Available online at www.sciencedirect.com
ScienceDirect
Electric Power Systems Research 78 (2008) 58–73
ELECTRIC POWER SYSTEMS RESEARCH
www.elsevier.com/locate/epsr

Control of a 3-phase 4-leg active power filter under non-ideal mains voltage condition

Mehmet Ucar, Engin Ozdemir *

Kocaeli University, Technical Education Faculty, Electrical Education Department, 41380 Umuttepe, Turkey

Received 29 August 2005; received in revised form 2 October 2006; accepted 13 December 2006
Available online 25 January 2007

Abstract

In this paper, instantaneous reactive power theory (IRP), also known as *p–q* theory based a new control algorithm is proposed for 3-phase 4-wire and 4-leg shunt active power filter (APF) to suppress harmonic currents, compensate reactive power and neutral line current and balance the load currents under unbalanced non-linear load and non-ideal mains voltage conditions. The APF is composed from 4-leg voltage source inverter (VSI) with a common DC-link capacitor and hysteresis–band PWM current controller. In order to show validity of the proposed control algorithm, compared conventional *p–q* and *p–q–r* theory, four different cases such as ideal and unbalanced and balanced-distorted and unbalanced-distorted mains voltage conditions are considered and then simulated. All simulations are performed by using Matlab-Simulink Power System Blockset. The performance of the 4-leg APF with the proposed control algorithm is found considerably effective and adequate to compensate harmonics, reactive power and neutral current and balance load currents under all non-ideal mains voltage scenarios.

Keywords: 4-Leg shunt active power filter; Instantaneous power theory; Non-ideal mains voltage; Unbalanced load

1. Introduction

The widespread increase of non-linear loads nowadays, significant amounts of harmonic currents are being injected into power systems. Harmonic currents flow through the power system impedance, causing voltage distortion at the harmonic currents' frequencies. The distorted voltage waveform causes harmonic currents to be drawn by other loads connected at the point of common coupling (PCC). The existence of current and voltage harmonics in power systems increases losses in the lines, decreases the power factor and can cause timing errors in sensitive electronic equipments.

The harmonic currents and voltages produced by balanced 3-phase non-linear loads such as motor drivers, silicon controlled rectifiers (SCR), large uninterruptible power supplies (UPS) are positive-sequence harmonics (7th, 13th, etc.) and negative-sequence harmonics (5th, 11th, etc.). However, harmonic currents and voltages produced by single phase non-linear loads such as switch-mode power supplies in computer equipment which are connected phase to neutral in a 3-phase 4-wire system are third order zero-sequence harmonics (triplen harmonics—3rd, 9th, 15th, 21st, etc.). These triplen harmonic currents unlike positive and negative-sequence harmonic currents do not cancel but add up arithmetically at the neutral bus. This can result in neutral current that can reach magnitudes as high as 1.73 times the phase current. In addition to the hazard of cables and transformers overheating the third harmonic can reduce energy efficiency.

The traditional method of current harmonics reduction involves passive *LC* filters, which are its simplicity and low cost. However, passive filters have several drawbacks such as large size, tuning and risk of resonance problems. On the contrary, the 4-leg APF can solve problems of current harmonics, reactive power, load current balancing and excessive neutral current simultaneously, and can be a much better solution than conventional approach.

The IRP theory introduced by Akagi et al. [1,2] has been used very successfully to design and control of the APF for 3-phase systems. This theory was extended by Aredes et al. [3], for applications in 3-phase 4-wire systems. The IRP theory was mostly applied to calculate the compensating currents assuming ideal mains voltages. However, mains voltage may be

* Corresponding author. Tel.: +90 262 3032248; fax: +90 262 3032203.
E-mail address: eozdemir@kou.edu.tr (E. Ozdemir).

0378-7796/$ – see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.epsr.2006.12.008

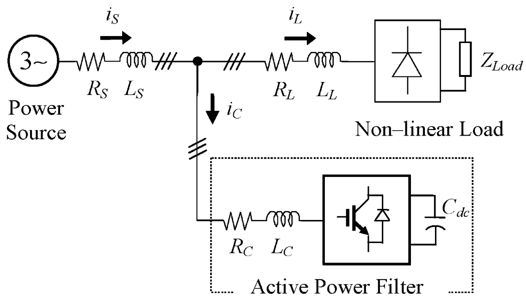

Fig. 1. The basic compensation principle of the shunt APF.

unbalanced and/or distorted in industrial systems. Under such conditions, control of the 4-leg APF using the *p–q* theory does not provide good performance. For improving the APF performance under non-ideal mains voltage conditions, new control methods are proposed by Komatsu and Kawabata [4], Huang et al. [5], Chen and Hsu [6], Haque et al. [7], Lin and Lee [8], Chang and Yeh [9] and Kim et al. [10]. This paper presents a new control algorithm for the shunt 4-leg APF even for all non-ideal mains voltage and unbalanced non-linear load condition. Performance of the proposed scheme has been found feasible and excellent to that of the *p–q* theory under unbalanced non-linear load and various non-ideal mains voltage test cases.

