voltage level is adequate and the maximum values are quite acceptable. The minimum values show the occurrence of some voltage dips with low depth and/or short duration. These dips will be discussed later on.

B. Harmonic distortion

Voltage total harmonic distortion (THD) and the average harmonic spectrum are presented in Fig. 6 and Fig. 7.

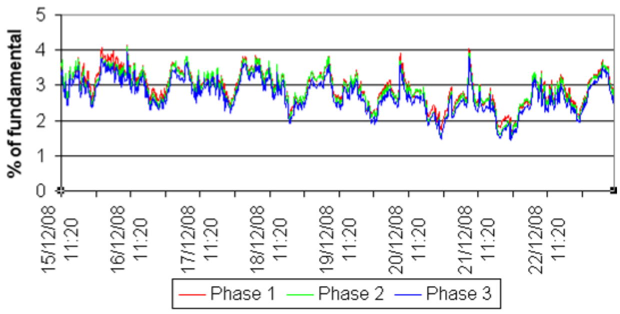

Fig. 6 – Voltage harmonic distortion at the main switchboard of a mould industry unit.

Voltage THD values are normal, most of the time about 3% and always lower than 5%. The harmonic spectrum is the normal spectrum for a three-phase network, with predominance of the 5th and the 7th harmonics.

[2] NP EN 50 160:2001 is the Portuguese version of the European Norm 50 160:1999.

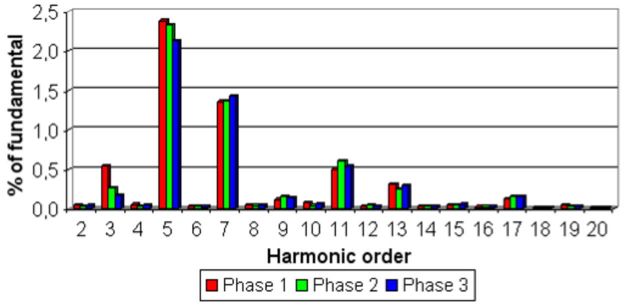

Fig. 7 – Average harmonic spectrum of the voltage.

The current THD is shown in Fig. 8. Fig. 9 and Fig. 10 show harmonic spectrum of the current for two different periods. Fig. 9 depicts the spectrum for the period when the THD has the higher value (Thursday, 1h50m). RMS currents are 82.40, 85.3 and 72.3 A for phase 1, 2 and 3, respectively. Fig. 10 depicts the spectrum for the period when the power demand has the higher value (Monday, 9h50m). RMS currents are 209.60, 205.2 and 179.5 A for phase 1, 2 and 3, respectively.

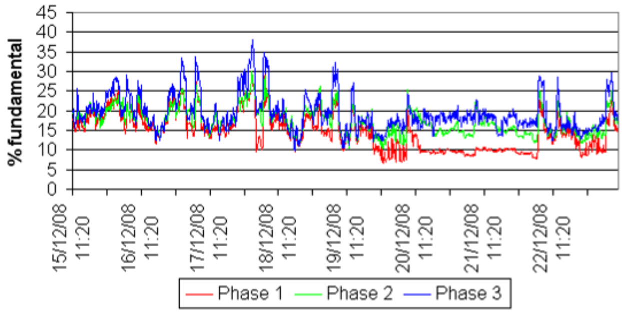

Fig. 8 – Current harmonic distortion at the main switchboard of a mould industry unit.

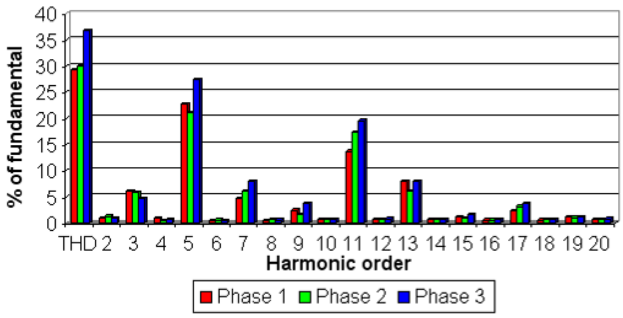

Fig. 9 – Harmonic spectrum of the current for the 10 minute period with the higher THD.

