Active Filter Using A New Direct Power Control (DPC0) Under Imbalanced And Distorted Conditions

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***Abstract*—In this paper, we present a new technique for active compensate of harmonics and reactive power, based on the method of instantaneous active and reactive power by introducing a new Direct Power Control called DPC0 where we imposed a reference power (pref) as null and the reference reactive power (qref) which was also imposed null with conventional DPC. We have also introduced two extractions multivariable filters "MVF" which are highly selective, and consequently making the compensation currents harmonics and reactives to obtain a unity power factor, and a good sinusoidal current source even under imbalanced and distorted conditions.**

The simulation was done in the Matlab/Simulink environment, for system power diode PD3 debits on an inductive load. The simulation results showed clearly the effectiveness of this new technique.

Key words: Active filters; Direct power Control DPC; DPC0; Harmonic; instantaneous active power.

I. INTRODUCTION

The harmonic pollution affects all grids, industry or domestic. No modern environment can escape to this pollution equipment such as computers, servers, air conditioning, speed rectifiers, discharge lamps, microwave ovens, televisions, halogen lights... All these loads so called "non-linear"; participate considerably in damaging the "quality" of the grid current and voltage [1] [2].

The different identification methods of disturbing current can be grouped into two families.

The first one uses the fast Fourier transform in the frequency domain to extract the current harmonics. This method is well suited for loads where the harmonic content varies slowly. It also gives the advantage of select the harmonics individually and only choose to compensate the most predominant. It should be noted that this method requires a lot of computing power to achieve real-time all the necessary transformations to extract the harmonics [3]

The second family is based on the calculation of instantaneous power in the time domain. Some of these methods are based on the calculation of harmonic powers of nonlinear loads. Others may be used to compensate for both the harmonic currents and the reactive power, based on the subtraction of the fundamental active portion of the total current. [4]

The method of instantaneous active and reactive powers was originally developed by Akagi [1] [2] [5]. This method has the advantage of choosing the perturbation to compensate with precision, rapidity and easiness of implementation.

The principle of direct control of power electronic converters in MLI was proposed for the first time in 1986 [6] and was later developed in many applications. The purpose of the direct control of these systems was to eliminate the block pulse width modulation and loops internal regulations of controlled variables, replacing them with a predetermined switching table, whose entries are the tracking errors reference controlled variables and the output is the control vector.

The first configuration of this type of control has been proposed in [7], for the direct control of instantaneous active and reactive powers of three-phase PWM rectifier without voltage sensors network. After, this approach is developed, and various configurations have been proposed [8]. The common objective of this review was to ensure the removal of sinusoidal currents while guaranteeing a unity power factor with a decoupled control of active and reactive power. [9]

The DPC standard imposes the reference reactive power (qref) as null, while the reference active power (pref) is calculated from the product of the controller output DC bus with the voltage Vdc.

The proposed DPC0 requires two references (pref and qref) as null.

This paper, presents the study of a new technique of control called DPC0, based on the DPC technique but with a modification of the reference power (pref). In section II, we have given the famous characteristics of the quality enenrgy such as power factor and harmonic distortion rate. The different types of passive and active filtering were discussed in section III. Section IV contains the principle of classical DPC, heavers the principle of DPC0 is given in Section V, followed by the results of simulation in Matlab-Simulink in Section VI. At the end, we give a conclusion about the advantages of proposed technique DPC0.

II. THE QUALITY OF ENERGY

The quality of energy can be characterized by:
- Power factor:

$$F_p = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2 + D^2}} \quad (1)$$

With P : Active power,
S : Apparent power,
Q : Reactive power,
D : Deforming power.

- Total Harmonic Distortion:

$$THD_i(\%) = 100 \times \sqrt{\sum_{2}^{\infty}\left(\frac{I_h}{I_1}\right)^2} \quad (2)$$

III. THE DEPOLLUTING HARMONICS

The respect of standards required if a non-linear load is connected to the network voltage, to design a system that reduces harmonics, such as filtering. There are two types of filtering: passive and active.

A. *Passive feltering*

Its principle is to insert upstream of one or more load circuits tuned to reject harmonics. A passive filter is composed of passive elements such as inductors, capacitors and resistors, which form impedance whose value varies depending on the frequency.

However, these filters have some drawbacks:
- The resonance
- The size,
- Weight.

