Control of Hybrid Active Filter Without Phase Locked Loop in the Feedback et Feedforward Loops

Mohamed Abdusalam[1], Philippe Poure[2] and Shahrokh Saadate[1]

[1] Groupe de Recherche en Electrotechnique et Electronique de Nancy (GREEN), CNRS UMR 7037
[2] Laboratoire d'Instrumentation Electronique de Nancy (LIEN), EA 3440
Université Henri Poincaré, B.P.239, 54506 Vandoeuvre lès Nancy, cedex - France
Tel: ++33.3.83.68.41.31 Fax: ++33.3.83.68.41.33
E-mail: {Mohamed.Abdusalam, Shahrokh.Saadate}@green.uhp-nancy.fr, Philippe.Poure@lien.uhp-nancy.fr

Abstract. This paper presents a new hybrid active filter control without PLL in the feedback and feedforward loops. This filter is dedicated to suppress the harmonic currents produced by nonlinear loads. The proposed control generates the harmonic current references by only using the α-β transformation and Self Tuning Filters (STFs). The major aims were to simplify the calculation steps in the feedback and feedforward loops and to validate by simulation the efficiency of this new control. STFs have been introduced instead of high pass and low pass filters in the feedback and feedforward loops respectively. Because of the use of STFs, no more PLL is necessary. This method reduces the complexity of the control scheme and consequently facilitates the digital implementation of the control system. Simulation results for a non linear load consisting in a diode rectifier feeding a (R, C) parallel load demonstrate the performances of the proposed control.

Key words

Self-Tuning Filter, hybrid active filter, harmonic currents, control, feedback and feedforward loops.

1. Introduction

Harmonic currents are the source of adverse effects for many types of equipments such as heating in distribution transformer, perturbation of sensitive control equipments and resonances with the grid. These harmonic currents are mostly generated by the power conversion units and the power electronic equipments. Many solutions have been studied in the literature to mitigate the harmonic problems, such as filtering (passive, active, and hybrid) with various topologies (shunt, series or both). These solutions have been proposed to improve the power quality of the grid [1]-[3].

The passive filter is the simplest way to eliminate the harmonic currents. However, it has many drawbacks such as the series or parallel resonance with the system impedance. More, passive filtering cannot completely eliminate all of the harmonic currents. Active filters are widely used to overcome to the drawbacks of the passive filters and improve power quality. However, the cost of active filters in industrial applications could be very high because of the large power rating of the used power converter. These cost considerations limit the applications of active filters in power systems [4], [5].

In the last few years, many different topologies of hybrid active filters with various control strategies have been proposed in the literature as lower cost alternatives to active filtering for harmonic compensation. Nowadays, hybrid active filters are considered as one of the best solutions for improving power quality [6]-[11].

As well known, active filter system performances mostly depend on the accuracy of the harmonic isolation and on the current control technique used to generate the switching patterns for the inverter [12]. In the literature, we can read many methods for active filter control based on the synchronous reference frame (SRF) and implementing a low-pass or high-pass filters to produce the harmonic references.

This paper presents a new control scheme of hybrid active filter using a simple method to generate the harmonic current references (harmonic isolation). This new control is only based on the α-β transformation and on the use of Self Tuning Filters (STF). In the next section, harmonic isolation is detailed. In the third section, the effectiveness of the proposed method is verified by computer simulation.

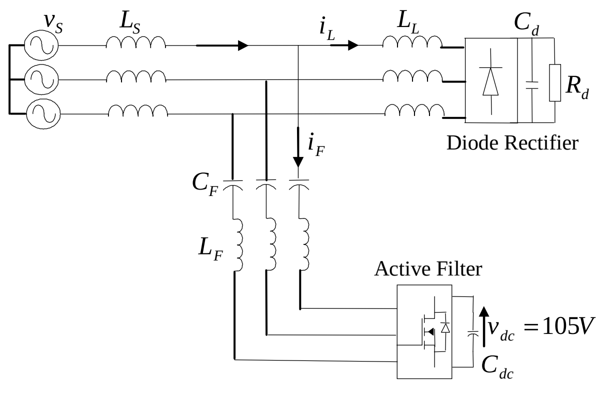

Fig. 1. Parallel hybrid active filter configuration.

