Electrical Energy Measurements for Rome LV Customers by Distributed Web-Server Instruments

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***Abstract*-Power Quality (PQ) measurements for low voltage (LV) customers, domestic and business, have been carried out in order to detect the behaviour of the electric net over time and the quality of the electric energy being bought. In order to measure PQ parameters, we realized an instrument based on web server personal computers, which are common in office or in domestic environment. This allows us to conjugate the high PC calculus capability with the possibility to send data via internet to a central server; moreover, the use of the existing hardware infrastructure makes the instruments extremely cheap.**

I. INTRODUCTION

With the constant rise of raw materials' prices and the consequent increase of the power supply purchase costs, the necessity to evaluate the quality of this good is becoming more and more important[1,2,3]. In fact, the low prices of the power supply have, in the recent past, discouraged PQ analyses leaving them only to professionals and experts that normally work in the research environment. In the electrical market, only big companies have specialists, the energy managers, able to buy the energy needed for the proper functioning of business [4] with the idea to try to make the costs, related to consumptions, matched with the quality of the energy purchased. Anyway the absence of continuative measurements carried out on the electrical net makes impossible to evaluate the quality of electrical energy, forcing the companies to adopt alternative solutions to compensate the possible lack of quality. It is the case of big companies like Telecom Italia that, in order to assure the continuity of the service, adopts complex and redundant electric plants, but also of LV customers that, for example, use UPS connected to their PCs. This is reflected into additional costs which are almost exclusively covered by the customers[5].

LV customers are particularly affected by this problem: both because their little commercial dimensions lower their capability to bargain over the price of power supply and, above all because they cannot fully realize their needs and expectations towards this good. This incapacity is strictly due to the "lack of knowledge" of the electrical energy since we do not have biological sensors and so we have big difficulties to estimate it [6].

To compensate this situation the first thing to do is constantly measuring the electrical net evaluating the PQ parameters. Currently this is difficult to obtain because of the high costs of high accuracy PQ analyzers [7].

In this article we propose the results of a first measurements campaign in the Rome area realized by means of instruments distributed over the territory, inserted in LV plant, with the aim to analyze the PQ parameters of power supply for LV customers. After a discussion regarding the design choices for the instrument, we will show the first monitoring results.

II. THE LOCAL INSTRUMENT

The instruments are conceived to be cheap with the idea to be easily placed in the final customers' site in order to realize a net more and more widespread. The peculiarity of this instrument is the exploitation of an already existent web architecture for other aims. In fact, inside offices, shops or houses, LV customers do own servers, which are always active and constantly connected to the internet. We thought of using the high calculus capability of these PCs, often not adequately exploited, to locally elaborate the electrical energy samples coming from an analogical interface connected to the PC audio card that acts as an A/D card. After the data acquisition and elaboration, the results are sent to a central server placed at the University of Roma Tre. Using existing PCs, it is obvious that the costs are reduced, as compared to the analogical interface and to the set up procedure.

Currently, the local instrument is composed of three principal parts:

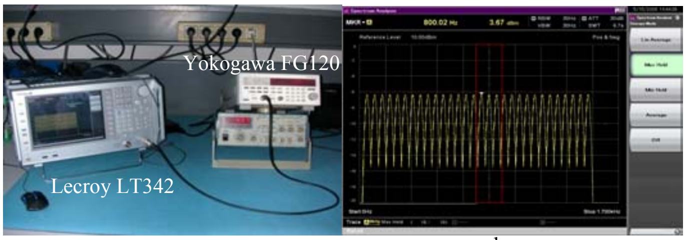
- a PC, which the customers already own and often used for other aims; for example as web server or net data storage system, always switched on and always connected to the internet with an ADSL line;
- an analogical interface with sensors for current e and voltage connected to the stereo "line in" of the PC audio card;
- the software capable of analyzing PQ parameters.

A. The PC and the Audio Card Calibration

It is not important the model of the PC, the only significant element is that it must have an audio card. Therefore, it is necessary, to characterize some important parameters as R_{in} and the maximum input voltage and calibrate it, to verify its transfer function and, in case it is necessary, equalize it by software.

