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An eight-switch three-phase VSI for power factor regulated shunt active filter

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Abstract

A three-phase neutral point clamped (NPC) inverter operated as a shunt ac line conditioner is presented. Eight power switches and four clamping diodes with voltage rating $v_{dc}/2$ are used in the proposed inverter. The presented inverter can compensate current harmonics and reactive power generated from the nonlinear loads, and supply the demanded dc side power of the inverter. If there is no nonlinear load connected to the system, the adopted inverter is operated as a power factor pre-regulator. If there is no output load connected to the dc side of the inverter, the inverter is operated as a shunt active filter. If a nonlinear load is connected to the ac source and a dc load is connected to the inverter, the adopted inverter is operated as an integrated power quality compensator to draw the sinusoidal line currents from the ac mains. To supply the necessary active power for the dc side load and compensate the power losses of inverter, a proportional-integral (PI) controller is used to obtain the active power for the inverter. A space vector pulse-width modulation (SVPWM) is used to track the line current commands. Simulation and experimental results based on a laboratory scale-down prototype are presented to verify the effectiveness of the proposed control scheme.

Keywords: VSI; Power factor regulated; Shunt active filter

1. Introduction

A great increase of nonlinear loads in electric systems has been noticed in recent years. Current or voltage pollutions by nonlinear loads result in low power factor, low efficiency of power system, current or voltage distortion, and losses in the transmission and distribution lines. Passive power filters have the advantages of simple circuit and easy implementation for reducing power pollution. However, the drawbacks of passive filters are sensitive to the line frequency, fixed compensation characteristics, and series and parallel resonance with the system parameters. Active power filters have been developed [1–5] to reduce harmonics in power systems instead of passive filters to eliminate harmonics. The shunt active filters connected in parallel with ac mains can be implemented with a voltage source inverter. The functions of the shunt active filters are operating as a current source, generating current harmonics required by the nonlinear loads, and regulating dc-link of the voltage source inverter. The conventional six-switch three-phase voltage source inverter is the most common circuit to implement shunt active filter. A cost-effective voltage source inverter with a reduced switch count configuration was presented in [6,7] for ac drive and shunt active filter applications. Multilevel inverters have been proposed in the literatures [8–12] for high power applications such as reactive power compensation and motor drive. The advantages of multilevel inverters are low voltage stress of power semiconductors, less current or voltage harmonics, and less electromagnetic interference. Multilevel inverter based on neutral point clamped (NPC) scheme is the most common topology in the high power motor drive and utility applications. However, the disadvantages of the NPC inverters are many power semiconductors used in the circuits and complex control scheme. Three-phase NPC rectifier/inverter was proposed in [13] to draw the sinusoidal line currents in phase with mains voltages and

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to drive the ac motor. However, 12 power switches and six clamped diodes are used in the rectifier and inverter, respectively.

A NPC inverter with less power switches is presented in this paper. The main advantages of proposed circuit topology are reduced number of switches, lower switch ratings, higher efficiency and simple structure. Eight power switches and four clamping diodes are used in the proposed inverter. The size of the proposed circuit is reduced compared with the conventional NPC inverter with 12 power switches and six clamping diodes. The proposed inverter is used to work simultaneously as a power factor pre-regulator as well as an active power filter to eliminate current harmonics, to compensate reactive power, and to supply the active power for the demanded dc power of the inverter. The analysis of the proposed inverter is presented. A voltage control loop is used to obtain the magnitude of the line current commands. A space vector pulse-width modulation (SVPWM) is derived to track the compensated current commands. Finally, the performance of the proposed control scheme is evaluated by the simulation and experimental results obtained from a laboratory scale-down prototype.

2. Circuit configuration and operation principle

The circuit configuration of the adopted inverter for power quality compensation is shown in Fig. 1. A three-phase voltage source inverter with two NPC legs is used in the system. Three inductors L_c are used in the inverter to achieve voltage boost operation and current filtering. Two split dc capacitors $C1$ and $C2$ are used on the dc side to smooth the dc terminal voltage. Four clamping diodes (D_{a1}, D_{a2}, D_{b1} and D_{b2}) and eight power switches (S_{a1} through S'_{b2}) are used in the adopted inverter to achieve three-level PWM operation. The phase c of three-phase mains is directly connected to the midpoint of the split dc capacitors. A three-phase nonlinear load is connected to the ac mains and a dc load is connected to the dc side of inverter. The nonlinear load will generate current harmonics and reactive power to the supply system. For the unity power factor operation, the ac mains should supply the necessary average inverter power for the dc side load as well as average nonlinear load power. The active filter will compensate harmonics and reactive power drawn from the nonlinear loads such that the input power factor of the system is close to unity.

To avoid the short circuit in each inverter leg, the switches S_{xy} and S'_{xy} $(x = a,\ b;\ y = 1,\ 2)$ are complementary each other. There are two independent power switches in each NPC leg. Each power switch can be controlled to open or close. Four possible switching states (2^2) can be found in each leg. However, there are only three valid operating states in each leg to generate three different voltage levels $v_{dc}/2$, 0, $-v_{dc}/2$ on the ac terminal to neutral point voltage. For example, power switches S_{a1} and S_{a2} are closed to obtain voltage $v_{ao} = v_{dc}/2$. In this operating state, the compensated current i_{ca} is decreasing because boost inductor voltage is negative. If the power switches S'_{a1} and S'_{a2} are closed, the ac side voltage $v_{ao} = -v_{dc}/2$. In this state, the compensated current is increasing because boost inductor voltage is positive. Power switches S'_{a1} and S_{a2} are closed to obtain $v_{ao} = 0$. In this state, the compensated current is increasing (or decreasing) if the line voltage v_{sac} is positive (or negative). Therefore, three voltage levels are generated on the ac terminal voltages v_{ac} and v_{bc}. Two switching signals f_a and f_b related to inverter leg-a and leg-b are defined and expressed as

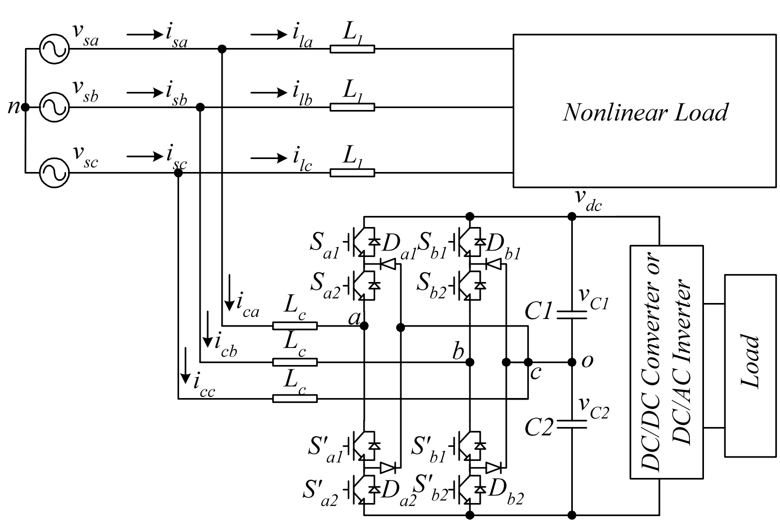

Fig. 1. Proposed NPC inverter for the integrated power quality compensation.