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Harmonic and reactive power compensation with shunt active power filter under non-ideal mains voltage

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Abstract

This paper presents a new control algorithm for an active power filter (APF) to compensate harmonic and reactive power of a 3-phase thyristor bridge rectifier under non-ideal mains voltage scenarios. Sensing load current, dc bus voltage and source voltages compute reference currents of the APF. APF driving signals are produced with these signals via a hysteresis band current controller. Matlab/simulink power system toolbox is used to simulate the proposed system. The proposed method's performance is compared with conventional instantaneous power (*p*–*q*) theory. The simulation results are presented and discussed showing the effectiveness of the control algorithm. The proposed algorithm is found quite satisfactory to compensate the reactive power and harmonics under non-ideal mains voltage conditions. The increased performance of the active power filter under different non-sinusoidal mains voltage and dynamic load conditions are extensively demonstrated.

Keywords: Active power filter; Non-ideal mains voltage; Instantaneous power (*p*–*q*) theory

1. Introduction

In a modern power system, increasing of loads and non-linear equipment's have been demanding the compensation of the disturbances caused for them. These non-linear loads may cause poor power factor and high degree of harmonics. Active power filter (APF) can solve problems of harmonic and reactive power simultaneously. APF's consisting of voltage-source inverters and a dc capacitor have been researched and developed for improving the power factor and stability of transmission systems. APF have the ability to adjust the amplitude of the synthesized ac voltage of the inverters by means of pulse width modulation or by control of the dc-link voltage, thus drawing either leading or lagging reactive power from the supply. APF's are an up-to-date solution to power quality problems. Shunt APF's allow the compensation of current harmonics and unbalance, together with power factor correction, and can be a much better solution than conventional approach (capacitors and passive filters). The simplest method of eliminating line current harmonics and improving the system power factor is to use passive LC filters. However, bulk passive components, series and parallel resonance and a fixed compensation characteristic are the main drawbacks of passive LC filters.

In APF design and control, instantaneous reactive power theory was often served as the basis for the calculation of compensation current [1,10,11]. In this theory, the mains voltage was assumed to be an ideal source in the calculation process. However, in most of time and most of industry power systems, mains voltage may be unbalanced and/or distorted. Under such scenarios, this theory may not be valid for application.

The *p*–*q* theory, since its proposal, has been applied in the control of three-phase active power filters. However, power system voltages being often non-ideal, in distorted voltage systems the control using the *p*–*q* theory does not provide good performance. For improving APF performance under non-ideal mains voltages, new control methods are proposed by Komatsu and Kawabata [2] and Huang et al. [3] and Chen and Hsu [4]. In this paper, the proposed control algorithm

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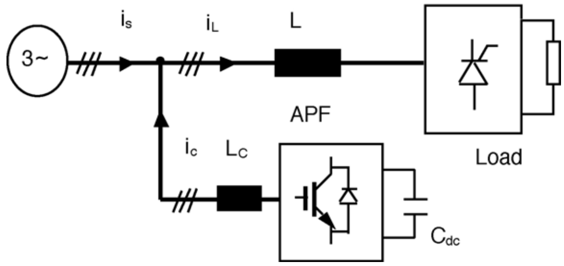

Fig. 1. Block diagram of APF.

gives adequate compensating current reference even for non-ideal voltage system. Consequently, it is primarily concerned with the development of APF performance under non-ideal or distorted mains voltage conditions. This paper presents a new technique with instantaneous power theory (*p*–*q* theory) as a suitable method to the analysis of non-linear three-phase systems and for the control of APF. Performance of the proposed scheme has been found feasible and excellent to that of the instantaneous reactive power algorithms under various non-ideal mains test scenarios.

2. Active power filter

Fig. 1 shows basic APF block diagram including non-linear load on three-phase supply condition. In this study, three-phase controlled thyristor bridge rectifier with ohmic–inductive loading are considered as a non-linear load on three-phase ac mains. This load draws non-sinusoidal currents from ac mains and can be controlled by changing its firing angle.

APF overcome the drawbacks of passive filters by using the switching mode power converter to perform the harmonic current elimination. Shunt active power filters are developed to suppress the harmonic currents and compensate reactive power simultaneously. The shunt active power filters are operated as a current source parallel with the non-linear load. The power converter of active power filter is controlled to generate a compensation current, which is equal but opposite the harmonic and reactive currents generated from the non-linear load. In this situation, the mains current is sinusoidal and in phase with mains voltage.

A voltage-source inverter having IGBT switches and an energy storage capacitor on dc bus is implemented as a shunt APF. The main aim of the APF is to compensate harmonics, reactive power and to eliminate the unwanted effects of non-ideal ac mains supplies only unity power factor sinusoidal balanced three-phase currents.

3. Instantaneous power theory

In three-phase circuits, instantaneous currents and voltages are converted to instantaneous space vectors. In instantaneous power theory, the instantaneous three-phase currents and voltages are calculated as following equations. These space vectors are easily converted into the α–β orthogonal coordinates [5].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\mathrm{a} \\ i_\mathrm{b} \\ i_\mathrm{c} \end{bmatrix} \tag{2}$$

Considering only the three-phase three-wire system, the three-phase currents can be expressed in terms of harmonic positive, negative and zero sequence currents. In Equations (1) and (2), α and β are orthogonal coordinates. v_α and i_α are on α axis, v_β and i_β are on β axis. In three-phase conventional instantaneous power is calculated as follows:

$$p = v_\alpha i_\alpha + v_\beta i_\beta \tag{3}$$

In fact, instantaneous real power (p) is equal to following equation:

$$p = v_a i_a + v_b i_b + v_c i_c \tag{4}$$

Instantaneous real and imaginary powers are calculated as Equations (5):

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{5}$$

In Equation (5), $v_\alpha i_\alpha$ and $v_\beta i_\beta$ are instantaneous real (p) and imaginary (q) powers. Since these equations are products of instantaneous currents and voltages in the same axis. In three-phase circuits, instantaneous real power is p and its unit is watt. In contrast $v_\alpha i_\beta$ and $v_\beta i_\alpha$ are not instantaneous powers. Since these are products of instantaneous current and voltages in two orthogonal axes, q is not conventional electric unit like W or Var. q is instantaneous imaginary power and its unit is Imaginer Volt Ampere (IVA) [1]. These power quantities given above for an electrical system represented in *a*–*b*–*c* coordinates and have the following physical meaning [6].

$\bar{p}$, the mean value of the instantaneous real power—corresponds to the energy per time unity which is transferred from the power supply to the load, through *a*–*b*–*c* coordinates, in a balanced way.
$\tilde{p}$, alternated value of the instantaneous real power—it is the energy per time unity that is exchanged between the power supply and the load through *a*–*b*–*c* coordinates.
$\bar{q}$, instantaneous imaginary power—corresponds to the power that is exchanged between the phases of the load. This component does not imply any exchange of energy between the power supply and the load, but is responsible for the existence of undesirable currents, which circulate between the system phases.
$\tilde{q}$, the mean value of the instantaneous imaginary power that is equal to the conventional reactive power.