

A nine-level hybrid current source inverter using common-emitter topology and inductor-cell

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ABSTRACT

A different circuit structure of nine-level current source power inverter is presented and discussed in this manuscript. The proposed topology is based on the common-emitter inverter topology equipped with an inductor-cell circuit. The common-emitter inverter works as the main inverter circuits delivering a three-level AC current waveform. The inductor-cell circuit produces the intermediate output current levels for nine-level current output waveform. Proportional integral current controller was applied to regulate the current streaming thru the inductor-cell. Multi triangular carrier signals based sinusoidal pulse width modulation method was utilized to obtain a lower waveform distortion. The proposed nine-level inverter circuit was tested and examined. The test results verified that the new nine-level inverter circuit worked well producing a nine-level current waveform with less low-frequency harmonic components.

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1. INTRODUCTION

Basically, electrical power can be classified into two main forms, i.e. DC and AC power. In many cases, the DC power is simpler than the AC power because of its characteristics. Transmitting of DC power is also simpler than the AC power [1]. There are not phenomena such as skin effect, oscillation, or voltage unbalance between phases. Furthermore, there is no reactance property of the conductor in the DC power system. The DC power may be generated by a DC power generation system such as DC generator machine, photovoltaic module, and fuel cell system. However, currently most of power loads need AC voltage or AC current even in some loads the supplied AC power must be processed into DC using additional power converter circuits [2-4].

The power converters are required to proceed the DC power to be AC power, and vice versa. The converter used to alter the DC power into AC power is called power inverter. In the power inverter, the frequency, magnitude, and phase angle values of AC voltage and current can be regulated as required. Mainly, there are two categories of power inverters, i.e. voltage source inverter and current source one [5-8]. The first type proceeds a DC input voltage become a certain AC output voltage. The DC input bus uses capacitors to obtain a stable DC input voltage. Hence, short circuit condition is prohibited in this type of inverter, as it will cause large current that will damage the inverter circuits [9, 10]. In the second inverter type, the power inverter transforms the DC input current into a desired AC current. This inverter utilizes power inductor to generate a stable DC input current. Different with the voltage source type inverter, in this inverter type an open circuit condition is forbidden, because a large voltage change will happen in the inductor that may destroy the circuits [11, 12].

In order to obtain higher power of inverter circuits, a multilevel inverter has been introduced. This multilevel inverter generates a multistep AC output waveform from a single or multi DC input power [13-16]. When the input power is a single or multiple DC voltage sources and the output is a multistep AC voltage, the power inverter is called as multilevel voltage source inverter [17, 18]. In contrast, when the DC input power is a single or multiple DC currents and the output waveform is a multistep AC current, the inverter is called as multilevel current source inverter circuits [19-22]. Instead of higher power capability, a better output waveform can be produced using multilevel inverter circuits [23].

Reference [24] and [25] proposed a basic three-level current source inverter called as three-level common-emitter current source inverter (CECSI), because of its common-emitter configuration. This three-level inverter circuits is figured in Figure 1. Four unidirectional controlled switches, i.e. T_1 , T_2 , T_3 and T_4 , with common-emitter connection are required in this circuit to deliver a three-level output current waveform using two DC current sources. To generate a ninelevel current waveform, reference [26] discussed the use of inductor cells and a sole three-level CECSI as displayed in Figure 2. Twelve controlled switches were needed in this nine-level inverter circuits. Another approach was proposed in reference [27] and [28], where multi DC current modules are connected to the basic three-level common-emitter inverter.

This research develop a nine level inverter circuits using combination of inductor-cell and DC current module circuits connected to the main three-level common emitter circuits. Using this new nine-level inverter, switching devices and the power supplies of driving circuits could be simplified. Basic principle operation of the circuits was discussed. The nine-level inverter circuits was tested and examined using computer simulations.

