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Power Quality Studies Using a Developed Low Cost Power Quality Monitor

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***Abstract* – This work presents two studies to evaluate the power quality in two facilities: a diagnosis centre in a Public Hospital and a simulation laboratory with a computer cluster, together with a printing centre and the air conditioning equipments of the Physics Department of a public University. Both these installations require a high level of power quality in order to avoid productivity losses as well as economic losses, and to maintain a high level of service quality. These studies will apply international standards to ascertain the power quality at these locations and will use a custom made prototype power quality monitor developed by the authors. It uses Hall effect voltage sensors, Rugowski Coil flexible current sensors and its processing system was developed with *LabVIEW*™.**

***Index Terms* - Power Quality Monitoring, Virtual Instrumentation, Data Acquisition, *LabVIEW*™.**

I. Introduction

POWER quality is nowadays a key issue for the producers, distributors and consumers. The most common problems, like harmonics, short term voltage variations (sags, swells and interruptions), long term voltage variations (undervoltages, overvoltages and interruptions), transients, unbalance, frequency variations and others, can cause several problems to the consumers which require high levels of power quality for their processes, and such occurrences can have dire economical consequences [1].

Power quality studies are the necessary first step in order to determine the nature of the existing problems at a given installation, so that measures can be taken to solve or at least reduce these problems to acceptable levels. Several international standards related to power quality and electrical system monitoring, like IEEE 1159, IEC 61000 and EN 50160, help to classify and even offer possible solutions to the problems described above, but specialized equipment is necessary in order to determine exactly which problems affect a given facility [2-4].

Because many of the commercially available equipments are either too expensive (about 12,000€), or have too many limitations, it was decided to develop a new low-cost power quality monitor, with a cost of about 3,000€, that could be an alternative to the equipment existing in the market.

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II. Characteristics of the Power Quality Monitor

The developed low-cost Power Quality Monitor, shown in Figure 1, consists of a Personal Computer with a mini ITX motherboard (*VIA C3*™/ *VIA Eden*™ *EBGA* processor, running *Windows XP*), a data acquisition card (*National Instruments* NI-6220), and a custom made hardware module [5]. The card can read 8 analogue signals in differential mode, with a 16 bit resolution and a 250 ksamples/s sampling rate, as well as 24 I/O digital lines.

To read the voltages and currents of the electrical systems a hardware module was developed, comprising four voltage sensors (LEM LV 25-P, Hall effect) with 10 kHz bandwidth and four current sensors (LEM-FLEX® - RR3020, flexible Rugowski Coil) with 10 Hz to 20 kHz bandwidth. The current sensors offer the possibility of choosing from three scales (30 A, 300 A and 3,000 A), and it is not necessary to disconnect the electrical system that will be monitored in order to use them. The measured signals are the three phase-to-neutral voltages and the neutral-to-ground voltage, as well as the three phase and the neutral currents (comprising a total of 8 electrical signals).

Fig. 1. Power Quality Monitor

The Power Quality Monitor software applications were developed by the authors using the graphical programming tool *LabVIEW*™. Basically these applications allow the equipment to work as a power quality monitor or as an oscilloscope, allowing the real time visualization and storing of voltages and currents (31.25 ksamples/s per channel), and the calculation of True RMS values, power and energy, harmonic distortion, and other parameters. It also has the capability of producing reports and sending e-mail messages to selected destinations. The three software applications used on this power quality study are briefly described below.

A. Application "Scope and THD"

This is a typical example of virtual instrumentation, as this application mimics a digital oscilloscope with 8 isolated channels (4 for voltages and 4 for currents). It includes the normal functions of a standard scope, like the time base, vertical amplifier gain, trigger setup (slope, level and source), and readouts (signal frequency, True RMS values, DC values, peak to peak values, etc). It is also possible to calculate the THD and all the individual harmonics (frequency, amplitude, and phase angle).