2. The 4-leg shunt active power filter

Fig. 1 shows the basic compensation principle of the shunt APF. A shunt APF is designed to be connected in parallel with the load, to detect its harmonic current and to inject into the system a compensating current, identical with the load harmonic current. Therefore, the current draw from the power system at the coupling point of the filter will result sinusoidal as shown in Fig. 2 and Eq. (1). Fig. 2 shows load current (i_L), compensating current reference (i_C) and desired sinusoidal source current (i_S) waveform, respectively.

$$i_S = i_L + i_C \quad (1)$$

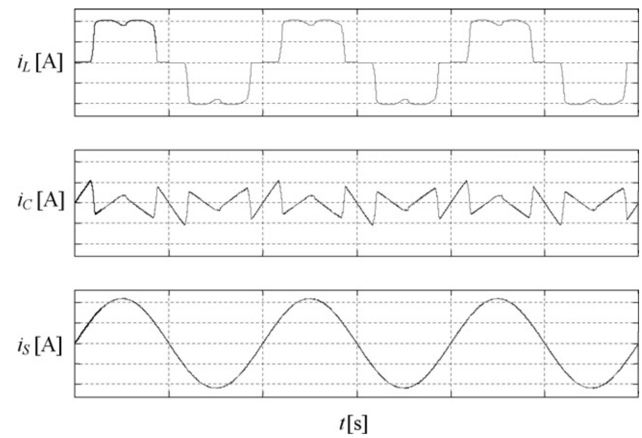

Fig. 2. Load, APF and source current waveforms.

In 3-phase 4-wire systems, two kinds of VSI topologies such as 4-leg inverter and 3-leg (split capacitor) inverter are used. The 4-leg inverter uses 1-leg specially to compensate zero-sequence (neutral) current. The 3-leg inverter is preferred for due to its lower number of switching devices, while the construction of control circuit is complex, huge DC-link capacitors are needed and balancing the voltage of two capacitors is a key problem. The 4-leg inverter has advantage to compensation for neutral current by providing 4th-leg and to need for much less DC-link capacitance and has full utilization of DC-link voltage.

Fig. 3 shows the power circuit of a 4-leg shunt APF connected in parallel with the 1-phase and 3-phase loads as an unbalanced and non-linear load on 3-phase 4-wire electrical distribution system. The middle point of each branch is connected to the power system through a filter inductor.

The APF consists of 4-leg VSI, 3-legs are needed to compensate the 3-phase currents and 1-leg compensates the neutral current [11]. The 4-leg VSI has 8 IGBT switches and an energy storage capacitor on hysteresis–band current controllers is used to obtain the VSI control pulses for each inverter branch. High order harmonic currents generated by the switching of the power

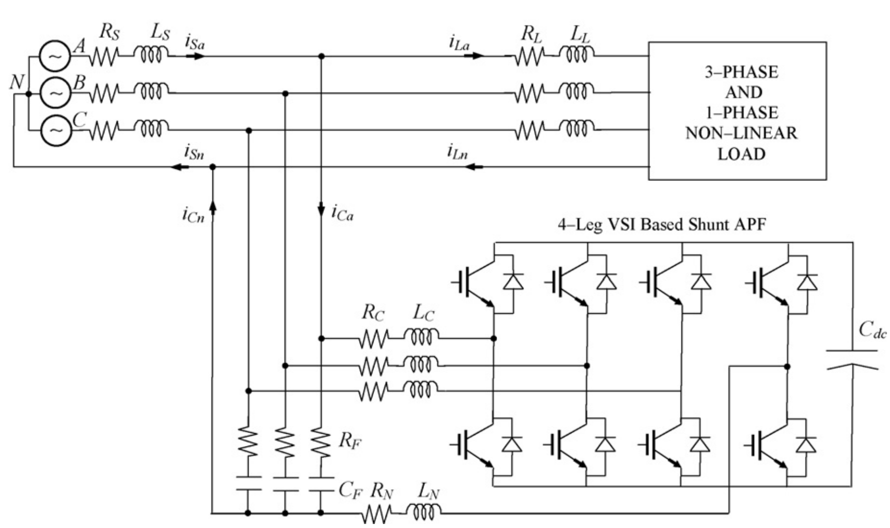

Fig. 3. Power circuit of the 4-leg shunt APF.