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A DSP-based active power filter for low voltage distribution systems

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Abstract

The use of nonlinear loads, which inject undesired harmonic currents into low voltage distribution systems, is increasing rapidly. Active power filters are being considered as a potential candidate for solving harmonic problems in order to meet harmonic standards and guidelines. A new digital signal processor (DSP)-based control method for a single-phase active power filter (APF) is presented in this paper. Compared to conventional analog-based methods, the DSP-based solution provides a flexible and cheaper method to control the APF. The proposed scheme employs a carrier-based control that requires less feedback information compared to other reported solutions. Only one current sensor is used to sense the nonlinear load current and two voltage sensors to sense the input supply voltage and the dc bus voltage. The proposed method provides both harmonic elimination and power factor correction. The PSpice simulation and experiments using the DSP-based prototype are made to verify the feasibility of the method.

Keywords: Harmonic distortion; Active filters; Digital signal processors; Power quality; Power filter; Power system harmonics

1. Introduction

Power electronics-based systems, such as static power converters, and motor drives have become more and more popular due to their high efficiency, low cost, flexibility of control and significant energy savings. However, the nonlinear characteristics of these systems are responsible for harmonic pollution of the power distribution system. Harmonics in power distribution systems result in many adverse effects such as: overheating of distribution transformers, low power factor, interference with precision instruments and communication equipment, malfunction of protection equipment, voltage distortion within facilities, overloaded neutral conductors and high levels of neutral to ground voltage. As a result, effective elimination of harmonics from the distribution system has become important both to the utilities and the end users. Passive approaches, although simple, tend to be bulky and expensive at lower harmonic frequencies. Also, a separate LC filter is required for every major harmonic. Moreover the possibility of exciting a resonance condition with the ac system impedance further worsens the situation. Active power filters, which effectively inject compensating currents into the ac lines, have become an attractive alternative to other methods due to its fast response and flexibility. The harmonics of all orders can be compensated by one piece of equipment and better harmonic compensation characteristics can be obtained due to the use of the high controllability and quick response of switch-mode power electronic converters. An integral part of an active compensation device is the detection unit which generates the reference signals. Various methods, e.g. dead beat control, sliding mode control, artificial intelligence, adaptive hysteresis band reactive power control, have been presented in the literature for this purpose [1–5].

In recent years, digital signal processors (DSP) are being used in a variety of applications that require sophisticated control. DSP-based control for active power filters have been proposed in some papers in which general purpose and floating-point DSPs are used [6,7]. A DSP-based single-phase active power filtering solution is proposed in this paper. The proposed technique uses a fixed-point DSP to effectively eliminate system harmonics. The use of fixed point DSP provides a simpler and cheaper solution compared to other existing solutions proposed in literature referenced above. The proposed technique also provides reactive

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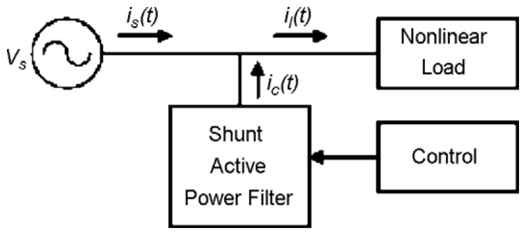

Fig. 1. Active power filter (APF) block diagram.

power compensation or power factor correction. The proposed technique requires only the load current information to estimate the fundamental current information which is then used to calculate the required compensation current using the DSP algorithm. As a result the proposed scheme requires fewer current sensors than other solutions which require both the source current and the load current information [1–5].

2. Basic operation principle of the proposed control method

Fig. 1 shows the compensation principle for a shunt active power filter. The nonlinear load current $i_l(t)$ consists of the fundamental component $i_1(t)$ and harmonic currents $i_h(t)$,

$$i_l(t) = i_1(t) + i_h(t) \tag{1}$$

The APF block supplies compensating currents to cancel the harmonic current components from the source current $i_s(t)$. The compensating current $i_c(t)$ that needs to be supplied by the APF can be obtained by subtracting the fundamental component of the load current from the load current.

$$i_c(t) = i_l(t) - i_1(t) \tag{2}$$

If the active power filter is required to provide reactive power compensation and power factor correction in addition to harmonic compensation, Eq. (2) must be modified. In that case, the APF must supply the reactive component of the fundamental load current in addition to the harmonic currents. Hence, Eq. (2) should be modified such that the compensating current $i_c(t)$ is obtained by subtracting the active component of the load current from the total load current $i_l(t)$.