B. *Active feltering*

The purpose of the active filters is to generate either the currents or harmonic voltages so that the source current or the source voltage again becomes near sinusoidal. The active filter is connected to the network either in series or in parallel depending on compensation type, voltage or current harmonics, either associated with passive filters. [10]

The shunt active filter power presents advantages and disadvantages compared to passive filters. [11][12]

1) Advantages
- The size of the active filter is reduced.
- The compensation capacity harmonics and power factor is greater.
- Flexibility and adaptability are better.

2) Disadvantages:
- High cost,
- High size.

The general structure of the active filter parallel is composed of two blocks (fig.1): power section and control section.

Power section consists of:
- a voltage source inverter
- an energy storage circuit, often capacitive
- an output filter.

Control section consists of:
- block of currents identification
- a PLL
- DC bus regulation
- Injected currents regulation
- Inverter control (fig.1). [13]

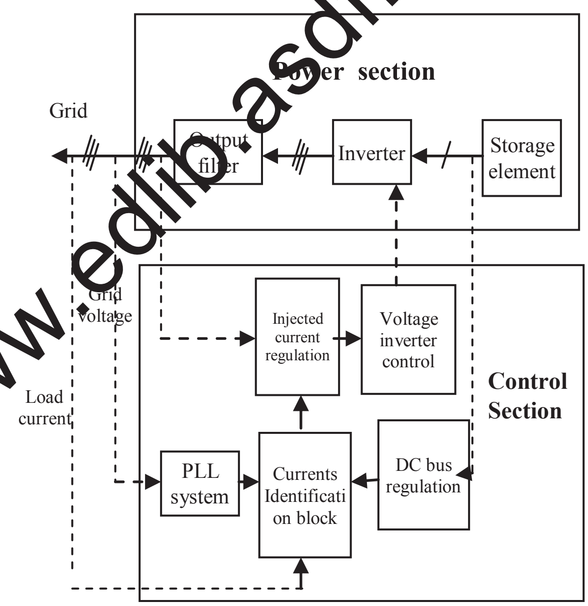

Fig. 1: General structure of shunt active filter

IV. PRINCIPE OF DIRECT POWER CONTROL DPC[9] [14]

DPC control strategy applied to shunt active power filter (SAPF) is illustrated in the block diagram of Fig.2. It is to select the appropriate from a switching table based on errors, which are limited by a hysteresis band, present in the active and reactive power state.

Two important aspects guarantee the proper functioning of the system:
- An exact determination of the switching states.
- Fast and accurate estimation of active and reactive power.

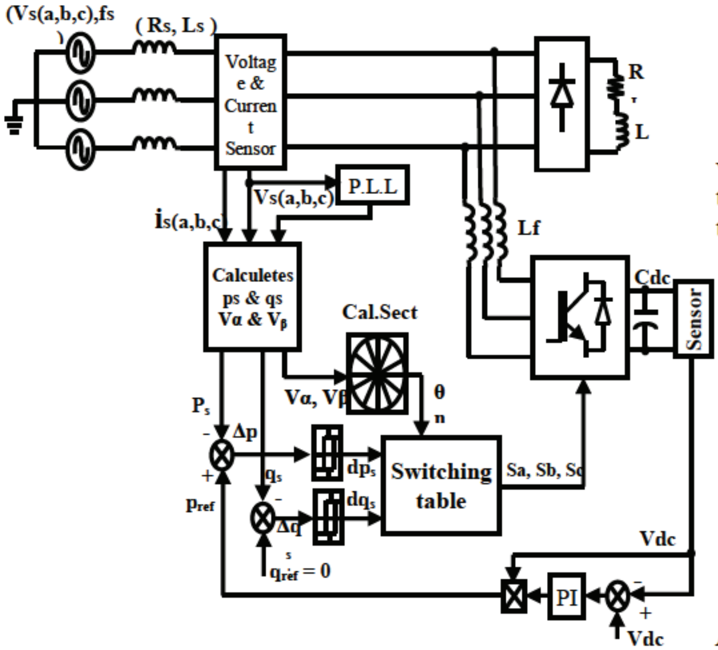

Fig. 2: Synoptic control SAPF with DPC control

A. Instantaneous active and reactive powers

Based on the measurement of voltage and current source, active and reactive instantaneous power can be calculated by the expressions: [15]

$$p(t) = v_{sa}.i_{sa} + v_{sb}.i_{sb} + v_{sc}.i_{sc} \quad (3)$$

$$q(t) = \frac{1}{\sqrt{3}}\left[(v_{sa} - v_{sb})i_{sc} + (v_{sb} - v_{sc})i_{sa} + (v_{sc} - v_{sa})i_{sb}\right] \quad (4)$$