A preventive calibration of the instrumentation, necessary to characterize the audio card, it is also necessary. We used a Yokogawa FG120[8] function generator calibrated, both in amplitude and in frequency, in a specialized Anritsu laboratory certified by the Italian Calibration System. For the first we connected the function generator to a digital multimeter Fluke 8840A[9] with true RMS option and to a Lecroy Waverunner LT342[10] oscilloscope to verify if the Yokogawa fixed V_{PP} sinusoidal waves output would be constant in the time. By this test we verified that the function generator gives voltage linear values. For the frequency calibration we used an Anritsu MS2691A[11] spectrum analyzer. Thanks the “flatness function”, it is possible to record and to show a frequency array spaced of 50 Hz starting from 50 Hz up to 1500 Hz and pre fixed on the function generator.

Figures 1a and 1b show the calibration bench and the linear response of the Yokogawa on the oscilloscope monitor.



a b

Figure 1. Calibration instrumentations bench (a) and the response of the Yokogawa FG120 function generator (b).

The function generator low secondary harmonics emissions are reported in table 1 for a fundamental of 50 Hz:

TABLE I

SECONDARY HARMONICS EMISSION FOR YOKOGAWA FG120

Frequency	50 Hz fundamental	100 Hz	500 Hz	1 kHz	1.5 kHz
Amplitude	0 dB reference amplitude	-73 dB	-80 dB	-82 dB	-85 dB

After the function generator calibration we determined the audio card characteristics that are summarized in table 2 for the first PC.

TABLE II

AUDIO CARD CHARACTERISTICS

No distortion input dynamic	Nominal input voltage	Input Resistance	Low cut off frequency	Crosstalk
$V_{max} = 2.8\ V_{PP}$ [@ 1 kHz]	$V_n = 2\ V_{PP}$	$R_{in} = 10\ k\Omega$	17 Hz	none

The first step has been to determine the input impedance of the line-in building a measurement circuit by the following electric scheme (Fig. 2).

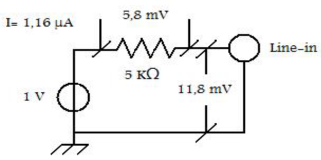


Figure 2. Measurement circuit to determine the audio card input impedance.

Applying a voltage reference of 1 V coming from the function generator and using a measurement resistance of 5 kΩ (±0.1%), we measured a voltage of 5.80 mV on the digital multimeter. Using this it is possible to determine the current that flows on the resistor equal to 1.16 mA and so the R_{in} equal to: R_{in} = 11.8 mV/1.16 μA = 10.17 kW.

The procedure has been executed for both channels leaving without load the channel not analyzed.

After that, to determine possible crosstalk phenomena between the two input channels, we used a 1 kΩ resistor on the channel previously left idle, observing if on the other channel was induced interference. Repeated this procedure for both channels we analyzed the data by an FFT don’t checking interference.

Then we verified the input stage dynamic characterizing the maximum input voltage to avoid saturation phenomena. We fixed the Yokogawa sinusoidal output voltage to a frequency of 1 kHz and a incremental amplitude started from 0.2 V_{PP} up to the saturation limit characterized at 2.8 V_{PP}. After this limit the card saturates and distortion phenomena start to appear.

Another test allows us to determine the audio card low cut off frequency: fixing the Yokogawa output voltage to a value of 2 V_{PP} we varied the frequency decreasing it starting from a value of 1024 Hz up to 2 Hz. Fig. 3 shows that the low cut off frequency is equal to 17 Hz (-3 dB) while to 50 Hz we have -1 dB. Fig. 3 shows the audio card low frequency response.

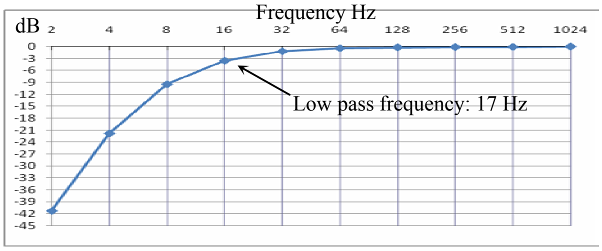


Figure 3. Audio card frequency characteristic.