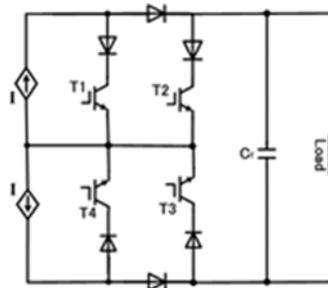


Figure 1. Basic three-level CECSI [24-30]

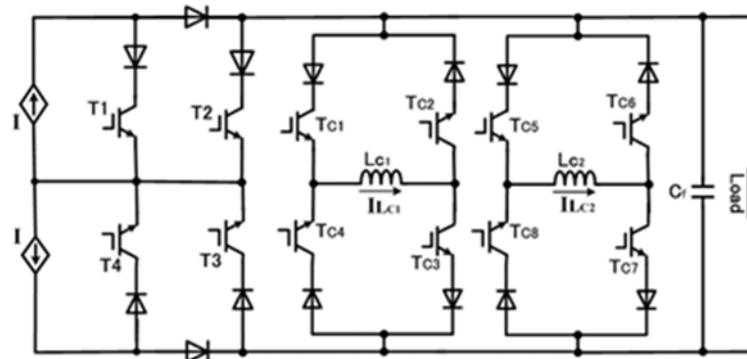


Figure 2. Traditional nine-level inverter [26]

2. PROPOSED NINE-LEVEL INVERTER CIRCUITS

Based on the basic three-level common emitter circuit configuration, a new nine-level inverter circuits is presented in Figure 3. The circuits consist of ten controlled switches as shown in this figure. The controlled switch is connected in series with a diode to perform a single directional current controlled power switch. The main inverter circuits constructed by six controlled switches connected in common-emitter configuration, hence a simpler driving circuits can be applied in this circuits.

The inductor cell circuits consist of four controlled switches, i.e. T_{C1} , T_{C2} , T_{C3} and T_{C4} . The power inductor is placed across this cell. Using the basic charging and discharging properties of this inductor cell, a

ninelevel current waveform will be generated [26]. The basic operations of the circuits are shown in Table 1. Furthermore, Figure 4 is the inverter circuit including the DC current control circuits with DC input inductor L_1, L_2, L_3 and L_4 and controlled switches T_{L1}, T_{L2}, T_{L3} and T_{L4} . These dc inductors and switches are utilized to generate the DC currents for inverter.

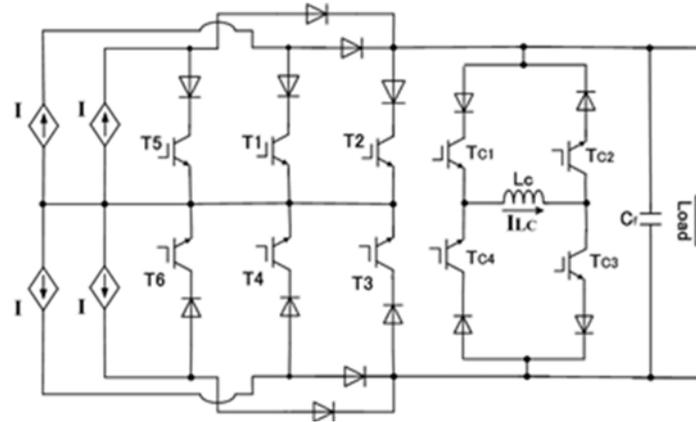


Figure 3. Proposed nine-level hybrid inverter

Table 1. Operation modes of the inverter

Modes	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T _{C1}	T _{C2}	T _{C3}	T _{C4}	I _{PWM}
1	0	0	1	1	0	1	1	1	0	0	+2I
2	0	0	1	1	0	1	0	1	0	1	+3/2I
3	0	0	1	1	1	1	0	0	1	1	+I
4	0	0	1	1	1	1	1	0	1	0	+1/2I
5	1	1	1	1	1	1	1	1	0	0	0
6	1	1	0	0	1	1	0	1	0	1	-1/2I
7	1	1	0	0	1	1	1	1	0	0	-I
8	1	1	0	0	1	1	1	0	1	0	-3/2I
9	1	1	0	0	1	0	0	0	1	1	-2I