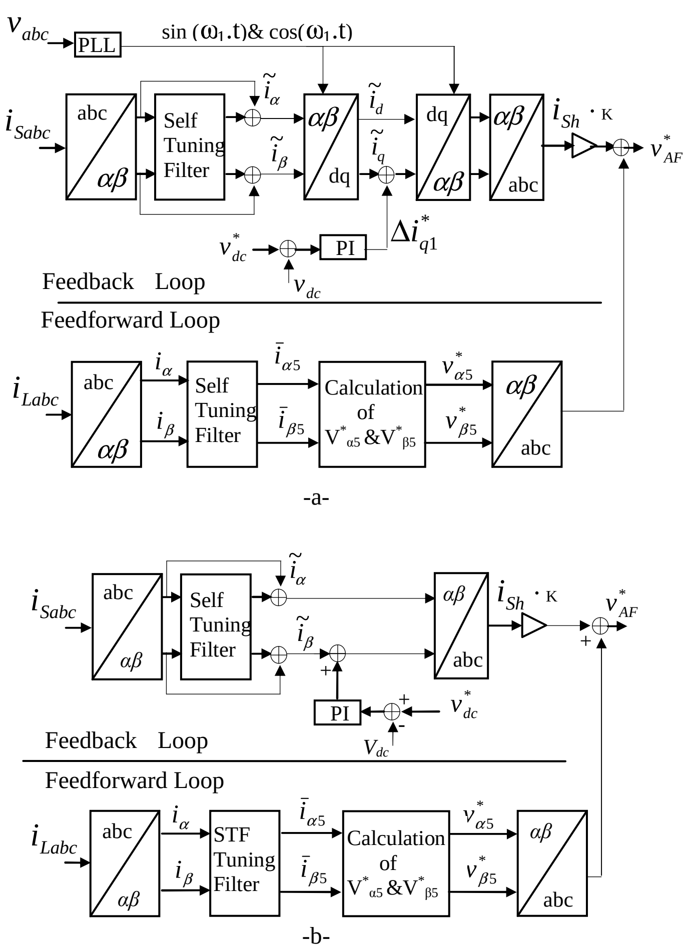

Fig. 2. Control schemes : (a) based on the d-q et α-β transformations.(b) based only on the α-β transformation.

2. Harmonic Reference Generation

The hybrid active filter topology studied in this paper consists in a three-phase LC filter tuned to the 7th harmonic frequency, connected in series with an active filter without any transformer. The passive filter absorbs the 7th harmonic currents generated by the load whereas the active filter improves filtering performances of the passive filter.

The associated control scheme combines a feedback and a feedforwad loop. The feedback control is applied to diode rectifier input harmonic currents, whereas the feedforward loop is usually dedicated to the most dominant 5th harmonic current component to improve filtering characteristics of the hybrid filter.

A. Feedforward Loop

The calculation steps and the STF principle used to produce the harmonic current references in the feedforward loop have been detailed in the papers [13] and [14].

Fig. 1 presents the block diagram of the control proposed in the paper [14] where the controller is based on the d-q et α-β transformations. However, for the proposed method, neither Phase Locked Loop (PLL) (for sin(5ω_1.t) and cos(5ω_1.t) calculation) nor d-q transformation are necessary to calculate the feedforward voltage references [14].

Consequently, the feedforward loop has been simplified: only a STF and the classical α-β transformation are used [14]. By this way, calculations are greatly reduced for this feedforward loop. However, a PLL still remains in the feedback loop. The aim of this paper is to simplify this loop.

B. Feedback Loop

In the proposed feedback loop, the use of a PLL (for sin (ω_1t) and cos (ω_1t) caculation) is no more necessary. That means that the calculation of d-q current components is neither applied for V_{dc} regulation.