B. Hysteresis controller

The main idea of the CPD is to maintain active and reactive instantaneous power in a desired band. This control is based on two hysteresis comparators using as input the error between the reference values and estimated signals of active and reactive power.

$$\Delta p_s = p_{ref} - p_s \quad (5)$$

$$\Delta q_s = q_{ref} - q_s \quad (6)$$

The two hysteresis comparators two levels used to establish two logic outputs dps and dqs taking the state "1" for an increase in the controlled variable (ps and qs) and "0" for a decrease:

$$si\ \Delta p_s \geq hp \ \ dp_s = 1;\ si\ \Delta p_s \leq -hp \ \ dp_s = 0 \quad (7)$$

$$si\ \Delta q_s \geq hq \ \ dq_s = 1;\ si\ \Delta q_s \leq -hq \ \ dq_s = 0 \quad (8)$$

C. Choice of sector

The calculation of the angular position of the vector of the mains voltages in the stationary α-β plane requires knowledge of the components vα vβ, which can either be calculated from measurements of the mains voltages, this position is defined by the following equation:

$$\theta = arctg(\frac{v_\beta}{v_\alpha}) \quad (9)$$

In turn, the number of the sector where the vector of voltages is determined by comparing the angle θ with the terminals of each of the twelve sectors that are defined by the equation below:

$$(n-2)\frac{\pi}{6} \leq \theta_n \leq (n-1)\frac{\pi}{6} \quad n = 1, 2, \ldots, 12 \quad (10)$$

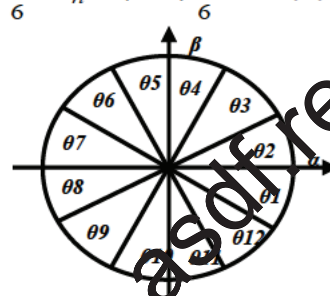

Fig. 3. Representation of the sectors in the vector space (α, β)

D. Table Switching

Once the logic outputs of the hysteresis comparators established following the sector number where is the vαβ vector, the vector of voltages to be applied to the rectifier input is selected from the Classic switching table as shown the following table:

TABLE I
THE VECTORS IN SWITCHING TABLE OF DPC

S_p	S_q	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6	θ_7	θ_8	θ_9	θ_{10}	θ_{11}	θ_{12}
1	0	v_6	v_7	v_1	v_0	v_2	v_7	v_3	v_0	v_4	v_7	v_5	v_0
	1	v_7	v_7	v_0	v_0	v_7	v_7	v_0	v_0	v_7	v_7	v_0	v_0
0	0	v_6	v_1	v_1	v_2	v_2	v_3	v_3	v_4	v_4	v_5	v_5	v_6
	1	v_1	v_2	v_2	v_3	v_3	v_4	v_4	v_5	v_5	v_6	v_6	v_1

v1(100), v2(110), v3(010), v4(011), v5(001), v6(101), v0(000), v7(111).

E. The PI controller

DPC control must control regulation of the DC bus to maintain the voltage across the capacitor (Vdc), varying around the reference voltage (Vdcref), for this advantage of a PI controller is used.

Figure 4 shows a diagram of the PI controller used in the simulation.

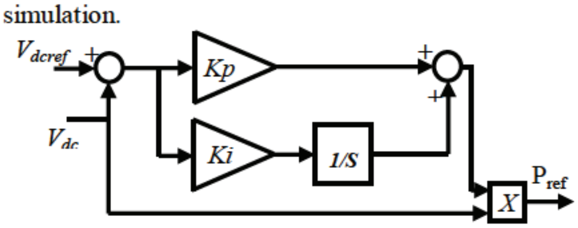

Fig.4 PI controller structure used in simulation for DPC

The values of Kp and Ki are given by the following relations:

$$k_i = C_{dc}.\omega_0^2 \quad (11)$$

$$k_p = 2.C_{dc}.\xi.\omega_0 \quad (12)$$

IV. PRINCIPE OF PROPOSED DIRECT POWER CONTROL DPC0

Figure 5 shows the new structure of the proposed DPC. This command (DPC0) requires the reference of power (pref = 0), as well as reference reactive power (qref = 0). The reference power (pref) is calculated using two variables multi filters (MVF).

Pc is the power required for maintaining the voltage of the DC bus near of Vdcref.