With this application all signals can be visualized simultaneously, with a sampling rate of 25 kHz per channel. This sampling rate can actually increase if fewer signals are being acquired. If just one channel is observed, then the sampling rate will be of 250 kHz, for two channels the sampling rate drops to 125 kHz, and so on. It also includes the capability to automatically generate HTML and Word reports with information regarding the measured signals. Thanks to the template used, it is also possible to manipulate the data using other software tools like Matlab or Excel.

B. Application "Events PQ (Power Quality)"

This application acquires, in continuous mode, the three phase-to-neutral voltages (v_{an}, v_{bn} and v_{cn}), the neutral-to-ground voltage (v_{ng}), the three phase currents (i_a, i_b and i_c) and the neutral current (i_n). Simultaneously, all the necessary procedures to create strip charts, to detect sags and swells, and wave shape type anomalies, are executed every cycle, and all the important information is saved to a file. Figure 2 shows two of the interface screens of the analysis tool: "Strip Chart" and "Wave Shape".

The monitoring period is user defined, and can last between 1 minute and 30 days. In the end of the monitoring process the relevant data can be automatically sent to multiple destinations via e-mail.

C. Application "Classical Values"

This application calculates a number of parameters used on the analysis of an electrical system: True RMS values and phase angles for each of the acquired signals, phase impedances, voltage and current unbalance, total and displacement power factor, power (active, reactive, harmonic and apparent), active energy (kWh) and "reactive" energy (kVArh). A phasor diagram of the voltages and currents is also plotted in real time using only the fundamental component of each of the signals.

III. Power Quality Studies

The first electrical installation to be monitored was the imagiology sector of a Portuguese Public Hospital. This sector includes several equipments like CT scanners, X-Ray machines, ultrasonography machines and also MRI machines. The main problem of this sector of the hospital concerns the CT scanner; sometimes the equipment would stop responding and it was necessary that a specialized technician would reinstall the software. The main goal of this study was to determine the origin of the problem that corrupts the memory of the CT scanner and also to determine the profile of this

