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Power Quality Measurements at an Automobile Factory. Conclusion

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Abstract- The value of power quality (PQ) is decided by economic consequences of a PQ deficiency. For example, the cost of damage caused by an outage can range from millions of euros for a small number of consumers, those with highly automated production plants, like actual automobile factories to nearly nothing for the vast majority.

With this work, the intention is to complete a previous, sufficiently representative, study based on data acquisition and measurements of harmonics inside PSA PEUGEOT CITROËN, an automobile factory located in Vigo (Spain) that prepare 2.162 cars per day and has about 9.000 employees. The idea is take the harmonic measurement in the cut line No 8 (7E) and propose for harmonic mitigation an active power filter centralized for this line controlled by a microprocessor.

Key words: Power quality, harmonics, active filters

I. INTRODUCTION

Harmonics, inter-harmonics, voltage flicker and unbalance are the power quality problems which are introduced to the power system as a result of nonlinear loads like press and arc solders that are the kind of equipment that CITROËN has in the zone of study. The nonlinear voltage-current characteristic of these loads can cause harmonic currents which when circulating by the inner network can produce harmonic voltages which can affect to other sensible loads like the robots.

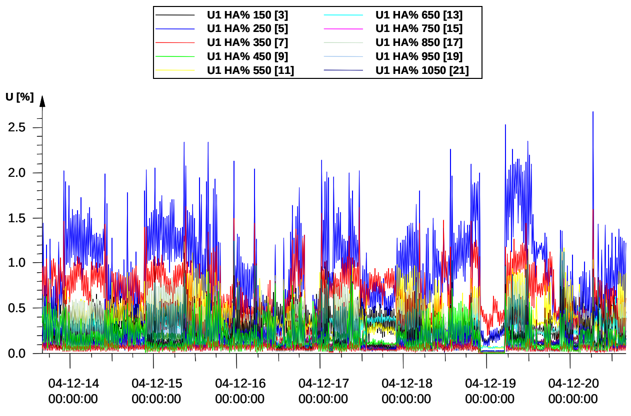

Fig.1. Voltage odds harmonics ratio chart of the 8 cut line corresponding at "R" phase (in 7E).

II. MEASUREMENTS

We have developed a measurement campaign of power quality in different zones of the factory but in this paper we'll present the results and the mitigation solutions by an active power filter with an appropriate control strategy in the "Embutición" zone**.** This one is the zone of the factory where they prepare the different metal pieces that form part of the car body. The measurements were taken at the transformer 7E which supply electricity at some pneumatic press. This specific zone is called cut line 8. For take the measurements we have used an Unilyzer 812, photo1, installed at the control panel, photo 1, of the current and voltage transformers corresponding to this power transformer.

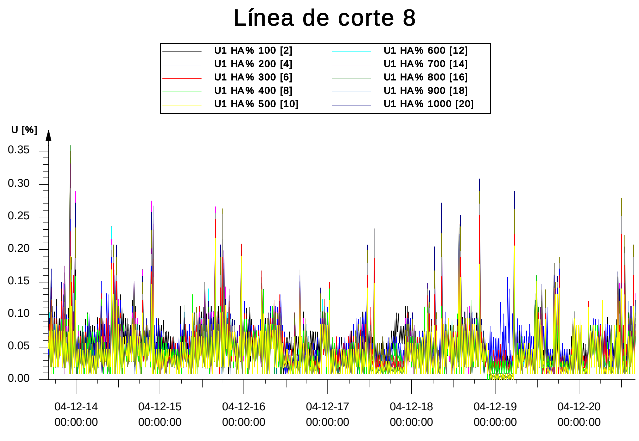

Fig.2. Voltage evens harmonics ratio chart of the 8 cut line corresponding at "R" phase (in 7E).

Photo 1. Unilyzer 812 installed at the control panel.

