Power Quality As An Opportunity To Implement The Productivity And To Reduce The Costs

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***Abstract* - The article describes the hardware and software of the instrument placed in some European countries able to collect Power Quality (PQ) data. These instruments are provided by one of the bigger UPS farmer in the world. The collected data have been analyzed by Roma Tre University that has elaborated some statistical evaluation of the European PQ. Some economical evaluation on the industrial productivity, connected with the lack of PQ, are also presented. It is also shown a possible creation, in the future, of new corporations able to face PQ problems with the aim to provide new kind of service for those customers particularly sensible to PQ.**

***Index Terms* – Power Quality, Clarke's transformation, Production, Save Costs.**

I. INTRODUCTION

Power quality is the branch of the science that study all the variations that can appear on ideal current and voltage waveform in a generic electric power network[1].

Because the constant grow up of electric and electronic equipments connected to the electrical network the links between their reliability and the lack of electrical energy quality have became an important topic not only in a restricted technical and scientific circle but also in field only apparently far as the economic and the legislative ones[2].

So the variations by the ideal waveform have been defined by thirteen normed parameters provided by the International Electrotechnical Commission (IEC) [3] that are the results of the scientific studies around the description and characterisation of the physical phenomena and sources of power quality problems, around the impact on the equipments and on the power system, around the mathematical description of the phenomena using indices or statistical analysis to provide a quantitative assessment of its significance, around the measurements techniques and guidelines, around emission limits for different types and classes of equipment, around immunity or tolerance level of different types of equipment, around testing methods and procedures for compliance with the limits and mitigation guidelines[4].

The variations can cause a lots of problems to the reliability of the power system sometime extremely expensive for the production[5].

This article will be focused on the reflections that a better power quality can help to improve the national productivity and to reduce the effective costs of the electrical power system.

For this purpose, the paper will show an overview of some power quality data obtained using integrated instruments placed in all over the Europe and active for quite a few years. It will be also presented some statistical evaluations to derive some important convictions about the power quality situation. In paragraph II will be presented the instrumentation used both the hardware and the software. Paragraph III will show the data analysis.

Moreover, following the liberalization of energy market, it will be explored the possibility to define new relationships between service companies spatially closed that need to satisfy some strictly needs in terms of power quality. This approach avoids expensive

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duplication of specific system to warranty these limits and creates an energy spin-off also for companies which activities are far from production and selling of energy. Paragraph IV will show the costs of lacking of power quality and it will be analyzed a specific case in which will be suggest a possible way to better manage some buildings with the idea to reduce the costs, and, at the end, in paragraph V, it will be drawn the conclusions of our discussion.

II. THE MEASUREMENT SYSTEM

A. Hardware

The hardware of the instrumentation is based on a Texas Instrument's DSP, with a program at its inside for the evaluation of the acquired samples. The DSP is connected through an A/D converter to an electronic analogical interface that directly picks up the signal on the net. The analog interface is a tri-channels, one for phase, hybrid system realized by an amplifier and a voltage divider. It compresses the signal up to 0.02 with a dynamic of ± 10 V and has an accuracy of 2‰. The signal so reduced is sent to the A/D converter that has a resolution of 12 bits and frequency sampling of 6 kHz. The block scheme of the hardware, reported in Fig. 1, shows the connection between the logic section and the power section of the UPS. About the last one, it is possible to say that the UPS inverter continuously supplies the critical AC load. The rectifier derives power from the commercial AC source and converts it into DC power for the inverter and the battery charger. The battery charger keeps the battery in a fully charged and optimum operational condition. The inverter converts the DC power into clean and regulated AC power which is supplied to the critical load (conditioned line).

The static switch monitors and ensures the inverter to track the bypass supply frequency. This ensures that any automatic transfer to the bypass supply (due to an overload etc.) to be frequency synchronised and does not cause any interruptions to the critical load. In the event of an inverter overload, manual stop or failure, the static switch will automatically transfer the critical load to the bypass line without interruption.

