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Real time simulation and experimental validation of active power filter operation and control

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Abstract

Nonlinear loads inject harmonics into electric power systems distribution network, which deteriorate power quality and affect the sensitivity of connected electronic equipment. Shunt active power filter (APF) is an important piece of depolluting equipment that is used in power systems to cancel current harmonics, compensate reactive power and balance supply loads. In this paper an APF setup is studied and analyzed using RT-Lab real-time simulator and controller. A simple control method is used to extract the harmonic contents of the supply currents. The pulse width modulation (PWM) technique is therefore applied to command the power switches to generate the reference current for the APF. Experimental results validate the real time model and the control method is used to properly compute and track the reference current, results show efficient filtering of the load harmonics and load balancing is also successfully achieved.

Keywords: Shunt active power filter; Real-time simulation; Reactive power compensation; Harmonic elimination; Power quality

1. Introduction

Voltage and current harmonics are matter of concern in most research on power networks. Power quality issues are attractive for most researchers in power engineering. Use of nonlinear loads is increased significantly which generates harmonic and reactive power that is not acceptable due to high power losses. Rectifiers are the most existed nonlinear loads that change the drawn current waveform shape due to harmonic components leading to power losses and resonance problems. The harmonic components are the sinusoidal currents with the frequencies different from

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the system frequency. Therefore the sum of these waveforms is periodic while there is not any similarity to sinusoidal wave which is desirable in power systems [1,12].

Active power filter is composed of an inverter and the associated controller. It can generate the harmonic content of the load current. When the APF is connected in parallel to the load, it can inject the harmonic current to the system, therefore the source just need to produce the sinusoidal current and active power [3,4,13]. APF performs this action using the appropriate controller to calculate the reference current that includes harmonic part of the load current [8,10,9]. APF is widely used in power network to eliminate the harmonics, compensate the reactive power and balance unbalanced loads in order to reduce the power losses of the power sources [11,12].

In this paper, an indirect current control method has been used to extract the load harmonic current. The Proportional Integral (PI) controller is tuned to fix the DC bus voltage even in a disturbance condition. The later section describes the system configuration. The control method has been clarified in Section 3. The practical results are illustrated and discussed in Section 4. The experimental results are discussed comprehensively to demonstrate the operation of the APF. The results containing the currents and voltages as well as the Total Harmonic Distortion (THD) prove the efficiency of controller. The prototype can be used to test many controllers and switching techniques for analyzing the APF in power system.

2. Three-phase shunt active power filter configuration

As mentioned former, APF contains an inverter with DC storage device (capacitor) connected in parallel to the load to eliminate the current harmonics and compensate the reactive power [6,11]. Fig. 1 shows a three-phase APF connected to the power system in parallel with a nonlinear load. The inverter can convert DC to AC by various switching states. In this paper, a three-phase two-level voltage source inverter (VSI) has been used to produce the reference current. Recently various multilevel inverter topologies have been introduced that can be employed in APF applications.

3. Indirect current control method

To compensate the current harmonics of a nonlinear load in power systems, the source currents ($i_{s123}(t)$) should be extracted. The fundamental content of source currents will be used to calculate the reference currents ($i^*_{123}(t)$). The derived reference current should be modulated to generate the associated pulses that order the inverter switches to inject the appropriate currents ($i_{F123}(t)$) into the system which can compensate the load harmonics [6,5,7].

The controller used in this case has two parts: first, the current extraction part and second; the PI controller which is used to balance the inverter DC link voltage. Fig. 2 shows the overall view of the control process.

As it is clear in Fig. 2, the DC bus voltage (V_{dc}) is sensed and compared with the reference value (V_{dcref}). The PI controller plays an important role to fix the DC voltage and balance it during any disturbance in the system parameters such as load. The output value of the PI is multiplied by a sinusoidal unit wave which is in phase with the source voltage. This step is done to make the source current in phase with the source voltage which leads to unit power factor of the three-phase supply. The source current must track this reference current, therefore the difference of these currents for three phases is sent to the PWM modulation block to produce the appropriate pulses. The conventional PWM method is used to compare the reference wave with the carrier wave and modulate the input signal. The firing pulses command the switches to generate calculated reference current which is injected to the system to suppress the source harmonic current and make it sinusoidal in phase with the voltage waveform.

Eq. (1) is the output of the PI controller.

$$I^*_{\max} = K_p(V_{dcref} - V_{dc}) + \frac{K_i}{S}(V_{dcref} - V_{dc}) \tag{1}$$

where $I^*_{\max}$ is the output of the PI controller which determines the peak value of the reference current. K_p and K_i are the proportional and integral coefficients that are tuned to regulate the DC bus voltage against deviation. Fixing the DC voltage is an important part of the controller in APF applications which requires accurate design and tuning. If the DC voltage changes during the time, the filtering aim would not be performed well and undesired harmonics are injected into the grid that increases the power losses. Besides, there are unwanted disturbances in the system such