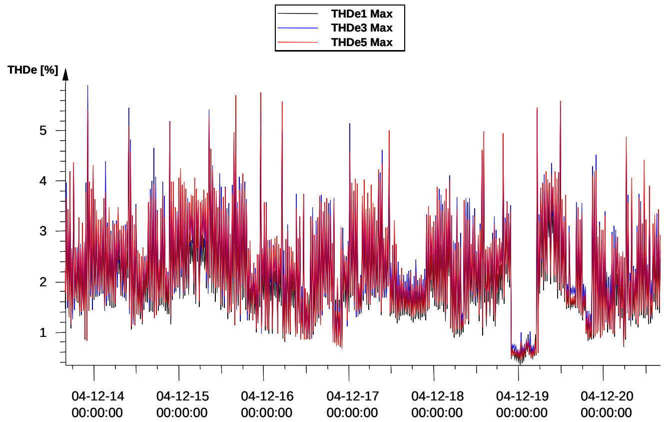

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Fig.3. Maximum total harmonic distortion of the three phases chart of the 8 cut line (in 7E).

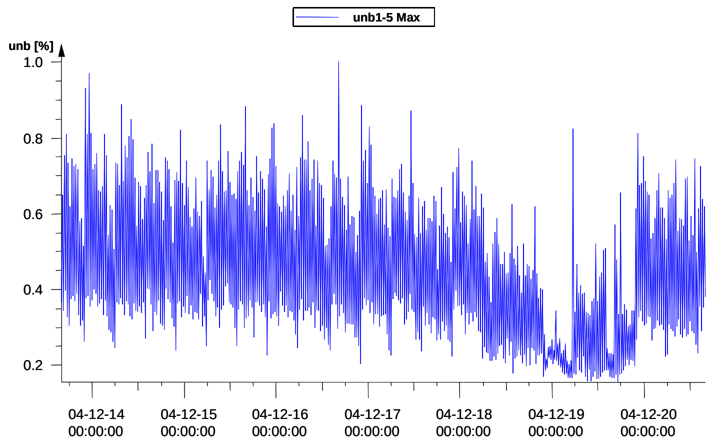

Fig.4. Maximum unbalance chart of the 8 cut line (in 7E).

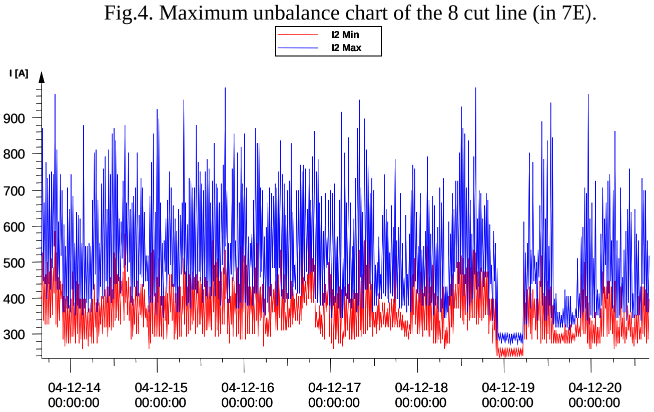

Fig.5. “R” phase maximum/minimum current chart of the 8 cut line (in 7E).

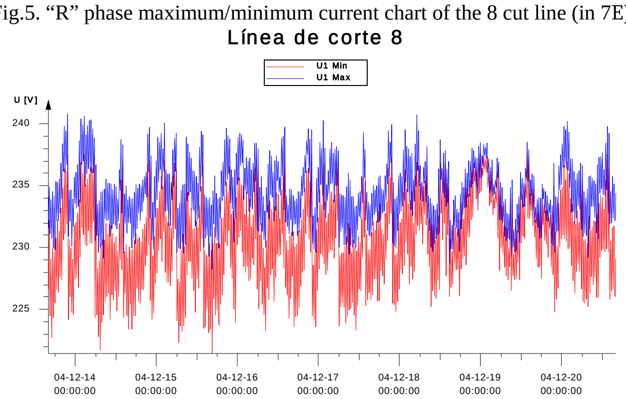

Fig.6. “R” phase maximum/minimum voltage chart of the 8 cut line (in 7E).

