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On design and implementation of three phase three level shunt active power filter for harmonic reduction using synchronous reference frame theory

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ABSTRACT

Shunt active power filter is commonly used to eliminate current harmonics generated in the source side due to presence of non-linear loads. This scheme consists of three phase three level diode clamped multilevel inverter and a DC capacitor that act as a shunt active power filter to mitigate the supply current harmonics and inject the required reactive power to non-linear loads. In this paper, using synchronous reference frame algorithm, a three phase three level SAPF is implemented on an embedded platform. In SRF theory, reference signals are transformed from a–b–c stationary frame to 0–d–q rotating frame. The reference signals in the 0–d–q rotating frame are controlled to get the desired reference signals using PI controller. The PWM signal generation for the three phase three level inverter is computed directly from the sampled amplitudes of the reference phase voltages. The practical implementation of the SAPF is realized using Xilinx XC3SD1800A – FG676-4 Spartan 3A DSP FPGA controller. This system is simulated using MATLAB/SIMULINK and the simulation results are compared with prototype hardware model for validating the effectiveness of the proposed system. Based on the studies, it is concluded that the SAPF is easy for implementation for reducing the Total Harmonic Distortion below 5% as per IEEE-519 standard.

Introduction

The use of power electronics equipment has resulted in direct increase in harmonics in the large scale power system. Traditionally, this problem can be rectified by connecting passive filters in the grid combined with an inductor and a capacitor. Though this method offers a low cost solution, the system impedance and load characteristics are affected significantly. In addition, this method has the limitations of fixed compensation, larger component size, and can also excite resonance conditions. The shunt active power filter is an attractive solution to mitigate the current harmonics as well as reactive-power problems and power factor corrections. Jain and Agarwal in [1] have proposed a shunt active power filter with complete design, simulation and experimental investigation for mitigating harmonics and reactive power of non-linear load using two level inverter and the current compensation is determined using hysteresis control algorithm. In [2], a two level Voltage Source Inverter (VSI) has been used to implement active power filter connected to the AC bus through a transformer. This method is mainly used to compensate medium power range non-linear load due to limitation of semiconductor devices. In [3], fuzzy logic control algorithm is proposed for generating reference current and maintaining capacitor voltage for three level inverter based active filter. The fuzzy algorithm is implemented using MATLAB simulation tool box only. The reactive power compensation is vague in the result analysis. In [4], a control algorithm is reported for SAPF using SRF theory and it presents simulation model with two level voltage source converter. In [5], the SAPF with three phase three level inverter using conventional Space Vector Pulse Width Modulation (SVPWM) is proposed and an experimental model is presented to validate the simulation results. In [6], the hardware implementation of shunt active filter using two level inverter is dealt wherein Adaline based current estimation technique is proposed to maintain a constant DC bus voltage using PI controller and switching of VSC is achieved using hysteresis-based pulsewidth-modulation with indirect current-control scheme. This paper proposes the simulation and hardware implementation of the SAPF with three phase three level diode clamped inverter using SRF theory.

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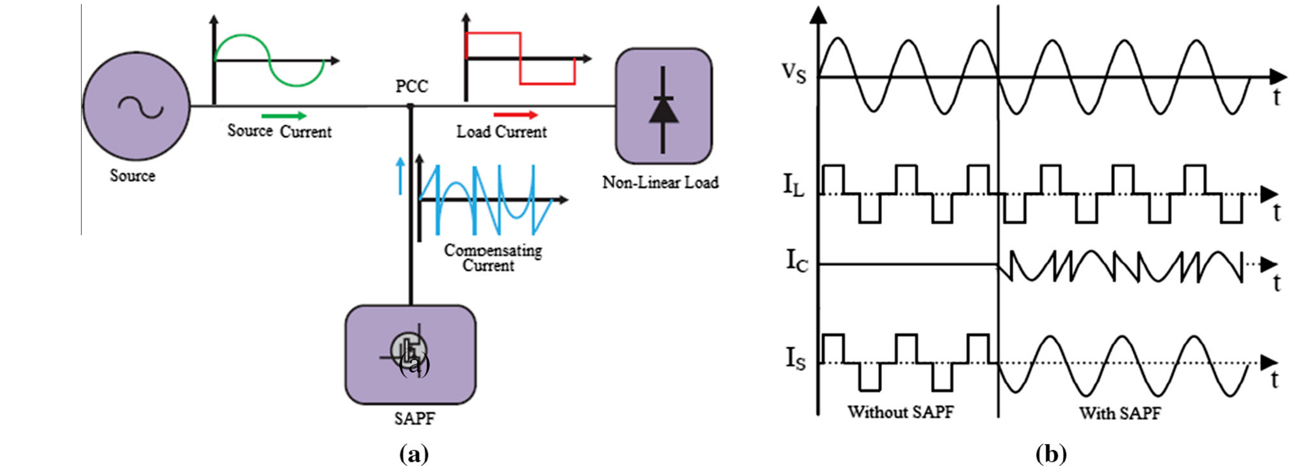

Fig. 1. (a) Shunt active power filter and (b) schematic waveforms.