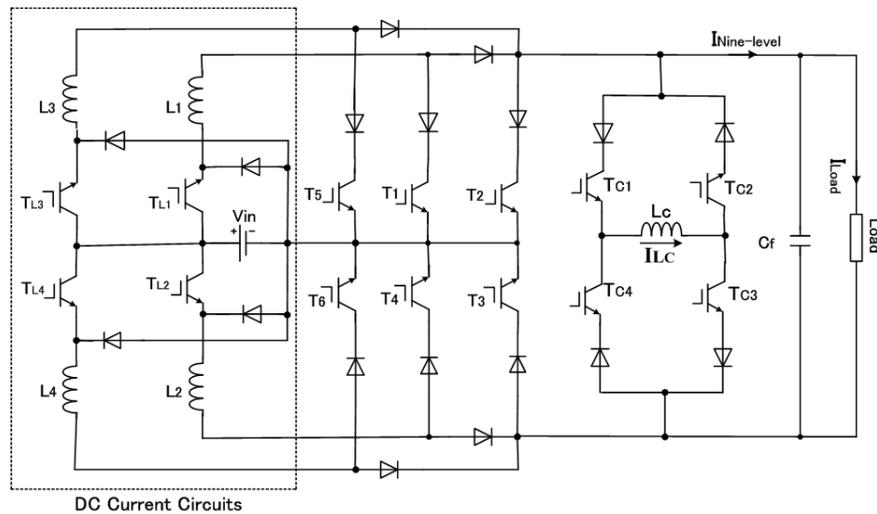


Figure 4. Nine-level inverter with dc current circuits

To regulate the current in the inductor, a proportional integral (PI) current controller is applied as presented in Figure 5. The amplitude of inductor-cell current was determined as a half of magnitude of the main dc input currents. This inductor-cell circuit function to create the intermediate levels of the nine-level current waveform. Furthermore, carrier based sinusoidal modulation was applied to generate a PWM AC current waveform with less harmonic distortion as shown in Figure 6. Eight triangular carriers were used. Each carrier has the same frequency but with different offset value. These carriers were modulated by a single sinusoidal signal to generate PWM driving signals of inverter power circuits.

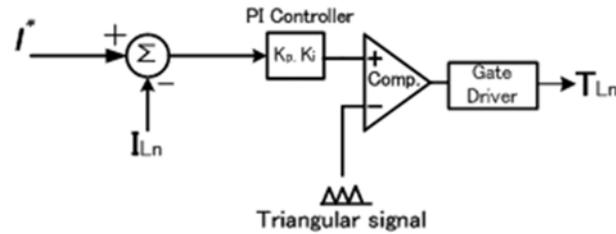


Figure 5. Current controller [27, 30]

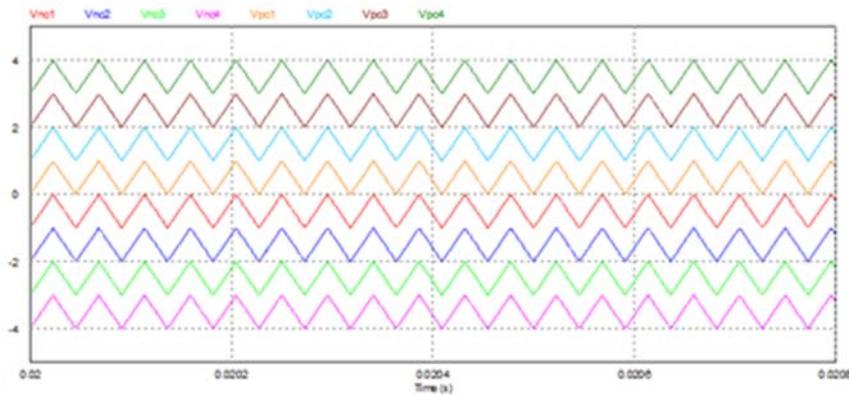


Figure 6. Modulation method [18, 27]

3. TEST RESULTS AND ANALYSIS

To test the basic operation and characteristic of the new nine-level inverter circuits, some computer simulations were performed using software of Power PSIM. The test parameters of the proposed new nine-level inverter circuits are presented in Table 2. The enormity of dc current sources is set to be 5 ampere. Four dc input current circuits were connected to the inverter circuits as shown in Figure 4. A small inductor 0.3 mH was used for the inductor-cell circuits. The frequency of triangular carriers is 22 kHz to avoid the noise caused by the switching operation. Using high switching frequency, a smaller output capacitor filter (C_f) size can be achieved. In this experiment, the filter capacitor was 5 μ F. The inverter was connected to an electrical load, i.e. power resistor 12 Ω and power inductor 1.2 mH connected in series.