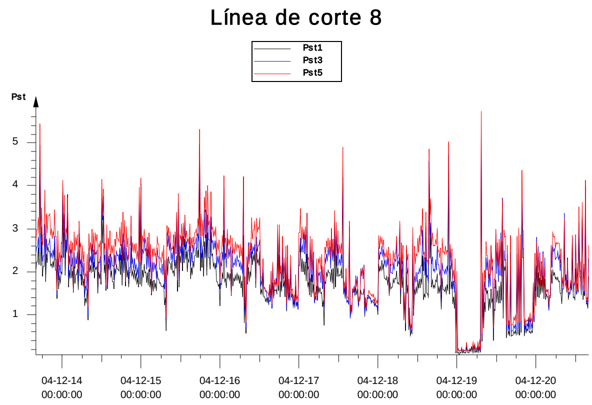

Fig.7. Pst flicker at the three phases (in 7E).

TABLE I. SUMMARY OF THE MEASUREMENTS

		Measurements Summary	
		EN 50160	Measured
Frequency	Maximum	50,5	50,1358
	Minimum	49,5	49,8931
Voltage Variations	Maximum	25	240,8311
	Minimum	20	227,3869
Plt Flicker	Maximum	0,8	3,4
Pst Flicker	Minimum	1	5,7
Harmonics (% Un) Maximum Values	2º	2	0,5
	3º	5	0,7
	4º	1	0,5
	5º	6	2,8
	6º	0,5	0,5
	7º	5	1,6
	8º	0,5	0,5
	9º	1,5	0,6
	10	0,5	0,4
	11	3,5	1,4
	12	0,5	0,5
	13	3	0,7
	14	0,5	0,4
	15	0.5	0.5
	16	0,5	0,3
	17	2	1,2
	18	0,5	0,4
	19	1,5	0,8
	20	0.5	0,3
	21	0,5	0,4
THD	Maximum	8	5,9
Unbalance	Minimum	2	1

Like we can see at the figures 1,2,3 and table I, really there are not great problems with the levels of harmonics in this measurement point of the inner network and all of then are within the standard EN50160 but the staff of the factory want to reduce more this level of harmonics and then we propose a shunt active power filter with a simple Three-Leg Full Bridge inverter controlled by a micro-computer and when the active filter is installed then it is necessary to take new measurements for see the harmonics level but also the flicker level because now, like we can see at figures 7, 8 and table I, the flicker short time Pst and long time Plt levels are over the limit of the standard. The levels of flicker has been expected take into account the type of loads that we have in the factory.

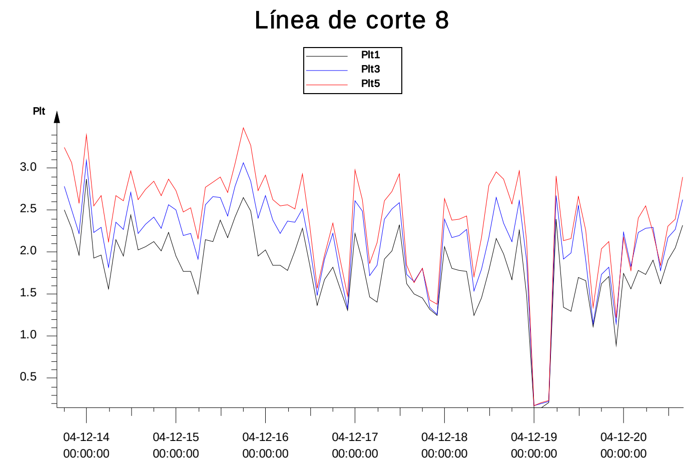

Fig.8. Plt flicker at the three phases (in 7E).