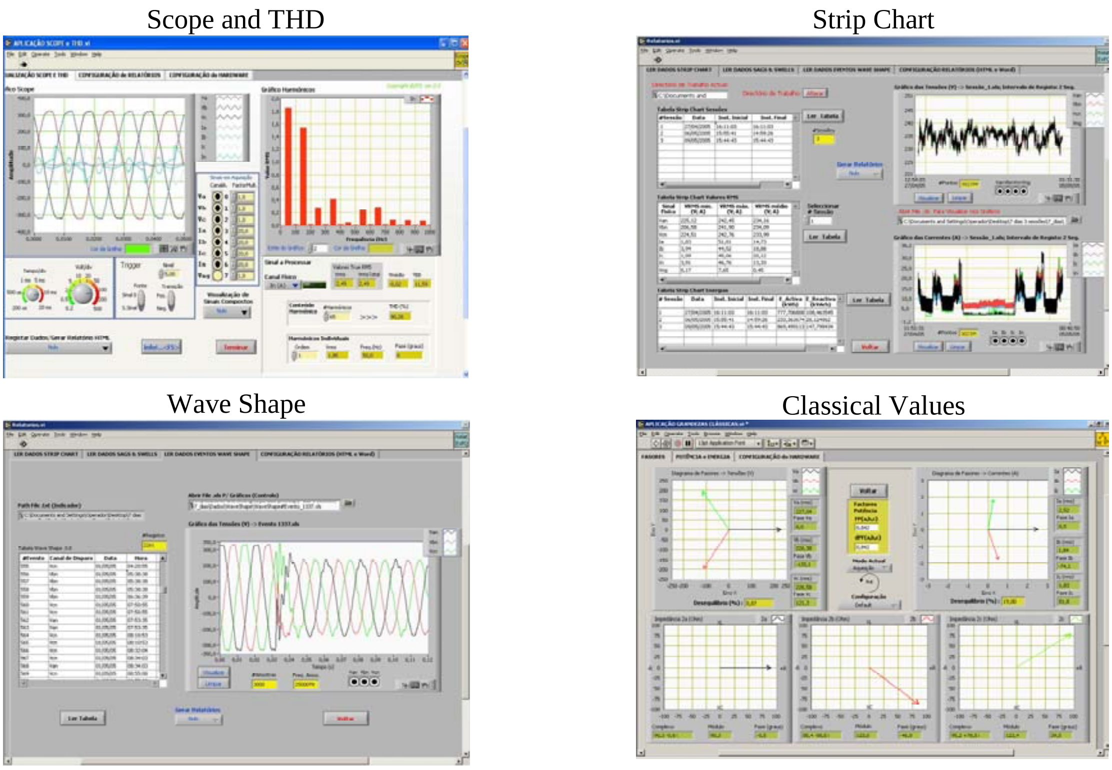

Fig. 2. Graphical environments of the main developed applications

sector in terms of waveforms and energy consumption. Besides a 7 day monitoring, a test was made which consisted of cutting off the mains power and letting the cogeneration supply the electrical power to the hospital. The transition period during the first seconds after a failure of the mains power is suspected of causing the problems of the CT scanner.

The second installation to be monitored was a sector in the Physics Department at University of Minho. This sector has a cluster of 51 PCs, a printing service with 2 printers, and a plotter, and 2 air-conditioners. The PCs are protected by offline UPSs in case there is a power failure. Because of the number of non-linear loads this installation has a high harmonic content, with a high crest factor which makes it necessary to use higher power rating UPSs.

The study started with a preliminary analysis of the voltage and current signals during normal working hours at the electrical panel where the study will be made with the application "Scope&THD". When this initial phase is concluded the system is configured for a 7 days monitoring process, with the application "Events PQ" configured to compare the monitored signals with the specifications provided by the standard EN50160. This monitoring period will trace a more precise profile of the installation in terms of voltage and current levels during work and idle periods.

A. Scope and THD Results

This application was used to register voltage and current waveforms of both installations during normal working hours. Figures 3-5 show the waveforms at the hospital and figures 6-9 show the signals acquired at the physics laboratory. It was not possible to register the neutral-ground voltage at the hospital because in the electrical panel where the measurements took place the neutral and ground cables were common.

The voltage and current signals were visualized and stored during a period of 120 ms (6 cycles). Tables I and II show the True RMS values and also the THD for each signal at the hospital and at the physics lab respectively.

TABLE I
CALCULATED VALUES FROM MEASURED SIGNALS

Measured Signals	True RMS values	THD (%)
v_a	228.7 V	3.3
v_b	228.5 V	2.8
v_c	229.2 V	2.4
i_a	61.4 A	10.7
i_b	79.6 A	9.9
i_c	55.8 A	6.3
i_n	11.1 A	90.9

It is possible to observe that the current waveforms at the hospital were changing continuously due to interharmonics present in the system, which happens when the MRI machines are working.

The main problem at the physics laboratory is the crest factor in the current waveforms, because of the computers. The unbalance is also relatively high.

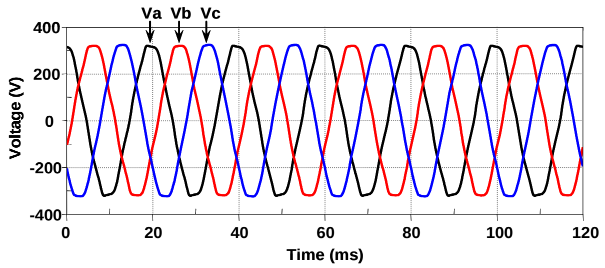

Fig. 3. Phase voltages of the system (hospital)

