Power quality in a university campus: the user's perspective.

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Abstract. This paper presents preliminary results from a power quality audit conducted at a university's campus over last year. Voltage and current were measured at various academic buildings; it was found that the main problems for the equipment installed were voltage sags and surges. These phenomena are purely random in nature. The paper examines the causes and effects of power disturbances that affect computer or any other microprocessor based equipment and analyses the auto-protection capabilities of modern power supplies. The convenience of "enhanced power supply" or "low-cost customer-side" protection solutions is also discussed. Finally it is addressed the role of the Standards on the protection of electronic equipment and the implications for the final costumer.

Key words.

Power quality survey, commercial and residential installation, servicing sensitive electronic equipment.

1. Introduction.

With the generalized use of personal computers, microelectronic-based instrumentation and other susceptible devices, the subject of power quality and its relationship to vulnerability of equipment is becoming an increasing concern not only to the utility companies but, what is more, to the end-customer. Although it is common to consider utilities as the source of all power disturbance problems, they frequently argue that there are circumstances beyond their control. Things like lightning, large switching loads, non-lineal load stresses, inadequate or incorrect wiring and grounding or accidents involving electric lines. These can create problems to sensitive equipment if it is designed to operate within narrow voltage limits, or it does not have adequate ride-through capabilities to filter out fluctuations in the electrical supply [1].

The University of Córdoba (UCO) is a mid-sized university –the UCO has 21.000 students, more than 1.200 teaching faculty and 700 employees-, which offer humanities, legal and social sciences, earth sciences and science and technology. In particular the Rabanales Campus is devoted to food and agricultural sciences, science and technology. The majority of the University's scientific production is carried out on the campus, which is at the forefront of research in Andalusia and ranked among the top research institutions of Spain.

The Rabanales Campus is supplied through a 20kV feeder emanating from the near substation of "La Lancha". This feeder serve 17 academic buildings which includes the data centre, the departmental R&D laboratories, the veterinary hospital, the main library, the lecture hall building, the "Lucano" residence hall for students, the sports facilities and the train station. Each building has inside one 1000kVA delta-wye transformer which step-down the 20kV to 230/398V for the panel boards distributed through the building floors.

While the campus server room is properly served via an UPS, it has been necessary to recognise that the normal electrical conditions outside, in the rest of the campus, are subject to generalised power perturbations. This situation has been the cause of subtle problems such as computer lockups and electronics component wear. However, it also has caused more devastating damage as data loss, disk crashes and burnt electronics in almost all of the buildings.

The UCO maintenance department required the collaboration of the local utility Endesa-Sevillana, which monitored the service entrance of the campus, concluding that the problems found was not under his responsibility and that the electric service voltage variations were within the *EN-50160* standard limits. Thus, the UCO proposed to the authors the analysis of power disturbances of the Rabanales campus. Some of the mayor objectives of the power quality study were:

- Correlating the dates presented in the utility report.
- Identifying the power disturbances root causes.
- Characterizing the electromagnetic compatibility (EMC) level of equipments and installation.
- Developing guidelines that help faculty and personnel to understand the power quality concern.
- Providing recommendations for cost-effective solutions.

It is possible to say that solving power quality problems within commercial consumers premises is a rather complex task involving, generally speaking, the following steps:

- Power Quality monitoring in order to characterize the main involved disturbances as well as the actual immunity level of the installation,
- Analyzing the sensitive processes and identifying the critical parts,
- Choosing the adequate immunization techniques
- Costs estimation: balance between the costs caused by the disturbances and the investment and costs related to the immunization project
- Decision of implementing the solution

power anomalies that disrupted the equipment operation during a two-year time span. The Allen-Segall study concluded that 88.5% of AC power problems were transient related. Allen and Segall found that the most disruptive (49%) of power problems stemmed from oscillatory, decaying transients.
Today, most electronic equipment uses switch mode power supplies whose susceptibility to transients and common mode noise is far greater than traditional linear power supplies. Other studies [8] recorded nearly double the frequency of disturbances at Bell Telephone sites.

