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Shunt Active Power Filter for Current Harmonics Suppression Using Hysteresis Control

L. Zellouma, A. Omeiri and S. Saad
Department of Electrical and Electromechanical Engineering,
Faculty of Sciences Engineering, University of Badji Mokhtar, Annaba, Nigeria

Abstract: This study presents a simulation of a shunt active power filter for the suppression of current harmonics generated by a three-phase diodes rectifier converter. The shunt active power filter is a voltage source inverter using hysteresis control. To ensure the self adaptation of the active filter with the changes of the load a continuous diagram of regulation of the voltage and current injected are carried out. The results obtained by simulation gave good results to the levels of the reduction of the harmonics.The harmonic rate of distortion to calculate after filtering is lower than 5%, which is less than the international recommendations and standards.

Key words: Shunt active power filter, hysteresis control, current harmonics

INTRODUCTION

The increasingly frequent use of the power electronics converters (rectifier, inverter) becomes the principal cause of the pollution of the network electrical distribution of. They behave then like generators of harmonics while consuming reactive power.

These harmonics are at the origin of many problems and influential on the environment of the converter and cause the heating, ageing, destruction of the apparatuses and disturbance of the telephone lines, etc.

To minimize the effect of the harmonics of voltage and current, the supplier is brought to take precautions before connecting a new consumer or a new load. In certain country of the standards, rules and limits are imposed to the supplier and to the consumer of the electrical power to reduce harmonic pollution. Standard IEEE-519 proposes to use the calculation of the polluting power of an industrial facility to authorize the connection of a customer to a network.

Currently, all research is directed towards the active filtering of the harmonics, especially after the arrival of new components of power electronics (thyristor GTO, transistor MOSFET and IGBT). The success of this type of filtering is also with the development of the techniques of control of inverters (PWM, Hystérésis and more recently vectorial PWM) (Akagi, 1997; 1995; Karimi *et al*., 2005).

Several research related to this problem relates primarily to the model of power of the filter, the laws of control and the methods of generations of the signals of references. In this research we are interested in the adaptation of the active filter to the variation of the load.

This adaptation is the principal advantage of the active filter compared to the passive filter which becomes ineffective once the load changes suddenly of the variations.

To attenuate the harmonic disturbances, the passive filters are traditionally used. Their principle consists in deviating the harmonic current in low impedance placed in parallel with the polluting load to avoid its propagation in the network.

The traditional solution containing passive filters is penalized because of obstruction and resonance. Moreover, the passive filters cannot adapt to the evolution of the network and the polluting loads. Today the active filters are not only used for the suppression of the harmonics, but also for the compensation of reactive energy (Karimi *et al*., 2005).

The active filter is connected in parallel on the network. It injects into this last of the harmonic currents equal to those absorptive by the polluting load, but in opposition of phase. The current with dimensions network will be thus sinusoidal (Fig. 1).

CONTROL STRATEGY AND CURRENT HARMONICS IDENTIFICATION

The control by hysteresis, also called control in all or nothing, is a nonlinear order which uses the error existing

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Corresponding Author: L. Zellouma, Department of Electrical and Electromechanical Engineering,
Faculty of Sciences Engineering, University of Badji Mokhtar, Annaba, Nigeria

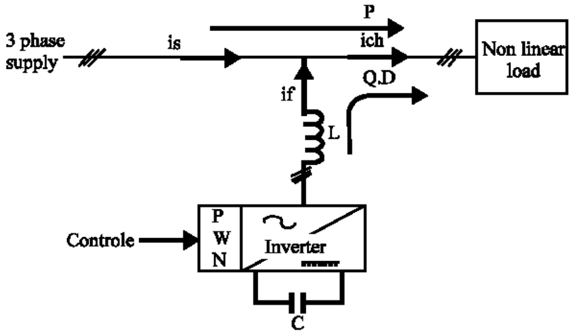

Fig. 1: Active power filter operation

between the current one of reference and the current produced by the inverter, this error is compared with a gauge called band of hysteresis.