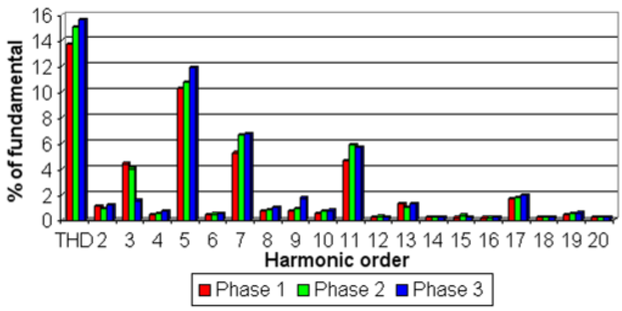

Fig. 10 – Harmonic spectrum of the current for the 10 minute period with the higher power demand.

In both situations, the form of the spectrum is similar and quite typical. The key differences are the influence of the third harmonic on THD and the dissimilarity on harmonic content of phase 3 in the highest demand period. This is explained by an unequal distribution of single-phase loads by the three phases. As corroborated by the RMS values of currents and switchboard analysis, loads like discharge lighting and computers are mainly fed by phases 1 and 2, generating currents with high 3rd harmonic content. Phase 3 is mainly used for three-phase loads, generating currents rich in 5th and 7th harmonics.

C. Flicker

The long-term flicker measured registered several values higher than 1, that is the reference value of NP EN 50160, as can be seen in Fig. 11. This is the result of high short-term flicker values, reaching values near to 10. Comparing the time of occurrence of these high values of flicker and the RMS value of voltage and dip occurrence, one can see that all high values of flicker are related to voltage dips.

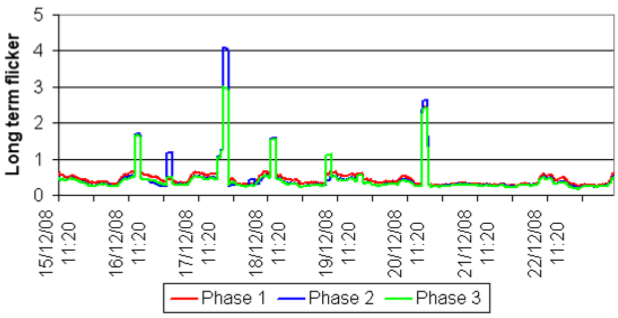

Fig. 11 – Long-term flicker.

D. Voltage dips

During monitoring campaign a total 13 dips were registered. The classification of these events is presented in Table III.

Averaging this to daily values and extrapolating them we could expect an average of 593 dips per year. Surely the number of events is not equal in time for the whole year. During winter season a higher number of occurrences is expected, particularly during unfavourable weather conditions. Taking into consideration that the monitoring was carried out in winter, but weather conditions were favourable (no heavy rain or strong winds), this could be assumed as a typical average value. This value is similar to the values registered in 30 kV substations in the centre of Portugal during 2007 by the distribution network operator.

The amplitude and duration of the registered dips is analogous to the results presented in Section 2, but the low quantity of events doesn't allow a best estimate, mainly for dips with higher depth.

Fig. 12 and Fig 13 show the detail of two dips, the dip with the biggest duration and the dip with the lower retained voltage, respectively. Like these, all other registered dips are three-phase dips with values of voltage similar in the three phases. The retained voltage in the first dip is 189.57 V and the duration is 282 ms and the second dip has a retained voltage of 154.32 V and duration of 60 ms.

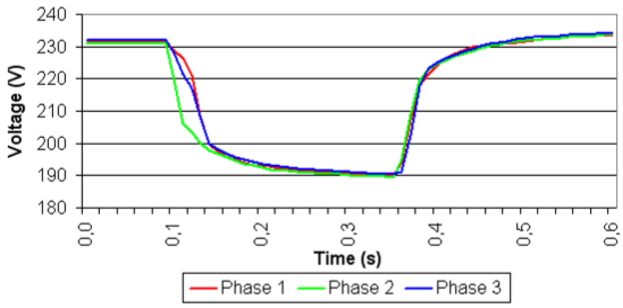

Fig. 12– Voltage dip registered at 18 December, 12h07m.

