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Advanced control strategy based Hybrid Active Power Filter for power quality improvement

SARRA Mustapha[1,*], DJAZIA Kamal[2] and BOUDECHICHE Ghania[1]

[1]*Electronique Department, E.T.A Laboratory, University of Bordj Bou Arreridj, Algeria.*
[2]*Electronique Department, University of M'sila, Algeria.*

**(mustapha.sarra@univ-bba.dz) Email of the corresponding author*

Abstract – This paper deals with an advanced control algorithm applied to a three phase shunt hybrid active power filter (SHAPF) for power-quality enhancement and reactive power compensation required by nonlinear loads. The suggested control establishes the reference current for the SHAPF using a reliable PLL based on High Selective Filters (HFS). The SHAPF is composed of a small-rated three-phase active filter and a single seventh tuned LC filter per phase that are coupled in series without the need of a matching transformer. The active filter's necessary rating is substantially lower than that of a traditional standalone active filter. All simulations are carried out using the Matlab-Simulink Power System Blockset. Several simulation results of the proposed control algorithm under steady-state and transient conditions are presented to confirm their validity and efficacy.

Keywords – Phase Looked Loop (PLL), High Selective Filter (HSF), Shunt Hybrid Active Power Filter, Power Quality.

I. Introduction

The increasing use of controlled systems based on power electronics (non-linear loads) in industry causes an increase in disturbance concerns in electrical distribution networks. These non-linear loads absorb non-sinusoidal currents, even if they are supplied by a sinusoidal voltage, they therefore behave as generators of harmonic currents and are also liable to exchange reactive energy. Thus, a regular increase in harmonic levels, current imbalances sometimes, as well as a significant consumption of reactive power are observed on the networks. This article illustrates a solution for depolluting these networks using a hybrid power active filter (FAPH) consisting of the combination of an Active power Filter (APF) and a passive power filter (PPF). This is a three-phase Shunt Active Filter based on a voltage inverter connected directly and without a transformer in series with a three-phase LC-type passive filter, tuned to the seventh harmonic order. The FAPH control strategy is based on the instantaneous active and reactive power method (p-q theory) proposed by Akagi et al. [1]-[9]

II. CONFIGURATION AND COMPENSATION PRINCIPLE

The hybrid filter is a topology that combines the advantages of passive filters and active filters. For this reason, it is considered one of the best solutions for filtering current harmonics from distribution networks. One of the main reasons for the use of the hybrid active filter is linked to the development of power semiconductors and their integration into compact architectures as well as the evolution of tools for implementing real-time control algorithms. Furthermore, from an economic standpoint, the hybrid filter has a significant advantage: it allows for a reduce in the cost of the active filter due to a reduction in the limitations, which are now important obstacles to their deployment. In this configuration of the SHAPF (Fig. 1), both active and passive filters are directly connected in series, without the intermediary of a transformer. The assembly is connected in parallel to the common connection point. In this case, the passive filter operates like a low impedance at the tuning frequency and like a high impedance at the fundamental frequency. This system has two advantages:

- The power dimensioning of the active filter is lower because the current passing through it is lower,
- The active filter is protected from any short circuit of the load.
- The value of the DC bus voltage is strongly attenuated.

The overall FAPH system to be studied consists of three parts:

- The three-phase power supply network,
- The non-linear load symbolized here by a diode bridge PD3 delivering in an R-L load,
- The hybrid filter (voltage structure inverter associated with a passive three-phase LC filter) with its control.

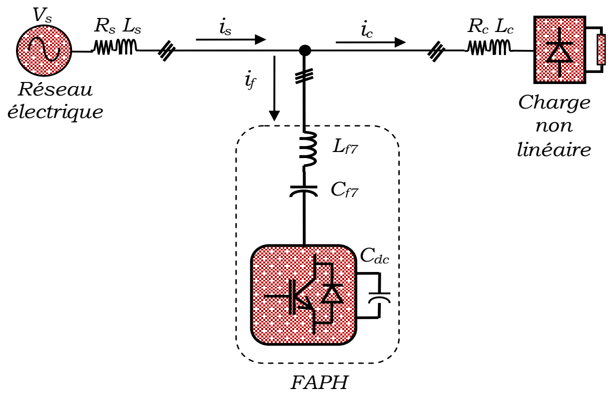


Fig. 1 Proposed SHAPF structure

The LC passive filter absorbs the 7th harmonic currents generated by the non-linear load and the active filter improves the efficiency of the passive filter. It also has the role of blocking the fundamental voltage of the network and thus reducing the voltage constraints of the active filter. Capacitance Cdc plays the role of a DC voltage source.The waveforms of the different currents of such a structure are shown in Figure 2.

