

A New Nine Level Inverter with Reverse Voltage Topology

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Abstract: Multilevel inverters have drawn tremendous interest in high power and high voltage application. Multilevel inverters have unique structure which makes it possible to reach high voltages with less harmonic content. The harmonic content of the output voltage waveform decreases as the number of output voltage increases. The main advantages are lower Total Harmonic Distortion (THD), less stress on the power switches and higher efficiency. The main disadvantage is the high number of power switches which makes the control method complex and hence high cost. This paper presents a nine level inverter using reverse voltage topology. This topology requires less power switches compared to conventional multilevel inverter and less carrier signals and gate drives. The proposed topology and its control method are explained and detailed simulation has been carried out in MATLAB/Simulink.

Index Terms: Multilevel inverter, power electronics, Phase Disposition SPWM, Reverse voltage topology.

INTRODUCTION

The multilevel inverters are used in high power and high voltage industry. The main advantages of multilevel inverters are lower Total Harmonic Distortion (THD), less stress on the power switches and higher efficiency. The harmonic content of the output decreases as the number of level increases. Many topologies have been introduced for multilevel inverters [1], [2]. Multilevel inverters enhances staircase waveform quality, it has less input current distortion, and lower electromagnetic interference. The multilevel inverters are used in drives, PV systems, and automotive applications.

The multilevel inverters are mainly classified as cascaded multilevel inverter [3], Diode clamped multilevel inverter [4], Flying capacitor inverter [5]. The control method of cascaded H Bridge multilevel is more convenient than other multilevel inverter because it doesn't have any clamping diode and flying capacitor. Cascaded multilevel inverter reaches higher reliability. The cascaded inverter is used for large automotive electric drives.

The main disadvantage is the increase in number of power switches that normally contributes to the complexity in controlling the power switches. Many methods have been developed to decrease the number of switches [6]. Modulation strategies applied to multilevel inverters are selective harmonics elimination [7] [8], carrier based pulse width modulation [9] [10], space vector modulation [11] [12], and fundamental frequency modulation [13] [14]. The pulse-width modulation (PWM) control [15] is the most efficient method of controlling output voltage within the inverters. The carrier based PWM schemes used for multilevel inverters is the most efficient method, realized by the intersection of a modulating signal with triangular carrier waveform.

This paper proposes a nine-level inverter with reverse voltage topology which requires less number of switches than conventional topologies.

CONVENTIONAL CASCADED H-BRIDGE INVERTER

Cascaded multilevel inverters are based on a series connection of several single-phase inverters and are capable of reaching medium output voltage levels using only standard low-voltage mature technology components. Typically, it is necessary to connect three to ten inverters in series to reach the required output voltage. Each inverter can be seen as a module with similar circuit topology and modulation scheme. When a fault occur it is possible to replace it quickly. This inverter is obtained by connecting H-bridge inverters in series and output is sinusoidal. Each inverter level can generate $+V_{dc}$, 0, $-V_{dc}$ [16] and the output voltage of multilevel inverter is the sum of the voltage that is developed by each inverter. The output voltage resembles sinusoidal waveform. The number of output voltage levels of multilevel inverter are $2n+1$, where n is the number of cells. It requires less number of components comparative to the diode clamped or the flying capacitor. Fig.1 shows a nine level cascaded H bridge multilevel inverter. The number of switching devices in n level cascaded multilevel inverter is $2(n-1)$, where n is the number of the output voltage level. For a nine level inverter 16 switches and 4 DC sources are needed. Compared with other topologies it requires less number of components and packaging is possible because each level has same structure. The structure of separate DC source makes it possible to use renewable energy sources. It is possible to use soft switching techniques to reduce the switching losses and device stresses.