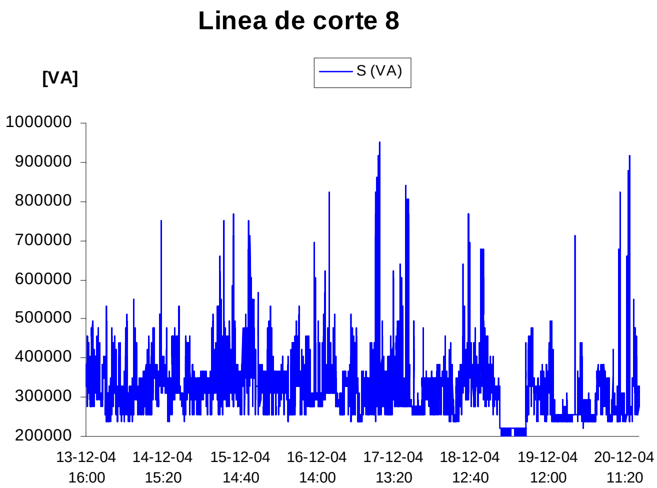

Fig. 9. Apparent Power at 7E

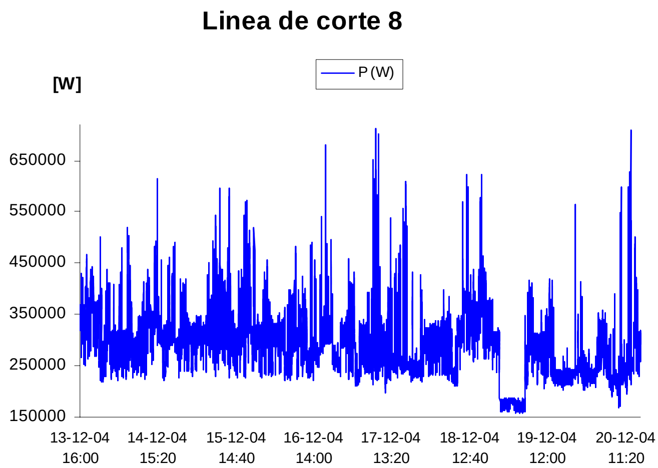

Fig. 10. Active Power at 7E

Photo 2. Photo 1. Unilyzer 812

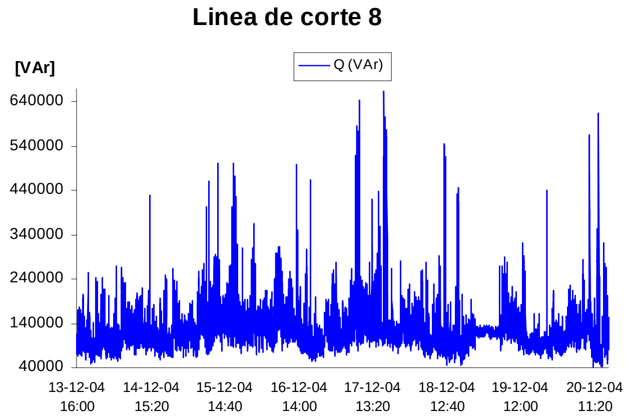

Fig. 11. Reactive Power at 7E

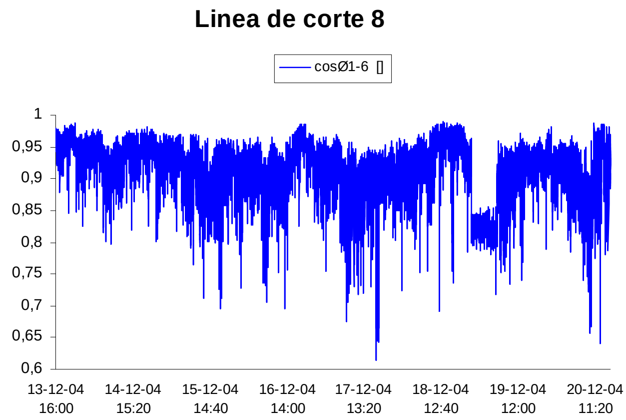

Fig. 12. Power Factor at 7E

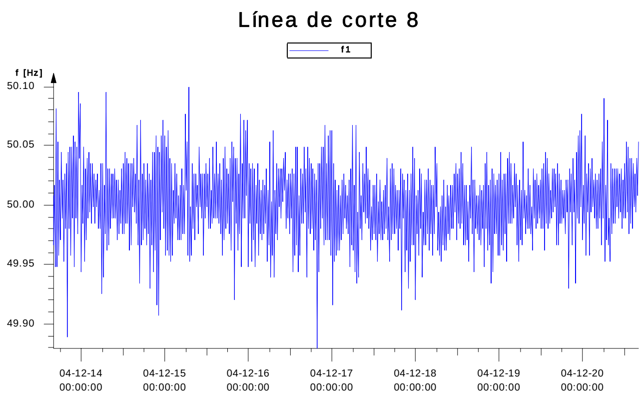

Fig. 13. Frequency variations at 7E

III. ACTIVE POWER FILTER

Systems with passive LC elements, such as capacity compensators, resonant passive filters of higher harmonics, or filters with structures and parameters determined by optimization methods have been traditionally used to compensate for power factor and other loading effects imposed by electricity users on the power network. However, widespread use of loads that involve power-electronic systems can cause major distortion of voltage and (especially) current waveforms, and even cause substantial dc currents to flow in power transformer secondaries. For these types of loads, the kinds of compensation systems mentioned above often prove to be unsatisfactory. Nowadays, power-system engineers are more likely to consider using other types of compensators, especially active power filters or hybrid systems (power filters with passive LC elements to increase system efficiency.

