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A Different Single-Phase Hybrid Five-Level Voltage-Source Inverter Using DC-Voltage Modules

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Abstract

This paper presents another circuit configuration of single-phase hybrid five-level voltage-source inverter obtained from the H-bridge inverter and DC-voltage modules. Some features are achieved by using the proposed inverter configuration such as its modular structure and minimum number of the power devices required to construct the inverter circuits. The proposed five-level inverter circuit is examined through computer simulation using PSIM software. Furthermore, laboratory experimental tests were also performed to verify the prototype of the proposed five-level inverter circuits. The computer simulation and experimental test results shows that the proposed hybrid five-level voltage source inverter works properly to generate a five-level voltage waveform and sinusoidal current with low harmonics contents.

Keywords*: voltage-source, inverter; H-bridge, five-level; voltage module*

1. Introduction

The need of high power converter, and the growth of modern power semiconductor switches such as power MOSFET and IGBTs boost the research interest in power converters such as multilevel voltage source inverters (MVSI) and its dual circuit, multilevel current source inverters (MCSI). They are capable to generate a high output power with lower gradient voltage or current, and higher quality of output waveforms resulting in less EMI noise and smaller size of output filter required by the converter [1]-[4]. The designation of multilevel ineverter includes the three-level inverter circuits, and the inverters with more level number of output waveform. Many topologies of multilevel inverters especially MVSI circuits have been presented and developed by researchers. Three major variants of MVSI topologies have been presented in the literatures. These topologies are the cascaded H-bridges MVSI with separate DC power sources, diode clamped MVSI, and flying capacitors MVSI topologies [1]-[5]. The configuration of cascaded H-bridge MVSI has a great advantage with its modular circuit configuration. Nevertheless, the requirement of isolated DC power sources, and the power switching device count can be the shortage of this inverter. The topology of diode clamped MVSI has been widely used in high power application such as high power motor drive. The third topology is the flying capacitor MVSI. The number of the capacitors used in the flying capacitor MVSI will cause problems such as the voltage balancing control of the intermediate level voltages. Another variant of MVSI, i.e. hybrid topology have been developed to eliminate some drawbacks in the three main topologies of MVSI previously defined.

A circuit configuration of MVSI achieved using series-connected sub-multilevel converter blocks and H-bridge inverter was presented in [6]. Reference [7] described a MVSI applying H-bridge VSI and additional bidirectional power switches. Nevertheless, the bidirectional power switches used in the inverter circuit configurations presented in [6] and [7] can be the lack of the circuits. In practical, the bidirectional power switches built by using configuration of two controlled power switches or combination of a single switch and four power diodes will increase the losses of the inverter. Another configuration of MVSI attained from the connection of several two-level power cells was presented in [8]. The requirement of many controlled power switches, and splitted DC voltage sources will add the cost and circuit complexity of the inverter. Reference [9] conveyed a symmetrical hybrid MVSI composed using three-level cells and H-bridge inverter. Total, eight power switches are required to create a five-level inverter circuit.

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In this paper, a different configuration of five-level hybrid VSI developed using H-bridge inverter and DC-voltage modules, is proposed. In the proposed topology, the DC voltage modules are connected in series. As a result it is possible to utilize non isolated DC voltage sources. All of the controlled power switches are a single switch (single IGBT or power MOSFET). The operation and performance of the proposed five-level hybrid VSI was examined and verified through computer simulations using PSIM Software and experimentally in laboratory prototype.