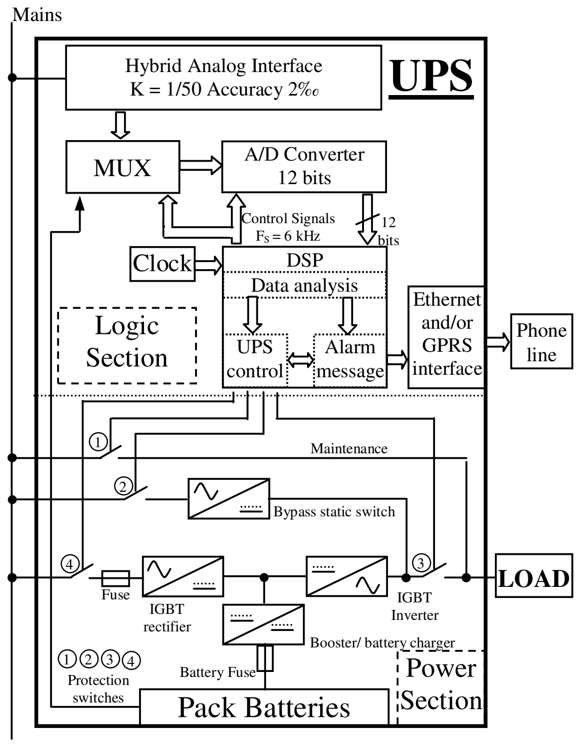

Fig. 1. Block Scheme of IGBT UPS.

Upon failure or reduction of the commercial AC source the inverter will supply the critical load, drawing power from the associated battery through the battery Booster. There will be no interruption to the critical load upon failure, reduction or restoration of the commercial AC source. While the UPS is powered by the batteries, indications will be provided of actual autonomy time remaining as well the duration of the mains failure. Upon restoration of the commercial AC source, even where batteries were completely discharged, the rectifier will restart automatically (walk in) and gradually take over both the inverter and battery charger. This function will be fully automatic and will cause no interruption to the critical load.

The sampling is managed by the DSP internal clock placed on board that assures an accuracy of one part in 10^{-6}.

The UPS assures a functioning in case of a black out up to some hours.

The instrument has an Ethernet interface to transmit data to a central server that receives the data from all probes and organizes them in such a way to have constantly the idea of how the power quality parameters on the electric network are evolving during the day. The card acquires samples with a time resolution of 1 second and stores them in a buffer on which the algorithm, permitting to evaluate the signal, acts.

B. *Software*

The algorithm is based on Clarke's transformation that allows the conversion of a balanced three-phases quantities into a balanced two-phase quadrature quantities so to realize a vectorial transformation of the picked up phases[6,7,8]. The vector control theory consists in an algebraic transformation of three phase voltage systems from the a-b-c co-ordinates to the α-β-0. In the new coordinates the voltage system is divided into three components: positive, negative and zero sequence, but if the three-phase voltages are balanced in a four-wire system, no zero sequence voltage is present so the 0 component can be eliminated. Considering a generic tri-phase coordinate system in which every axis is 2π/3 with each others, we call this coordinate system as X_{abc}. We also consider a bi-phase orthogonal system $X_{\alpha\beta}$ and we suppose that the a axis of the X_{abc} system is coincident with the α axis of the $X_{\alpha\beta}$.

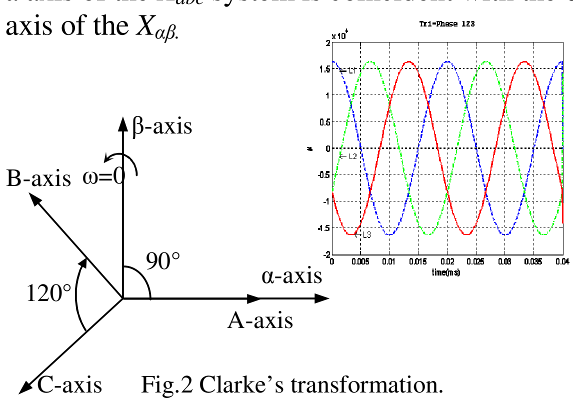

Fig.2 Clarke's transformation.

