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Highlighting the harmonic regime generated by electric locomotives equipped with DC motors

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Abstract. The paper presents the results of measurements made using the C.A. 8334 power quality analyzer on an electric locomotive equipped with DC motors. We carried out determinations of the current-voltage regime using a locomotive motor. The harmonic regime of the other motors being identical to the analysed one, we could easily deduce the effects caused by the entire locomotive. The data measured with the analyzer were firstly transferred into a computer system using the Qualistar software, followed by data processing in Excel, enabling therefore a graphical representation of the characteristic parameters of power quality. Based on the acquired data, we determined the power factor, as well as the active, reactive and apparent power.

The measurements revealed high values of the current harmonics, fact that required some measures to be taken for reducing the values of these harmonics. For this, we ran a simulation using the PSCAD/EMTDC software, by introducing LC filters in tune with the harmonic frequencies. The result was a significant reduction in the harmonic regime, either in the harmonics values or the power factor and reactive power.

1. Introduction

When referring to the electric power quality in a power system, we must always consider the need to supply the consumers with sinusoidal voltages whose values must fall within a well-defined range. The three-phase systems have been designed and built to operate in symmetric, balanced regimes. If one of the network or consumer elements is unbalanced, the regime becomes asymmetrical and the voltage and current systems lose their symmetry.

The most notable imbalances are cause by industrial consumers fed by high power, connected to the medium or high voltage electrical networks from which we can mention the transformation stations for the powering of electrical trains.

The number and the power of the nonlinear loads which from an electromagnetic point of view pollute the feeding electrical network grew and grow constantly. Their connection to the electrical network produces notable changes of the current, and keeping in mind the fact that their power in relation with the power of the feeding electrical network cannot be neglected, significant tension changes which deteriorates the quality of the electrical energy. Its quality depends both on the topology of the feeding network and on the quantity polluting harmonics inserted in the nonlinear loads network [1].

The sensitivity of customers to the quality of the received electrical energy varied for some categories of load. This is due to the impossibility of the loading to function correctly when fed with tensions which has variations that don't fit in the prescribed limits and the compensation measures against the abnormal function of the loadings will reflect in the costs [2].

To have a certainty in the correct functioning of the loadings from an electro energetic system there have been imposed specific norms for a series of measures that are operated in this system.

Framing the prescribed limits through rules or quality standards is not easy to realize in practical cases.

The established standards are generally different for various tension levels and most of the times, in practical work; some loadings need to produce by themselves the optimum powering tension.

This means resolving the problem of unwanted compensation for energy disturbances exterior to the charge, the result being to extend the life time of the charge [3].

The quality of electric energy can be determined with the help of qualitative indicators whose values are standardized both in our country and in Europe on all powering lines low, medium and high voltage.

Not obeying the rules or standards of some parameters inevitably leads to the dramatic decrease of the life time of the equipment or to an oversize of it to deal with the new functioning conditions [4].

2. Problem Formulation

The powering systems with electric energy in electric traction represent the vital part and their evolution allowed the evolution of technologies which are used in this domain. As presented in the previous paragraph, the types of powering systems are: in continuous current, in alternative single-phase current and three-phase alternative current [5].

The one-phase powering system with a tension of 25kV and a frequency of 50 Hz was imposed in the majority of the European states (Figure 1), through the facilities offered by the national networks and the reached travel speeds [1].