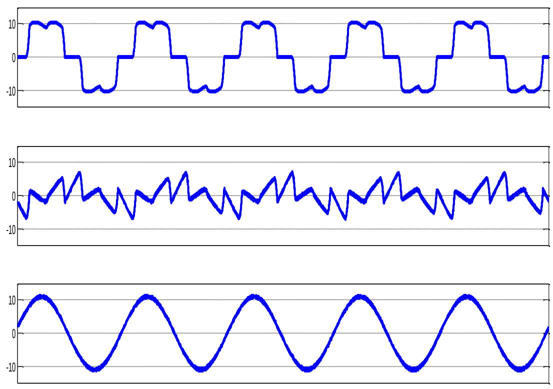


Fig. 2 Currents waveform: of load i_L (t), of filtre i_f (t) and of grid i_S(t)

Figure 3 presents the control strategy of the FAHP to determine the reference currents by exploiting the instantaneous active and reactive powers theory. The principle is based on the transition from a three-phase system made up of phase-to-neutral voltages and load currents, to a two-phase system (α-β reference) using the Concordia transformation, in order to calculate the instantaneous real and imaginary powers respectively P and Q. (V_α,V_β) and (I_α,I_β) represent the orthogonal components of the reference α-β associated respectively with the phase-to-neutral voltages (V_{sa}, V_{sb}, V_{sc}) of the three-phase three-wire system (without homopolar component), and to the currents (i_{ca}, i_{cb}, i_{cc}) absorbed by the nonlinear load. The α-β transformation is obtained using the following relation:

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & +\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \quad (1)$$

The instantaneous active power P(t) is defined by the following relation:

$$P(t) = V_{sa}.i_{ca} + V_{sb}.i_{cb} + V_{sc}.i_{cc} = V_\alpha.I_\alpha + V_\beta.I_\beta \quad (2)$$

Similarly, the instantaneous imaginary power q(t) may be described as follows:

$$q(t) = -\frac{1}{\sqrt{3}}\left[(V_{sa}-V_{sb}).i_{cc} + (V_{sb}-V_{sc}).i_{ca} + (V_{sc}-V_{sa}).i_{cb}\right]$$
$$= V_\alpha.I_\beta - V_\beta.I_\alpha \quad (3)$$

From relations (2) and (3), the following relation can be established:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \cdot \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (4)$$

Then, to determine the load's harmonic currents, the fundamental component is transformed into a DC component and the harmonic components into AC components.

Knowing that each of the powers p and q include a continuous and alternative parts, it will be written in the following form:

$$\begin{cases} p = \bar{p} + \tilde{p} \\ q = \bar{q} + \tilde{q} \end{cases} \quad (5)$$

Two high pass filters are then used to extract the AC components of the real and imaginary instantaneous powers respectively and . The currents in the α-β frame can be deduced by inverting the relation (4) as shown in equation (6)

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \cdot \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \cdot \begin{bmatrix} p \\ q \end{bmatrix} \quad (6)$$

The inverse Concordia transform is then used to extract the three-phase reference currents (Irefa, Irefb ,Irefc) given by the following equation:

$$\begin{bmatrix} I_{refa} \\ I_{refb} \\ I_{refc} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & +\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (7)$$

Losses in the active filter (switches and output filter) are the main cause liable to modify the mean voltage V_{dc} of the DC bus, and which therefore must be maintained at a fixed value. Regulation of this voltage V_{dc} must be done by adding active fundamental currents to the reference currents. The output P_c of the regulator is added, to within one sign, to the active disturbing power and gives rise to an active fundamental current thus correcting V_{dc}. The power P_c represents the active power required to maintain the voltage V_{dc} equal to the value of the desired reference voltage (V_{dc}*). The regulator employed here is a simple proportional regulator (K). The measured voltage V_{dc} is filtered beforehand in order to attenuate fluctuations at 300 Hz. By neglecting the switching losses in the inverter as well as the energy stored in the inductance of the output filter, the relationship between the power absorbed by the active filter and the voltage across the capacitor can be written in the following form:

$$P_c = \frac{d}{dt}\left(\frac{1}{2} C_{dc}.V_{dc}^2\right) \quad (8)$$

For small variations of the voltage V_{dc} around its reference V_{dc}*, the relation (9) can be linearized and becomes:

$$P_c = C_{dc}.V_{dc}^* \frac{d}{dt}(V_{dc}) \quad (9)$$

By applying the Laplace transformation, we obtain:

$$P_c(s) = C_{dc}.V_{dc}^*.s.V_{dc}(s) \quad (10)$$

So,

$$V_{dc}(s) = \frac{P_c(s)}{V_{dc}^*.C_{dc}.s} \quad (11)$$

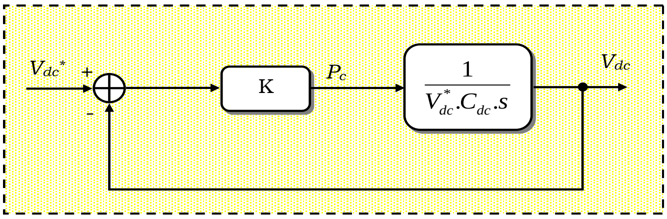


Fig. 4. Regulation of DC bus voltage V_{dc}.