The vector coordinates of the Fig. 4 that are represented in the X_{abc} coordinate system can be easily converted in the $X_{\alpha\beta}$ coordinate system with the following matrix transformation:

$$\left[X_{\alpha\beta 0}\right] = T_{\alpha\beta 0} \cdot \left[X_{abc}\right] \qquad (1)$$

where $T_{\alpha\beta 0}$ is the transformation matrix:

$$T_{\alpha\beta 0} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \qquad (2)$$

This transformation allows complex three-phase systems to be split into three decoupled systems and results in big advantages for designing closed loop control. This approach ensures the perfect sharing of the load between the UPS in parallel system, ensures the inverter phase lock with the reserve supply line also in presence of distorted mains, allows the implementation of sophisticated tools optimizing performances that are not subjected to changes in time and not depending on external conditions, remain perfectly stable in time.

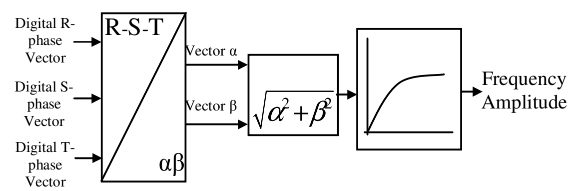

Fig. 3. Block Scheme of the Program.

Fig. 3 shows how the program acts on the signal: after the digitalization of the tri-phase signals, the Clarke's transformation is applied on the correspondent vectors; a module operator is applied on the consequent bi-phase quadrature system; finally a pass-bass filter deletes some possible spurious high-frequency components.

The program is able to monitor the actual frequency and amplitude of the mains and to determine the following electrical energy normed parameters, measured respecting the IEC 61000-4-30[9]:

1. Magnitude of the supply voltage;
2. Supply voltage variations;
3. Rapid voltage changes;
4. Supply voltage dips;
5. Short interruptions of the supply voltage;
6. Long interruptions of the supply voltage;

7. Temporary power frequency overvoltages between live conductors and earth;
8. Transient overvoltages between live conductors and earth;
9. Supply voltage unbalance.

When one of these parameters overcomes the norm limits the program is able to evaluate if opening or closing the protection switches to preserve the load by overvoltages or to avoid the effects of black out disconnecting it from the mains and feeding it with the pack batteries.

Our goal is the possibility to send, in real time, an alarm message directly to a control centre placed in Bologna, Italy, where the servers constantly store all the events happened and signaled by the UPSs coming from all over the world (in Europe there are more than 5,000 UPSs connected to the remote system)[6,7]. In this way, the history of the quality parameters analyzed by each UPS is completely traced during the lifetime of the UPS.

III. DATA ANALISYS

During past years, the servers have memorized all anomalous parameters monitored by UPSs placed in Europe and now it has a complete database of these parameters.

Next table summarizes an example of report for Mains Failure happened in Europe territory in a period included between the 1997 and 2009 even if the comparable data are available only from 2005 up to 2008.

TABLE I

NUMBER OF MAINS FAILURE RELEAVED BY UPSs PLACED IN EUROPE IN A PERIOD OF TWELVE YEARS

	Start Date	End date	UPS Number	Mains Failure Number
EUROPE	08/06/1997	30/06/2009	7,979	1,164,763

With reference to Fig. 4 that shows the number and the placement for each European country of the UPSs connected to the central control room, it has been possible to determine the normalized number of mains failures for four consecutive years (Fig.5). These have been obtained as the total number of seconds of

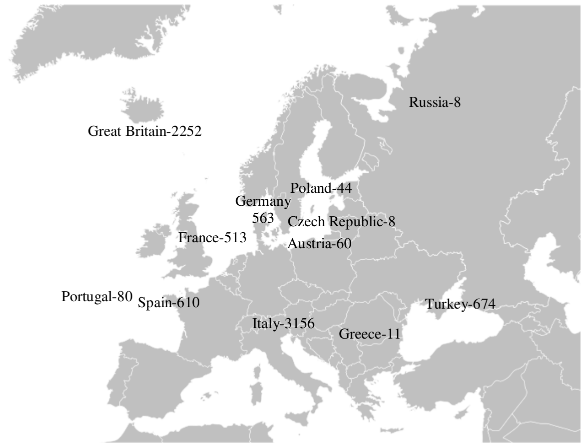

Fig. 4. Number of European UPSs divided for regions.

mains failures happened to every UPS of a particular European country divided for the total number of UPSs for that country.

Only nine countries than twelve studied have been considered in our analysis because for the others (Greece, Poland, Czech Republic) the restored data were not sufficiently complete.