According to Fig 2-b, the measured three phase supply currents, i_{sa}, i_{sb} and i_{sc} are the inputs of the feedback loop and are transformed into the α-β reference frame:

$$\begin{bmatrix} i_{S\alpha} \\ i_{S\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \qquad (1)$$

Then, a STF is introduced in the feedback loop and extracts the AC components directly from the currents in the α-β axis. This extraction is achieved by substracting the STF input signals from the corresponding outputs (see Fig. 2.b). The resulting signals are AC components, $\tilde{i}_\alpha$ and $\tilde{i}_\beta$, which correspond to the harmonic components of i_{Sa}, i_{Sb} and i_{Sc} in the stationary reference frame.

Next, after calculation based on α-β inverse transformation, we obtained the three-phase harmonic reference currents i_{Sha}, i_{Shb} and i_{Shc}. Each harmonic current i_{Sh} is amplified by a gain K to produce the three AC voltage references of the feedback loop, given by:

$$V_{Sh}^{*} = i_{Sh} \times K \qquad (2)$$

These references are added to the output voltage references established by the feedforward loop (equation (3)) to define the total voltage references for the active filter.

$$\begin{bmatrix} v_{a5}^{*} \\ v_{b5}^{*} \\ v_{c5}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{\alpha 5}^{*} \\ v_{\beta 5}^{*} \end{bmatrix} \qquad (3)$$

Finally, each voltage reference of the active filter is compared with a triangular waveform (frequency equal to

10 KHz) to generate the switching signals for the six MOSFETs.

A DC bus controller is required to regulate the DC bus voltage V_{dc} and to compensate the inverter losses. The measured DC bus voltage V_{dc} is compared with its reference value V^{*}_{dc}. The resulting error is applied to a Proportional Integral (PI) regulator. By this way, the active filter can build up and regulate the DC capacitor voltage without any external power supply.

3. Simulation Results

The efficiency of the proposed control scheme has been examined by computer simulation using MATLAB and associated toolboxes "Simulink" and "Power System Blockset". The studied hybrid filter consists in a three-phase LC filter tuned to the 7^{th} harmonic frequency, connected in series with a three-phase active filter based on MOSFET power semiconductors. The nonlinear load is a diode rectifier feeding an (R, C) parallel load. The parameters of the studied system are given in Table I. The optimal value of the feedback gain K is equal to 20 Ω which provide better filtering characteristics [13].

Table II, presents load and source currents THD as the harmonic-to-fundamental current ratio in (%). It demonstrates the effectiveness of the new control scheme by using STFs in the feedback and feedforward loops. As presented in this Table, the THD of the non-linear load i_L is equal to 27.8 % (because of the large amount of the 5^{th} harmonic current) while it is equal to 2.7 % for the source current i_S after filter operation.

The results we obtained demonstrate that a very low THD value can be reached by using the new control scheme studied in this paper. The passive filter absorbs the network voltage at the fundamental frequency. Consequently, the DC voltage of the inverter V_{dc} can be reduced as low as 105V. This enables the hybrid filter to use low-voltage MOSFETs which are less expensive than IGBTs.

Fig. 3 shows simulation results for the simplified method and illustrates the capability of successfully compensating the harmonic frequencies.

TABLE I
Simulation parameters

Capacitor : C_F	57.6 µF
Inductor : L_F	2.5 mH
Inductor: L_S	0.15 mH
DC bus voltage reference	105 V
Capacitor: C_d	1500 µF
Resistor: R_d	21Ω
Capacitor: C_{dc}	1500 µF
System frequency	60 Hz
System voltage	480 V

