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An efficient *a–b–c* reference frame-based compensation strategy for three-phase active power filter control

G.W. Chang [a,*], S.K. Chen [a], M. Chu [b]

[a] *Department of Electrical Engineering, National Chung Cheng University, Chia-Yi 621, Taiwan, ROC*
[b] *Umart Electronics MFG., Tainan 701, Taiwan, ROC*

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Abstract

The active power filter has been proved to be an effective method to mitigate harmonic currents generated by nonlinear loads as well as to compensate reactive power. In the implementation of a three-phase active power filter, it is crucial to have a procedure (i.e. the compensation strategy) to generate the reference compensation currents by its control circuit. This paper proposes a simple and efficient *a–b–c* reference frame-based strategy to determine the reference compensation currents for both three-phase three-wire and three-phase four-wire active power filters. Simulation and experimental results show that the proposed compensation strategy yields a simpler design of the control circuit than those obtained by using the conventional instantaneous reactive power theory (i.e. *p–q* theory). A competitive active filter performance is also achieved. © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Active power filter; Harmonics; Reactive power compensation; Instantaneous reactive power theory; Reference frame

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1. Introduction

Modern power-electronic devices have been widely used in end-use power applications. While these nonlinear loads provide end-user benefits of improved efficiency and process controllability, they degrade the overall electric power quality via re-shaping source voltages and/or currents at the same time. This process causes pollution in electric power system and often interferes with neighboring sensitive loads, such as computers and microprocessor-controlled devices.

The concept of using active power filters to mitigate harmonic problems and to compensate reactive power was proposed more than two decades ago [1,2]. Since then, the theories and applications of active power filters have become more popular and have attracted great attention [3–13]. Without the drawbacks of passive harmonic filters, such as component aging and resonant problems, the active power filter appears to be a viable solution for reactive power compensation as well as for eliminating harmonic currents.

In Refs. [3,4], Akagi et al. proposed an innovative concept based on the theory of instantaneous reactive power, or commonly called *p–q* theory in the α–β reference frame, which inspired the realization of three-phase active power filters. With this concept, there is no need to use reactive energy storage device in the active power filter implementation for reactive power compensation unless used for harmonic cancellation. Since the *p–q* theory was introduced, many instantaneous reactive power theory-based methods have been proposed for the compensation strategies of the active power filter [7,8,10,12] and have served as the basis of reference compensation current calculations for the active power filter.

In contrast to the widely used *p–q* theory for active power filter design in the α–β reference frame, the *a–b–c* reference frame-based design for active power filters has attracted less attention. This paper is a contribution towards the *a–b–c* reference frame-based compensation strategy. In the proposed method, the problem associated with determining the active power filter reference compensation currents is formulated as a nonlinear programming problem and is solved accord-

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* Corresponding author. Fax: +886-5-272-0862.
E-mail address: wchang@ee.ccu.edu.tw (G.W. Chang).

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ing to the Kuhn–Tucker conditions. It is shown that the physical meaning of the source current after compensation agrees with the active current definitions proposed by Fryze [14] and Czarnecki [15]. In addition, the control circuit design with the proposed method requires less effort on its implementation and maintains a good filter performance. The simulation and test results show that the proposed compensation strategy is suitable for both the three-phase three-wire and three-phase four-wire active power filters. Both reactive power and harmonic currents of the nonlinear load are suppressed effectively. Therefore, a good power quality and unity power factor at the source side can be achieved.

In this paper, the conventional instantaneous reactive power theory is first briefly reviewed. Next, the proposed compensation strategy for the three-phase active power filter is described. Then, simulation and experimental results are presented followed by the conclusion.

2. Review of the α–β reference frame-based compensation strategy

Fig. 1 shows the schematic diagram of an active power filter for harmonic cancellation and reactive power compensation, where v_k, i_{sk}, i_{lk}, i_{fk}, $k = a, b, c$, are source voltages, source currents, load currents, and filter injection currents, respectively.

According to the p–q theory, the load currents and source voltages of a three-phase three-wire system in the a–b–c reference frame can be transformed to the α–β reference frame by Eqs. (1) and (2) as follows:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = [\mathrm{T}] \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}, \tag{1}$$

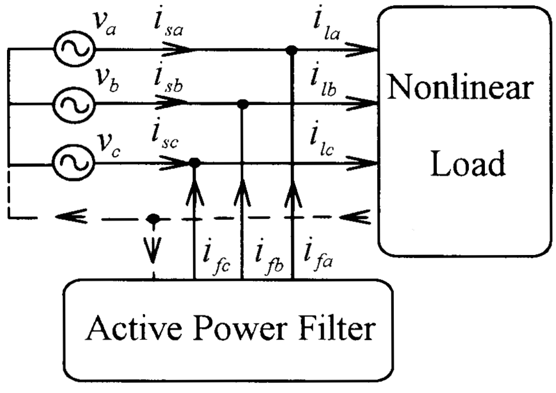

Fig. 1. Schematic diagram of the three-phase active power filter compensation system.

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} = [\mathrm{T}] \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix}, \tag{2}$$

where

$$[\mathrm{T}] = \begin{bmatrix} \sqrt{2/3} & -1/\sqrt{6} & -1/\sqrt{6} \\ 0 & 1/\sqrt{2} & -1/\sqrt{2} \end{bmatrix}. \tag{3}$$

Then, the instantaneous real and reactive power of the load can be obtained by Eq. (4):

$$\begin{bmatrix} p_l \\ q_l \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix}, \tag{4}$$

where p_l includes an average component $\bar{p}_l$ and a harmonic component p_{lh}, and q_l includes an average component $\bar{q}_l$ and a harmonic component q_{lh}. The reference compensation currents of the active power filter at the α–β axes are determined by Eq. (5) or (6) as follows:

$$\begin{bmatrix} i^*_{f\alpha} \\ i^*_{f\beta} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ q_l \end{bmatrix}, \tag{5}$$

$$\begin{bmatrix} i^*_{f\alpha} \\ i^*_{f\beta} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p_{lh} \\ q_l \end{bmatrix}, \tag{6}$$

where Eq. (5) is for reactive power compensation and Eq. (6) is used to compensate reactive power and to eliminate harmonic currents of the load simultaneously. Eq. (5) or (6) then can be converted to the a–b–c reference-frame quantities according to Eq. (7):

$$\begin{bmatrix} i^*_{fa} \\ i^*_{fb} \\ i^*_{fc} \end{bmatrix} = [\mathrm{T}]^{\mathrm{t}} \begin{bmatrix} i^*_{f\alpha} \\ i^*_{f\beta} \end{bmatrix}, \tag{7}$$

where $[\mathrm{T}]^{\mathrm{t}}$ is the transpose of [T].

From Eqs. (1)–(7), the procedure based on the conventional instantaneous reactive power theory for determining the compensation currents can be summarized as follows:

1. Measuring load voltages and currents in the a–b–c reference frame and transforming them to the α–β reference frame quantities.
2. Computing instantaneous real and reactive power of the load based on the results obtained in step (1).
3. Using high-pass passive filters to separate the instantaneous real harmonic power component from the results obtained in step (2).
4. Computing reference compensation currents of the active power filter in the α–β reference frame based on the selected power terms to be compensated in steps (2) and (3).
5. Transforming the compensation currents obtained in step (4) to the a–b–c reference-frame quantities.