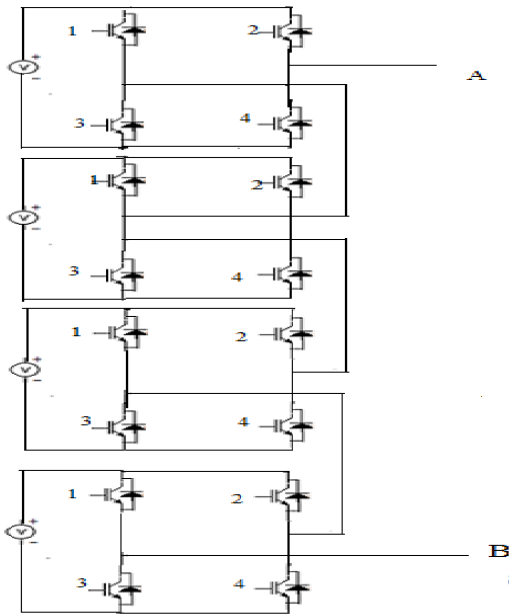


Fig.1 Nine level cascaded H-bridge inverter

PROPOSED NINE LEVEL INVERTER

Conventional cascaded multilevel inverters require large number of switches [17] and the power switches are combined to generate an output in positive and negative polarities. In the proposed multilevel inverter there is no need to use all the switches in high frequency [18]. This topology separates the output voltage into level and polarity generation parts. Level generation part generates levels in positive polarity. And the polarity generation part generates the polarity of the output voltage. Level generation part needs high frequency switches and polarity generation part requires low-frequency switches operating at line frequency. Fig 2 shows the general block diagram of reverse voltage topology. Fig.3 shows schematic diagram of a single phase nine levels reverse voltage topology. This multilevel inverter can be increased to higher voltage levels by increasing the middle section.

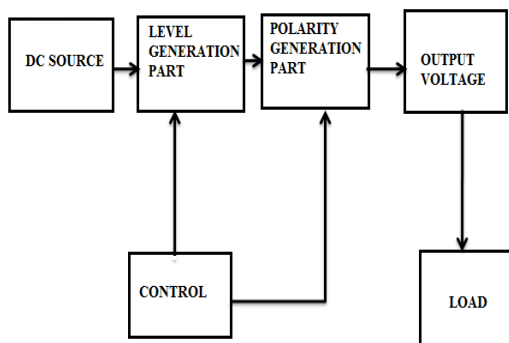


Fig.2 General block diagram

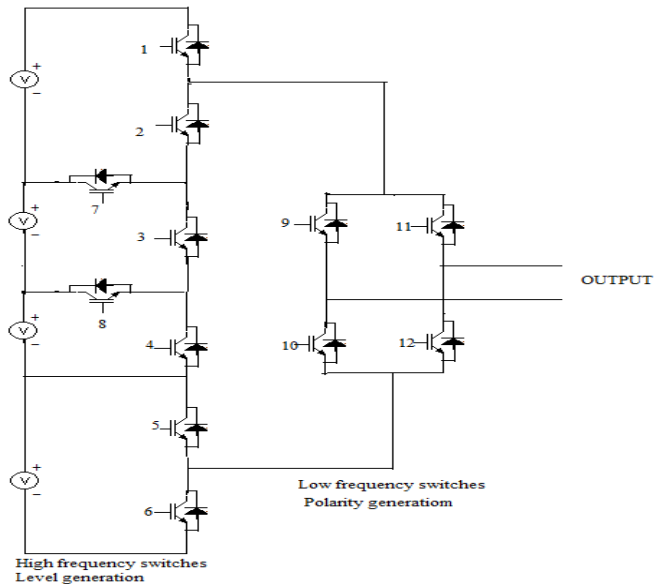


Fig.3 Nine level inverter with reverse voltage topology

This topology requires less switches and it can be applied to three phase application. The Phase Disposition (PD) SPWM needs only half the number of conventional carriers for SPWM. PD-SPWM for nine-level conventional converters requires eight carriers, but in the proposed system only four carriers are needed. To generate polarity, the positive voltage is fed to the polarity generation part. Multilevel inverter control with less number of carriers is the main advantage. Separate DC source is needed for this topology. The proposed multilevel inverter has better efficiency than conventional multilevel inverter. Fig.2 shows that nine inverter requires twelve switches and four DC sources. The left portion of the circuit in Fig.3 generates the required output levels and the right portion of the circuit generates the polarity of the output voltage. The right portion of the circuit is called polarity generation part; it reverses the output of the level generation part when the voltage polarity requires to be changed for negative polarity.

Modes Of Operation

The switching modes are selected such that the switching transitions become minimal for avoiding the unwanted voltage levels. This will minimize switching power dissipation. The sequence of switches (2-3-4-5), (2-3-4-6), (2-3-8-6), (2-7-6) and (1-6) are used for levels 0 up to 4, respectively. The output voltage is the sum of voltage sources. Table I shows the switching sequences.