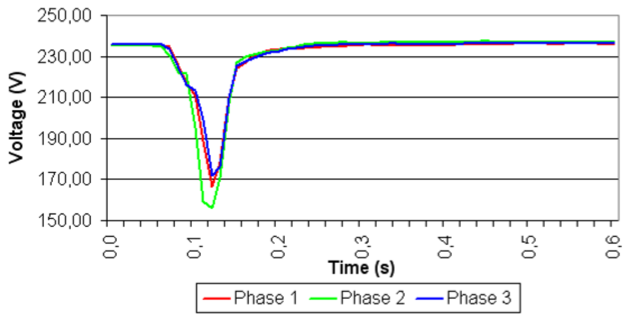

Fig. 13 – Voltage dip registered at 17 December, 19h41m.

Table III – RMS voltage events (aggregated) during a monitoring campaign at a mould industry unit in 8 days (15 to 23 December 2008).

Voltage (% of U_{ref})	Number of events / Duration (seconds)							
	]10m; 100m]	]100m; 500m]	]500m; 1]	]1; 3]	]3; 20]	]20; 60]	]60; 180]	]180; ∞[
]180; ∞]	0	0	0	0	0	0	0	0
]160; 180]	0	0	0	0	0	0	0	0
]140; 160]	0	0	0	0	0	0	0	0
]120; 140]	0	0	0	0	0	0	0	0
]110; 120]	0	0	0	0	0	0	0	0
[70; 90[	5	5	0	0	0	0	0	0
[40; 70[	2	0	0	0	0	0	0	0
[10; 40[	0	0	0	0	0	0	0	0
[1; 10[	0	0	0	0	0	0	0	0
[0; 1[	0	0	0	0	0	0	0	0

No damage or production losses were caused by any of these disturbances. As shown in Fig. 14, the dips registered are almost are plotted inside the voltage tolerance envelope. Only few events were plotted outside this envelope, but very close to it.

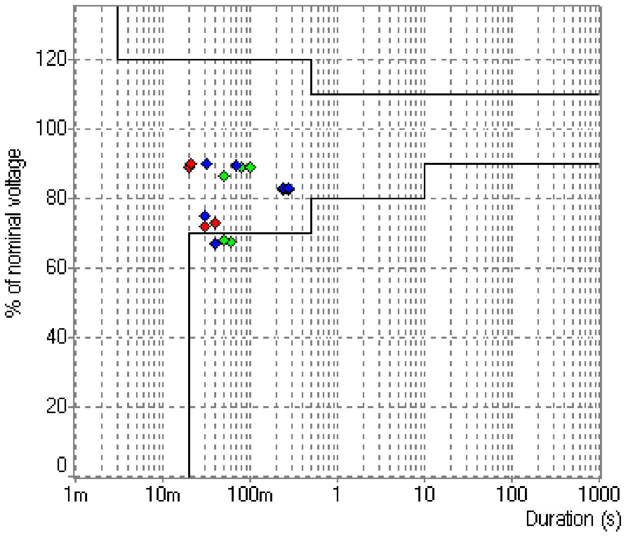

Fig. 14 – Voltage dips (non aggregated) plotted in ITIC curve.

5. Conclusions and outlook

The natural unfeasibility of the power systems to provide a disturbance free electrical energy has consequences on every consumer. This study, which focused on the mould industry, intended to show that industrial sectors employing technological processes are among the major victims of these problems.

In the first part of this paper, occurrence of dips was characterized for T&D networks in Portugal. The classification of dips is similar to other studies carried out, resulting in a typical distribution.

A monitoring campaign was carried out in a production line of large steel moulds, and its major findings were presented here. No significant measures can be suggested to mitigate power quality events. Some could be considered, such harmonic filters or ride-through capability for sensitive process controllers, but further studies, including techno-economic feasibility, should be made. Nevertheless, a suggestion that can be made is to balance the loads by the three-phases, switching some single-phase loads from phases 1 and 2 to phase 3, reducing the current unbalance of the system.

The work described here is part of an ongoing project, including more monitoring campaigns and more exhaustive analysis of the mould sector, which is expected to add a clearer understanding by the industry of the PQ issues, its causes and consequences. The industry representatives must acknowledge that, as a player in the electricity market, they must be actively involved, taking action in order to minimize the costs of PQ disturbances. This may be crucial to increase the competitiveness of this sector and assure the survival of many companies and jobs.

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