Power disturbance	Typical equipment problem	Typical cause of disturbance	Typical threshold level of disturbance	Typical duration of disturbance
Impulsive and oscillatory transient	Lock up Miscellaneous soft errors Hard disk crash Power supply failure Circuit board failure	Lightning, power network switching (large capacitors or inductors), SCR controlled loads, variable speed drives, photocopiers and operation of other load	0 to 4 p.u. rated RMS voltage	50 ns to 1 ms and oscillatory 0.3 ms to 5 µs
Voltage dip (sag)	Miscellaneous soft errors Reset-reboot	Power system fault, large load start-up, faulty circuit breakers and loose wiring	0.9 p.u. to 0.1 p.u. rated RMS voltage	Short duration: 0.5-30 cycles 30 cycles -3s 3s-1min. Long duration: >1min.
Voltage swell	Miscellaneous soft errors Power supply failure Circuit board failure	Power system fault and large load disconnect	1.1 to 1.8 p.u. rated RMS voltage	Short duration: 0.5-30 cycles 30 cycles -3s 3s-1min. Long duration: >1min.
Interruption	Hard disk crash Power supply failure	Power system faults, local circuit breaker trip, loose wiring and equipment failure	< 0.1 p.u. rated RMS voltage	Short duration: 0.5-3s 3s-1min. Long duration: >1min.

Table 1. Disturbances on computer-related equipment.

The paper is organised as follows. In section 2 we present the typical power disturbances that affect electronic equipments; section 3 is devoted to the methodological approach, discussion and analysis of preliminary results; in section 4 we describe the customer-side solutions proposed; and Section 5 is devoted to conclusions.

2. Power disturbances.

One of the initial obstacles facing anyone attempting to understand power quality is the different terminology employed by utility engineers and by manufactures and users of disturbance analysers. Although it is possible to follow proper definitions as they are commonly understood by these two groups [2], this paper uses the electromagnetic compatibility approach to describing power disturbances as classified in [3].
A computer or any other microprocessor-based equipment is said to be subject to the power disturbances summarized in table I [4], [5], [6].
George W Allen and Donald Segall conducted one of the most respected studies [7], and, although based in the USA in 1974, their report is still quoted today. They monitored AC power to IBM equipment at 200 locations in 25 cities across the USA, and recorded the various AC

The well-known ITIC (Information Technology Industry Council) curve [9], formerly named CBEMA (Computer Business Equipment Manufacturer's Association) curve, is generally used to evaluate operational voltage limits for electronic equipment power supplies. The curve establishes magnitude and duration limits within which input voltage variations do not affect the reliability of the electronic equipment. As can be seen, the steady-state tolerance envelop is in the range of ±10% from the nominal voltage. Within this range, the equipment will behave properly. For shorter time event the tolerance is expanded. For example, voltage sags down to 70% of nominal is permitted for up to 0.5 s, while on the opposite, voltage swells can be permitted rises of up to 120%. ITIC curve were specifically derived for use in the 60 Hz 120 V distribution voltage systems. The guideline expects the European user to exercise their own judicial decision when translating that curve on equipment operating under 50 Hz 240 V distribution voltage system [10].

3. Methodology and results.

In order to identify the most likely causes of problems detected, on-site inspections of equipment and installations were conducted over the first week of this study. The power site survey has followed well-known approaches [3], [11], [12]. Many power quality problems can be resolved with an appropriate compliment with the latest edition of the “Reglamento electrotécnico para baja tension” (REBT), the Spanish national electrical code. In addition, in the power site visit, we followed the guidelines proposed in [2], [4], [13]. This process included:

- A walk-down of the facility’s electrical system to inspect the condition of equipment and becoming familiar with the electrical system.
- Interviewing facility electrical personnel and end-users on failure of equipment.
- Identifying and collecting the electronic equipment that is most sensitive to power disturbances.
- Requesting and reviewing equipment literature and electromagnetic compatibility characteristics.

Even though the installation is not really new, a detailed on-line diagram of the electrical system was not available. Thus, a complete schematic of the system was developed. In each building the air conditioning system and the elevator are powered via separate branch circuit while in each floor, sub-panel serves both the fluorescent lights and the electronic equipments separately. These power circuits are likely to contain over 75 PCs and terminals, several printers, copiers, facsimile machines, but in addition, chromatographer, spectrometers, ultra violet spectrophotometers and numerous microprocessor-based control and instrumentation devices.

The monitoring device selected was a portable, stand-alone, three-phase power quality analyser [14]. Some of the key monitor requirements were: ability to transfer the surveyed data to in-house computer program, appropriate numerical storage and inexpensive and easy to use. Once the sites were selected, the monitor was connected to the low voltage building entrance and to the different floor subpanel circuits.

The types of disturbances and threshold levels used in the power quality survey study are listed in table II. Voltage and current values as well as power were logged on the more problematic buildings for periods of one day, one week and one month.

Disturbance type	Threshold setting
Sag (Dip)	< 10% 230 volts rms
Swell	> 6% 230 volts rms
Interruption	0 volts rms

Table II. Power line monitoring thresholds.