TABLE I
Switching Sequences For Each Level

Level / Mode	0	V_{dc}	$2V_{dc}$	$3V_{dc}$	$4V_{dc}$
1	2,3,4,5	2,3,4,6	2,3,8,6	2,7,6	1,6

B. Control Strategies

The carrier based PWM technique fulfills switching states by comparing a modulating signal V_A and a carrier waveform V_C . The modulating signal V_A is a sinusoidal at frequency F_C and amplitude V_A and the triangular signal V_C is at frequency F_C and amplitude V_C . In this topology phase disposition-SPWM is adopted for its simplicity and all the carriers are in phase with each other. Here phase disposition SPWM is used for driving the high frequency switches and low frequency polarity generation part drive signals are generated with the line frequency (50Hz), and they only change at zero-voltage crossings. For a conventional cascaded multilevel inverter, (n-1) triangles are used, in the proposed topology a-phase modulation signal is compared with (n-1)/2 triangle waveforms for an n level inverter. The modular and four carriers are shown in Fig. 4

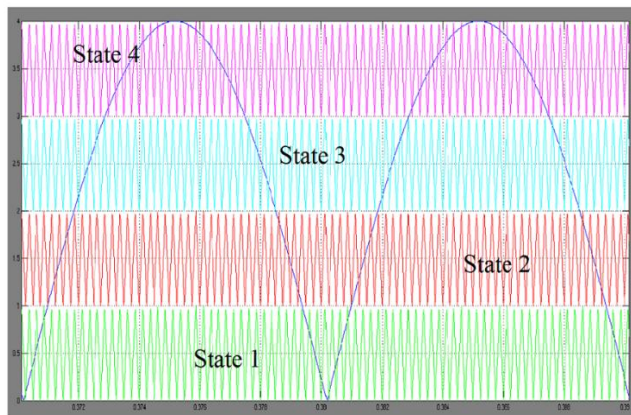


Fig 4. Modulator and SPWM carrier

C. Number of components

The reliability of the system is indirectly proportional to the number of its components. One of the main advantages of this topology is that it requires less high-switching frequency components. As the number of high-frequency switches is decreased, the reliability of the converter is increased. Hence, the reliability is highly improved in this topology. Also high frequency switches and diodes are expensive and easily damaged. $2(N-1)$ switching devices are required for an N level conventional cascaded H bridge multilevel inverter where N is the number of the output voltage level. In this topology only $(N-1) + 4$ switches are needed for an N level inverter. The number of switches in this topology is less and it will decrease with increase in voltage levels. Switches in the full bridge converter are switched at line frequency. Required components for different topologies are given in Table II

SIMULATION RESULTS

Modulation techniques are used in multilevel inverter to synthesis a controlled output voltage. There are various modulation techniques, of which phase disposition pulse width modulation is used here. Simulation of the proposed topology of multilevel inverter is performed using matlab.

Table II
Number Of Components For Single Phase Inverters

Inverter type	Proposed multilevel inverter	Cascaded H bridge
Main switches	$((N-1)+4)$	$2*(N-1)$
Flying capacitors	0	0
Main diodes	$((N-1)+4)$	$2*(N-1)$
DC bus capacitors/isolated supplies	$(N-1)/6$	$(N-1)/2$
Clamping diodes	0	0
Total numbers	$(13N+35)/6$	$(27/6)*(N-1)$

Simulation results are given below. Here phase disposition SPWM is used for driving the high frequency switches and low frequency polarity generation part drive signals are generated with the line frequency (50Hz), and they only change at zero-voltage crossings. In this proposed topology, a-phase modulation signal is compared with $(n-1)/2$ carriers for an n level inverter and all the carriers are in phase. Since this converter works only in positive polarity, this topology requires half of the conventional carriers for SPWM controller.

DC power supplies are adjusted to 50V and the switching frequency is 4KHz. Output voltage is 400V_{P.P.}. The simulation diagram of proposed multilevel inverter with inductive load is shown in Figure 5. The subsystem in Fig 5 shows the phase disposition PWM generation. The resulting THD of the proposed system is shown in Fig.10.