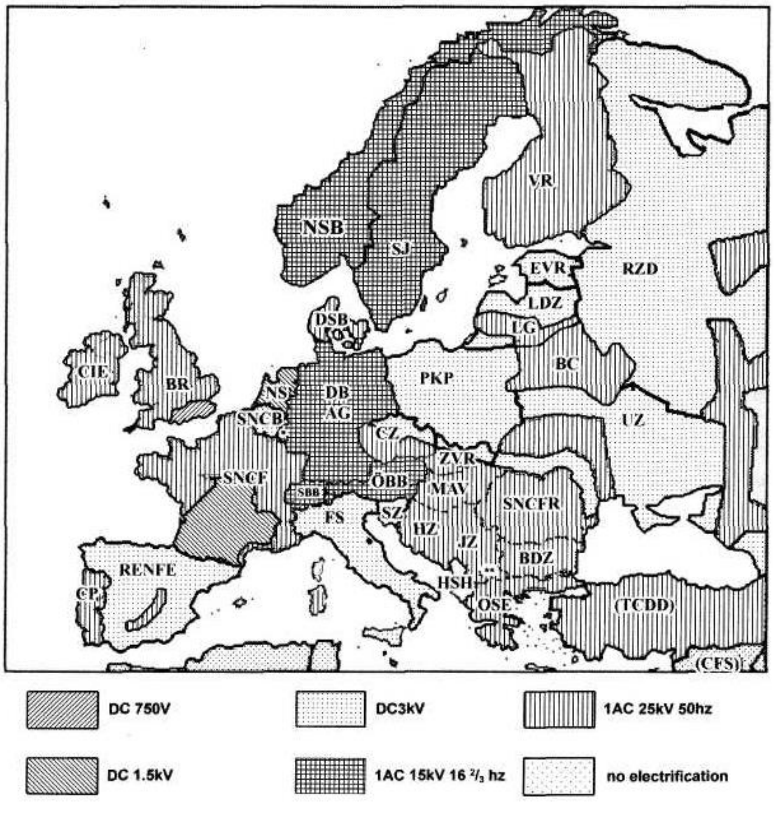


Figure 1. Powering systems with electric energy of the European railways [1]

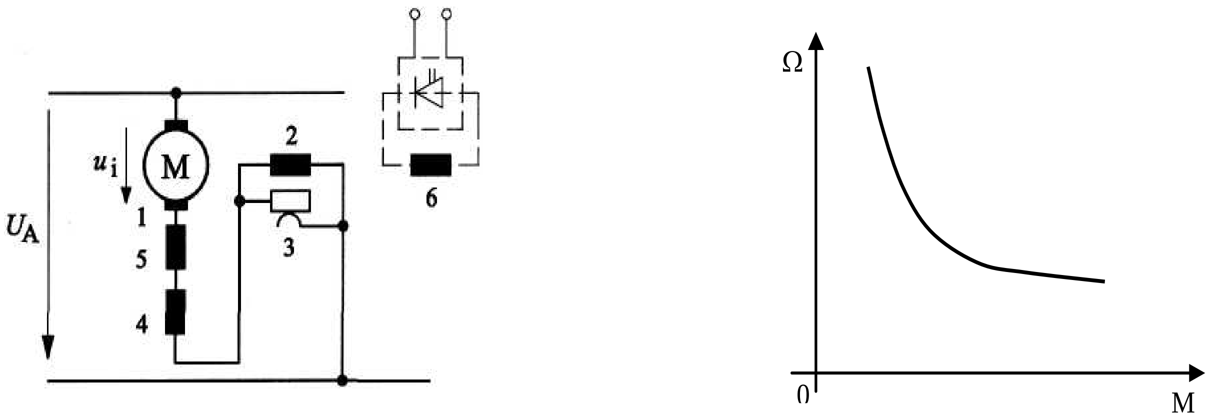
The electric railway traction has both advantages and disadvantages in comparison to the diesel-hydraulic or diesel-electrical traction [6]. On main transport ways one can find the next advantages:

- Low cost of energy
- Using hydroelectric and coal resources
- Ecologic functioning with reduced noise
- The possibility of regaining braking energy
- The presence of a generator is not required on the vehicle's engine, obtaining a double power for the same mass (7MW for 4 axis and m_E = 85t in comparison to 3,5MW and m_E = 130t).
- A speeding cruise of over 200km/h and a bigger trailed mass.
- Possibility of the electric traction engine to overload
- Maintenance costs are reduced
- Many functioning hours with easy maintenance
- It does not require preheating of engines
- The electric engine vehicles are cheaper that the diesel ones.

As a disadvantage one can mention the initial high price of the contact way construct and of the feeding substations.

