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Active power filter based on three-phase two-leg switch-clamped inverter

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Abstract

A novel three-phase two-leg switch-clamped inverter is presented to achieve multilevel pulse-width modulation (PWM) operation, harmonics elimination, reactive power compensation and dc-link voltage regulation. Four active switches with voltage stress of dc-link and two ac switches with voltage stress of half dc-link are used in the proposed inverter. In this paper, the proposed inverter is operated as a controllable current source to supply the necessary active power for the compensation of inverter losses, to suppress current harmonics, and to compensate the reactive power drawn from the non-linear loads. Therefore, the balanced and sinusoidal line currents are drawn from the ac source. Two control loops are used in the adopted control scheme to maintain the constant dc-link voltage (outer loop with low-bandwidth control) and to achieve the line current command tracking (inner 1oop with high-bandwidth control). The mathematical model of the proposed converter for the operation active power filter is derived and the control scheme is provided. Computer simulations and experimental results based on a laboratory scale-down prototype are presented to verify the effectiveness of the proposed control scheme.

Keywords: Pulse-width modulation (PWM); Semiconductors; Inverter

1. Introduction

Owing to the widely applications of power converters in the industry products, power pollution has been a serious problem in the distribution system. The power pollutions due to large non-linear loads result in low power factor, low efficiency of power system, voltage distortion, and losses in the transmission and distribution lines. Active power filters have been developed [1–4] to solve these problems. The active power filter implemented with a voltage source inverter is connected in parallel with the load, and the combined filter and load then draws a sinusoidal current from the transmission line or distribution system that is connected to the ac source. The shunt active power filter is considered as a controllable current source to supply the equal-but-opposite harmonic current and reactive current drawn from the non-linear loads such that the ac source only supplies the active current to the loads. To obtain the compensated current for the active filter, the instantaneous reactive power theory, neutral network scheme, and sliding mode scheme and synchronous transformation scheme have been adopted to achieve the improvement of power quality. Multilevel inverters are recently researched and presented for the high power and medium voltage applications, such as static var compensator, active power filter [5–7], and motor drives [8–10] due to their ability to obtain waveforms with better harmonic spectrum and attain higher voltages with a lower maximum device rating. However, the drawbacks of the multilevel inverters are many power semiconductors used in the circuits and complex control scheme. Three-level neutral-point-clamped rectifiers are proposed [11,12] to draw the sinusoidal line currents in phase with mains voltages. The input power factor is unity. However, 12 power switches and six clamped diodes are required in the rectifier. The control scheme is also very complicated.

A novel three-phase two-leg inverter based on switch-clamped topology with less power switches is presented for active power filter operation. Only four active switches

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with voltage stress of dc-link and two ac switches with voltage stress of half dc-link are used in the proposed inverter to achieve three-level pulse-width modulation (PWM). The cost and the size of the adopted inverter are reduced compared with the conventional three-phase three-level switch-clamped PWM inverter. The function of the adopted inverter is to draw the necessary active current for the compensation of inverter losses and the equal-but-opposite harmonic and reactive currents of the non-linear load. Two control loops are used in the system to generate the compensated current. The synchronous transformation control scheme is used in the control loop to obtain the active and reactive current components. The proportional-integral voltage controller is used in the outer loop to obtain the amplitude of reference line current. The active line current is equal to the active current of non-linear load and the active current to compensate the inverter losses. The hysteresis current control scheme is adopted in the inner loop to track the compensated current and achieve fast dynamic response owing to the load variation. The performances of the proposed control scheme are evaluated by computer simulations and experimental results obtained from a laboratory scale-down prototype.

