

# Predictive Current Controlled Shunt Active Power Filter Working under Unbalanced Supply Conditions

Nadhir Mesbahi<sup>1,2</sup>

- 1) Department of Electrical Engineering, University of El-Oued, P.O. Box 789, El-Oued 39000, Algeria
- 2) Department of Electrical Engineering, Badji Mokhtar-Annaba University, P.O. Box 12, 23000 Annaba, Algeria  
nadhir-mesbahi@univ-eloued.dz

Ahmed Ouari, Amar Omeiri, Hocine Bouchikha

- Department of Electrical Engineering, Badji Mokhtar-Annaba University, P.O. Box 12, 23000 Annaba, Algeria  
ahmed.ouari@univ-annaba.org  
omeiri.amar@univ-annaba.org

**Abstract**— This paper has presented a predictive current control method of shunt active power filter (SAPF) under unbalanced supply conditions. Two parts are included: one is the computation of compensating reference current of SAPF and the other is predictive current control for SAPF to track the current reference. The reference current computation method is based on the use of high selectivity filters (HSF). The use of HSF instead of classical extraction filters (low pass filters) allows extracting directly the voltage and current fundamental components in the  $\alpha$ - $\beta$  axis without phase locked loop (PLL). The performance of the proposed algorithm is evaluated by means of computer simulations using Matlab/Simulink.

**Keywords**—power quality; shunt active power filter; harmonics; unbalanced supply conditions.

## I. INTRODUCTION

The proliferation of nonlinear loads such as diode converters, thyristor converters, adjustable speed drives, electronic starters and cycloconverters results in a variety of undesirable phenomena in power systems. Conventionally, passive LC filters have been used to eliminate line current harmonics and to improve the power factor. But the passive filters have many disadvantages, such as fixed compensation, large size and resonance problems. To solve above mentioned problems, there has been much research activity in the use of active power filters (APFs) to weaken the harmonic components and to overcome the other disturbances.

In recent years, various active power filter configurations with their respective control strategies have been proposed as a viable solution to the problems created by nonlinear loads [1]. One of the most popular active power filters is the shunt active power filter SAPF.

The performance of the SAPF depends on the design of the structure, types of controllers and methods used to obtain the reference current [2]. Among these control techniques, direct power control (DPC) has increasingly gained attention in the last years as a robust and simple control scheme. Many control techniques have been used to improve the performance of the active filters in the situation of unbalanced conditions, but they most need to get synchronous rotation angle by using PLL and are difficult to implement. Besides the problems of harmonic distortion, there exist also low power factor and

unbalanced load currents at the point of common coupling (PCC) due to the power delivered by the nonlinear loads [3,4]. To overcome the limitations mentioned before, this paper presents a modified version of direct instantaneous power control strategy for three-phase shunt active power filter. In this novel scheme the high selectivity filters(HSF) have been utilized instead of the classical extraction filters(low pass filters). This allows to regulate directly the instantaneous active and reactive powers injected by the active filter, without any current control loops and phase locked loop involved. Moreover, this algorithm works effectively not only under balanced supply voltages, but also under distorted or unbalanced conditions.

## II. SYSTEM DESCRIPTION

Shunt active power filter can suppress the current harmonics in the distribution networks by generating and injecting current harmonics (compensating current) at the PCC which have the same magnitude but opposite in phase of the current drawn by the nonlinear loads. Thus, the resulting total current drawn from the ac mains is sinusoidal.

Fig. 1 shows the power circuit configuration of shunt active power filter for the compensation of harmonics generated by a nonlinear load.

The SAPF studied in this paper is normal in structure, which is composed of a grid-connected three-phase voltage source inverter (VSI), with line inductors  $L_f$  in the ac side and the dc capacitor  $C_{dc}$  in the dc side. The control scheme mainly contains two parts: harmonic extraction method and current control loop.

## III. REFERENCE CURRENT CALCULATION

Many approaches such as notch filter, instantaneous  $p$ - $q$  method, modified  $p$ - $q$  method, synchronous detection method, synchronous  $d$ - $q$  frame method, flux based control and non-linear least squares approach are used in active power filter applications.

In this paper, we propose a new harmonic detection method, based on a (HSF) and this algorithm works effectively not only under balanced supply voltages, but also under distorted or unbalanced conditions.