The latter test allows verifying the real sampling frequency used by the audio card (nominally 8 ksamples/s). We used the Yokogawa FG120 function generator to record in one second a sinusoidal signal of 50 Hz, counting how many samples were contained in ten periods. This procedure permits to determine the exact sampling time to be correctly taken in account in DFT.

B. The Analog Interface

We used, as voltage sensor, a transformer LEM LV 25-P[12] while, as current sensor, a current transformer LA 55-P[13] both suited for electronic measurements of DC and AC voltages.

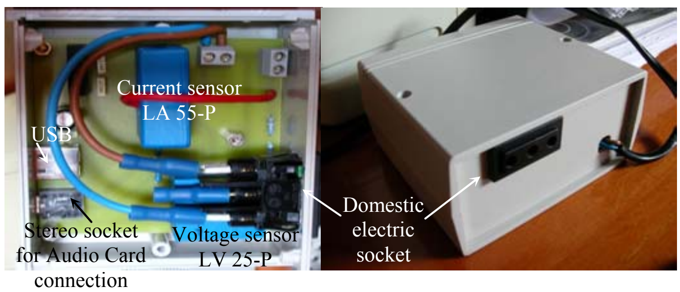


Figure 4. Analogical interface circuit.

The first shows a bandwidth of 0 ÷ 40 kHz while the second 0 ÷ 200 kHz. They are active sensors and need a supply of ± 5

V, carried out by a DC/DC integrated converter fed through the USB port of the PC. Every sensor is connected to a channel of the stereo socket of audio card by a stereo jack. In Fig. 4 is shown the analog interface inserted in a proper box.

C. The Software

Exploiting the Windows DLL[15], in particular the "winmm.dll", it is possible to manage the audio card to acquire data from the line-in. The software, developed in Visual Basic 6.0[16], allows us to choose the sampling frequency, to acquire data for a prefixed time window and to elaborate the data by a DFT algorithm. To not overload the server and so to better menage the acquisition with the server activities of the PCs, we decided to acquire 1 buffer every ten seconds. Each buffer is composed by 8,192 samples obtained at a sampled frequency of 8 kHz, frequency standard previewed by the acquire card, for a total acquisition time equal to 1.024 s. After the acquisition the software elaborates the data and the next acquisition starts for 10 s after the previous. With this temporization the principal activities of the server is not limited.

The software gives us the frequency of the fundamental and of the harmonics with a resolution of 0.1 Hz and with an accuracy, joined to the previous audio card sample rate calibration, equal to ±20 ppm. It gives the true RMS value of Voltage and Current with accuracies of ±0.2% and ±0.5% respectively joined with the multimeter used during the calibration. Moreover it gives the percentage of harmonics up to 24th respected the fundamental (THD) both for current and voltage, Apparent, Active, Reactive and Deforming Power.

If the software doesn't identify an exceeding of norm limits[14] for also only one of the analyzed parameters, the samples are immediately deleted and the software records the values of the parameters in a file with date and time.

Otherwise, if the norm limits are exceeded, the software saves also a second file with the series of the samples acquired. In this way, it is possible to verify the samples to establish what problem has been occurred during the acquisition.

During the program debugging, it has been useful to have a visualization section of the program to check the exactness of the data elaboration and to facilitate the visualization of the harmonics level. Fig. 5 shows the visualization section of the program. This section is deactivated in the normal acquisition process.