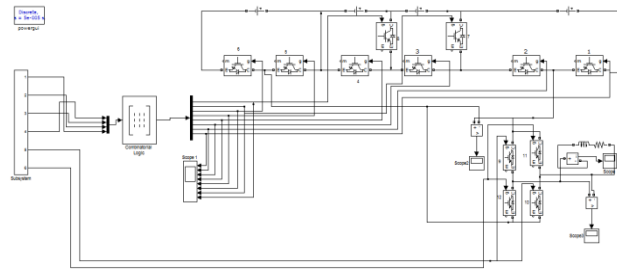


Fig.5 simulation diagram

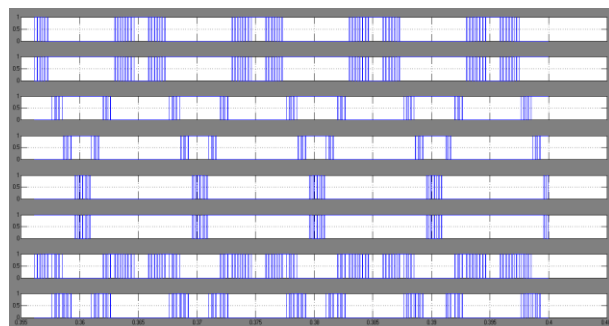


Fig.6 Complete gate signal for level generation part

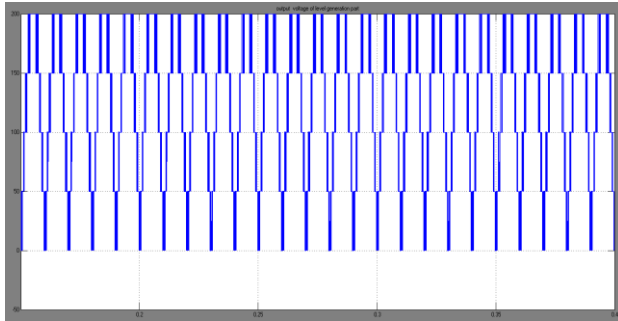


Fig.7 Voltage of the level generation part

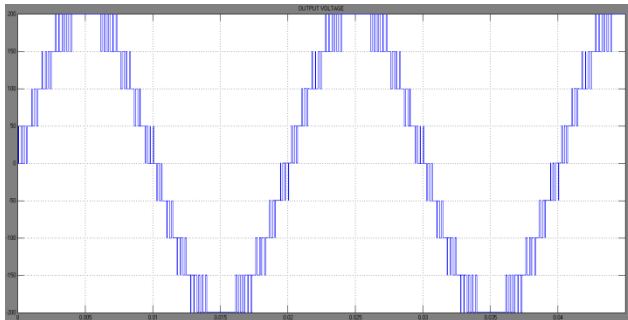


Fig.8 Output voltage of proposed nine level inverter with inductive load

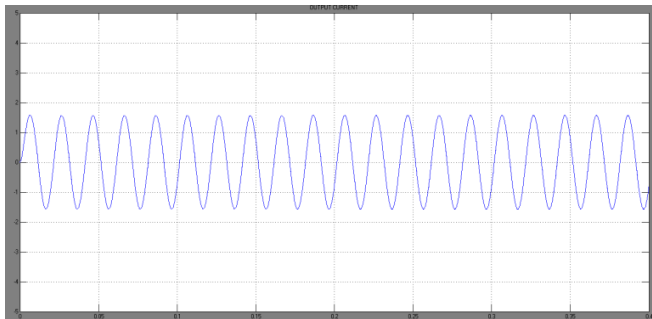


Fig.9 Output current of proposed nine level inverter with inductive load

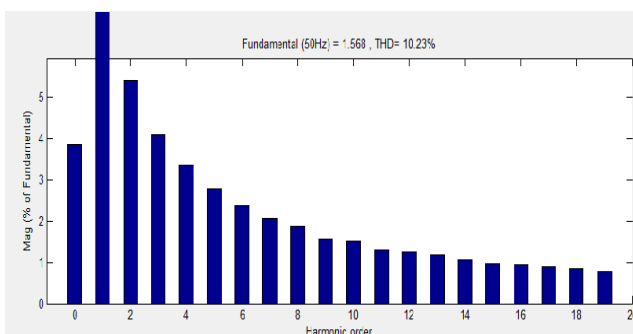


Fig.10 THD in % for proposed nine level inverter with inductive load

CONCLUSION

Multilevel inverters have been used in many industrial applications like HVDC, FACTS, EV, PV systems, UPS and Industrial drive applications. In the proposed topology switching operations are separated into high and low frequency parts. Instead of using cascaded inverter topology, proposed topology is more convenient for all these applications because it has less complex control method, associated cost is less and gives less THD. Hence proposed topology is more convenient than conventional cascaded inverter. The background study based on the various aspects of the PWM firing scheme was analyzed. The carrier based PWM scheme using the Phase Disposition (PD) strategy is used here. PD-SPWM control method is less complex since it uses only positive carriers for PWM control.

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