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Implementation of active power filter with asymmetrical inverter legs for harmonic and reactive power compensation

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Abstract

An asymmetrical voltage source inverter is proposed to operate as an active power filter to eliminate harmonics and compensate reactive power drawn from the nonlinear loads such that a sinusoidal line current is drawn from the ac source. Two inverter legs are used in the adopted circuit configuration. One inverter leg is operated in the line frequency and the other leg is operated in the high switching frequency to track the compensated current command. In the proposed control scheme, a voltage compensator, a carrier-based current controller and a proportional integral-based dc link controller are used to achieve balanced capacitor voltages, to track line current and to obtain a constant dc bus voltage, respectively. Based on the pulse-width modulation (PWM) control scheme, a three-level voltage pattern is generated on the ac terminal of the inverter. Computer simulation and experimental results are provided to verify the effectiveness of the control scheme.

Keywords: Active power filter; Harmonics; Inverter legs

1. Introduction

Owing to the growth of the nonlinear loads such as switching mode power supplies, light controllers, interruptible power supplies, electric furnaces, ac voltage regulators and adjustable speed drives, power pollution is produced and reflected into distribution and transmission networks. Power pollution resulted in low power factor, leads to voltage notch and reduces utilization of distribution system. This results in the increase in losses and interference with power equipment. One of the most important issues of the power electronic designer is the reduction of current or voltage harmonics created by the converters. The passive filter is often used to improve the power quality for its simple circuit configuration. Bulk passive elements, fixed compensation characteristics, and series and parallel resonance are the main drawbacks of this scheme. The active power filters [1–5], custom power devices [6–8] and FACT controllers [9–12] based on inverter topology are developed to improve the power quality in the load side, the distribution system and the transmission system, respectively. The voltage source inverter can be connected to the system with the shunt, series or series–shunt combination. The FACT controllers are used to control the power flow in the transmission system. The custom power devices are adopted in the distribution system to provide a stable receiving voltage by controlling the reactive power from the inverters. The active power filters are used in the load side to suppress the harmonics and compensate the reactive power generated from the nonlinear load. Shunt active filter is operated as a controlled current source connected in parallel with the nonlinear load to inject harmonic and reactive currents into the ac source. The injecting harmonic and reactive currents are equal-but-opposite the load harmonic and reactive currents. Therefore, line current only supplies the active current to the nonlinear load. The line current is a sinusoidal wave with nearly unity power factor.

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A single-phase shunt active filter is presented to suppress the load harmonics and compensate the reactive power. The adopted voltage source inverter is based on an asymmetrical inverter leg to achieve three-level pulse-width modulation (PWM). Three-level PWM inverter has less voltage harmonics generated on the ac terminal of the inverter compared with two-level PWM operation. Conventional neutral-point diode-clamped inverter or flying capacitor inverter needs clamped diodes or flying capacitors in the circuit to achieve multilevel PWM operation. In the adopted inverter, no flying capacitor and clamped diode are used in the circuit configuration. The adopted control scheme is based on the carrier-based current controller in the inner loop and the dc bus voltage controller in the outer loop to track the current command and regulate dc-link voltage. First, the detailed circuit configuration, operating principle and control scheme of the proposed inverter to suppress the harmonics and compensate the reactive power are presented. Finally, the performance of the proposed control scheme is evaluated by computer simulations and experimental results based on a laboratory prototype.