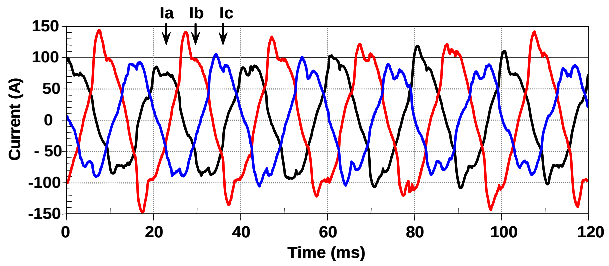

Fig. 4. Phase currents of the system (hospital)

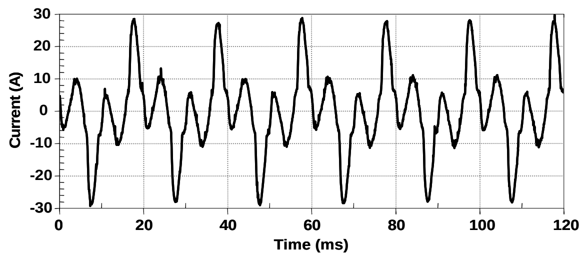

Fig. 5. Neutral currents of the system (hospital)

TABLE II
CALCULATED VALUES FROM MEASURED SIGNALS

Measured Signals	True RMS values	THD (%)
v_a	227.5 V	3.1
v_b	226.5 V	3.1
v_c	225.0 V	2.9
v_{ng}	0.8 V	121.8
i_a	10.0 A	37.6
i_b	7.7 A	21.0
i_c	12.1 A	37.8
i_n	9.9 A	151.5

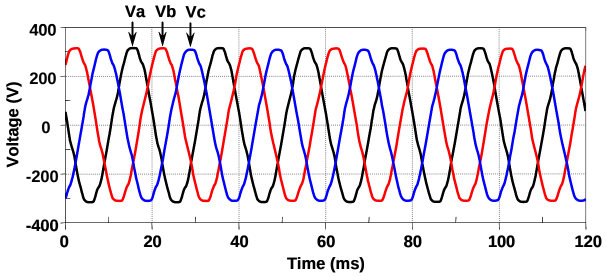

Fig. 6. Phase voltages of the system (physics lab.)

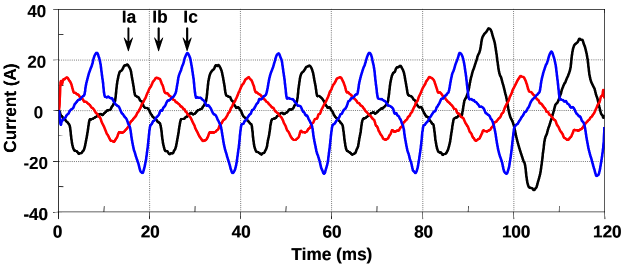

Fig. 7. Phase currents of the system (Physics lab.)

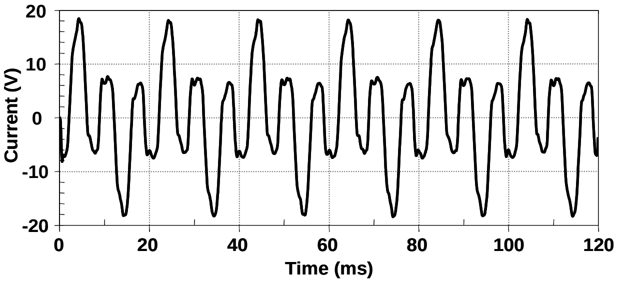

Fig. 8. Neutral currents of the system (Physics lab.)

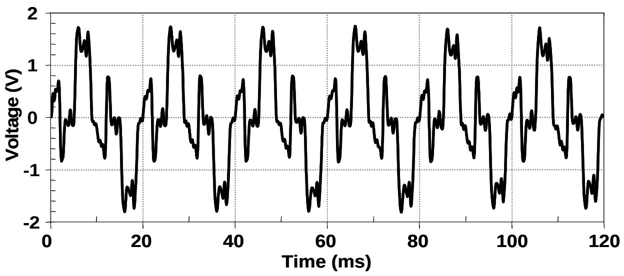

Fig. 9. Neutral-ground voltage of the system (Physics lab.)