The determination of the currents of references is based on the transformation α-β to obtain the real and imaginary powers. Let us note by (Vα, Vβ) and (Iα, Iβ) the orthogonal components of the reference mark α-β respectively associated with the voltage with connection with the parallel active filter (Vs) and with the currents absorptive by the polluting loads (Is) (Alali *et al.*, 2004; Abaali *et al.*, 2005; Bruyant and Machmoum, 1998).

$$\begin{bmatrix} Va \\ Vß \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Vs1 \\ Vs2 \\ Vs3 \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} Ia \\ Iß \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Is1 \\ Is2 \\ Is3 \end{bmatrix} \tag{2}$$

The real and imaginary instantaneous powers are given by the scalar and vector product of voltage and current.

$$p = V * I = V_\alpha I_\alpha + V_\beta I_\beta \tag{3}$$

$$q = V \wedge I = V_\alpha I_\beta - V_\beta I_\alpha \tag{4}$$

In matrix form :

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{pmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{pmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} \tag{5}$$

Inverting (5), the currents can be recall-calculated in α-β coordinates as shown in Eq. 6:

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{sß}^2} \begin{bmatrix} Vs\alpha & -Vsß \\ Vsß & Vs\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \tag{6}$$

In general, both p and q powers consumed by the load contain dc and ac components; therefore, their equation can be written in the following form.

$$\begin{cases} p = \bar{p} + \tilde{p} \\ q = \bar{q} + \tilde{q} \end{cases} \tag{7}$$

Considering Eq. 6 and 7, the current in α-β coordinates can be decomposed in active and reactive components due to fundamental voltages and currents.

The references currents in α-β coordinates are calculated according to the compensating objectives this is defined by:

$$\begin{bmatrix} I\alpha \\ I\beta \end{bmatrix} = \underbrace{\frac{1}{\Delta} \begin{bmatrix} Vs\alpha & -Vsß \\ Vsß & Vs\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix}}_{\text{Active current}} + \underbrace{\frac{1}{\Delta} \begin{bmatrix} Vs\alpha & -Vsß \\ Vsß & Vs\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \bar{q} \end{bmatrix}}_{\text{reactif current}} + \underbrace{\frac{1}{\Delta} \begin{bmatrix} Vs\alpha & -Vsß \\ Vsß & Vs\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix}}_{\text{Harmonic current}}$$

With:

$$\Delta = V_{s\alpha}^2 + V_{sß}^2 \tag{8}$$

Three phase distorted currents representing identified currents (reference currents I_{ref}), are calculated from (α-β) inverse transformation shown in the relation (9) presented below.

$$\begin{bmatrix} Iref1 \\ Iref2 \\ Iref3 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} Ih\alpha \\ Ih\beta \end{bmatrix} \tag{9}$$

Finally, this algorithm can be represented as shown in the block diagram of Fig. 2.

CONTROL OF THE ACTIVE POWER FILTER

So that the active filter adapts to the variation the load one must act on two essential parameters which are

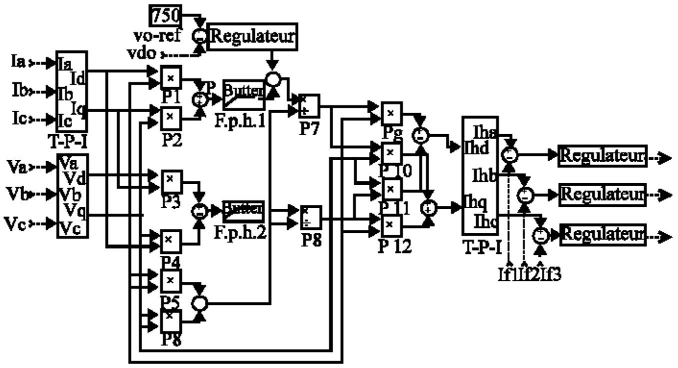

Fig. 2: Block diagram of APF current harmonics detection

the direct voltage at the entry of the inverter and the current of the parallel active filter (Alali *et al.*, 2004).

Dc voltage control: The capacitor average Voltage (V_{dc}) has to be maintained at a fixed value. The main cause of its variation is the active filter losses (switches and output filter). The energy storing capacitor voltage control must be done by the adjunction in reference currents of active fundamental currents.