For a typical building entrance, and after a 13 days period measurement, it was evident that the voltage harmonics level was relatively high. The campus starts activity at 7.00, this is characterised by the rise in the harmonic level at about this time. As expected the dominant harmonic is the fifth harmonic, this follows the typical daily load pattern. It has its maximum of 5.45%, at about 16.16 (THD= 2.41%), this is measured the Friday. However, the 6% compatibility limit for that harmonic order established in *EN-50160* standard was not violated. For this period, the 7^{th} harmonic maximum is 0.91. The most likely cause for the level of the 5^{th} harmonic would be the electronic equipment power supplies. The general rule is that work activity provides, roughly, the largest pollution levels at mid afternoon while during the morning harmonic pollution is lower; since measurement shown were performed in summer, this is likely to be addressed to the incidence of air conditioner actuation between 12 p.m and 19 p.m. and the lack of lighting loads in the morning.

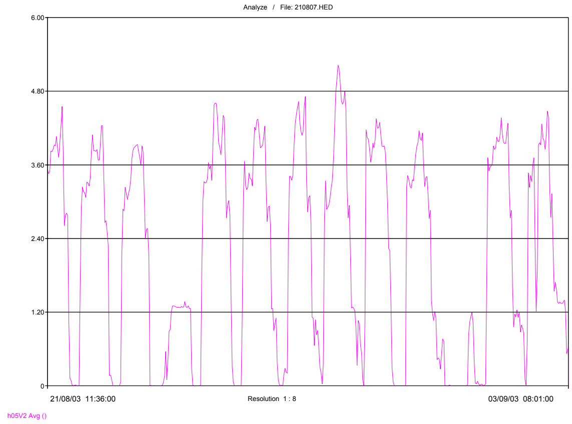

Figure 1. Voltage 5^{th} harmonic week pattern at LV typical building entrance.

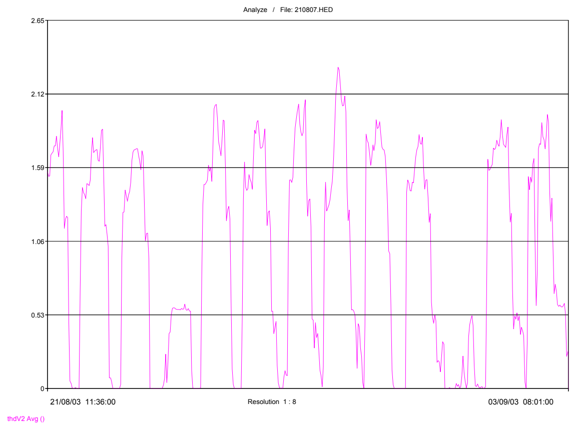

Figure 2. Voltage THD week pattern at LV typical building entrance.

In figures 3 and 4 is shown the current 3^{rd} , 5^{th} and 7^{th} harmonic levels and the current THD. These harmonic levels are under the UNE-EN-21000-3-4 standard limits, but the THD maximum is 27.54, which violates the 20% established limit for the entire installation.

Figure 3. Current 3^{rd} , 5^{th} and 7^{th} harmonics at LV typical building entrance.

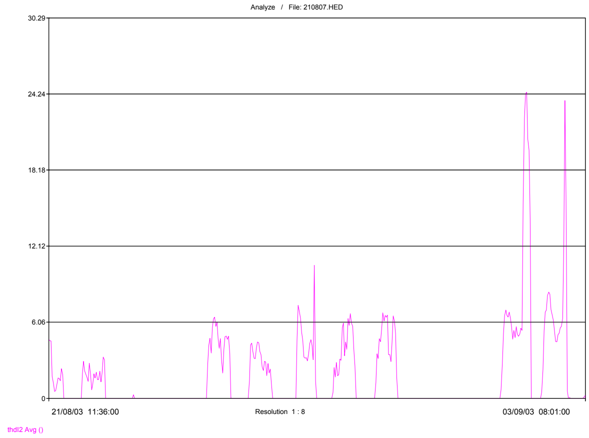

Figure 4. Current THD at LV typical building entrance.

However, a harmonic source can be traced from multiple measurements in the system. The closer one gets to the source, the higher the current distortion level will be. For example, the highest degree of current distortion has been found in the organic-chemical laboratory. There has been continuous disconnection of the Residual current circuit breakers (RCCB) caused by the impact of spectrometers and chromatographers current, which can be seen on figure below.