The equivalent scheme of the traction engine (Figure 2) contains the field winding, switching and compensation in series with the main winding. The field activity can be obtained in the following ways:

- The classic cars are provided with the excitation winding connected in series with the armature. It results a "soft" characteristic specific to the electric traction (Figure 2.b), with a high torque at start and acceleration and a rapid reduction with increasing speed thereof [3].



1- winding induced and collector
2- excitation winding
3- shunting
4- switching winding
5- compensation winding
6- Separate excitation powered by a chopper

Figure 2. a) The equivalent scheme of the traction engine of continuous current; b) it's mechanical characteristic

To operate at a constant power in parallel with the excitation winding resistances are connected to obtain a weaker field. For braking the reversal of the excitation field must be done with contractors.

- Branch excitation or separates is preferred in other industrial applications. If these are powered with a converter that can create load dependent current (simulating the series excitation) they can be used in traction. In this case the loosing of the field and the braking can be easily realized.

• At modern locomotives with thyristors and converters a mix system is used in which the excitation filed of the excitation winding in series in 50% of the total [7].

Traction substations with one-phase transformers connected in V/V are equipped with two identical one-phase transformers, connected to the three-phase powering system and to the contact line in the presented way (Figure 3) [8].

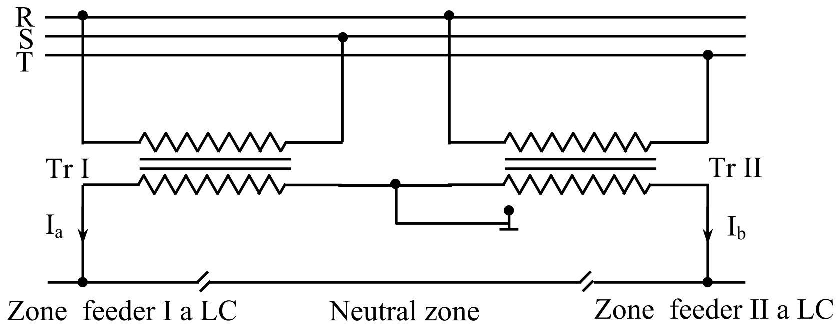


Figure 3. Traction substation with one-phase transformers connected in V/V

The scheme with two transformers tied in V/V ameliorates the tension dissymmetry which are introduced by the one-phase traction charge in the powering electric system, being in this way superior to the Y/Δ/Δ scheme [8].

By cyclic successive binding mode to the phases of the powering system, for a total of three of multiples of three traction substations, the reversed currents are notably or even entirely reduce, so the one-phase traction charges are completely equilibrated, allowing in the same time the parallel functioning of the related substation transformers and therefore the feeding from two heads of the feeder zones of the contact ways.

Also, like in the case of the Y/Δ/Δ scheme, binding the traction substations with the V/V scheme to the phases of the system lead to the notable reduction or even to the total compensation of the 3rd harmonic introduced by the locomotives with rectifiers in the systems.

The public networks of 50 Hz impose limitations regarding the recovered energy when braking and from this point of view the vehicles must be equipped with braking resistance and choppers [9].

The paper deals with some aspects regarding the electric power quality, on theoretical and practical levels, based on the measurements carried out on a locomotive motor using a C.A. 8334 power quality analyzer [10].

The front panel of the analyzer is shown in Figure 4.

Figure 4. C.A. 8334 Power quality analyzer [2]

IOP Conf. Series: Materials Science and Engineering **294** (2018) 012050 doi:10.1088/1757-899X/294/1/012050