B. Strip Chart Results

The Strip Chart interface allows the visualization of statistic data (minimum, maximum and average values) and the trend during the complete monitoring period of the currents and voltages, as well as the energy consumption during this period. Thanks to the trend graphics it is possible to distinguish between the working days and the weekend, and also between the working hours and the night period. With this data it is possible to determine the peak working periods, and also the current consumption when no productive activity is being undertaken which may mean unnecessary energy consumption.

The analysis of the strip chart of the Public Hospital, illustrated in Figure 10, shows data during a weekend and also a national holiday, but the current consumption during these periods, and also at night, never drops considerably, because some of the diagnosis machines must work continuously or at least be on standby.

The monitoring session at the Physics Department, shown in Figure 11, did not reveal any serious problems at this installation during the 7 days monitoring period. There was a considerable amount of harmonics and the crest factor was high in the current waveforms, however the PCs, UPSs and remaining equipment at this installation were prepared to deal with these problems.

There was another session at the Public Hospital, to determine what happened when the mains power was disconnected and the emergency systems started feeding the installation.

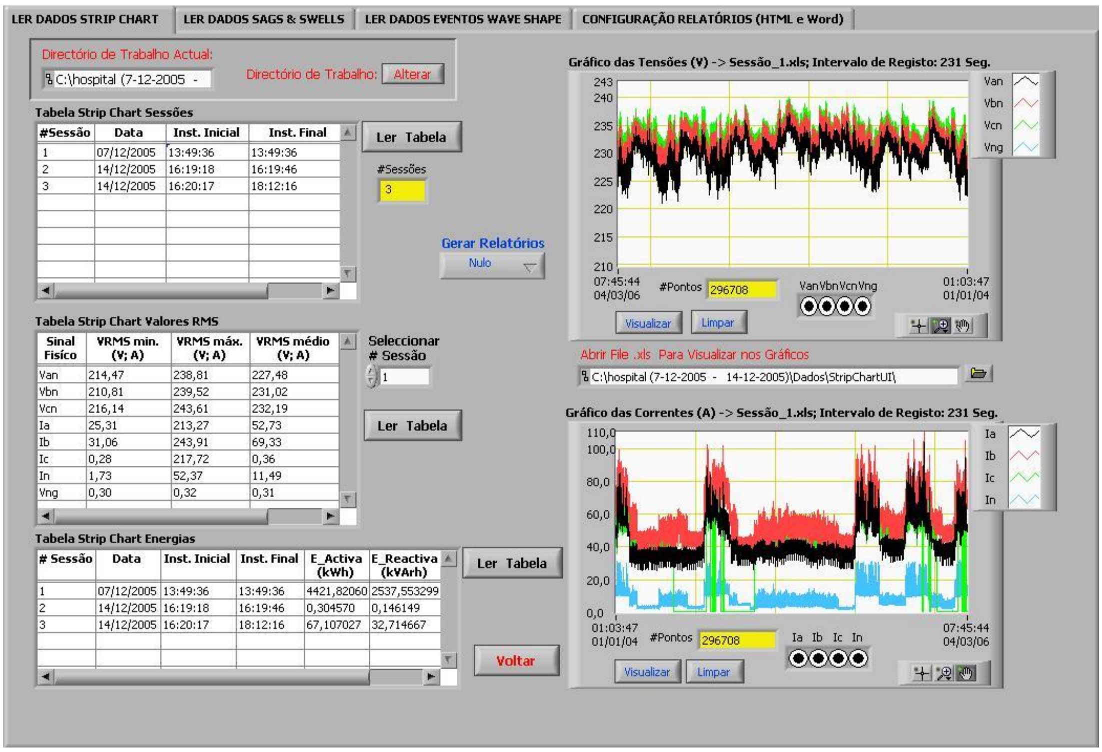

Fig. 10. Strip chart data of first session (hospital)

Fig. 11. Strip chart data of first session (Physics lab.)