2. Proposed Inverter Circuit Configuration and Its Principle Operation

2.1. *Operation Principle of Proposed Inverter Circuit*

Figure 1 shows the circuit configuration of the DC-voltage module, and its basic operation [10]. The proposed multilevel VSI is achieved by connecting the H-bridge inverter with single or more DC-voltage modules to generate a multilevel voltage waveform. Figure 2 shows the circuit configuration of the proposed hybrid five-level VSI. It is clear that in this circuit, all of the DC voltage sources are connected in series. Hence, non-isolated DC voltage sources can be applied in this topology. Furthermore, all power switches are a single switch, i.e IGBT or power MOSFET, no need bidirectional power switch. A higher number of output voltage waveform can be achieved by connecting more DC-voltage modules. If there are *X* DC-voltage-modules connected to the H-bridge VSI, the level number of the output voltage waveform (Y) can be expressed as:

$$Y = 3 + 2X \tag{1}$$

and the count DC voltage sources (V) is:

$$V = X + 1 \tag{2}$$

In the proposed inverter topology, a single-phase five-level VSI needs a single DC-voltage module and an H-bridge inverter with total six power switches. Table 1 presents the switching combinations of the proposed hybrid five-level VSI for five-level output voltage waveform generation, i.e. V, V/2, 0, -V/2 and –V voltage levels. It is assumed that the magnitudes of the DC-voltage sources are the same as V/2 volt.

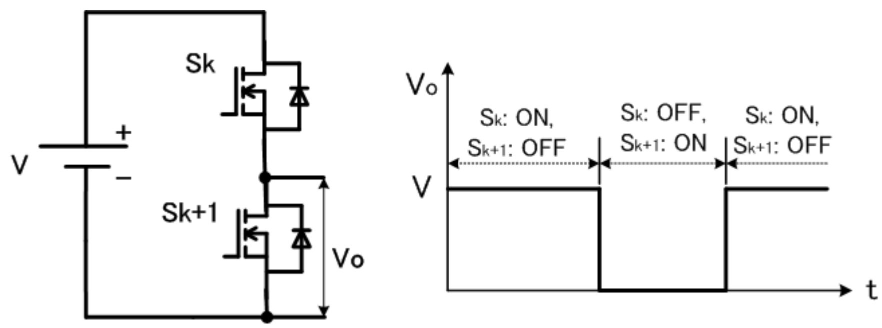


Figure 1. DC voltage-module, and its basic operation [10]

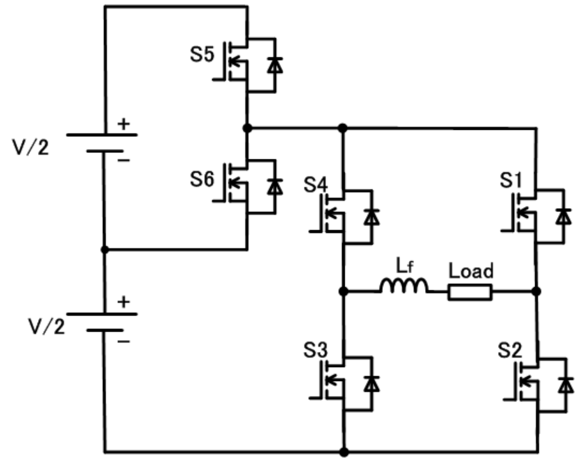


Figure 2. Proposed single-phase hybrid five-level VSI [10]

Table 1. Switching states of hybrid five-level VSI

S_1	S_2	S_3	S_4	S_5	S_6	Output Voltage
0	1	0	1	1	0	V
0	1	0	1	0	1	V/2
0	1	1	0	0	0	0
1	0	1	0	0	1	-V/2
1	0	1	0	1	0	-V

2.2 Pulse Width Modulation Technique

In order to generate a better output voltage waveform, a pulse width modulation (PWM) technique is utilized in the the proposed inverter circuits. In this paper, multi-triangular carrier waveforms with level-shifted sinusoidal PWM technique is employed to generate the gating signals for the inverter power switches as shown in Figure 3 and Figure 4. All triangular carrier waveforms are in phase, and with the same frequency. The frequency of the output current waveform is determined by the reference sinusoidal waveform, which is also the fundamental frequency of the PWM voltage waveform. The frequency of the triangular carrier waveform determines the switching frequency of inverter circuits [10]-[12].