The output controller Pc is added to the distorted active power $\tilde{p}$ giving an active fundamental current that corrects V_{dc}. The power P_c represents the active $\tilde{p}$ power required to maintain V_{dc} voltage equal to the value of the desired reference Voltage (V_{dcref}). The used controller is a simple proportional controller (K_c).

A first order filter is added at the proportional controller output in order to filter distortions at 300Hz Neglecting inverter commutation losses and the storing energy in the output filter inductance, the relation between the power absorbed by the active filter and the voltage across the capacitor is as follows: Alali *et al.*, (2004).

$$Pc = \frac{d(\frac{1}{2}C_{dc} \times V_{dc}{}^{2})}{dt} \tag{10}$$

Noting that (10) is a non linear relation. For low variations of V_{dc} voltage around its reference $V_{dcre}f$, it can be linearized through the following relations:

$$p_c = c_{dc} \times V_{dcref} \frac{d(V_{dc})}{dt} \tag{11}$$

$$\Rightarrow V_{dc}(s) = \frac{P_c(s)}{V_{dcref} c_{dc} S} \tag{12}$$

The control of dc voltage can be represented as shown in Fig. 3.

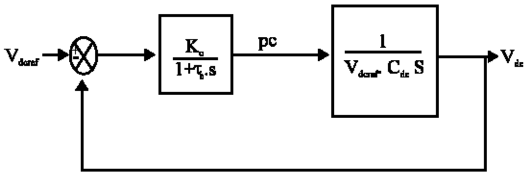

Fig. 3: DC voltage control block

REGULATION OF THE CURRENT OF THE PARALLEL ACTIVE FILTER

While neglecting effects of capacity C_{dc} and of resistances of filter of exit on current of reference I_{inj} (for the harmonics low frequencies which is far from the frequency of commutation), we can write the following relation characterizing the current of the active filter I_{inj}.

$$Lf \frac{d}{dt_{Iinj}} = V_f - V_s \tag{13}$$

Let us note by ΔI_f the difference between the current of reference and the current measured starting from the following relation:

$$\Delta I_f = I_{ref} - I_{inj} \tag{14}$$

From the Eq. 13 and 14, we obtain the expression below:

$$Lf \frac{d}{dt} \Delta I_f = (V_s + L_f \frac{d}{dt} I_{ref}) - V_f \tag{15}$$

The first term of the right part of the relation (15) can be defined like reference voltage standard (V_{fref}), which gives us the following expression:

$$V_{fref} = V_s + L_f \frac{d}{dt} I_{ref} \tag{16}$$

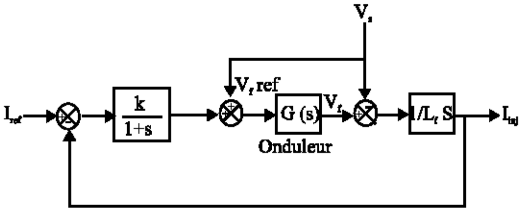

Fig. 4: Current control block

The difference between V_{fref} and V_f then produces an error on the current. According to the relation (16), the reference voltage standard is made up of two terms at different frequencies. The first represents the voltage of the directly measurable Vs network. Second is equal to the voltage drop at the boundaries of Lf inductance, when this one is crossed by a current equal to that of the reference. This term must be worked out by a regulator of current, as shows it.

We simply use for each phase a regulator proportional followed by a first order low-pass filter. The role of this filter is to attenuate the high frequency signals coming from the PWM. The diagram of the regulation is represented on Fig. 4.

SIMULATION BY MATLAB

The simulation programs developed under MATLAB Simulink, make it possible to visualize on an interval of time given the evolution of the currents and voltage in the various branches of the circuit of.

The simulation of the filter is made for two types of load RL and RC.

Active filter compensation rapidity is studied during the changing of a non linear load.

RESULTS AND DISCUSSION

The obtained results showed clearly the adaptation of the active shunt filter to different load variations as illustrated in Fig. 5 and 8.

Active filter supply voltage supply is a capacity with its voltage sensitive to active power interchange between load and power system (Fig. 6 and 7). To maintain this voltage to a noticeably constant level a control loop is designed as shown in dc control block scheme shown in Fig. 3. Shunt active filter injected current is controlled as shown in Fig. 4. These two control block diagrams have shown an excellent active filter adaptation to different load variations.