Mathematical formulae used to compute the various parameters [10]
Half-period voltage and current RMS values.
Single RMS voltage half-period i + 1 phase:

$$\mathrm{Vdem}(i)=\sqrt{\frac{2}{N}\cdot\sum_{n=0}^{N}V(i,n)^2} \quad (1)$$

Compound RMS voltage half-period i + 1 phase:

$$\mathrm{Udem}(i)=\sqrt{\frac{2}{N}\cdot\sum_{n=0}^{N}U(i,n)^2} \quad (2)$$

RMS current half-period i + 1 phase:

$$\mathrm{Adem}(i)=\sqrt{\frac{2}{N}\cdot\sum_{n=0}^{N}A(i,n)^2} \quad (3)$$

1 sec RMS values for voltage and current:
Single RMS voltage i + 1 phase;

$$V_{rms}(i)=\sqrt{\frac{1}{N}\cdot\sum_{n=0}^{N-1}V(i,n)^2} \quad (4)$$

Compound RMS voltage i + 1 phase:

$$U_{rms}(i)=\sqrt{\frac{1}{N}\cdot\sum_{n=0}^{N-1}U(i,n)^2} \quad (5)$$

Courant efficacy phase i+1:

$$A_{rms}(i)=\sqrt{\frac{1}{N}\cdot\sum_{n=0}^{N-1}A(i,n)^2} \quad (6)$$

Neutral RMS current:

$$A_{rms}(3)=\sqrt{\frac{1}{N}\cdot\sum_{n=0}^{N-1}(A(0,n)+A(1,n)+A(2,n))^2} \quad (7)$$

N : Number of samples in a second
Calculation of the total harmonic distortion factor (THD):

$$V_{thd}(i)=\frac{\sqrt{\sum_{n=2}^{50}V_{harm}(i,n)^2}}{V_{harm}(i,1)} \quad (8)$$

$$U_{thd}(i)=\frac{\sqrt{\sum_{n=2}^{50}U_{harm}(i,n)^2}}{U_{harm}(i,1)} \quad (9)$$

$$A_{thd}(i)=\frac{\sqrt{\sum_{n=2}^{50}A_{harm}(i,n)^2}}{A_{harm}(i,1)} \tag{10}$$

i : phase (0; 1; 2) n : rang (2…50)
Different power levels 1 sec.
Active power i + 1 phase:

$$W(i)=\frac{1}{N}\sum_{n=0}^{N-1}V(i,n)\cdot A(i,n) \tag{11}$$

Apparent power i + 1 phase:

$$VA(i)=V_{rms}(i)\cdot A_{rms}(i) \tag{12}$$

Reactive power i + 1 phase:

$$VAR(i)=\frac{1}{N}\cdot\sum_{n=0}^{N-1}VF(i)\left(n-\frac{N}{4}\right)\cdot AF(i,n) \tag{13}$$

Power factor i + 1 phase:

$$PF(i)=\frac{W(i)}{VA(i)} \tag{14}$$

To emphasize with ease the effects introduced by the traction vehicles in the powering network more measures will be presented resulted from different measuring situations.

In Figure 5 we show the effective variation of the electric current in a DC motor with which the locomotive is equipped.

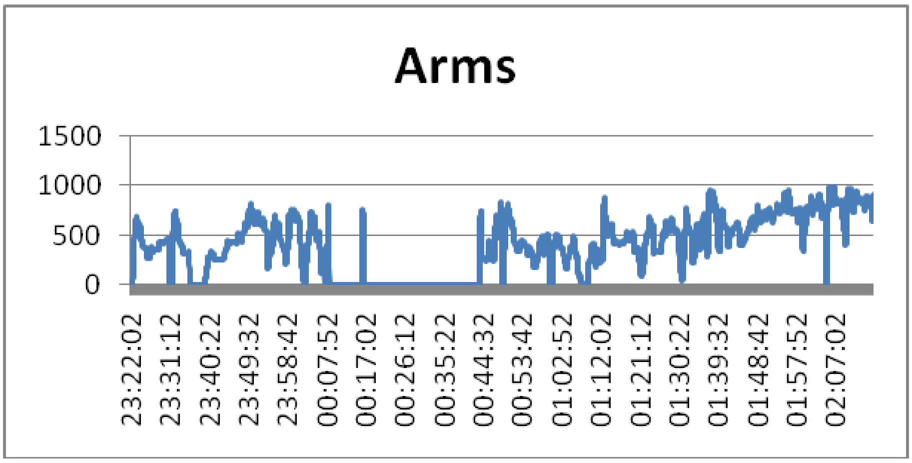


Figure 5

The periods for which we obtained zero plateau correspond to the time intervals in which the locomotive was stopped, and the high variation of the current is caused by the relief variation on the route.

