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# Voltage and current disturbances elimination with reactive power compensation using unified power quality conditionner

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# Voltage and Current Disturbances Elimination with Reactive Power Compensation Using Unified Power Quality Conditioner

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***Abstract*--This paper presents a study on the harmonic depollution of the electric power network as well as the compensation of reactive power by Unified Power Quality Conditioner (UPQC) (Parallel[2] and Series[1] Association Active Filters). The presentation of the system of filtering starts initially with the presentation of the modeling of the whole of the system (electrical network, polluting load and unified power quality conditioner. In the second place, the principle of identification by the trigonometric method for harmonic voltages and instantaneous real and imaginary powers method for harmonic currents are developed, followed by the presentation of the hysteresis strategy control applied on the two inverters of the conditioner. The following part is devoted to the presentation of regulation system of the terminal condenser voltage of the autonomous conditioner. At the end are presented the digital simulation results.**

***Index Terms*--Voltage and current disturbances, Unified power quality conditioner, Parallel active filter, Series active filter, Two level voltage inverter, Reactive power, Hysteresis Control.**

## I. Introduction

The static converters absorb non-sinusoidal currents even if they are fed under sinusoidal voltages, they also absorb reactive energy. They behave then like generators of harmonic currents. These harmonic currents constitute a source of harmful problems for the network and the converter itself. By the other hand, some polluted electrical networks behave like source of disturbances for some sensible electrical loads. Traditional solutions of depollution are conceived primarily by passive filters. The lack of adaptability as well as the problem of resonance between the filter and inductance of the network was the great inconvenient of this depollution technique. Thanks to the development of the electronics of power, new structures of depollution of the networks appeared under the name of active filter in order to adapt an effective solution to the problems of harmonics and the strong consumption of reactive energy.

## II. System Modelisation

In the figure (1) is given the synoptic diagram of the association active filter (parallel and series)-electric network-non linear load [3].

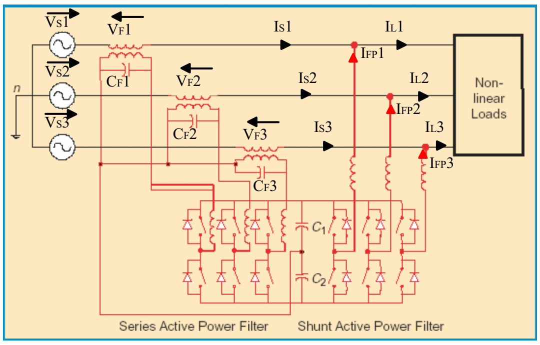


Fig. 1. Unified power quality conditioner.

### *A. Electrical network and non-linear load modelisation*

The network is presented by a three phase polluted voltage source balanced system while the polluting load is comparable to a three-phase source of currents, this latter generates the harmonic currents of order $6k\pm1$ and absorbs a reactive energy from electric network. Mathematical models of electrical network and non-linear load are as follow:

$$V_{si} = V_{si\,f} + V_{si\,h} \quad \text{and} \quad I_{Li} = I_{Li\,f} + I_{Li\,h} \tag{1}$$

where
i=1,2,3 : Phases indices.
$V_{si\,f}$ : Fondamental source voltage component.
$V_{si\,h}$ : Harmonic source voltage component.
$I_{Li\,f}$ : Fondamental load current component.
$I_{Li\,h}$ : Harmonic load current component.

### *B. Active filter (parallel and series) modelisation*

Both of parallel and series active filters are compared to a three-phase two level voltage inverter, this latter is controlled in current (in case of parallel active filter) and in voltage (in case of series active filter). To each switch is associated a function $F_{ij}$ known as connection function, with i=1,2,3 and j=1,2, such as:

$$F_{ij} = \begin{cases} 1 & \text{if switch is activated} \\ 0 & \text{if switch is disactivated} \end{cases} \tag{2}$$

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$$\begin{pmatrix} V_{F1} \\ V_{F2} \\ V_{F3} \end{pmatrix} = \frac{1}{3} Vc \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \begin{pmatrix} F11 \\ F21 \\ F31 \end{pmatrix} = Vc \begin{pmatrix} F1 \\ F2 \\ F3 \end{pmatrix} \quad (3)$$