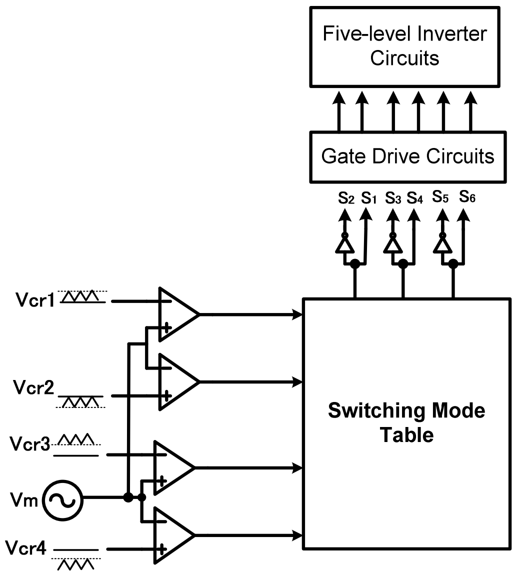


Figure 3. Modulation circuits of the proposed five-level inverter

Table 2. Test parameters

DC power source voltage	100 V
Inverter switching frequency	22 kHz
Load	R = 20 Ω , L = 5 mH
Fundamental frequency	60 Hz

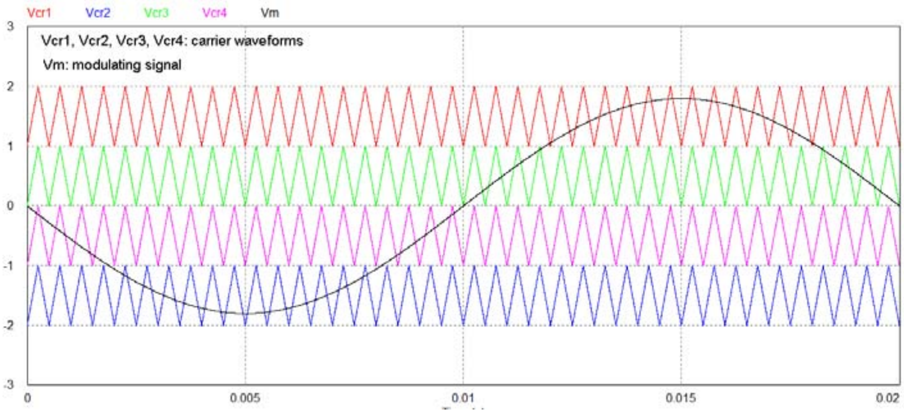


Figure 4. Level-shifted multi-carrier based sinusoidal PWM

3. Results and Analysis

Computer simulations and experimental tests are conducted in order to examine the operation of the proposed inverter circuits by using PSIM software. This part presents some computer simulation and experimental test results of the proposed hybrid five-level VSI. The simulation parameters are presented in Table 2. The single-phase hybrid five-level VSI as shown in Figure 2 is tested. The hybrid five-level VSI circuit is connected with an inductive load, i.e. resistor R = 20 Ω, and inductor L = 5 mH. The switching frequency of the inverter's switches is chosen to be 22 kHz in order to avoid switching noise. The frequency of the output current is 60 Hz. The magnitude of the DC-voltage source is 100 V, each. Figure 5 shows the computer simulation test results of the proposed hybrid five-level VSI. It can be seen that a proper five-level PWM voltage waveform was delivered to the load by the proposed inverter circuits. A sinusoidal load current waveform, I_{Load}, also flows through the load.