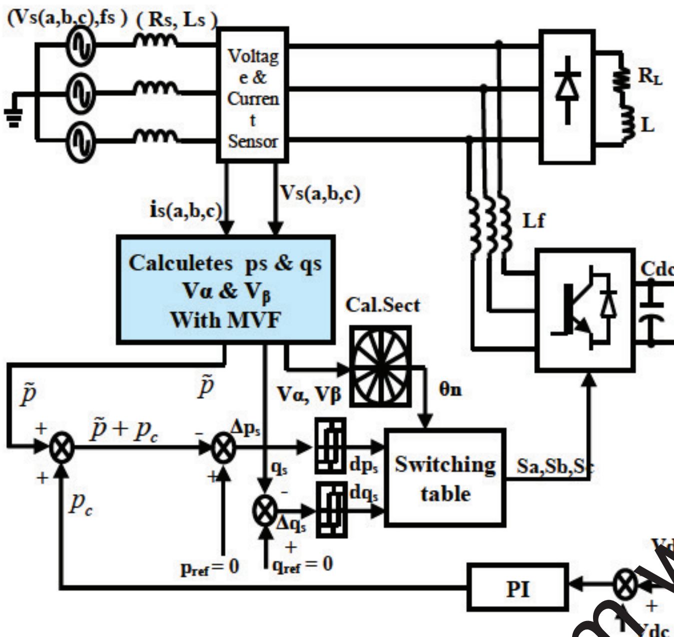

Fig.5 Synoptic control SAPF with MVF and DPC0 control

A. *The multivariate filter (MVF)*

To improve the performance of the method of conventional instantaneous power, we implement a filter bandwidth, highly selective, called "multi-variable filter" (MVF).

The role of MVF is to extract the fundamental component of the signal (voltage or current) directly along the αβ axes, without phase or amplitude variation. The transfer function of this filter can be given as follows:[16]

$$H(s) = \frac{\hat{x}_{\alpha\beta}(s)}{x_{\alpha\beta}(s)} = k\frac{(s+k)+jw_c}{(s+k)^2+w_c^2} \qquad (13)$$

We note that the pulse ω = ωc, the phase shift introduced by the MVF is zero and the gain unit (also corresponding to 0 dB). Thus, the output signals are equal to the input signals for the pulse. In addition, the MVF has a high attenuation for all other different pulses ωc, including the DC component of the signals. Note also that the decrease in the value of K increases the selectivity of the MVF. (fig.6)

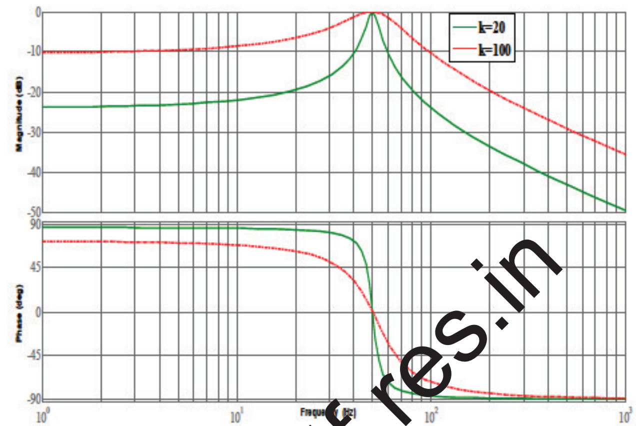

Fig3 bode diagram

From the transfer function (13), we obtain:

$$\hat{x}_\alpha(s) = \frac{k}{s}\left[x_\alpha(s)-\hat{x}_\alpha(s)\right] - \frac{w_c}{s}\hat{x}_\beta(s) \qquad (14)$$

$$\hat{x}_\beta(s) = \frac{k}{s}\left[x_\beta(s)-\hat{x}_\beta(s)\right] + \frac{w_c}{s}\hat{x}_\alpha(s) \qquad (15)$$

The block diagram of the MVF is shown in Figure 7

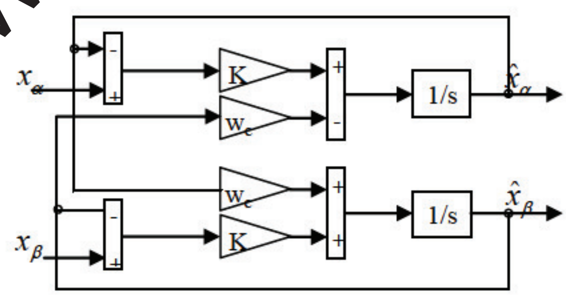

Fig.7: Block diagram of the multivariable filter

Figure (7) shows the principle proposed to identify the reference currents. In the proposed new method, the reference currents are identified using a modified version of the method pq associated with two FMVs. The AC components of active and reactive instantaneous power is obtained by the equation (16): [17]