Shunt filter is used for the compensation of undesired harmonic currents in a way that it generates identical harmonic current components with the opposite phases (into the supply network). The resulting current is then clears off the harmonic. Current supplied from the supply network is filtered and the voltage distortions, which are caused by the load, are modified and the supply network's effect is improved. Active filter is capable of compensating the current by a neutral conductor; this solution requires a 4-leg bridge inverter. If it is not necessary to compensate the current by a neutral conductor in the case of a symmetrical load, with an unbalance level within the standard like in Citroën factory, without a third harmonic current then a 3-leg bridge inverter is enough.

In the lasts years, recent efforts have been concentrated on the development of active power filters. In this paper the development of a shunt active power filter is proposed, with a control system based on the p-q theory.

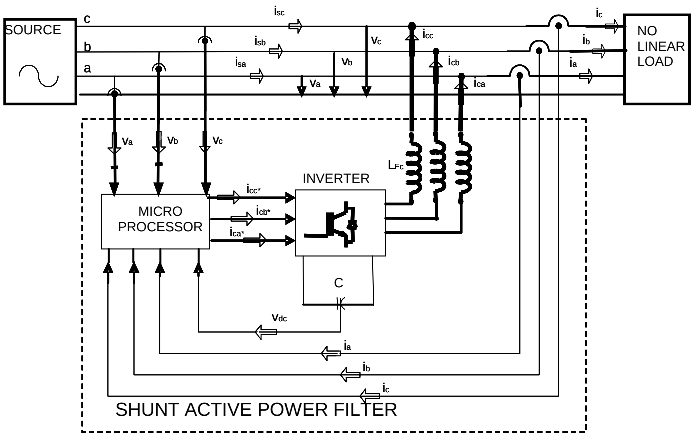

Fig. 14. Block diagram of the shunt active filter proposed.

The shunt active filter is constituted by the controller block (standard microprocessor-μP),the inverter block (IGBT module), the DC bus (with a single capacitor, or two) and the coupling to the power system block (with a inductance, or two, for each phase and neutral wire).

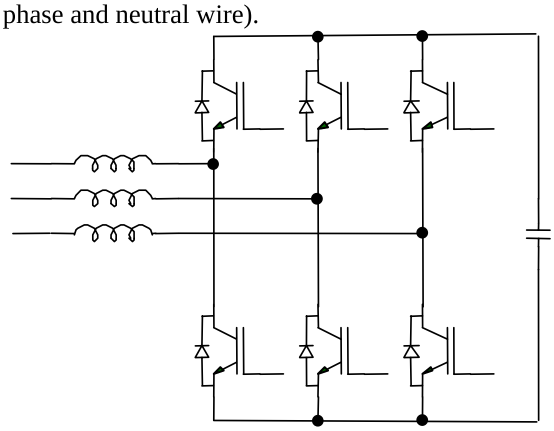

Fig. 15. Three-Leg Full Bridge Converter (TLFBC)

Concerning with the Fig. 15 inverter topology we must to say that:

- ✓ It is difficult to obtain an analytical expression for DC-bus voltage evolution.
- ✓ DC-bus capacitors rating is done taking into account steady-state conditions.