In order to verify the operation of the proposed hybrid five-level VSI configuration experimentally, a laboratory prototype of the hybrid five-level VSI was set-up using MOSFETs as power switches. The test parameters of the experimental circuits are similar with the computer simulation parameters as shown in Table 2. The DC input voltage sources of the inverter are obtained from two-DC power supllies. Figure 6 shows the prototype of the hybrid five-level VSI, presenting the main power inverter circuits. Figure 7 presents the experimental test results of the hybrid five-level VSI showing the five-level PWM voltage and sinusoidal load current waveforms at modulation index 0.93. It is shown that the proposed hybrid five-level VSI works well generating a five-level PWM output voltage waveform. Figure 8 (a) presents the low harmonic components of the five-level PWM voltage waveform. Furthermore, Figure 8 (b) shows the harmonic spectra of the voltage waveform including the switching harmonic components centered at 22 kHz.

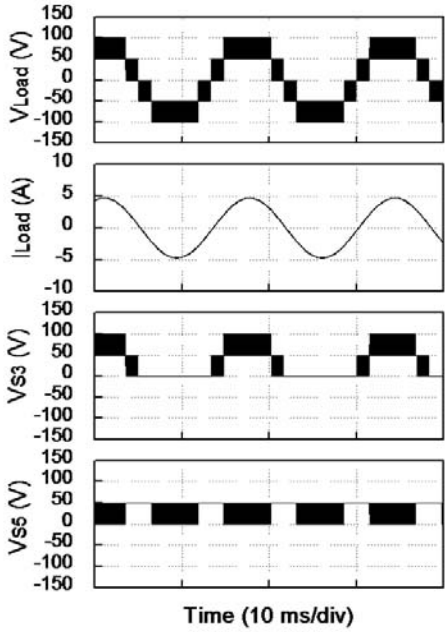


Figure 5. Five-level voltage waveform (V_{Load}), load current (I_{Load}), drain-source voltage of switch S_3 (V_{S3}), drain-source voltage of switch S_5 (V_{S5})

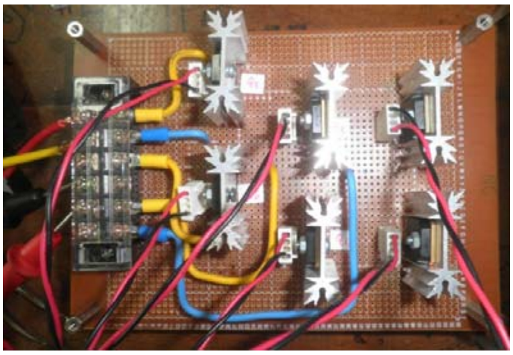


Figure 6. Main power circuits of proposed five-level inverter

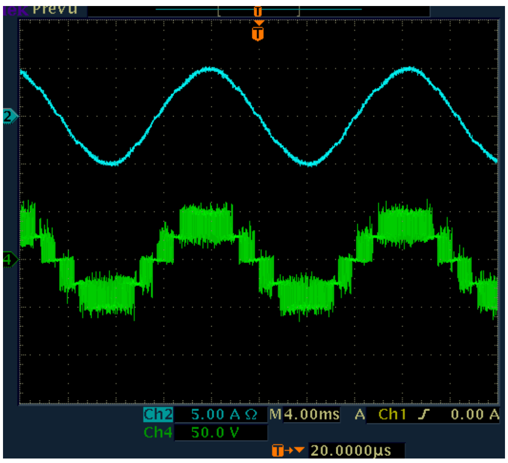
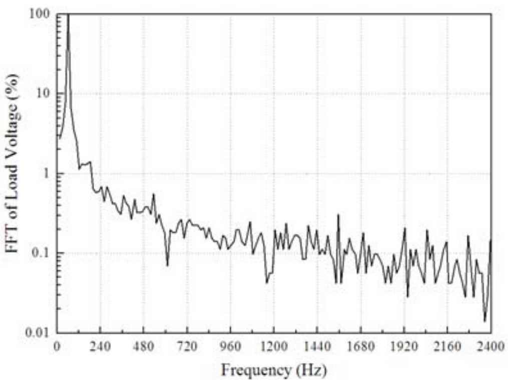
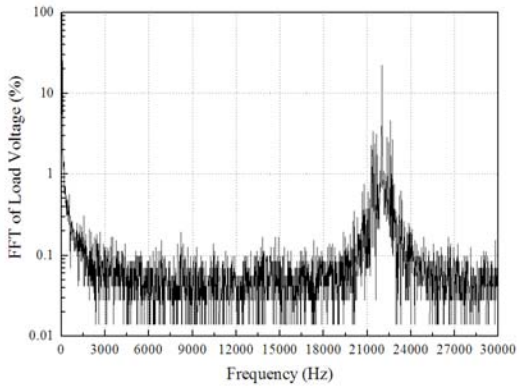