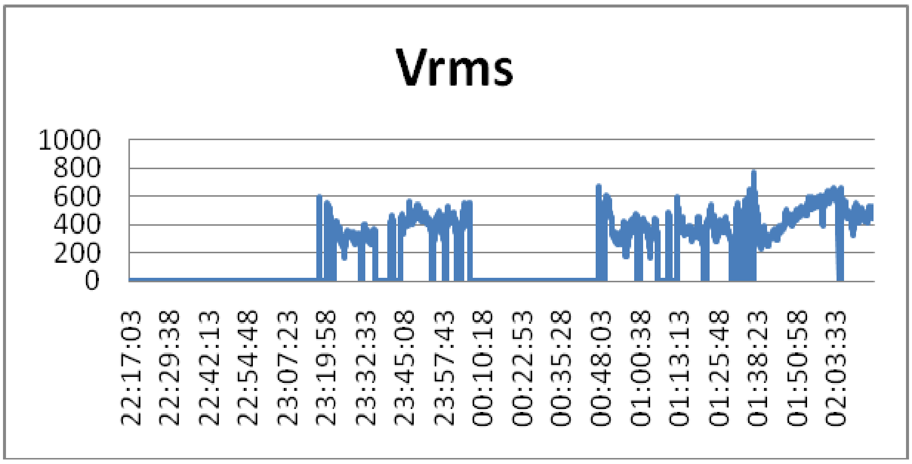


Figure 6

In Figure 6 we show how the effective voltage varies in a DC engine with which the locomotive is equipped.

There is a small variation compared to the electric current variation.

In Figure 7 we show the harmonic distortion power factor, whose high values go beyond the ones provided by the European standard.

For this reason, measures should be taken to reduce the THD factor.

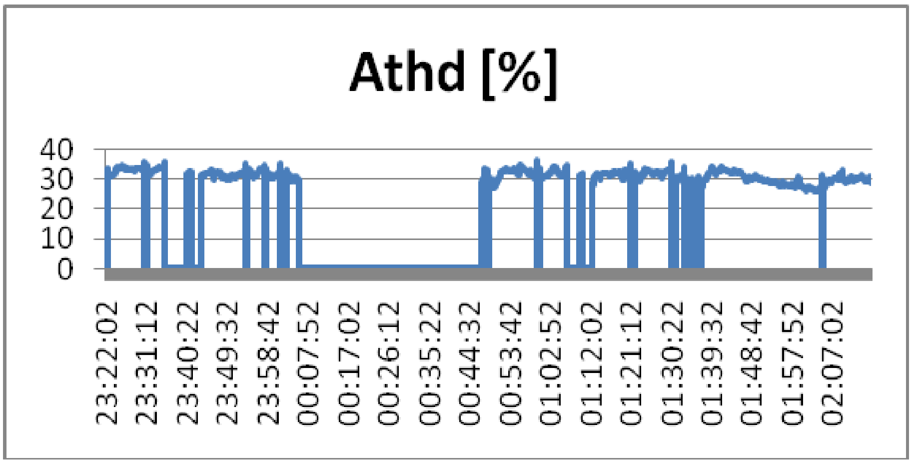


Figure 7

In Figure 8 we show the voltage harmonic distortion factor. As expected, the values are substantially lower compared to the ones obtained for the electric current, but in some cases they exceed the limits accepted by the international standards.

Based on the measured voltage and current values, we obtained the active power variation shown in the Figure 9. There is a high fluctuation of the power values throughout the entire data acquisition process.

We have also obtained the reactive power variation shown in the Figure 10. There is a high fluctuation of the power values throughout the entire data acquisition process, the values exceeding 1.4MVAR.

In Figure 11 we show the waveform for the apparent power. There is a concordance with the active and reactive power variation, the apparent power being the sum of these two types of power.

In the Figure 12 we can see a power factor value close to 0.85, with small variations around this value.