$$I_F = \frac{1}{L_F}\left(D \cdot V_C - V_S\right) \tag{1}$$

$$V_C = -\frac{1}{C} \cdot D^T \cdot I_F \tag{2}$$

$$I_F = \left[i_{Fa}\ i_{Fb}\ i_{Fc}\ i_{Fd}\right]^T \tag{3}$$

$$V_C = \left[v_{C1}\ v_{C2}\right] \tag{4}$$

$$V_S = \left[v_{Sa}\ v_{Sb}\ v_{Sc}\ 0\right]^T \tag{5}$$

$$D = \begin{bmatrix} d_a & 1-d_a \\ d_b & 1-d_b \\ d_c & 1-d_c \\ d_d & 1-d_d \end{bmatrix} \tag{6}$$

Flowing currents through the capacitors:

$$I_C = \left[i_{C1}\ i_{C2}\right]^T \tag{7}$$

$$i_{C1} = \frac{1}{V_{dc}}\left[v_{C2} i_{F0} - p_{F3\phi} - \frac{1}{2} L_F \frac{d}{dt} \sum_{l=a,b,c,d} \left(i_{Fl}\right)^2\right] \tag{8}$$

$$i_{C1} = \frac{1}{V_{dc}}\left[-v_{C1} i_{F0} + p_{F3\phi} + \frac{1}{2} L_F \frac{d}{dt} \sum_{l=a,b,c,d} \left(i_{Fl}\right)^2\right] \tag{9}$$

Where: $i_{F0} = i_{Fa} + i_{Fb} + i_{Fc} + i_{Fd}$ (10)

and: $p_{F3\phi} = v_{Sa} i_{Fa} + v_{Sb} i_{Fb} + v_{Sc} i_{Fc}$ (11)

Energy stored in the DC-bus:

$$w_{dc} = \int_0^t \left(v_{C1} i_{C1} + v_{C2} i_{C2}\right) dt + w_{dc}(0) \tag{12}$$

$$\Delta W_{dc} = W_{dc} - W_{dc}(0) = \int_0^t \left(v_{C1} i_{C1} + v_{C2} i_{C2}\right) dt = \tag{13}$$

$$= \int_0^t \left(p_{F3\phi} + \frac{1}{2} L_F \frac{d}{dt} \sum \left(i_{Fi}\right)^2\right) dt = -\int_0^t \left(p_{F3\phi} + p_{L_F}\right) dt$$

Taking into account the power losses:

$$\Delta w_{dc} = \int_0^t \left(p_{F3\phi} + p_{\text{int}}\right) dt \tag{14}$$

Where: $p_{\text{int}} = p_{loss} + p_{L_F}$ (15)

Instantaneous power developed by the APF:

$$p_{F3\Phi} = p_{L3\phi} - p_{S3\phi} = \tilde{p}_{L3\phi} - \tilde{p}_{S3\phi} - \bar{p}_{\text{int}} \tag{16}$$

$$q_F = \bar{q}_L + \tilde{q}_L - \tilde{q}_S \tag{17}$$

$$\begin{bmatrix} p_{S0} \\ p_S \\ q_S \end{bmatrix} = \begin{bmatrix} 0 \\ \bar{p}_S + \tilde{p}_S \\ \tilde{q}_S \end{bmatrix} \tag{18}$$

$$\begin{bmatrix} p_{L0} \\ p_L \\ q_L \end{bmatrix} = \begin{bmatrix} \overline{p}_{L0} + \tilde{p}_{L0} \\ \overline{p}_L + \tilde{p}_L \\ \overline{q}_L + \tilde{q}_L \end{bmatrix} \tag{19}$$

$$\left|\Delta w_{dc(\max)}\right| = \frac{\left(1+\sqrt{2}\right)e^{-\sqrt{2}}\left|\Delta P_L\right|}{k\left(1-2\xi_h \dfrac{\varpi_f}{\varpi_h}\right)} \tag{20}$$

$$w_{dc} = \frac{1}{4}C\left(v_{C1} - v_{C2}\right)^2 = \frac{1}{4}Cv_{dc}^2 \tag{21}$$

$$\Delta w_{dc} = \frac{1}{4}C\left[v_{dc}^2 - v_{dc(ref)}^2\right] \tag{22}$$

$$C \geq 4\frac{\left|\Delta W_{dc(\max)}\right|}{\left|V_{dc(ref)}^2 - V_{dc(\lim)}^2\right|} \tag{23}$$

With this filter it is possible to effectively:

- ✓ Compensate the harmonic currents
- ✓ Compensate reactive power (correcting power factor to the unity).
- ✓ Balance the power supply currents (distributing the loads for the three-phases in equal form).
- ✓ Compensate the zero-sequence current.