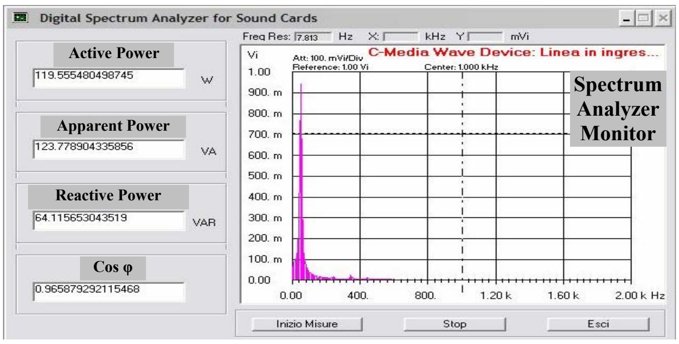


Figure 5. Graphic section of the software.

III. EARLY RESULTS

At the moment, two instruments are active, placed in two different parts of Roma: at Roma Tre University and in an house in Torvaianica in the south part of the city (respectively star and square on the map of Fig. 6) where the PCs are normally used also as server. In the first case the load is the PC itself, in the second case, the analogic interface is connected to a multiple socket connected to an A++ efficiency energy class refrigerant and an electric oven. There are no differences in the electrical energy supply, in fact both the buildings are simply connected to the main without specific dedicated lines. We acquired data for 10 days and the results of our analysis are following synthesized. In the first case the RMS average voltage is 217 V with a standard deviation of 1.095 V and it never exceed the limit. Being the PC a no linear load it hasn't significant to talk about power, instead it is very interesting to see the current input due to its PWM supplier. The next graph shows the voltage and current trend for this load and it has been almost always the same in these ten days.

Figure 6. Position of instruments in Rome territory.

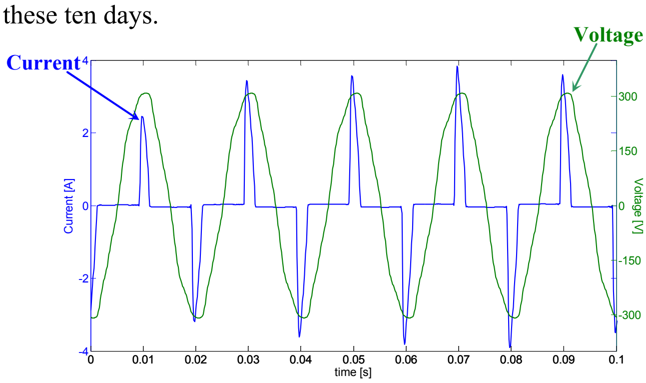


Figure 7. Voltage and Current trend for a PC load.

How it can be seen, the voltage waveform is not a perfect sine wave, but it is significantly distorted. This is clearly due to the kind of loads inside the University that are mainly no linear as computers and instrumentations.

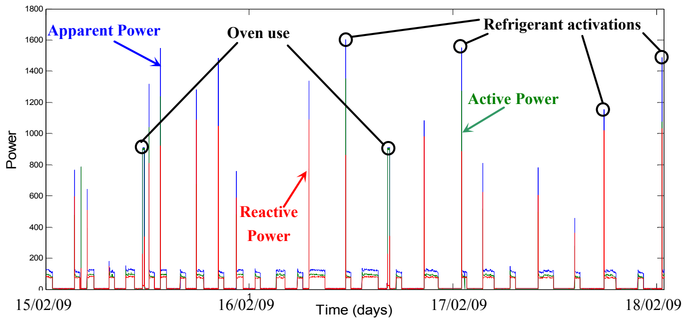


Figure 8. Active, Reactive and Apparent trend for three days (15-18/02/2009) of the second site.

For the second site the RMS average value is 238 V with a standard deviation of 2.2 V and it exceeds the limit of 2.2%. In this case the type of load makes extremely interesting the power analyses. Fig. 8 shows the Active, Reactive and Apparent Power of data acquired by the instrument during three normal working days (15-18/02/2009).

It is possible to know the asynchronous activations and the deactivations of the refrigerant and sometimes the activations and the deactivations of the oven. In case of activation of the only refrigerant the power factor has an average value of 0.78. At the start of the activation, the apparent power reaches a peak of 1.6 kVA. The contribution of the electric oven is almost exclusively active power with a value of about 800 W and, consequently, the power factor is practically equal to 1.