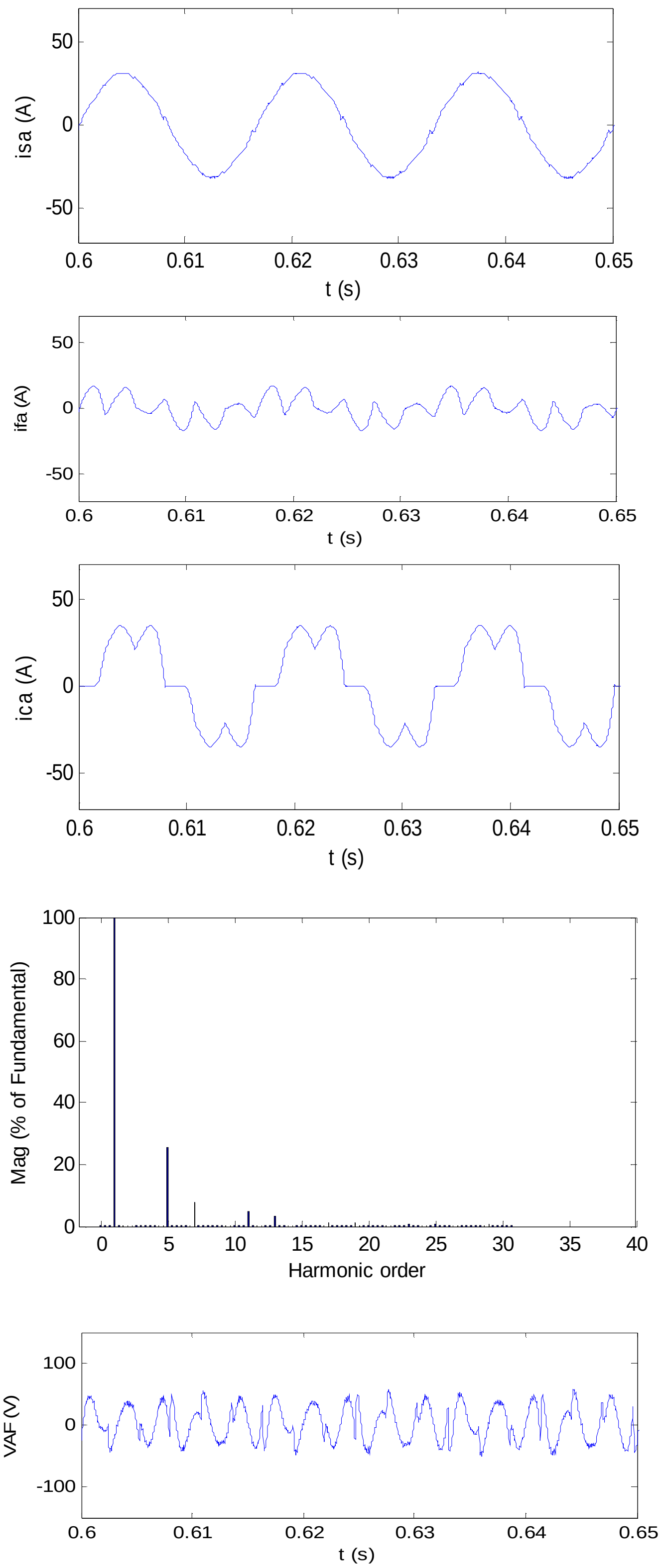

Fig. 3. Simulation results for the proposed control scheme (phase a). From top to bottom: Source current i_{Sa} (A), Filter current i_{Fa} (A), Load current i_{La} (A), and Active filter voltage V_{AF} (V).

TABLE II
THD values for the load and source currents and harmonic-to-fundamental current ratio (%)

	5th	7th	11th	13th	17th	19th	23th	THD (%)
i_L (A)	26	7.5	4.75	3.2	1.54	1.44	0.97	27.8
i_S (A)	0.28	1	0.47	0.48	0.49	0.51	0.69	2.7

4. Conclusion

This paper has presented a new hybrid active filter control without PLL to suppress the harmonic currents produced by nonlinear loads. The major aims were to simplify the calculation steps in the feedback and feedforward loops as presented in Fig.2 and to validate by simulation the efficiency of this new control. STFs have been introduced instead of high pass and low pass filters in the feedback and feedforward loops respectively. This method reduces the complexity of the control scheme and consequently facilitates the digital implementation of the control system. Simulation results demonstrate the good performances of the proposed control. Morever, the STF can be tuned to any frequency. By this way, complementary feedforward control can be added for other harmonics filtering without major complication of the global control.

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