$$\begin{bmatrix}\tilde{p}\\ -\tilde{q}\end{bmatrix} = \begin{bmatrix}\widehat{V_\alpha} & \widehat{V_\beta}\\ -\widehat{V_\beta} & \widehat{V_\alpha}\end{bmatrix}\begin{bmatrix}i_{h\alpha}\\ i_{h\alpha\beta}\end{bmatrix} \qquad (16)$$

with ihα and ihβ defined by:

$$i_{h\alpha} = (i_{\alpha d} - \hat{i}_{\alpha d}) + (i_{\alpha inv} - \hat{i}_{\alpha inv}) \qquad (17)$$

$$i_{h\beta} = (i_{\beta d} - \hat{i}_{\beta d}) + (i_{\beta inv} - \hat{i}_{\beta inv}) \qquad (18)$$

The terms ihα and ihβ contain harmonics, direct and inverse components.

The fundamental component of the instantaneous reactive power is defined by:

$$\bar{q} = \hat{v}_\beta \hat{i}_\alpha - \hat{v}_\alpha \hat{i}_\beta \qquad (19)$$

After adding the alternating component of the instantaneous active power, active power pc necessary to regulate the voltage vdc.

The reference active power pref can be written as follows:

$$p_{ref} = \tilde{p} + p_c \qquad (20)$$

With :

- $\tilde{p}$ alternating power is related to the sum of the disruptive components of the current and voltage.
- p_c is the necessary active power to regulate the continuous output voltage vdc

VI. Results of the Simulation

A. *With the DPC control*

Figure 8 shows the THD current source isa and the dynamic behavior of the filter when changing the state of the source also when changing the load.

Phase (1): This is before connecting the filter before time 0.5 s; THDis = 27.89%

Phase (2): the is balanced and undistorted at time 0.05 to 0.2s; THDis = 3.49%

Phase (3): the source is balanced but with distortion at time 0.2 to 0.3s; THDis = 4.95%

Phase (4) the source is unbalanced with distortion at time 0.05 to 0.2s; THDis = 5.89%

Phase (5): the source is unbalanced and undistorted at time 0.05 to 0.2s; THDis = 3.59%

Phase (6): load change from 0.5 s; THDis = 2.78%.

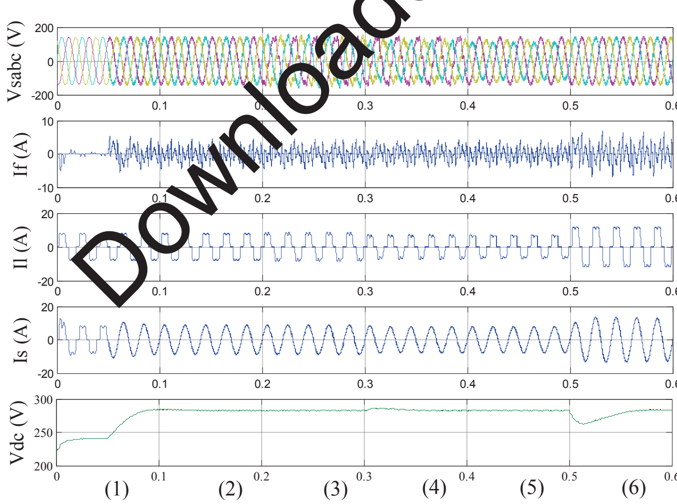

Fig.8 The dynamic behavior of the filter

B. *With the control DPC0*

Figure 9 shows the voltage source and current source, the load current and the filter current for deferent case of the source (balanced, unbalanced, with or without distortion)