The closed loop DC bus voltage regulation is represented by the block diagram of Figure 4 taking into account the proportional regulator K whose parameter must be chosen so as to obtain a minimum response time in order not to harm the dynamics of FAPH. Finally, to control the FAHP, a fixed-band hysteresis-type current regulator is implemented for its simplicity and robustness. [5]-[19].

III. SYSTEM MODELING AND SIMULATION

To simulate the proposed FAHP, a simulation model is developed under Matlab\SimulinkTM environment by exploiting the SimPowerSystems toolboxes. The general structure of the complete system studied consists of:

- A three-phase three-wire electrical network represented by the quantities (Vs, Rs, Ls),
- A non-linear load represented by a diode rectifier bridge (PD3), delivering on an inductive load (Rd, Ld),
- FAHP, consisting of a three-arm voltage inverter with IGBTs, an energy storage capacitor Cdc playing the role of a DC voltage source Vdc, a passive output filter (LF, CF) tuned to the 7th harmonic.

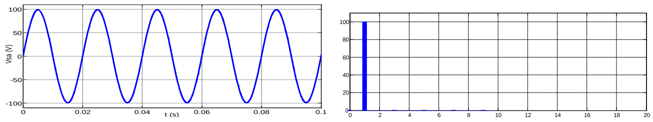
The simulation parameters are summarized in the table below:

Table 1 : Parameter values of the studied system.

Electrical network		non-linear load		SHAPF		Regulator	
Vs	100 V	R_c,	0.01Ω	C_{dc},	1100µF	K_p	30
		L_c	566µH	V_{dc}	55 V		
R_s	0.1Ω,	R_d,	16.15Ω	L_{f7},	3.5mH	H	0.2
L_s	50µH	L_d	1mH	C_{f7}	110µF	B	

IV. SIMULATION RESULTATS

Initially, the simulation according to the parameters of table 1, only concerns the electrical network with the nonlinear load, the FAPH being disconnected from the system.



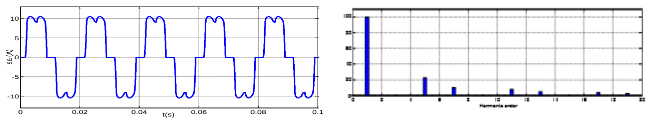


Fig. 4 (a) Network voltage Vsa(t) and its harmonic spectrum; (b) Mains current isa(t) and its harmonic spectrum,