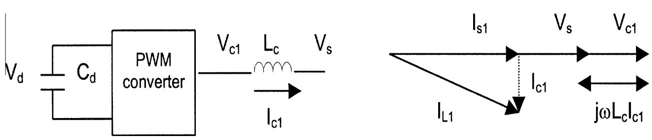

Fig. 2. Vector diagram.

Table 1
Simulation parameters.

Input AC voltage	100 V_{P-P}
Frequency	50 Hz
Source impedance	R_s = 0.1 Ω and L_s = 0.002 H
Filter impedance	R_f = 0.1 Ω and L_f = 0.66 mH
DC-capacitor (C_{dc})	1100 µF, 300 V

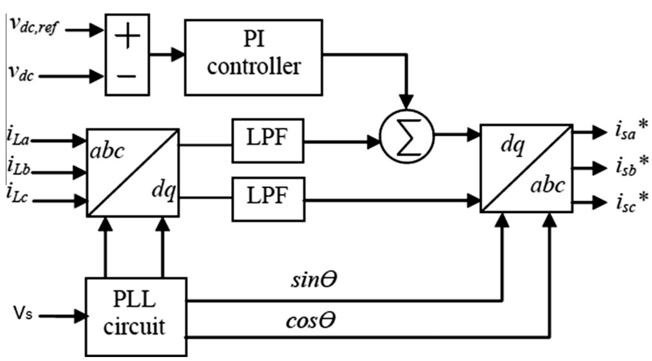

Fig. 3. Block diagram of SRF algorithm.

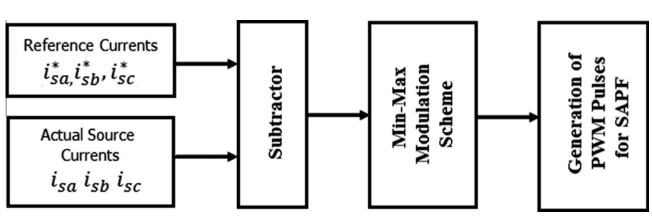

Fig. 4. Block diagram of PWM signal generation.

Shunt active power filter

SAPF consists of voltage source converter with DC link capacitor which generates compensating current with 180° phase opposition and injects at the Point of Common Coupling (PCC) in the grid, so as to cancel out the current harmonics caused by the non-linear load. SAPF compensate current harmonics by injecting equal-but-opposite harmonic compensating current. The components of harmonic currents contained in the load current are cancelled by the effect of the active filter, and the source current remains sinusoidal and in phase with the respective phase to neutral voltage. With an appropriate control scheme, the active power filter can also compensate the load power factor [7].

Compensation principle of SAPF

The basic compensation principle of the shunt active power filter is shown in Fig. 1(a) and its schematic waveforms are presented in Fig. 1(b). The SAPF is controlled to draw or supply a compensating current I_c from or to the utility respectively so that it cancels current harmonics on the AC side [1]. A shunt active power filter can be used to eliminate current harmonics and reactive power compensation in source side. The instantaneous current and the source voltage are expressed as follows:

$$i_s(t) = i_L(t) - i_C(t) \quad (1)$$

$$v_s(t) = V_m \sin \omega t \quad (2)$$

If a nonlinear load is applied, then the load current becomes nonlinear and is expressed using Fourier series as follows:

$$i_L(t) = I_1 \sin(\omega t + \varnothing_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varnothing_n) \quad (3)$$

The instantaneous load power is then given by

$$p_L(t) = v_s(t) i_L(t) \quad (4)$$

which is then rewritten as follows

$$p_L(t) = V_m \sin \omega t \{I_1 \sin(\omega t + \varnothing_1) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varnothing_n)\} \quad (5)$$

Eq. (5) is expressed as follows:

$$p_L(t) = V_m I_1 \sin^2 \omega t \cos \varnothing_1 + V_m I_1 \sin \omega t \cos \omega t \sin \varnothing_1 + V_m \sin \omega t \sum_{n=2}^{\infty} I_n \sin(n\omega t + \varnothing_n) \quad (6)$$