2. Circuit configuration

The circuit configuration of the proposed single-phase active power filter with asymmetrical inverter legs is shown in Fig. 1. Four active switches are used in the inverter leg-a and two active switches are adopted in the leg-b. One boost inductor is used in the ac side and two capacitors are adopted in the dc side. The voltage stress of power switches S_{a_2} and S'_{a_2} is equal to half the dc bus voltage, and the voltage stress of active switches S_{a_1}, S'_{a_1}, S_b and S'_b is equal to dc bus voltage. Power switches in the leg-a are operated in the high switching frequency to generate three voltage levels on the ac terminal to neutral point voltage v_{ao}. However, power switches in the inverter leg-b are operated in the line frequency to generate two voltage levels on the ac terminal to neutral point voltage v_{bo}. If we assume that two capacitor voltages v_{C_1} and v_{C_2} on the dc bus are equal, five voltage levels (v_{dc}, $v_{dc}/2$, 0, $-v_{dc}/2$ and $-v_{dc}$) are generated on the ac terminal voltage v_{ab}. There is a nonlinear load connected between the ac mains and the adopted inverter. The nonlinear load consisted of a diode bridge rectifier followed by a bulk capacitor and a resistor load. The proposed voltage source inverter, which is capable of regenerative power flow, is adopted as a shunt active filter to eliminate harmonics and compensate reactive power generated from the nonlinear load. By the proper control scheme, a sinusoidal line current with a nearly unity power factor is drawn from the ac source.

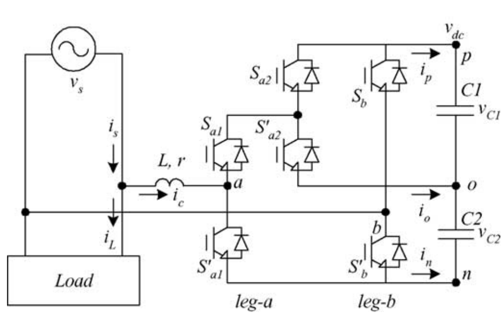

Fig. 1. Adopted single-phase active power filter based on asymmetrical inverter legs.

3. Operation principle of the proposed inverter

There are six active switches in the proposed single-phase voltage source inverter to achieve three-level PWM operation, to eliminate harmonics and to compensate the reactive power drawn from the nonlinear load. Four and two active switches are used in the inverter leg-a and leg-b, respectively. To prevent active switches in each leg from conducting at the same time, the constraints of power switches are given as:

$$S_{xy} + S'_{xy} = 1 \tag{1}$$

where S_{xy} (or S'_{xy}) = 1 if switch S_{xy} (or S'_{xy}) is turned on, or S_{xy} (or S'_{xy}) = 0 if switch S_{xy} (or S'_{xy}) is turned off; x = a, b; y = 1, 2. Based on the constraint in (1), three independent power switches S_{a_1}, S_{a_2}, S_b can be used in the proposed inverter to control the input current i_c and regulate the dc bus voltage. In the system analysis, all elements in the inverter are assumed ideal and the output voltage is constant during one switching period. According to the on and off states of power switches, two switching functions are defined as:

$$g_a = \begin{cases} 1, & \text{if } S_{a_1} = S_{a_2} = 1 \\ 0, & \text{if } S_{a_1} = S'_{a_2} = 1 \\ -1, & \text{if } S'_{a_1} = 1 \end{cases} \tag{2}$$

$$g_b = \begin{cases} 1, & \text{if } S_b = 1 \\ -1, & \text{if } S'_b = 1 \end{cases} \tag{3}$$

Based on the defined two switching functions g_a and g_b, the equivalent circuit of the adopted active filter system is shown in Fig. 2. The ac side to neutral point voltages can be expressed as:

$$v_{ao} = \frac{g_a(g_a+1)}{2} v_{C_1} - \frac{g_a(g_a-1)}{2} v_{C_2} \tag{4}$$

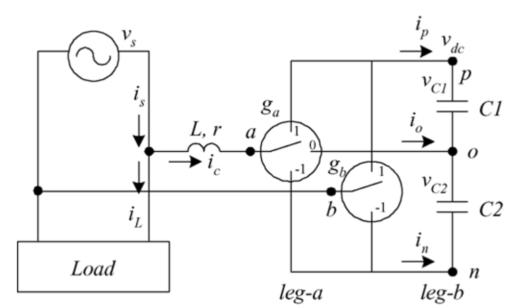

Fig. 2. Equivalent circuit of the adopted active power filter.