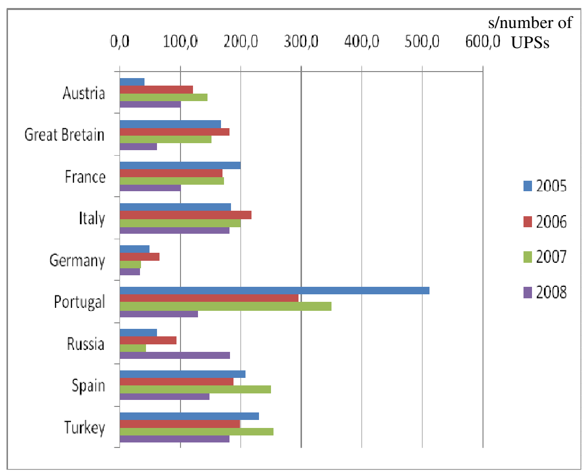

Fig. 5. Normalized number of seconds of mains failure for each European countries in four different years.

It is possible to do some considerations:

1) the worst quality is easily identifiable in Portugal and it is probably due to the orography of the territory and the strong influence on climate of Atlantic Ocean;

2) the best situation is findable in Germany where the average of the mains failures for UPS in the 2009 is about 33

minutes; this is due to the peculiarity of this country that has an high inhabitants density distributed on very rich industrial cities;

3) it is identifiable a trend that points out a light improvement of the number of mains failures during the past four years for each country; with reference to Russia we have to underline that the number of UPSs under control is too few to allow a correct statistic;

4) it is possible to group the countries in three categories definable on the base of the overall quality: the first is composed by two countries (Austria, Germany, Russia) with a low average of the mains failure, the second composed by five countries (Great Britain, France, Italy, Spain, Turkey) with a medium number of the mains failures, and, at the end, Portugal with a high overall time of mains failure even if the improvement trend is absolutely the best.

The next graph shows the worst cases of mains failures for each country. As it is possible to see, in eight countries, in at least one year between of the four examined, there is a case that reaches a mains failures with a length of time equal to one day. This is independent by the country and is extremely indicative of the electrical energy restore intervention time by the electrical operators. Obviously these are rare cases which the difficulty to reach the place where UPS is placed is high or the case of black out is particularly difficult to solve.

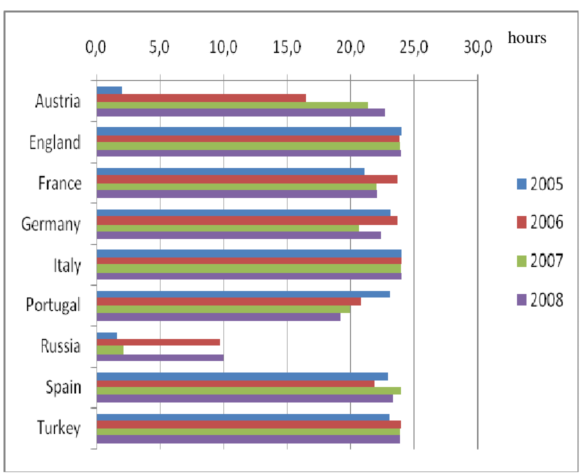

Fig. 6. Number of hours for worst cases of mains failure for each Italian region in three different years.

IV. COSTS

While the performance of the European electric utility industries is good, even this level of performance is not sufficient to protect customers with highly sensitive loads from economic losses. These customers must invest in on-site equipment to ensure higher levels of reliability and power quality than is delivered from the electric grid.

Industries and individual facilities vary widely in the costs imposed by power quality problems.

Measured in terms of costs per kVA per event, costs range 3÷8 € per kVA for the textile industry to 80÷120 € per kVA event for electronic industries. In TLC companies a possible downtime can cost, for a cellular communications facility, more than 40 k€ per hour; while, a brokerage house would experience several million in damages if it were shut down for an hour. These costs can include:

- Damaged plant equipment.
- Spoiled or off spec product.
- Extra maintenance costs.
- Cost for repair of failed components.
- Loss of revenue due to downtime that cannot be made up.
- Additional labour costs.