In both cases the frequency and the THD are below the norm limits.

Table 3 shows, respectively for the two sites, how many times, expresses in percentage respect the total number of acquisitions, the nth harmonic exceeds the norm's limit, the average value respect the fundamental and the correspondent standard deviation. As it is possible to see in the first case, the level of the second harmonic often exceeds the limit. In the second site, cause the high level of the fundamental, the harmonics exceeds the limits few times than the first site.

TABLE III
HARMONIC DISTORTION TREND FOR UNIVERSITY (A) AND TORVAIANICA (B) SITES

Harmonics Order	Out of Limits %		Average % compared the fundamental value		Standard Deviation (V)	
	(A)	(B)	(A)	(B)	(A)	(B)
2nd	12.288	0.992	1.358	0.6993	0.601	0.363
3rd	0.004	0	1.584	0.4595	0.258	0.243
4th	0.004	0.036	0.222	0.2903	0.136	0.158
5th	0	0	1.104	1.5573	0.239	0.392
6th	0.013	0.4755	0.134	0.1618	0.072	0.103
7th	0.004	0	1.309	0.3813	0.220	0.178
8th	0.004	0.0011	0.111	0.1176	0.060	0.078
9th	0.477	0	0.946	0.2388	0.191	0.111
10th	0.004	0	0.109	0.0990	0.055	0.061
11th	0	0	0.945	0.1366	0.191	0.073
12th	0.009	0	0.085	0.0856	0.042	0.0449
13th	0	0	0.795	0.1093	0.207	0.060
14th	0.004	0	0.065	0.0757	0.036	0.042
15th	0.319	0.0119	0.290	0.1611	0.095	0.088
16th	0.004	0	0.075	0.0668	0.040	0.039
17th	0.004	0	0.229	0.0926	0.085	0.050
18th	0.004	0	0.059	0.0572	0.028	0.03
19th	0	0	0.138	0.0712	0.060	0.039
20th	0.004	0	0.048	0.0499	0.025	0.030
21rt	0.004	0	0.539	0.0687	0.028	0.036
22nd	0.004	0	0.049	0.0444	0.032	0.030
23rd	0	0	0.049	0.0575	0.025	0.032
24th	0.004	0	0.046	0.0408	0.022	0.026

How it could be expected, due to the non linear loads present, the THD of the University site is higher than the second site. The 2nd harmonic overshoots more often than the others because the instrument site is close to a mechanic laboratory running an old 1,5 kVA power drill that uses a direct current brake for its AC motor. This brake uses a half-wave rectifier that produces this type of distortion.

IV. CONCLUSIONS

Both cause the increase of energy costs and a more high sensibility towards energy problems, mainly linked with the possible saving in case of anticipate breaking of electrical devices , the needs to control and verify the quality of electrical energy is more and more pressing.

In this article we presented a new instrument based on an analogical self made interface connected between the mono phase LV main and the PC audio card.

The instrument exploits the big calculus capacity of PC so allowing an easy elaboration of the samples and an easy memorization of the power quality normed parameters analyzed. Exploiting an elaborative structure already existent and bought for other applications, the instrument is extremely cheap and so buyable also by LV, domestic or business, customers. The low costs will make easy a rapid distribution on territory of these instruments particularly recommended for those little shops or offices that have a server PC continuously active but not fully used. The instrument calibration process has been also described.

Two instruments have been constructed and, at the moment, they constantly acquire information about the net.

The early results show that a non linear load placed near the first site produces an increase of the 2nd on the electrical LV net, whose effects should be better analyzed and understood, verifying them on all the other devices connected to the same net. Moreover the voltage amplitude and current behaviors over time justify our interests in a better knowledge of the electric net by means of continuous measurements with the aim to correlate possible electrical machine malfunctionings with disturbances coming from the electrical net.

The next steps will be an improvement of the software that has to include an automatic calibration section for the PC audio card to avoid a tiring calibration job, and to increase the acquisition points on territory to know as better as possible the PQ parameters trend.

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