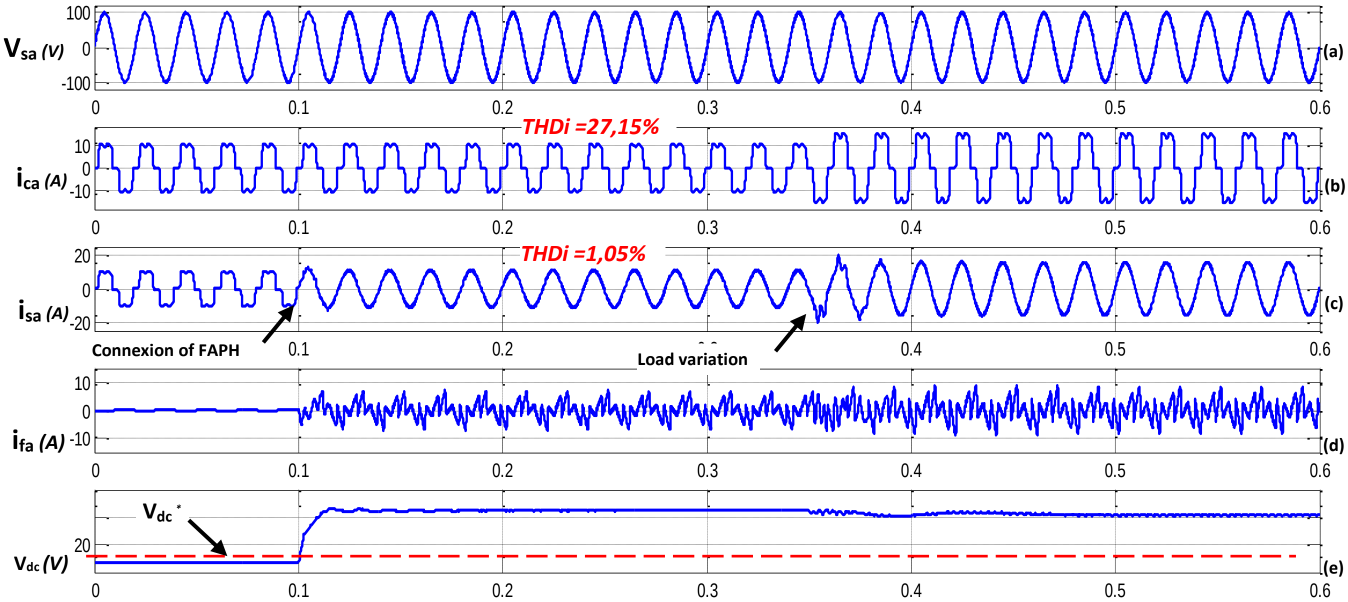


Figure 5: (a) Network voltage Vsa(t), (b) Load current ica(t), (c) Network current isa(t); (d) Current injected by the FAPH ifa(t) (e) DC bus voltage Vdc(t)

Figure 4 presents the simulation results of the network voltage Vsa and current isa (identical to the load current iCa) for phase a as well as their harmonic spectra, knowing that the FAPH is not yet connected to the network . The current THDi for this load is 27.15%, which proves that the electrical network is strongly disturbed by the nonlinear load generating harmonic currents. The purpose of the FAPH is to reduce this THD to a value below 5%, as required by the IEC standard.

Subsequently, the complete system (electrical network, non-linear load, FAPH) is simulated according to the following steps: After the system has been started, the FAPH is connected to the network at the instant t1=0.1s then at t=0.35s a load jump appears (Rd goes from 16.15 Ω to 8.075 Ω). This sequence makes it possible to evaluate the behavior of the FAPH in static and dynamic conditions. Figure 5 presents the waveforms of the network voltage Vsa (V), the load current ica (A), the network current isa (A) with a THDi, which decreases to 1.05%, the current ifa(A) injected by the FAPH and the DC bus voltage Vdc which stabilizes around its reference Vdc* = 55V instead of 282V for a pure active filter for the same network, as shown in figure 6.

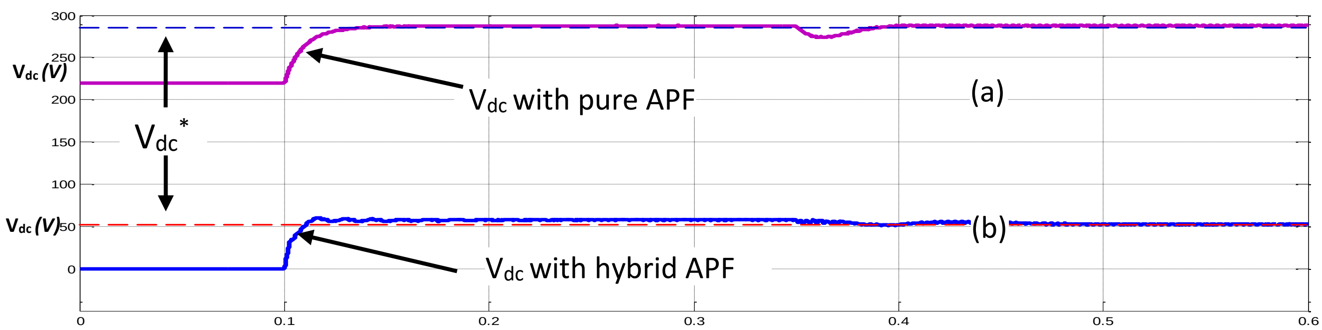


Fig. 6 DC bus voltage Vdc(t): (a) with pure APF, (b) with Hybrid APF

In Figure 6, a comparative study of the DC bus voltage level Vdc for the two topologies, namely pure FAP and Hybrid FAP, is presented. This proves the interest of using a FAPH as mentioned in the introduction of this article. [15]-[19].

V. CONCLUSION

In this article, a solution for the depollution of electrical networks by hybrid active filtering (FAPH) is explained. The control is based on the instantaneous active and reactive power technique. The proposed FAPH simulation results testify to the good quality of the filtering. Indeed, the network current has become almost sinusoidal with a THDi which decreases from 27.15% to 1.05% in simulation. The speed of compensation of the FAPH is proven during a sudden modification of the current caused by a variation of the load. In addition, the DC bus voltage regulation loop manages to pursue its reference which is reduced thanks to the proposed FAPH topology (Vdc*=55V instead of 282 V with a pure active filter for the same network).

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