Those customers who cannot afford to be without power for more than a brief period usually have on-site standby generators that can pick up all or a part of their load. There are also customers for which any disruption at all, either in loss of power or variation of power quality, can lead to severe economic loss. These customers generally require uninterruptible power supply (UPS) systems along with associated power control and conditioning equipment to correct surges, sags, harmonics, and noise.

Considering a sample of companies in Europe (two millions) have been evaluated the economic costs of power outages and power quality disturbances. The results of this analysis are shown in Table 2. The estimated cost of outages for the three sectors is 44 G€

per year. An additional 5.9 G€ in costs result from power quality disturbances other than outages. The cost for all industry is estimated at 120 to 190 G€ per year.

TABLE II

ESTIMATED TOTAL EUROPE COSTS OF POWER QUALITY DISTURBANCES PER YEAR

	Outage Costs G€	Power Quality Costs G€
Digital Economy	15	1
Continous-Process Manufacturing	5	2
Fabrication and Essential Service	24	2.9
Total PQ Sensitive Sectors	44	5.9
Estimate of All Business Sectors	**120÷190**	

V. IMPROVEMENTS

The presented costs are relative to lacking of PQ, for reducing it, it is possible to employ many techniques based on "expensive" apparatus, in particular if the power plant needs of energy storage[5,10].

Considering the wide diffusion of loads that needs of high quality electrical energy, it is spreader and spreader the distributed generation that warranties the quality. This obliges many customers to buy this type of apparatuses and plants and have to engage qualified personnel able to manage these devices and plants increasing the global costs.

Considering that these particular loads are concentrated almost always placed in industrial or urban areas, wanting optimize the costs, it is imaginable that in the next future can born specialized companies to provide these kind of services. These companies would have the ability to contemporaneously supply and manage more users placed in the same area allowing them to optimize the costs splitting them on more users.

These plants could be powered both by public mains and by alternative local power generator so helping to improve the national energetic balance.

Since few years, some telecommunication companies, as the Australian TLC one, made the spin off of their supply activities, implementing this idea.

V. CONCLUSIONS

The article, after a brief description of the instrumentation used, report a synthesis of Power Quality data collected by UPSs placed in a large number of European countries. The results point out that although the quality is acceptable for the most of customers, it becomes unacceptable for high sensitive loads, and, anyway, the costs joined to outages can be extremely heavy for some kind of business.

Studying the database all the European countries analyzed have an energy quality very similar presenting all the same problems that involve the final customers.

To face these kind of problems it is imaginable to create new specialized companies able to supply and manage more companies located in the same area. This approach allows to increase the efficiency and reduce the global costs sustained by the companies.

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VI. BIOGRAPHIES

Maurizio Caciotta: was born in 1945. He received the Phisic degree from "La Sapienza" University of Rome in 1970. Actually, he is full professor at "Rome Tre" University of Rome in the field of electric end electronic measurements. His activities are principally in the field of Power Quality, Perceived Power Quality, Signal Analysis and Recovery Historical and Cultural Goods.

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Maurizio Grossoni was born and raised in Rome where he graduated in electrotechnical engineering at "La Sapienza" University in 1973. Later on, he got a master's degree in telecommunication sciences from the Polytechnic Institute of Turin (1975). After a stint with the engineering industry and a short teaching experience with "La Sapienza" University, he joined Telecom Italia (formerly SIP SpA) where he held several key jobs in the carrier's power systems division before assuming full responsibility of the plants' engineering and development sector. He retired from Telecom Italia in 2005 but still maintains a consultancy agreement with his former employer and at the same time he is university teacher at Roma Tre University, member of CEI (the Italian Electrotechnical Institute) and member of TC-EE (Technical Committee Environmental Engineering) which is the technical body of ETSI. Maurizio Grossoni, has authored more than one hundred papers on basic and applied research about power plants, powering architectures, AC-DC systems, grounding and building and equipment cooling systems.

Fabio Leccese: was born in 1974. He received the Electronic Engineering degree from "Roma Tre" University of Rome in 2001, and the Ph.D. degree in Electronic Engineering in 2004. He is currently with the Department of Electronic, "Rome Tre" University of Rome as an assistant professor. He is mainly interested to the Power Quality, Perceived Power Quality and Signal Analysis.