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The use of instantaneous symmetrical components for balancing a delta connected load and power factor correction

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Abstract

This paper presents a novel way of generating the reference currents for an active filter and/or a static compensator. A compensator structure is proposed which is capable of balancing an unbalanced delta-connected load that may also draw harmonic currents. In addition to balancing the load, the supply side power factor is also made unity. The theory of instantaneous symmetrical components is used here to obtain three phase reference currents that are to be tracked by the compensator in a hysteresis band control scheme. The paper demonstrates the feasibility of such as scheme through simulation studies. © 2000 Elsevier Science S.A. All rights reserved.

Keywords: Load balancing; Power factor correction; Active filters; Power distribution system

1. Introduction

Variable reactive power compensation of non-linear and/or poor power factor loads has gained considerable attention lately. Many techniques have been proposed to improve the supply side power factor and to cancel out the harmonics generated by power electronic loads. These schemes usually employ single/three-phase voltage source inverters (VSIs) that are supplied from a dc storage capacitor and operate in current control mode to track a specified reference current waveform. The single most important issue in any of these schemes is the generation of these reference current waveforms, which when injected to the power system, cancel out the load harmonics and/or improve the supply power factor.

Of the various methods that have been proposed for generating the reference current waveforms, the instantaneous p-q theory [1–3] has gained considerable attention. This theory is utilized to compute the instantaneous reactive power from measured three-phase voltage and load current waveforms. The VSIs are then controlled to deliver this instantaneous reactive power. This method has been widely used in active power line conditioning. Various interpretations and/or improvements on the method have been reported in [4–7].

A simplified approach is one in which the phase of the desired source current is fixed with respect to the source voltage and the magnitude of the reference current waveform is generated from the feedback of dc storage capacitor voltage [8,9]. The loss or gain of charge stored by the capacitor is indicative of the instantaneous power balance between the source and the total load including the losses in the inverters. In an ideal situation, the compensator will supply pure reactive power. Thus a negative feedback of the capacitor voltage can be utilized to adjust the magnitude of the desired source current waveforms. These methods are simple but are only suitable for balanced or single-phase loads.

The balancing of an unbalanced delta-connected load is a classical problem. An excellent description of load balancing is given in [10] in which any unbalanced reactive delta-connected network is converted into a balanced resistive delta-connected network by suitable introduction of admittance in parallel with each branch. The solution, even though aesthetically pleasing, has been carried out only for sinusoidal steady-state conditions.

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In this paper we utilize the theory of symmetrical components for generating reference current waveforms to balance a given load. It has been observed that the instantaneous power in an unbalanced system contains an oscillating component that rides a dc value [11]. The objective of the compensating system is to supply this zero-mean oscillating power such that the dc component can be supplied by the source. The structure of the compensating system depends on the manner in which the load is connected. In the paper we concentrate on delta-connected loads. In the next sections we shall discuss the reference current generation scheme, followed by compensator structure and its associated control for maintaining the charge on the dc capacitor. We shall validate the formulation through detailed digital computer simulation studies.

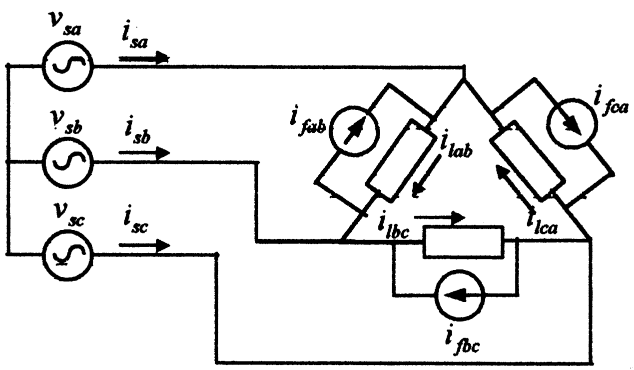

Fig. 1. Schematic diagram of the compensation scheme.

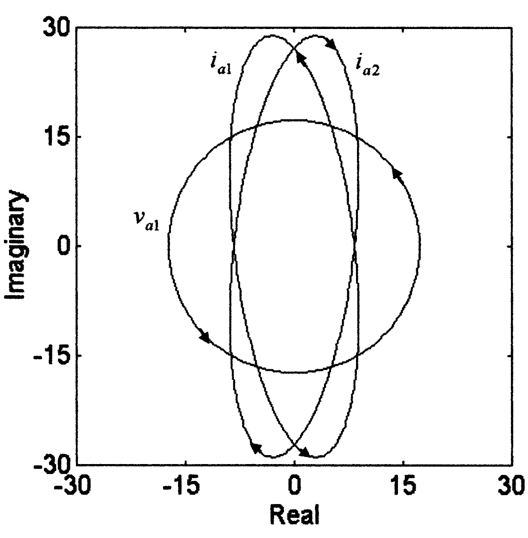

Fig. 2. Locus of instantaneous positive and negative sequence currents.

2. Generating the reference currents

The basic scheme is shown in Fig. 1 in which the compensator is represented by current sources. In reality, the compensator can be implemented through three single-phase VSI that operate in current control mode and track reference currents. The aim of the scheme proposed here is to generate the three reference current waveforms for i_{fab}, i_{fbc} and i_{fca}, denoted by i^*_{fab}, i^*_{fbc} and i^*_{fca}, respectively, such that the supply sees a balanced load. The scheme utilizes the measurements of the load currents i_{lab}, i_{lbc}, i_{lca} and the supply side voltages v_{sa}, v_{sb} and v_{sc}. No assumption on the nature of the load is required here. The compensator will produce desired results as long as its bandwidth is sufficient to follow the fluctuations in the load.

2.1. Theory of instantaneous symmetrical components

Let us first introduce the notion of the instantaneous symmetrical components. Let any three phase instantaneous currents be defined by i_a, i_b and i_c. The power invariant instantaneous symmetrical components are then defined by [12]

$$\begin{bmatrix} i_{a0} \\ i_{a1} \\ i_{a2} \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

where $a = e^{j120°}$. It is to be noted that the instantaneous vectors i_{a1} and i_{a2} are complex conjugate of each other and i_{a0} is a real quantity. If the line currents are balanced, i_{a0} is zero.

To illustrate the idea, let us consider the following three-phase unbalanced instantaneous currents, given by

$$i_a = 12 \sin \omega t\ A, \quad i_b = 33 \sin(\omega t - 100°)\ A,$$
$$i_c = 25 \sin(\omega t + 90°)\ A$$

where $\omega = 100\pi$ rad s^{-1}. The vectors i_{a1} and i_{a2} are computed for one cycle and the loci of the tip of these vectors are plotted in Fig. 2. In this figure, the direction of rotation of the loci is also indicated. It can be seen that these loci form a closed path. Moreover, the vector i_{a1} rotates in the counter clockwise direction while the vector i_{a2} rotates in the clockwise direction. Also, the same analysis is valid if we consider voltage signals instead of currents. For example, the locus for a balanced three-phase voltage of 20 V (peak) is also shown Fig. 2. As the voltages are balanced, this locus is a circle.