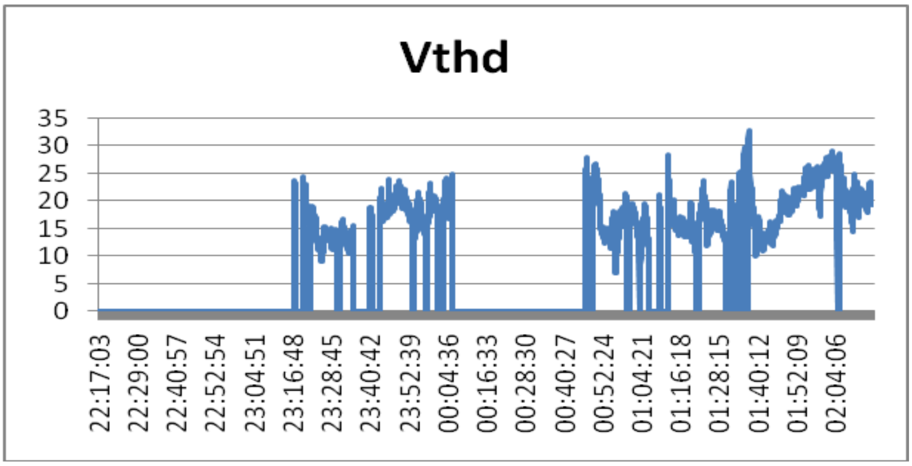


Figure 8

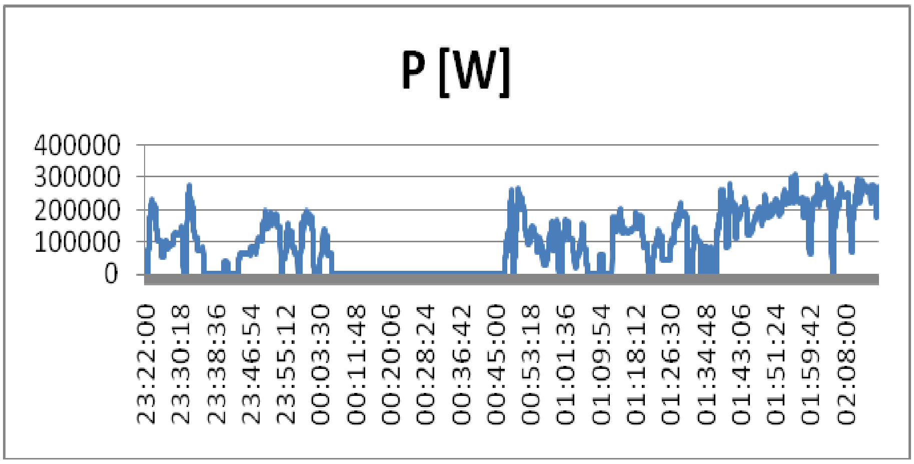


Figure 9

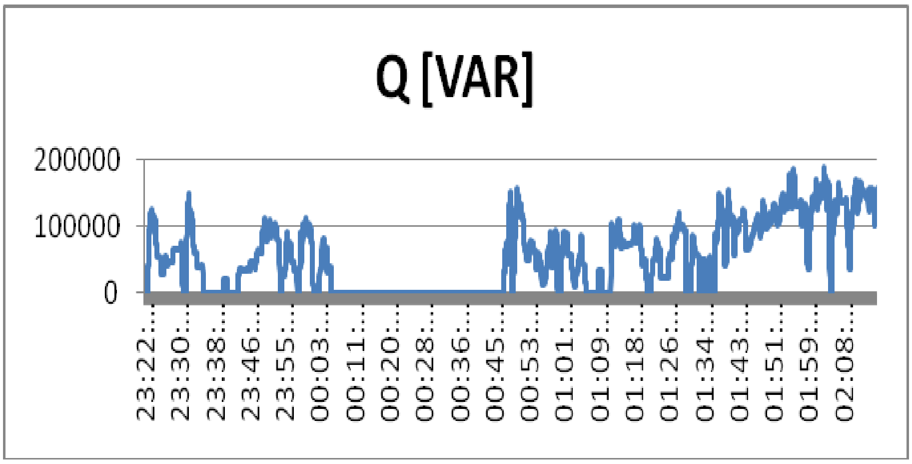


Figure 10

IOP Conf. Series: Materials Science and Engineering **294** (2018) 012050 doi:10.1088/1757-899X/294/1/012050