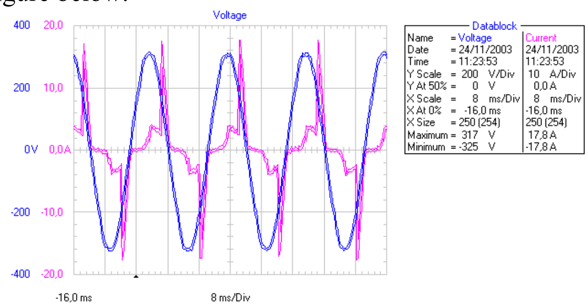

Figure 5. Voltage and Current of operating spectrometer.

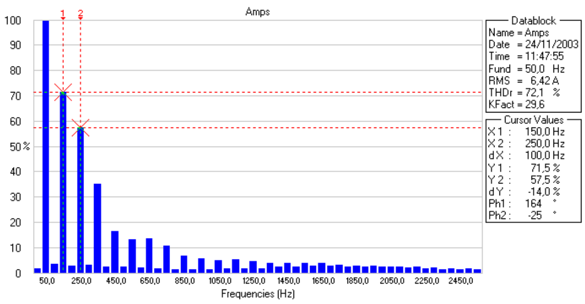

Figure 6. Current harmonics of operating spectrometer.

The current THD maximum for the complete laboratory is 58.98. Meanwhile, the maximum value for the neutral current is 83.51. The phase current 3rd, 5th and 7th harmonic levels have maximum of 20%, 11% and 5% respectively. The neutral current 3rd, 5th, 7th and 9th harmonic levels have maximum of 35%, 30%, 12% and 23% respectively. Figure 7 shows the typical neutral current daily pattern of the laboratory.

Figure 7. Neutral current.

In figure 9 a sample of site's rms voltage level as the function of the time of day is presented for the same 13 days period. Figure 8 indicates that, for all de buildings, disturbances fall within the voltage tolerance envelope of the ITIC curve. Thus, voltages were stable, with a daily fluctuation, and occasionally minor sag and swells, but in most of the cases outside of equipment requirements [15].

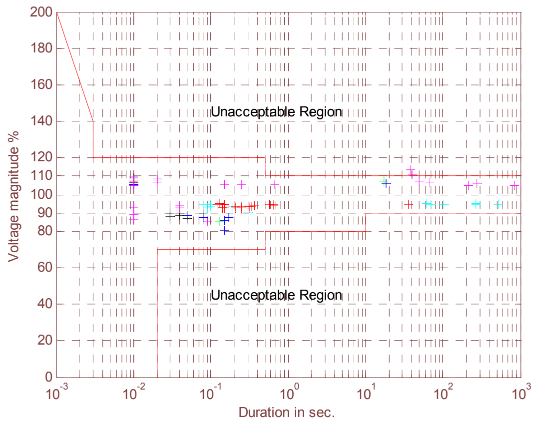

Figure 8. Anomalies detected at LV buildings entrance over the web on ITIC curve.

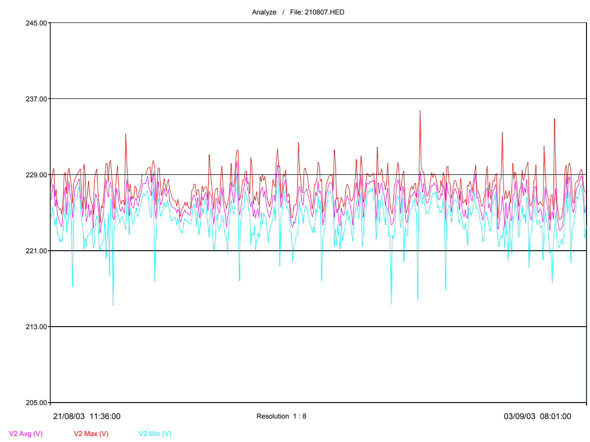

Figure 9. RMS voltage log graph at LV typical building entrance over the week.

Although no voltage outages were recorded, such findings over a relatively short power audit are not conclusive indications of long-term facility or utility continuity of service.

During the monitoring time, and after some recent power disturbance, computer power supplies were damaged (most likely due to transients as shown in figure below) and had to be replaced. Unfortunately our power quality analyser software is not able to identity, classify, or highlight these events. For this purpose we used of a low cost Fluke 43B analyser. Identification of transients involves the manually reviewing all event data and visually scanning all waveforms.