P-Q Theory. The p-q theory was developed by *Akagi et al* in 1983, with the objective of applying it to the control of active power filters. Initially, it was developed only for three phase systems without neutral wire, being later worked for three-phase four wires power systems by *Watanabe* and *Aredes.*

The Generalized Theory of instantaneous Reactive Power in three-phase circuits, also known as instantaneous power theory, or p-q theory. The p-q theory consists of an algebraic transformation (Clarke transformation) of three-phase voltages and currents in the abc coordinates to the $o\alpha\beta$ coordinates, followed by the calculation of the p-q theory instantaneous power components. the instantaneous Voltage of PCC Bus connection of the compositor are not used in the calculus of the power but we used the output PLL signals with are synchronised to the fundamental component PCC Bus voltage .

The load currents and transformed into $o\alpha\beta$ components using equations (24). The instantaneous powers are calculated using equation (25)

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{24}$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \sin(\theta) & -\cos(\theta) \\ \cos(\theta) & \sin(\theta) \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{25}$$

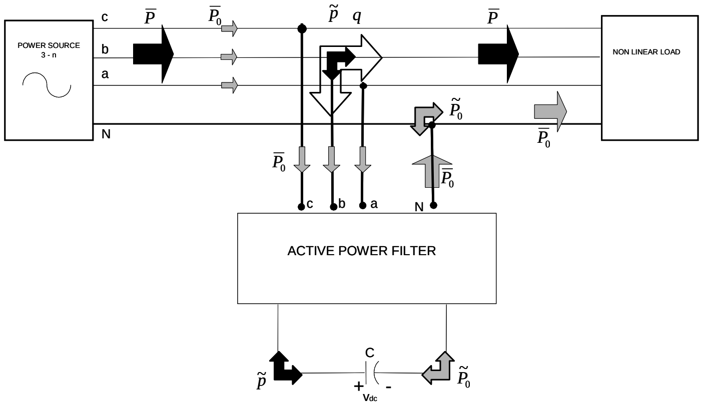

Fig. 14. Block diagram that show the power flow

Where:

p : Instantaneous real power, which corresponds to the energy per time unity which is transferred from the power supply to the load.

q : Instantaneous imaginary power, which corresponds to the power that is exchanged between the phases of the load. A high pass filter is used for the extraction.

$\overline{p}_o$: Instantaneous zero-sequence real power, which corresponds to the energy per time unity which is transferred from the power supply to the load through the zero-sequence components of voltage and current.

The harmonic power component $\tilde{p}$ .The term P_{dc} is the amount of active power that must be added to keep the DC capacitor voltages at its pre-set values. It is obtained from the DC voltage regulation loop; which is generally based on a simple P regulator.

The compensating current references are calculated in the $\alpha\beta$ by the equation (26).

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \begin{bmatrix} \sin(\theta) & \cos(\theta) \\ -\cos(\theta) & \sin(\theta) \end{bmatrix} \begin{bmatrix} \tilde{P} \\ q \end{bmatrix} \tag{26}$$

Since the zero- sequence current must be compensated, the reference compensation current in the o coordinate is i_o itself:

$$i_{c0}^* = i_0 \tag{27}$$

In order to obtain the reference compensation currents in the abc coordinates transformation $o\alpha\beta \rightarrow abc$ is applied using equations (28).