2. Circuit configuration and system analysis

The conventional two-level voltage source inverter is given in Fig. 1(a). Six power switches with voltage stress v_{dc} are used in the inverter. Three-phase two-leg inverter shown in Fig. 1(b) is an alternative approach to achieve two-level PWM operation for active power filter. For three-level PWM operation, Fig. 1(c) gives the three-phase circuit topology based on switch-clamped scheme. Six power switches with voltage stress v_{dc} and three ac switches with voltage stress $v_{dc}/2$ are employed in this circuit topology. The disadvantage of this circuit is that many power semiconductors are used in the circuit. The circuit configuration of conventional three-phase neutral-point-clamped (NPC) inverter consists of 12 active switches and six clamping diodes with the voltage stress of half the dc bus voltage. The total power semiconductors in the NPC inverter are 18. The proposed three-phase two-leg inverter based on switch-clamped is shown in Fig. 1(d) to perform three-level PWM operation. The ac source voltages are v_{sa}, v_{sb} and v_{sc}. The boost inductor and equivalent series resistor of the inverter are L and r. The dc side capacitors are $C1$ and $C2$. S_{a1}, S_{a2}, S_{b1} and S_{b2} are active switches with voltage stress v_{dc} in the inverter

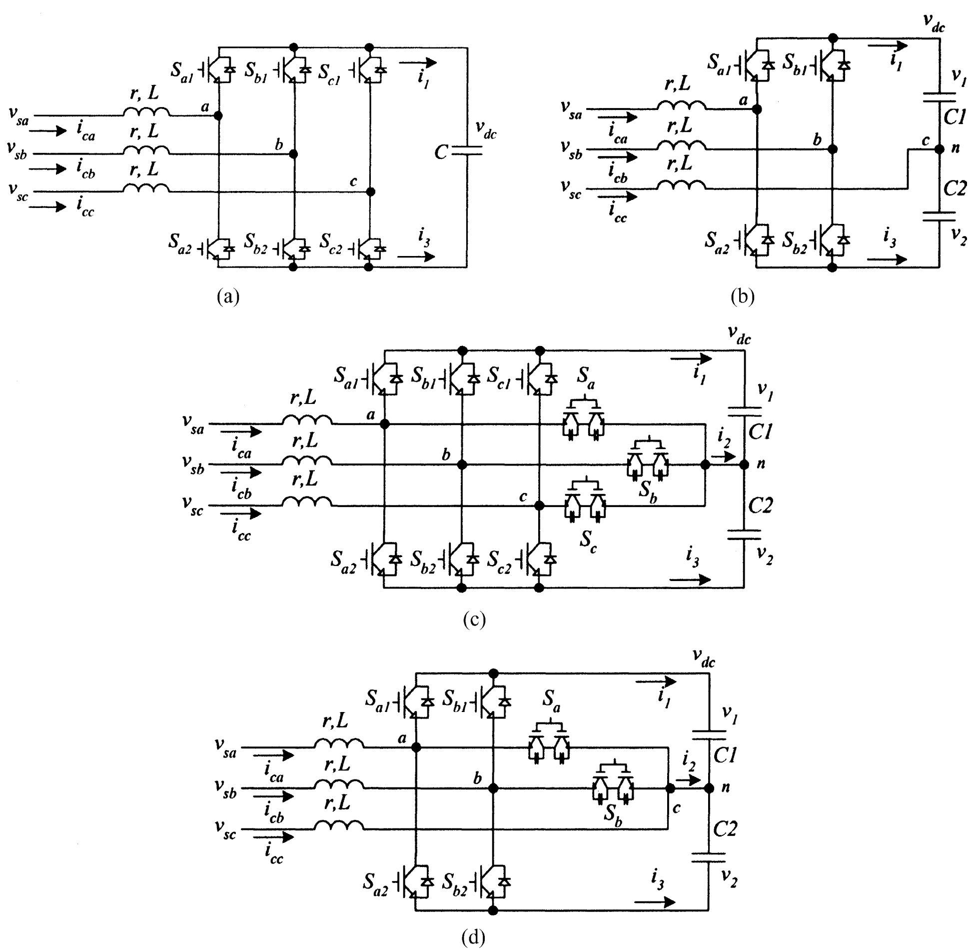

Fig. 1. (a) Conventional three-phase two-level inverter (b) conventional three-phase two-leg two-level inverter (c) conventional three-phase three-level switch-clamped inverter and (d) proposed three-phase two-level switched-clamped inverter.