Figure 7. Load current and five-level PWM output voltage waveforms





(a) (b)

Figure 8. Harmonic spectra of the five-level PWM voltage waveform: (a) low harmonic components, (b) including the switching harmonic components

4. Conclusion

In this paper a different circuit configuration of hybrid five-level VSI has been introduced and discussed. The proposed hybrid five-level VSI incorporates DC-voltage modules and three-level H-bridge VSI to produce a five-level voltage waveform. Minimum count of power switches required to construct this topology is a feature of the proposed inverter. Based on computer simulations and experimental test results, it has been confirmed that the proposed hybrid five-level VSI circuits works properly generating a five-level voltage waveform. A low distorted sinusoidal load current waveform was also attained using the proposed inverter.

References

[1] J. Rodiguez, JS. Lai, FZ. Peng. Multilevel inverter: a survey of topologies, controls, and application. *IEEE Trans. on Industrial Electronics*. 2002; 49(4): 724-738.

[2] M. Malinowski, K. Gopakumar, J. Rodriguez, MA. Pérez. A survey on cascaded multilevel inverters. *IEEE Trans. On Industrial Electronics*. 2010; 57(7): 2197-2206.

[3] Z. Du, B. Ozpineci, LM. Tolbert, JN. Chiason. DC-AC cascades H-bridge multilevel boost inverter with no inductors for electric/hybrid electric vehicle applications. *IEEE Trans. Industry Application.* 2009; 45(3): 963-970.

[4] CK. Lee, SYR. Hui, HSH. Chung. A 31-level cascade inverter for power applications. *IEEE Trans. Industry Application.* 2002; 49(3): 613-617.

[5] K. Crorzine, Y. Familiant. A new cascaded multilevel H-bridge Drive. *IEEE Trans. on Power. Electronics*. 2002; 17(1): 125-131.

[6] E. Babaei. A cascade multilevel converter topology with reduced number of switches. *IEEE Trans. on Power Electronics*. 2008; 23(6): 2657-2664.

[7] G. Ceglia, V. Guzman, C. Sanchez, F. Ibanez, J. Walter, MI. Gimenez. A new simplified multilevel inverter topology for DC-AC conversion. *IEEE Trans. On Power Electronics*. 2006; 21(5): 1311-1319.

[8] G. Waltrich, I. Barbi. Three-phase cascaded multilevel inverter using power cells with two inverter legs in series. IEEE *Trans. On Industrial Electronics*. 2010; 57(8): 2605-2612.

[9] DR. Caballero. *Cascaded symmetrical hybrid multilevel DC-AC converter*. in Proc. of ECCE2010. 2010: 4012-4019.

[10] Suroso, T. Noguchi. *A Multilevel Voltage-Source Inverter using H-Bridge and Two-Level Power Modules with a Single Power Source*. IEEE International Conference on Power Electronics and Drive System (PEDS). Singapore. 2011; 262-266.

[11] Suroso, T. Noguchi. Five-Level Common-Emitter Inverter using Reverse-Blocking IGBTs. *TELKOMNIKA*. 2012; 10(1): 25-32.

[12] Suroso, D. Trinugroho, T. Noguchi. H-Bridge based Five-Level Current-Source Inverter for Grid Connected Photovoltaic Power Conditioner. *TELKOMNIKA*. 2013; 11(3): 489-494.