The Strip Chart of Figure 12 shows that when the mains power was disconnected the voltage varied for a period that lasted several seconds. A cycle to cycle analysis indicated the voltage at phase *c* exceeded 260 V for 27 cycles, which ended up not affecting any equipment because of the short duration of the event. There was also a problem with the frequency of the system voltages that went up to 50.7 Hz, during the time that the cogeneration system was supplying the energy. This was not a problem in this test because the frequency can go up to this value for 50 minutes in 1 week, according to EN50160.

Fig. 12. Strip chart data of third session (hospital)

C. *Sags & Swells Results*

"Sags & Swells", a module of the "PQ Events" application, registered 78 events during the first monitoring session in the hospital, and registered 15 events during the first monitoring session in the Physics laboratory. Most events were either instantaneous (up to 30 cycles) or momentary (from 30 cycles up to 3 s), according to the classification given by the EN 50160 standard. Most of the events occurred at night, when the vast majority of the loads are disconnected. The greater part of these events were swells (exceeding the maximum value of 242 V specified by the standard EN 50160). Table III shows the most important events of this type registered at the hospital while the cogeneration system was supplying the hospital and serves as an example of the kind of information provided by the power quality monitor. A stored waveform is associated with each one of these events.

TABLE III
EXAMPLE LIST OF KEY SAGS AND SWELLS AT THE HOSPITAL

Date	Hour	Signal	Value RMS (máx./min.)	Duration	Type of event
14/12/05	17:54:55	Van	254	15 ciclos	Swell
14/12/05	17:54:56	Van	248	4 ciclos	Swell
14/12/05	17:55:31	Van	198	1 ciclos	Sag
14/12/05	17:55:31	Van	208	2 ciclos	Sag
14/12/05	17:55:44	Van	200	2 ciclos	Sag
14/12/05	17:55:58	Van	214	2 ciclos	Sag
14/12/05	17:56:22	Van	211	2 ciclos	Sag
14/12/05	17:57:06	Van	215	11 ciclos	Sag
14/12/05	17:57:09	Van	217	17 ciclos	Sag
14/12/05	17:57:16	Van	217	23 ciclos	Sag
14/12/05	17:57:17	Van	217	13 ciclos	Sag
14/12/05	17:54:55	Vbn	257	22 ciclos	Swell
14/12/05	17:54:56	Vbn	244	2 ciclos	Swell
14/12/05	17:56:01	Vbn	214	2 ciclos	Sag
14/12/05	17:54:55	Vcn	261	27 ciclos	Swell
14/12/05	17:55:31	Vcn	205	2 ciclos	Sag

D. *Wave Shape Results*

"Wave Shape", a module of the "PQ Events" application, reported 302 events related with the voltage waveforms at the hospital. Two examples of these events are shown in Figures 13 and 14. For the Physics laboratory there were registered 918 events, but they were mainly due to slight fluctuations in the rms values, and not to transients or other serious events. A typical example is shown in Figure 15.

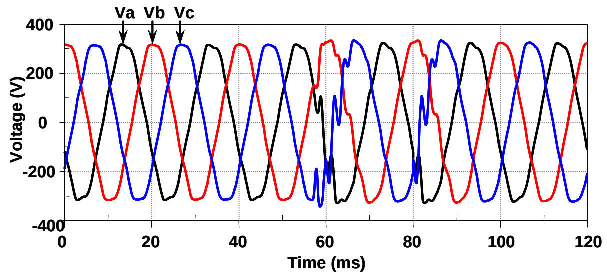

Fig. 13. Wave shape event (hospital)