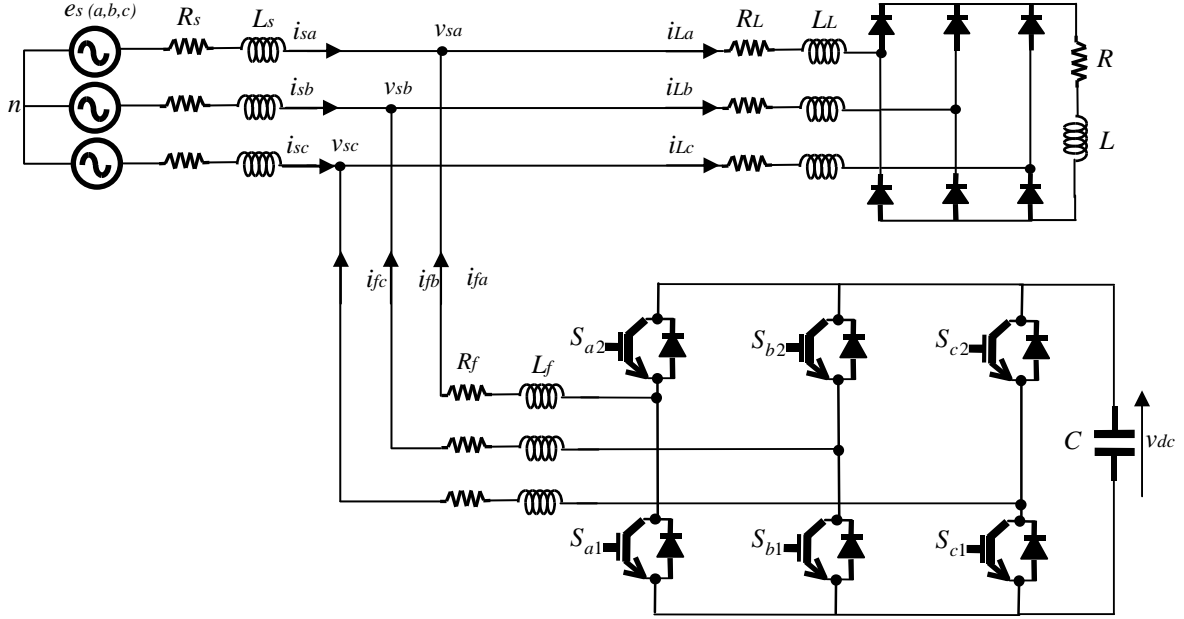


Fig. 1. Configuration of the SAPF.

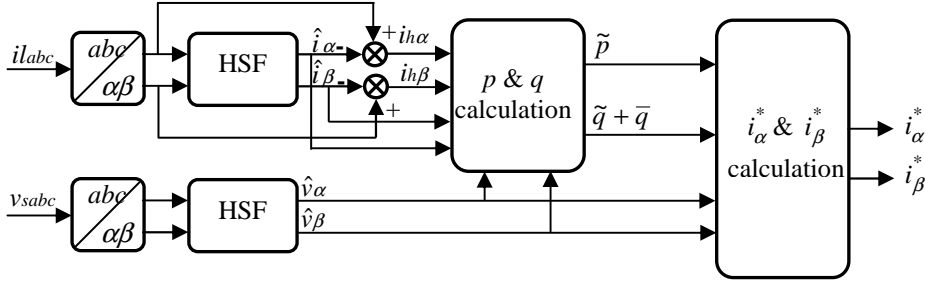


Fig. 2. Block diagram of the reference currents.

In this method the reference current signal is derived from the measured quantities by the use of the instantaneous reactive power theory associated with two HSFs. The main steps of this method are summarized in the diagram blocks of Fig. 2. The reference currents are identified using a modified version of the instantaneous active and reactive power theory. We used HSF instead of classical harmonic extraction based on high pass filters (HPF) or low pass filters (LPF). The HSF is dedicated to extract the fundamental component directly from unbalanced electrical signals (voltage or current) in  $\alpha - \beta$  reference frame [5], [6], [7], [8].

#### IV. PREDICTIVE CURRENT CONTROL

The current control suggested in this paper is based on the model predictive approach. The proposed predictive control strategy is based on the fact that only a finite number of possible switching states can be generated by a static power converter and that models of the system can be used to predict the behavior of the variables for each switching state. For the

selection of the appropriate switching state to be applied, a selection criteria must be defined. This selection criteria is expressed as a cost function that will be evaluated for the predicted values of the variables to be controlled. Prediction of the future value of these variables is calculated for each possible switching state. The switching state that minimizes the cost function is selected [9].