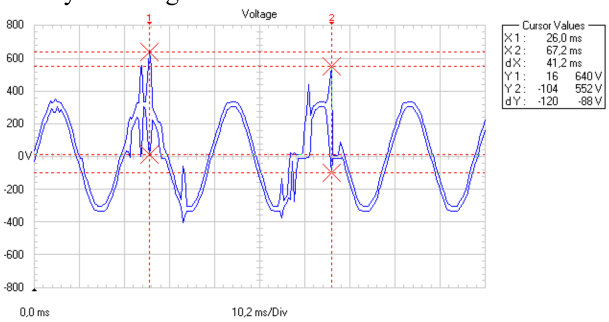

Figure 10. Individual LV transient detected at equipment power supply.

4. Customer-side solutions.

Table III provides an example of cost for some general mitigating technologies used for consumer equipment protection [16] [17] [18].

Mitigating equipment	Typical cost (€)	Operating and maintenance costs (% of initial costs per year)
Transient suppressor	15 ~ 100	5
UPS	500/kVA ~1000/kVA	25
Shielded isolation transformer	20/kVA ~60/kVA	15
Line conditioner	≤ 300/kVA	10
Standby UPS	100/kVA ~1000/kVA	25

Table III. Comparative cost of mitigating equipment.

Voltage sags at the terminals of sensitive equipment are often due to faults occurring at a much higher voltage level. Even though the load current is small compared to the fault current, the changes in load current during and after the fault still strongly influence the voltage at the equipment terminals. It has been discovered that the 85% of computer malfunctions attributed to poor Power Quality are caused by voltage sag or interruptions of under one second duration [1]. Typical ride-through capability of power supplies rage from 10 to 30 ms. This time is really too short to be of much help, if switching power supply where modified to one second of ride-through capability, the over kill installation of UPS's can be substituted by a lower-cost power conditioning system [2].

Computer manufacturers and their local distributors do no appear to have suitable power quality information readily available. Any information that can be obtained is limited and seems to require a lot of effort to obtain [19]

As a consequence, the almost only source of information is the power supply specification sheets. For example, in high-end power supplies from the vendors that INTEL recommends for his microprocessor system [20], the parameters of interest found on its specification sheets can be listed as shown in the following table 4. These power supplies are designed to provide protection from higher-than-normal voltages and currents, and provide a limited amount of power-line noise filtering or power factor correction PFC capability.

Parameter	Recommended value
Input Range (or operating range).	90 ~ 264 VAC.
Frequency	47 ~ 63 Hz.
Output over-voltage protection	+12±5%VDC. +5±5%VDC. +3.3±5%VDC. -12±10%VDC. -5±5%VDC.
Output over current protection	240VA
Hold-up time (or ride-through capability)	15 ~ 30 ms.
Mean time between failures (MTBF)	~ 100,000 h.

Table IV. Main power protection parameter of computer power supply.

Most of the inexpensive aftermarket power supplies do not have this sort of protection; concretely, in this study all the computer power supplies damaged belongs to inexpensive clone systems.

In these cases the first recommendation was to replace the damaged power supply by one recommended by INTEL. For these low-cost equipments, in addition, the second recommendation was to install individual TVSS devices. This is a cost-effective protection for most of the power problems generated within the building electrical distribution system. It is necessary to protect copiers, printers, and fax machines too.

On the other side, the recommendation for high-cost electronic equipment as spectrometers or chromatographers was to install commercial UPS's.

These above recommendations can be complemented with well-known ITE installation general guidelines [21] [22].

5. Conclusion

Solving power quality problems within commercial or residential consumers' premises is a rather complex task. The massive penetration of electronically controlled devices and equipment in low voltage distribution networks (the "digital society") could be responsible for the worsening of power quality problems.

It have been seen [13] that the level of immunity for some power quality phenomena would be insufficient to adequately protect terminating equipment from the disturbances defined in EN 50160. The 95% per week basis for assessing most parameters means that actual power quality could result in considerable disruption in equipment performance and yet meet EN 50160.

The power supply is a component many users ignore when acquiring for an microprocessor-based system, and it is therefore one that some system vendors might choose to skimp on. After all, a dealer is far more likely to be able to increase the price of a computer by spending money on additional memory or a larger hard drive than by installing a better power supply.

Thus, universities and other larger consumers, purchasing large numbers of computers and related electronic equipments, should always specify the withstand characteristics of the equipments being purchased.

Finally, for the authors, the European increasing trends in the consumption of power disturbance mitigation equipment reflects the growing consumer implication in this issue, which must be encouraged with the education through the distribution of guidelines and related information. Before considering any further levels of power protection, consumers should know that the power supply in his system could already afford him a substantial amount of protection. What is more, consumer must have a basic knowledge about the power-protection devices available and under what circumstances he should use them.

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