Vc : Voltage at the DC side of inverter.

with:

$$\begin{pmatrix} F1 \\ F2 \\ F3 \end{pmatrix} = \frac{1}{3} \begin{pmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{pmatrix} \begin{pmatrix} F11 \\ F21 \\ F31 \end{pmatrix} \quad (4)$$

The mathematical model of the total system will be as follows:

$$\begin{pmatrix} V_{FP1} \\ V_{FP2} \\ V_{FP3} \end{pmatrix} = \begin{pmatrix} Vs1 - V_{FS1} \\ Vs2 - V_{FS2} \\ Vs3 - V_{FS3} \end{pmatrix} + Rf \begin{pmatrix} I_{FP1} \\ I_{FP2} \\ I_{FP3} \end{pmatrix} + Lf \frac{d}{dt} \begin{pmatrix} I_{FP1} \\ I_{FP2} \\ I_{FP3} \end{pmatrix} \quad (5)$$

with:
$V_{FP1}$ , $V_{FP2}$ , $V_{FP3}$ : Output voltages of parallel active filter.
$I_{FP1}$ , $I_{FP2}$ , $I_{FP3}$ : Output currents of parallel active filter.
$V_{FS1}$ , $V_{FS2}$ , $V_{FS3}$ : Output voltages of series active filter (Since transformers are considered ideal Capacitors ($C_{F1}$ , $C_{F2}$ , $C_{F3}$) voltages are equal to $V_{FS1}$ , $V_{FS2}$ , $V_{FS3}$).

## III. IMPLEMENTATION OF CONTROL STRATEGY

### *A. Identification of the harmonic voltages by the trigonometric method*

This method is based on the estimation of the active and reactive fundamental voltage components of each phase to get the fundamental voltage component of each phase as shown in the figure (2). To get harmonic voltage of each phase, a simple subtraction of the fundamental component from the total voltage is sufficient.

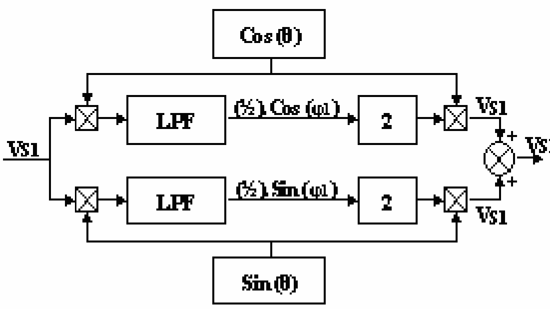



Fig. 2. First phase harmonic voltage identification with trigonometric method.

Same thing for the other phases with taking in consideration phase angles ((-2π/3) and (-4π/3)).

### *B. Identification of the harmonic currents by the method of instantaneous real and imaginary powers*

The figure (3) presents the diagram of harmonic currents identification with instantaneous real and imaginary powers method.

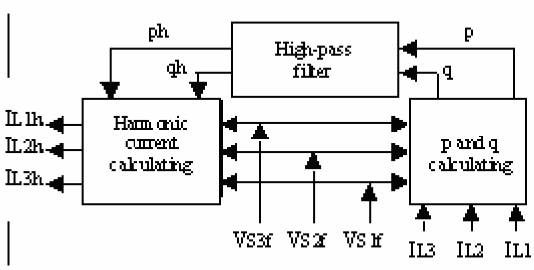



Fig. 3. Harmonic currents identification with instantaneous real and imaginary powers method.

$$\begin{bmatrix} V\alpha \\ V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} Vs\,1\,f \\ Vs\,2\,f \\ Vs\,3\,f \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} IL\,1 \\ IL\,2 \\ IL\,3 \end{bmatrix} \quad (7)$$

$V_{S1f}$ , $V_{S2f}$ , $V_{S3f}$ : Fundamental components of source voltages calculated by the trigonometric method.
The instantaneous real and imaginary powers, noted by p and q, are defined by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ -V\beta & V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \quad (8)$$

The powers are then filtered by high-pass filters, which gives ph and qh and the harmonic components of the currents will be:

$$\begin{bmatrix} Ic1h \\ Ic2h \\ Ic3h \end{bmatrix} = \sqrt{\frac{2}{3}} \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} ph \\ qh \end{bmatrix} \quad (9)$$

To compensate reactive energy, reactive power q will not pass by the high pass filter.