Fig. 2 shows an active power filter connected in shunt in a single-phase system. The system consists of an ac voltage source, $v_s(t)$, supplying a nonlinear load current $i_l(t)$ to a single-phase diode bridge rectifier circuit. The rectifier circuit represents a typical nonlinear load encountered in modern facilities. The active power filter comprises of a single-phase H-bridge inverter, a capacitor forming a self-regulating dc bus and an inductor connected between the supply and the inverter. The inverter switches are controlled by the DSP controller in order to generate the required compensating current, $i_c(t)$.

The following equations describe the procedure that is used to derive the compensating current, $i_c(t)$.

The source voltage, v_s, in Fig. 2 can be written as,

$$v_s(t) = V_s \sin(\omega t) \tag{3}$$

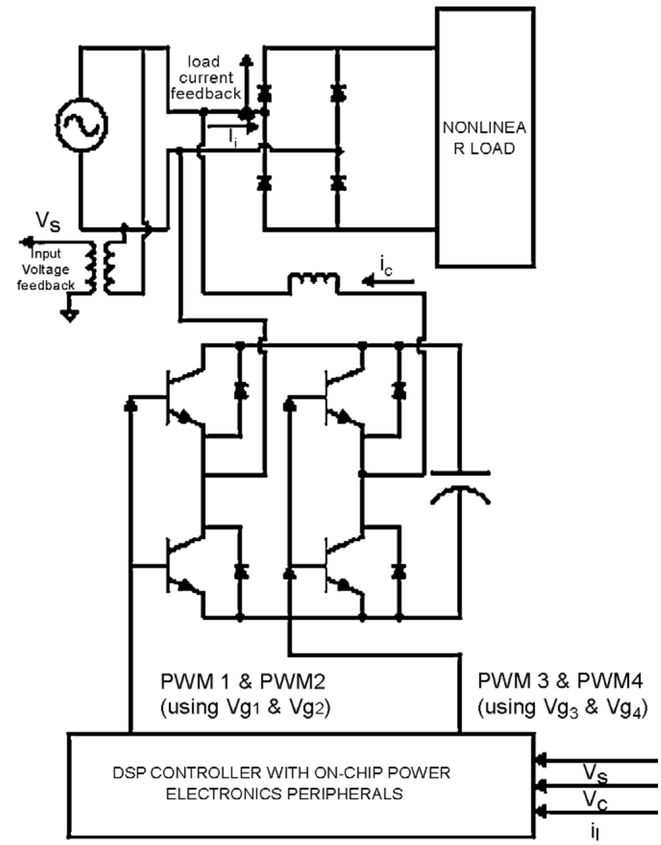

Fig. 2. Block diagram of the proposed active power filter (APF).

The nonlinear load current can be written as:

$$i_l(t) = \sum_{h=1}^{\infty} I_h \sin(h\omega t + \theta_h) \tag{4}$$

where I_h is the peak amplitude of the hth order harmonic in the load current and θ_h is the phase of the hth order harmonic in the load current.Then the load power is

$$\begin{aligned} p_l(t) &= v_s(t) i_l(t) = I_1 V_s \sin(\omega t)\sin(\omega t + \theta_1) \\ &\quad + \sum_{h=2}^{\infty} V_s \sin(\omega t) I_h \sin(h\omega t + \theta_h) = p_s(t) + p_c(t) \end{aligned} \tag{5}$$

In the above equation, $p_s(t)$ includes the power provided by the voltage source and $p_c(t)$ is the harmonic power, which needs to be compensated by the APF. Normally, $p_s(t)$ consists of active power and reactive power. If a unity power factor is desired, the reactive power must be provided by the APF instead of the power source. Therefore, the first term is further decomposed into two terms: the active power and reactive power,

$$\begin{aligned} p_s(t) &= I_1 V_s \sin^2(\omega t)\cos(\theta_1) + I_1 V_s \sin(\omega t)\cos(\omega t)\sin(\theta_1) \\ p_s(t) &= p_a(t) + p_r(t) \end{aligned} \tag{6}$$

where $p_a(t)$ is the active power and $p_r(t)$ is the reactive power. The peak value of the active current is $I_1\cos(\theta_1)$.

The last obstacle is to derive the amplitude. If the load power is integrated over one period, the load power can be expressed