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/\sqrt{2} & -1/\sqrt{2} \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \tag{28}$$

From all the powers components of the p-q theory, only the mean values of the instantaneous real power and of the instantaneous zero-sequence power must come from the power supply, because then effectively transfer energy to the load.

$$\begin{bmatrix} i^*_{S0} \\ i^*_{S\alpha} \\ i^*_{S\beta} \end{bmatrix} = \frac{\overline{p}_{Le} - \overline{p}_{L0}}{u^2_{\alpha 1} + u^2_{\beta 1}} \begin{bmatrix} 0 \\ u_{\alpha 1} \\ u_{\beta 1} \end{bmatrix} \quad (29)$$

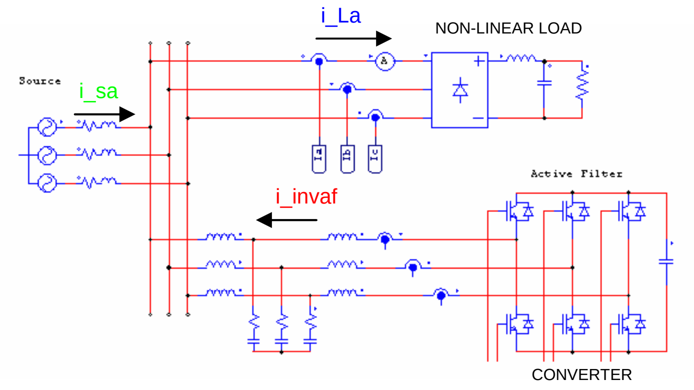

Fig. 15. Shunt active power filter selected scheme.

Active filter represents an additional electronic semiconductor converter, figure 15, connected to a non-linear load. The input current of the converter (APF) is controlled to produce the same levels of harmonic as well as non-linear load, although in an opposite phase. These two levels of harmonics are eliminated at the connection point, figure 16.

The controller receives the information of phase voltages, load currents and DC voltage, and based on its control algorithm, proceeds to the calculations of the p-q theory values, generating, or not, the necessary reference compensation currents, which are injected in the power system by the inverter block.

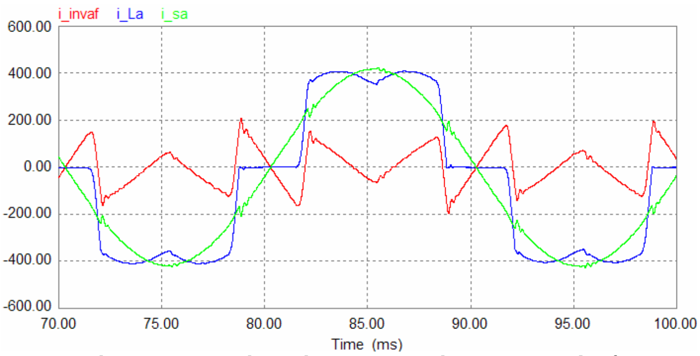

Fig. 16. a-phase ® currents chart. The currents are those represented at figure 15.

IV. CONCLUSIONS

Data collected at the control panel of the power transformer measurement site revealed not very significant levels of harmonics, all of which well within the limits set by the EN 50 160 standard. Nevertheless take in account that this one has a very high level of automation and robotic it is important insert filter for harmonics mitigation and a better power quality.

Another different thing are the values of flicker, like you can see at figures 7 and 8 and also at table I, the values of Pst (short time) and Plt (long time) flicker are beyond the standard values.

The following conclusions could be achieved regarding the active filter proposed and its control system:

- It compensates dynamically the harmonic currents.
- There is no risk of resonances.
- It corrects dynamically the power factor. Unity power factor (or any desired value) can be achieved.
- They do not disturb the electrical network.
- It is possible to compensate phase unbalance. They can be combined with passive filters (which may be already installed) in hybrid topologies, to diminish rated power.

The control strategy and the method for extracting harmonic references will depend on the compensation objectives. p-q theory is very effective in shunt active filter because desired currents are unknown and load dependent. Voltages may usually be considered sine waves.

Concerning with the unbalance, like we can see at figure 4 an table I, the maximum and minimum value are within the standard, EN 60150, nevertheless we can make some arrangements at the connection point of certain single-phase loads. The levels of unbalance perhaps do not justify the connection of a more expensive four legs converter.

In any case after we have installed the shunt active power filter it is necessary a new measurement campaign for probe if it is enough or it is necessary make some flicker or unbalance correction.

ACKNOWLEDGEMENT

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