### *C. Control of active filters (parallel and series) with conventional hysteresis regulator*

The unified power quality conditioner is controlled with conventional hysteresis regulator in his two parts (parallel and series active filters). The only difference is that the first is controlled to generate certain form of current (harmonic current) and the second is controlled to generate certain form of voltage (harmonic voltage).

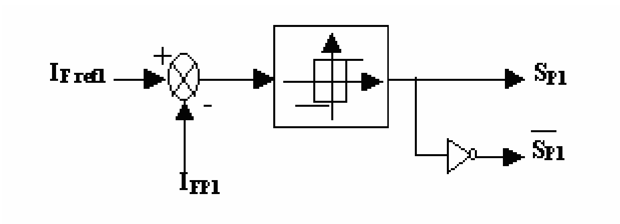



Fig. 4. Parallel active filter first phase current control with conventional hysteresis regulator.

This technique consists in changing output voltage polarity of each phase in parallel active filter to maintain filter output current within the hysteresis boundary around its reference.

$S_{P1}$ , $S_{P2}$ , $S_{P3}$ : Logical states of semi-conductors of two level inverter upper side in parallel active filter.

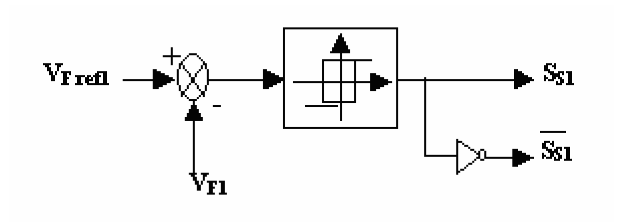



Fig. 5. Series active filter first phase voltage control with conventional hysteresis regulator.

This technique consists in changing output voltage polarity of each phase in series active filter to maintain this voltage within the hysteresis boundary around its reference.

$S_{S1}$ , $S_{S2}$ , $S_{S3}$ : Logical states of semi-conductors of two level inverter upper side in series active filter.

## IV. REGULATION OF CAPACITOR VOLTAGE

The regulation of the continuous voltage Vc at the boundaries of the capacitor being ensured by a regulator made up of a low-pass filter of time constant τc and proportional regulator with Kc as a gain, figure (6), which makes it possible to compensate losses in the inverter.

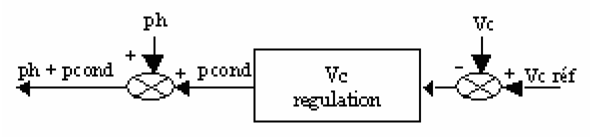



Fig. 6. Capacitor voltage regulation loop.

## V. DIGITAL SIMULATION RESULTS AND INTERPRETATIONS

The simulation was done by using the software programmation language C++ with following parameters:

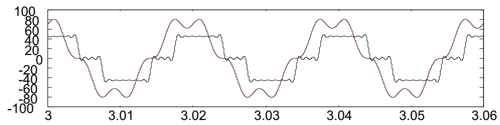
Electrical non-linear load parameters:
Ic = 45 A (Direct current of the rectifier used as non-linear load) , φ = π /6 rad (Phase angle between current and voltage at the input side of non-linear load).

Parallel active filter (P.A.F.) parameters:
LFP = 0.001 H , RFP = 0.001 Ω , Hystp = 1.5 A , C1 = C2 = 0.0041F , Vc=750 V.

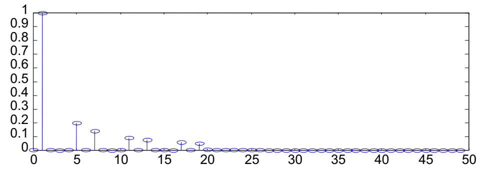
Series active filter (S.A.F.) parameters:
LFS = 0.004 H , RFS = 0.51 Ω , C FS = 0.001 F , Hysts = 5 V, Vc=750 V.