The current error for the next sampling instant can be expressed in orthogonal coordinates as follows [9]:

$$g = \left| i_{\alpha}^* - i_{\alpha}^p \right| + \left| i_{\beta}^* - i_{\beta}^p \right| \quad (1)$$

where  $i_{\alpha}^p$  and  $i_{\beta}^p$  are the real and imaginary part of the predicted filter current vector, and  $i_{\alpha}^*$  and  $i_{\beta}^*$  are the real and imaginary part of the reference current.

The voltage vector that minimizes the current error is selected and the respective switching state is applied to the VSI.

## V. SIMULATION RESULTS

For the simulations, Matlab/Simulink and the SimPowerSystem toolbox were used. Various simulation results are obtained under ideal and non-ideal supply conditions. The essential parameters selected for the simulation studies are listed in Table I.

TABLE I  
SYSTEM PARAMETERS

Parameter	Value
AC Supply voltage	220 V(rms)
Supply resistor	2 m $\Omega$
Supply inductor	0.01 mH
Supply frequency	50 Hz
Load AC resistor	1.2 m $\Omega$
Load AC inductor	0.3 mH
DC voltage	800 V
DC capacitor	8.8 mF
Filter resistor	0.2 $\Omega$
Filter inductor	2 mH
Rectifier load resistor	10 $\Omega$
Rectifier load inductor	5 mH

The total harmonic distortion (THD) of the source currents is taken to evaluate the harmonic elimination performance.

### A. Performance of the SAPF under Ideal Conditions of the Supply Voltages

Fig. 3(a)–(e) shows the waveforms of the supply voltages, source current without any filter connected in the system, the compensating current, source current when SAPF is connected and dc-link capacitor voltage respectively. The average percentage THD of source current is 27.22% without compensation, which reduces to 1.84% after connecting SAPF. The harmonic spectra of the phase-a load current and source current after compensation are shown in Fig. 4(a) and (b).

It can be clearly seen that the three-phase load current is seriously distorted with the nonlinear load. When the control strategy is applied to the SAPF, three-phase source current becomes balanced and sinusoidal. The dc-link capacitor voltage is adequately controlled around its reference value  $V_{dc}$  with a very slight ripple, showing that the proposed control strategy is effective.

### B. Performance of the SAPF under Non- Ideal Conditions of the Supply Voltages

For testing the performance of proposed SAPF configuration under unbalanced source voltages, the system is supplied with voltages as follows: values of grid voltages of phases “a”, “b”, and “c” are 220, 265, and 175 V, respectively. In this case, the unbalanced AC voltages of the power grid are presented in Fig. 5(a). The source currents delivered by the nonlinear load feeding by this unbalanced power grid are presented in Fig. 5(b). In this graph, the load currents became more distorted.