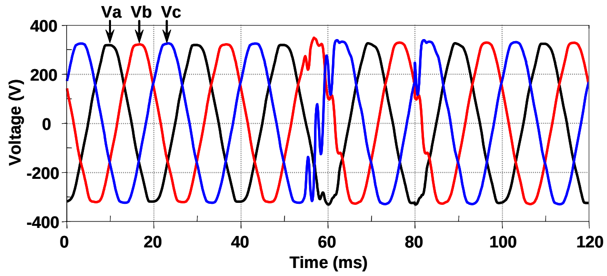

Fig. 14. Wave shape event (hospital)

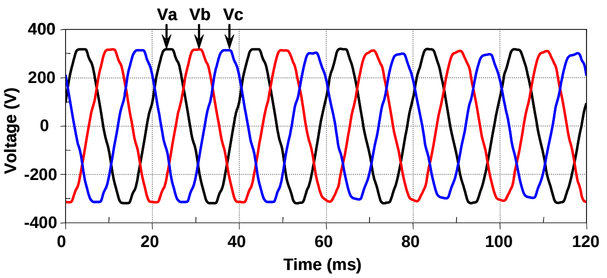

Fig. 15. Wave shape event (Physics lab.)

IV. Conclusion

The goal of this paper is to describe the main characteristics of a developed low cost Power Quality Monitor and presenting the capabilities with some case studies.

This equipment was used to perform power quality studies, and the most interesting power quality cases registered during the monitoring sessions were shown. The obtained results demonstrate the importance of having a power quality monitor continuously operating, especially in installations where power quality is a key factor for an industrial process. Some problems may have dire consequences, like malfunctions or interruptions in the operation of equipment, which might lead to a decrease in productivity, leading to economic losses.

The power quality monitor provides the user with information regarding the types of problems occurring at the installation which, in turn, can lead to pinpointing and solving these problems.

The power quality studies shown in this paper were done with the purpose of defining the main problems at a Public Hospital and at a Physics laboratory

The hospital had more serious problems, especially when the mains power failed and the cogeneration system had to supply the installation. The sags and swells registered during the transition period are probably the origin of the failures in the CT scanner, however this study was inconclusive because the equipment remained operational this time.

As for the second installation, it was possible to observe that there are no serious problems that compromise productivity at this location. Just the crest factor is relatively high, but the installation is prepared to handle with this problem at the power level currently installed.

V. References

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VI. Biographies

José Carlos da Cunha Costa was born in Braga, Portugal, on June 1978. He graduated in Industrial Electronics from University of Minho in 2004. His main research area of interest is Power Quality.

Ricardo Luís Guerreiro Pregitzer was born in Porto, Portugal, on April 1981. He graduated in Industrial Electronics from University of Minho, Portugal, in 2003. He is enrolled in M.Sc. at University of Minho, where he is working on the development of Active Power Filters. His main research areas of interest are Power Quality and Renewable Energies. The engineer Ricardo Pregitzer is a member of the Portuguese Engineering Council (Ordem dos Engenheiros).

José dos Santos Teixeira Batista was born in Bragança, Portugal, on August 1968. He graduated in Industrial Electronics and received the M.Sc degree from the University of Minho, in 1995 and 2003, respectively. Since 1997 he works in the Electrotechical Department of Polytechnic Institute Bragança. His main areas of interest are Power Quality and Data Acquisition.

João Luiz Afonso was born in Rio de Janeiro, Brazil, on May 1963. He graduated in Electrical Engineering and received the M.Sc degree from the Federal University of Rio de Janeiro, in 1986 and 1991, respectively. He received the Ph.D. degree in Industrial Electronics from University of Minho, Portugal, in 2000. From 1987 to 1992, he was a research engineer in CEPEL, Brazil. He joined the University of Minho in 1993, where he is an Assistant Professor in the Industrial Electronics Department. His main areas of interest are Active Power Filters, Power Quality and Renewable Energy. He is a member of the Portuguese Engineering Council (Ordem dos Engenheiros), and of the IEEE.