Electrical network parameters:
Vn=220 V , f=50 Hz (60 Hz).

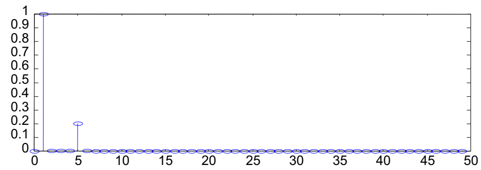
### *A. Without compensation of reactive power*



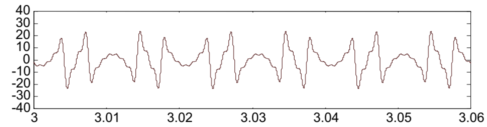
**a- Line voltage/4 and line current**



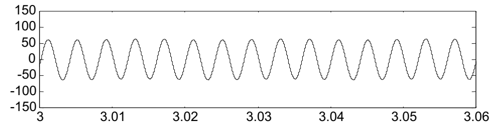
**b- Spectrum analysis of line current before harmonic current compensation (THD=28.31%)**



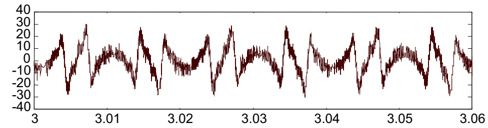
**c- Spectrum analysis of line voltage before harmonic voltage compensation (THD=20.10 )**