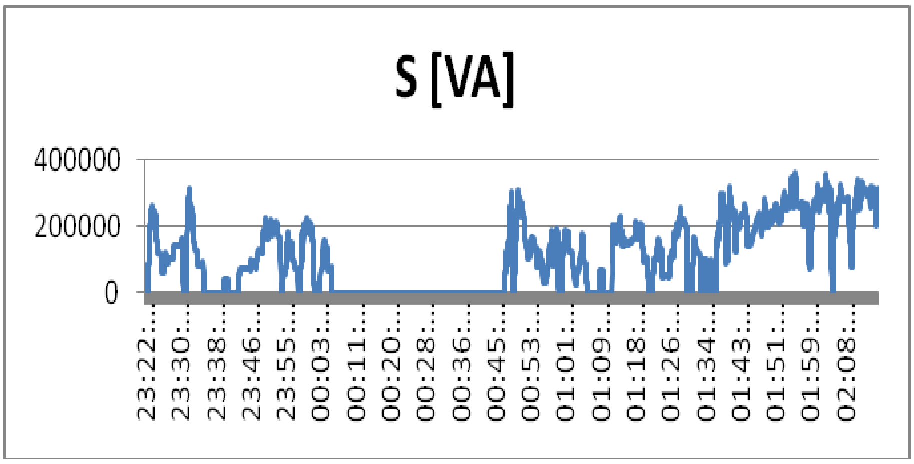


Figure 11

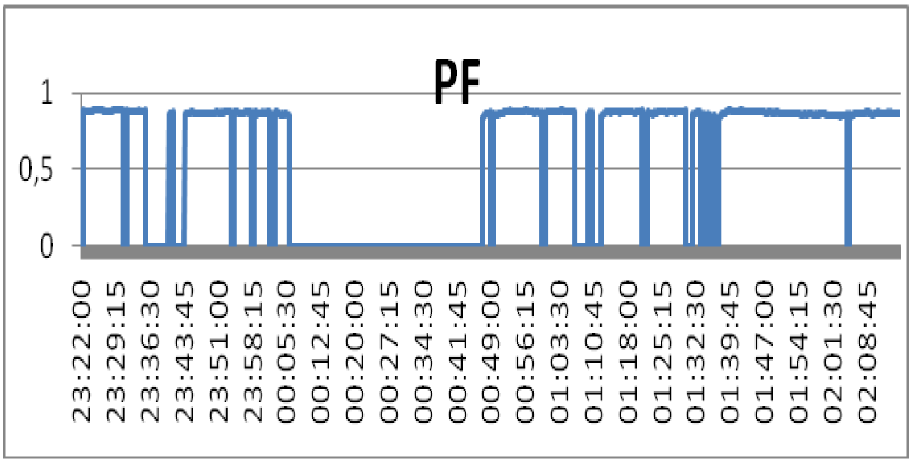


Figure 12

3. Conclusions

The experimental measurements are a real and pertinent database that has been obtained using a latest generation of high performance equipment, i.e. the C.A. 8334 power quality analyzer, France 2007.

The large amount of data, as well as the parameters determined in real time, the sampling period being set to 1 second, enables an accurate establishment of the existing deformation regime. It was found that (as we have expected) the main distorting factor is the current passing through the power supply conductors. The harmonic distortion factor of the current has values far beyond the accepted limits provided by the international standardization system.

The current variation analysis reveals a great similitude with the variation of active power and apparent power, leading to the conclusion that a highly distorting regime exists and needs to be compensated, even if the values of the voltage harmonic distortion factor falls close to the limit and, in some cases, even within the limits of compatibility.

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