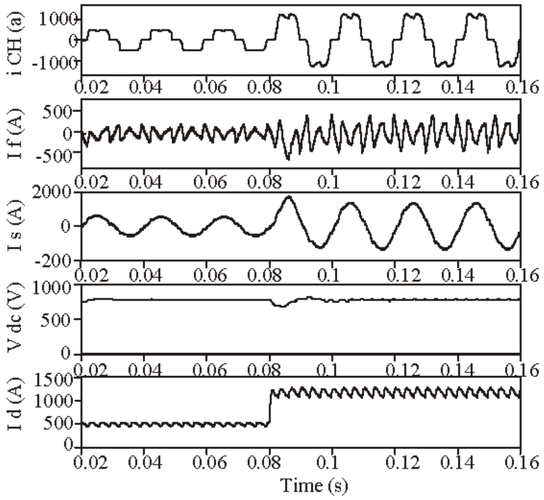

Fig. 5: Obtained waves for RL load

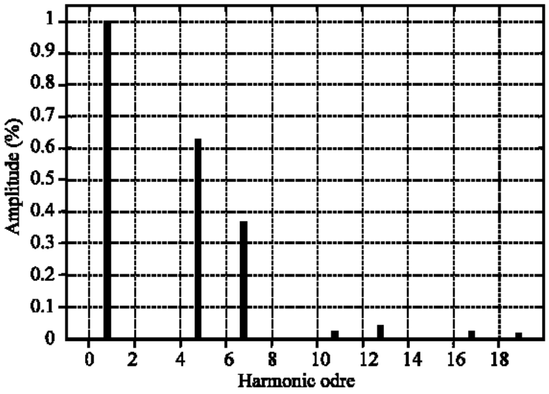

Fig. 6: Supply current spectrum without filter

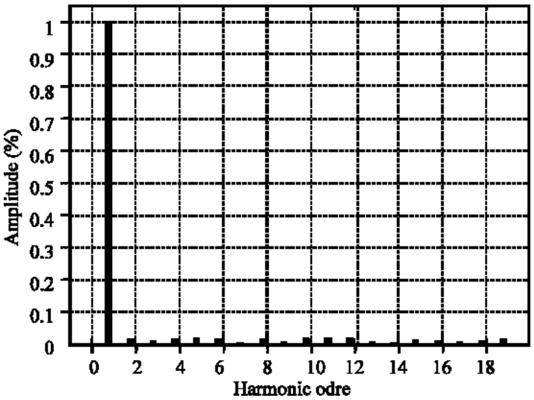

Fig. 7: Supply current spectrum with filter

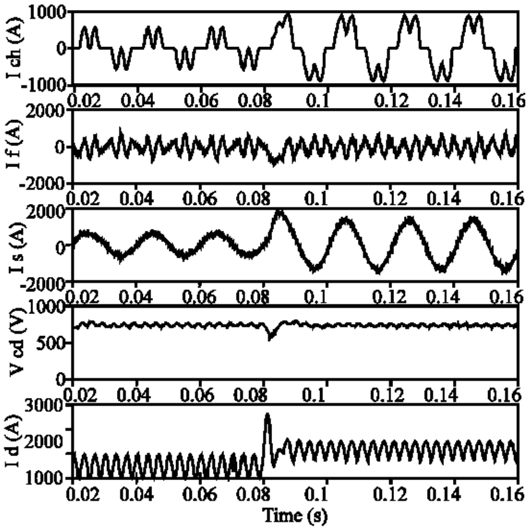

Fig. 8: Obtained waves for RC load

CONCLUSION

The active filter imposed the form of sinusoidal wave for the currents of the network with an instantaneous dynamics, the THD of its currents passes from 72.37% to less than 4.39% for load RC and 23.53 to 3.85% for load RL. These results better than those are obtained with the other methods of filtering. The standards stated with an aim of ensuring the electromagnetic compatibility of the electrical supply networks are respected; moreover we saw that it can also compensate for absorptive reactive energy, of the network. That allows the power factor to have a value very close to the unit. Future work goes directed towards other techniques of more powerful control of the inverters of the filters such as the PWMV instead of the order by hysteresis.

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