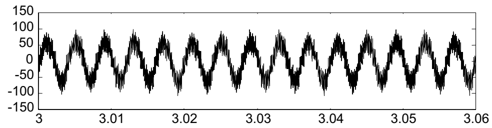
**d- Harmonic current reference**



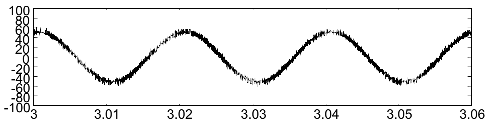
**e- Harmonic voltage reference**



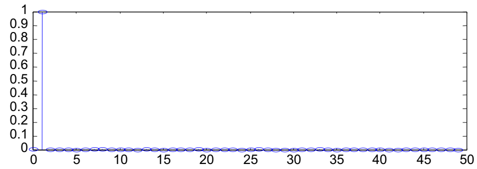
**f- Parallel active filter current**



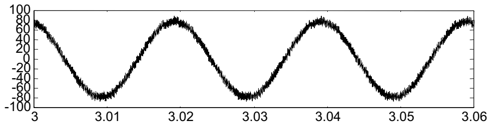
**g- Series active filter voltage**



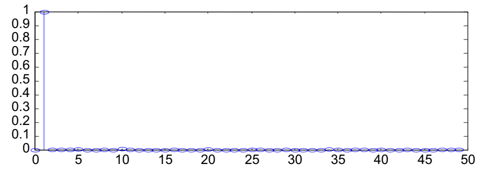

**h- Line current after harmonic current compensation**



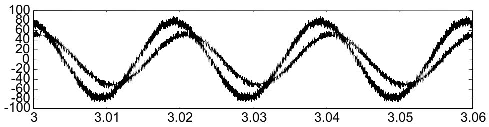

**i- Spectrum analysis of line current after harmonic current compensation (THD=02.11%)**



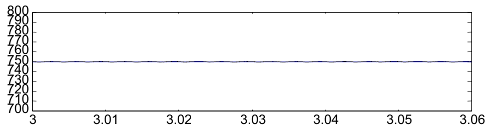

**j- Line voltage/4 after harmonic voltage compensation**



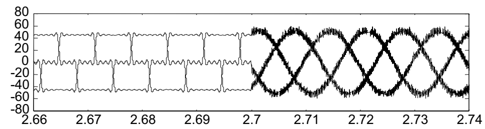

**k- Spectrum analysis of line voltage after harmonic voltage compensation (THD=01.70%)**



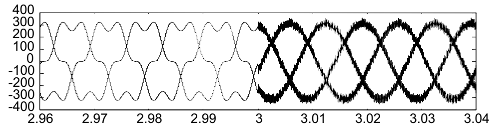

**l- Line voltage/4 and line current after harmonic voltage and current compensation**



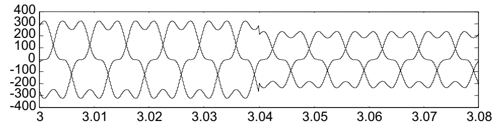

**m- Capacitor voltage with its refere**



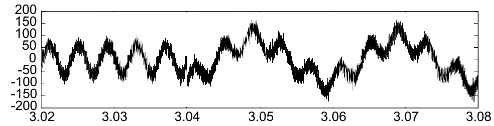

**n- Line currents before and after compensation of harmonic currents (at t=2.7s)**



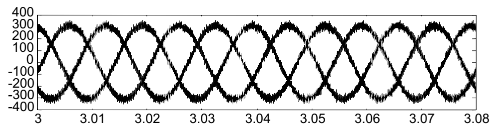

**o- Line voltages before and after compensation of harmonic voltages (at t=3s)**



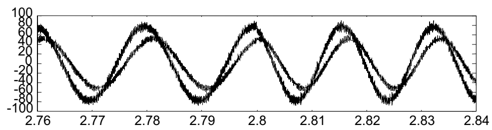

**p- Line voltages before and after undervoltage of 27% (at t=3.04s)**




**q- First phase series active filter voltage before and after under voltage with its reference**

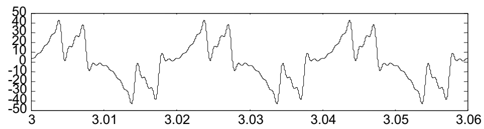



**r- Line voltages after compensation of harmonic voltages and undervoltage**

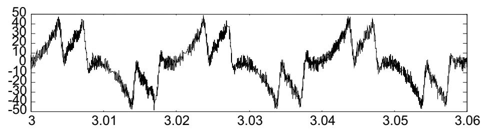



**s- Line voltage/4 and line current after harmonic voltage and current compensation with frequency variation from 50 Hz to 60 Hz (at t=2.8s)**

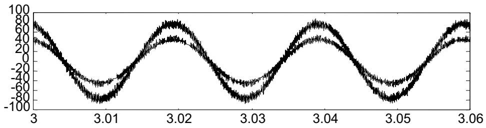
*B. With compensation of reactive power*



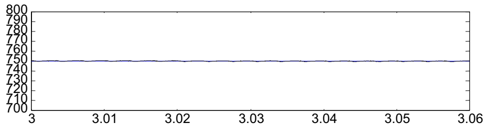

**a- Harmonic current reference**



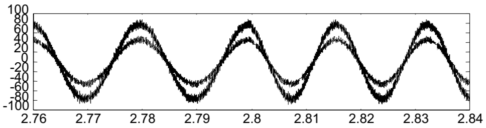

**b- Parallel active filter current**




**c- Line voltage/4 and line current after harmonic voltage and current compensation**




**d- Capacitor voltage with its reference**




**e- Line voltage/4 and line current after harmonic voltage and current compensation with frequency variation from 50 Hz to 60 Hz (at t=2.8s)**

The simulation of the system of active compensation using unified power quality conditioner was done in different electrical network conditions. These conditions such as harmonic currents, harmonic voltages, under voltage, frequency variations and reactive power allowed evaluating this kind of depollution techniques. The results show that unified power quality conditioner offers good filtering quality for line current as well as line voltage without forgetting its high performances in reactive power compensation even in variable frequency condition.

## VI. CONCLUSIONS

This paper makes it possible to have an idea on the performances of the unified power quality conditioner (UPQC) in elimination of electrical network disturbances such as harmonic currents, harmonic voltages, under voltage , frequency variations and reactive power. This depollution technique offers good quality of power in different conditions. It is performing and very adaptable.

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