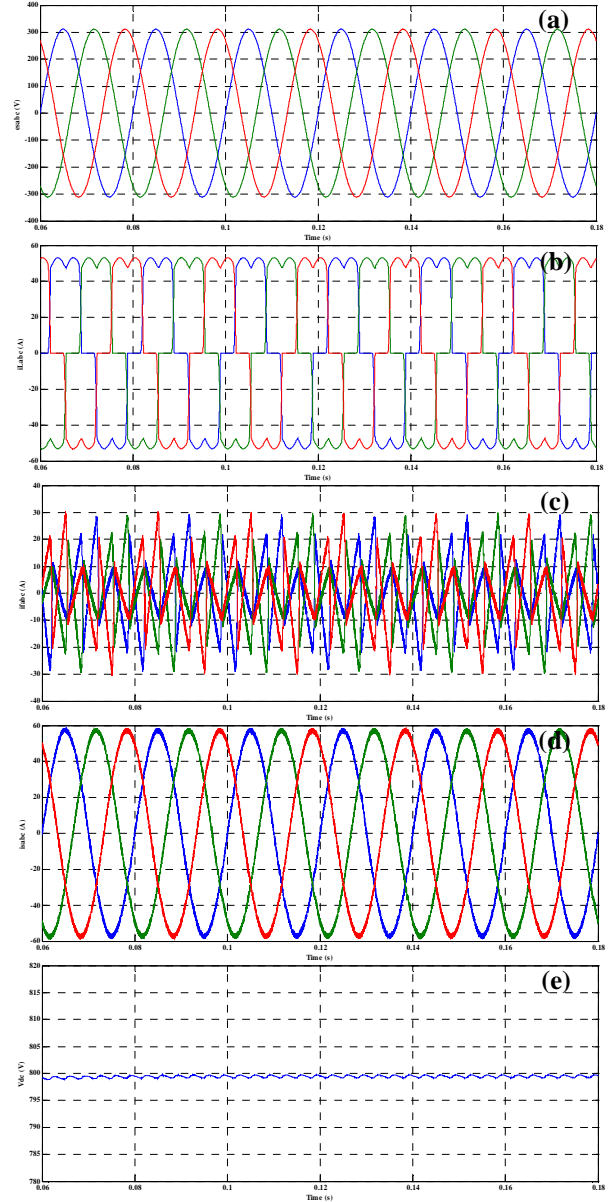


Fig. 3. Simulation results of the SAPF under balanced conditions .

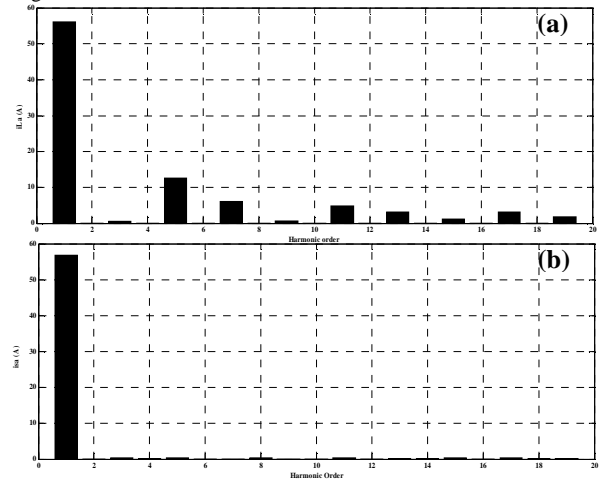


Fig. 4. Harmonic spectra of the source current in phase-a: (a) before and (b) after compensation.

When the compensation scheme is introduced in the SAPF, the resultant source currents are almost sinusoidal and balanced as shown in Fig. 5(d). The THD of the source currents before compensation are respectively 27.32%, 22.79% and 32.95% while those are equal to 2.11%, 1.80% and 1.84% after compensation.

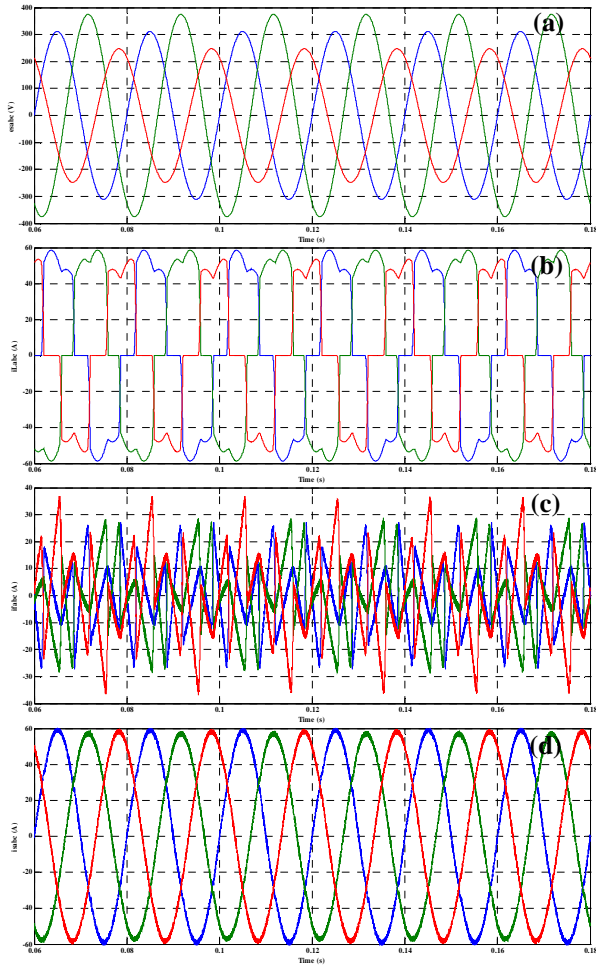


Fig. 5. Simulation results of the SAPF under unbalanced conditions.

## VI. CONCLUSION

This study has investigated predictive current control of shunt active power filter under unbalanced supply voltage conditions. The SAPF is controlled based on predictive control to eliminate the harmonics. The controller was also tested under severe supply voltage disturbance. The proposed control is easy to implement and it shows robustness and very good performance in both balanced supply voltages and unbalanced conditions.

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