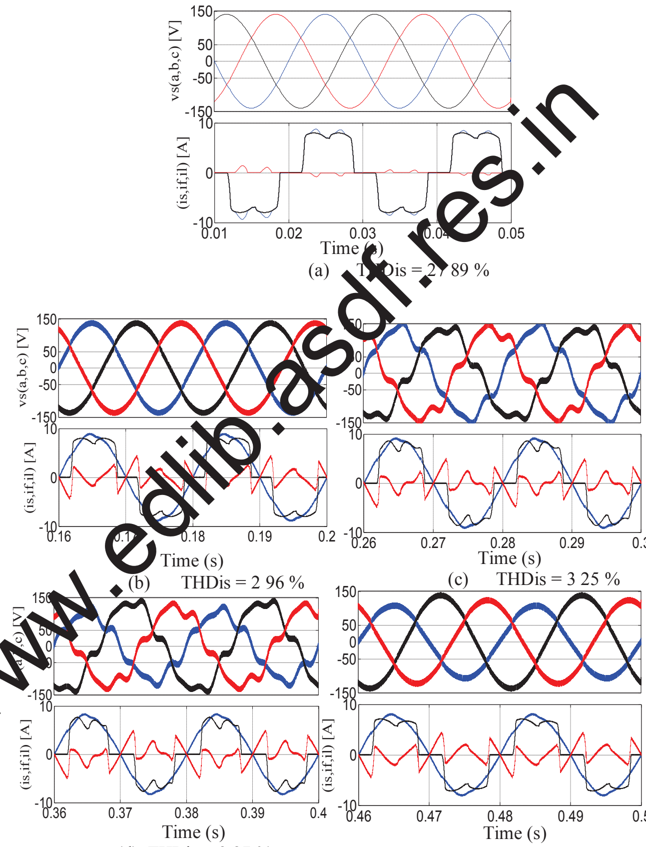

Fig 9 : the source voltages Vs (a, b, c) and the current source Isa, the current filter Ifa , and load current Ila with THD of the source current for deferent cases

- Case (a): before connecting the filter.
- Case (b): a balanced voltage source without distortion.
- Case (c): a voltage source balanced but distorted.
- Case (d): an unbalanced and distorted source voltage
- Case (e): an unbalanced source voltage without distortion

Figure 10 shows the dynamic behavior of the filter when changing the state of the and at the load change.

Phase (1): This is before connecting the filter before time 0.5 s; THDis = 27.89%

Phase (2): the is balanced and undistorted at time 0.05 to 0.2s; THDis = 2.96%

Phase (3): the source is balanced but with distortion at time 0.2 to 0.3s; THDis = 3.25%

Phase (4) the source is unbalanced with distortion at time 0.05 to 0.2s; THDis = 3.27%

Phase (5): the source is unbalanced and undistorted at time 0.05 to 0.2s; THDis = 3.25%

Phase (6): load change from 0.5 s; THDis = 2.72%.

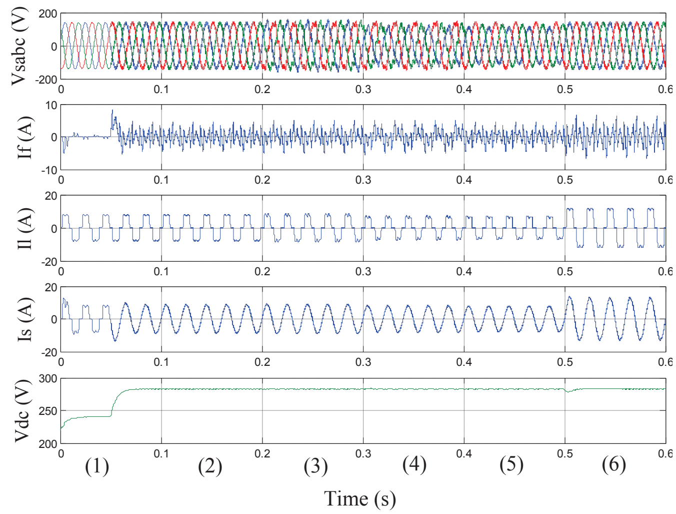

Fig.10 The dynamic behavior of the filter

VII. Conclusion

In this paper , we have presented the performance of the technique DPC that uses high selectivity filter MVF. As conclusion, we cane note that:

- Technical conventional DPC gives good results only for a balanced and undistorted network.
- MVF filter is very effective for extracting harmonic references and easy to implement.
- As this command we do not require a PLL for the identification of harmonics.
- This new technique allows us to compensate harmonics whatever the state of the network: balanced or unbalanced and / or distorted. Because in all cases network the simulation results gave a THDi <4% (standard norm).

TABLE 2

	DPC Classique			DPC0		
	THD_{Vsa} %	THD_{ila} %	THD_{isa} %	THD_{Vsa} %	THD_{ila} %	THD_{isa} %
case(1)	0.51	27.97	27.89	0.51	27.97	27.89
case(2)	[illegible]	28.17	3.49	6.04	28.05	2.96
case(3)	[illegible]	29.69	4.95	14.18	29.54	3.25
case(4)	17.78	35.00	5.89	18.57	35.89	3.27
case(5)	8.22	31.69	3.59	8.25	31.90	3.25
Case(6	5.90	27.64	2.78	5.97	27.62	2.72

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