Figure 7 is the simulation output figuring the waveforms of nine-level output current, current thru electrical load, and the capacitor filter current. Harmonic spectra of this nine-level current waveform is presented in Figure 8. The highest amplitude of the low harmonic order in this figure is the 3rd harmonic component. Its amplitude is 0.5%, only. The harmonics of PWM current flowed by way of the capacitor filter as current I_{Cf} . As a result, the current in the power load was a sinusoidal waveform. Furthermore, Figure 9 presents the dc currents in the inductors L_1 , L_2 , L_3 , L_4 and L_c . The same magnitudes of current were achieved. The magnitude of inductor cell current is half of these inductor currents, as it functions to perform the intermediate level currents of nine-level current. Finally, Figure 10 depicts the transient test results of the inverter, when the command current was changed. High speed response was achieved for the current transient waveforms of inverter circuits.

Table 2. Parameters of inverter circuits

No.	Parameters	Values
1	DC current	5 A
2	Inductor cell	0.3 mH
3	Triangular frequency	22 kHz
4	Fundamental frequency	50 Hz
5	Capacitor filter	5 μ F
6	Power load	12 Ω , 1.2 mH

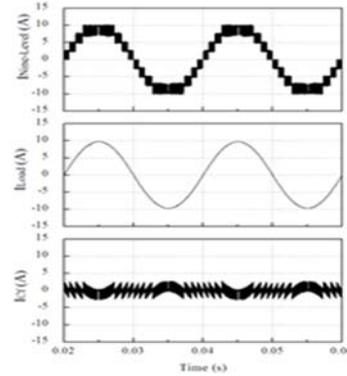
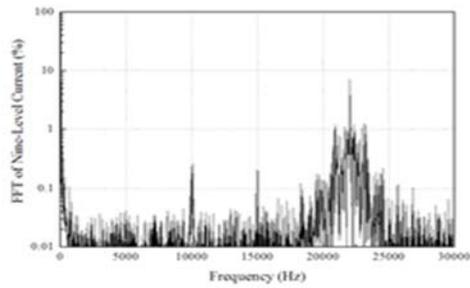
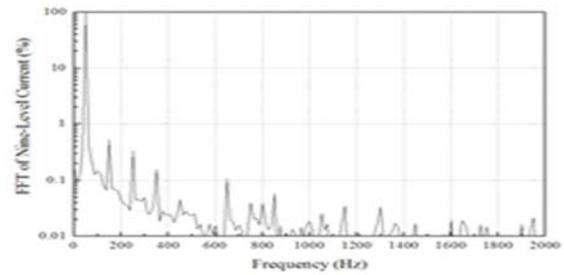


Figure 7. Measured waveforms of nine-level output current, load current and capacitor filter current.



(a)



(b)

Figure 8. Harmonic profiles of the nine-level current waveform

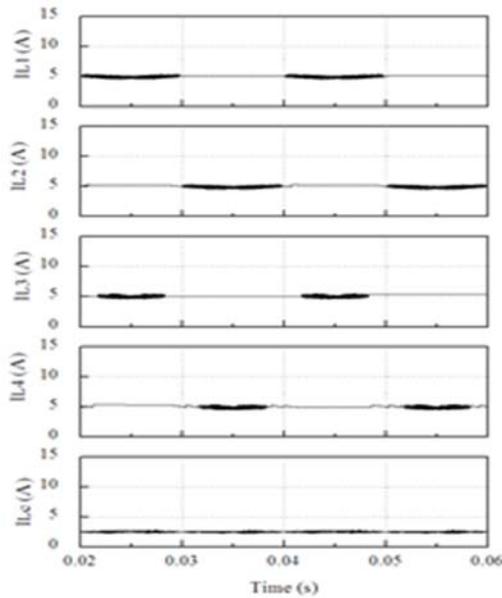


Figure 9. Waveforms of inductor currents

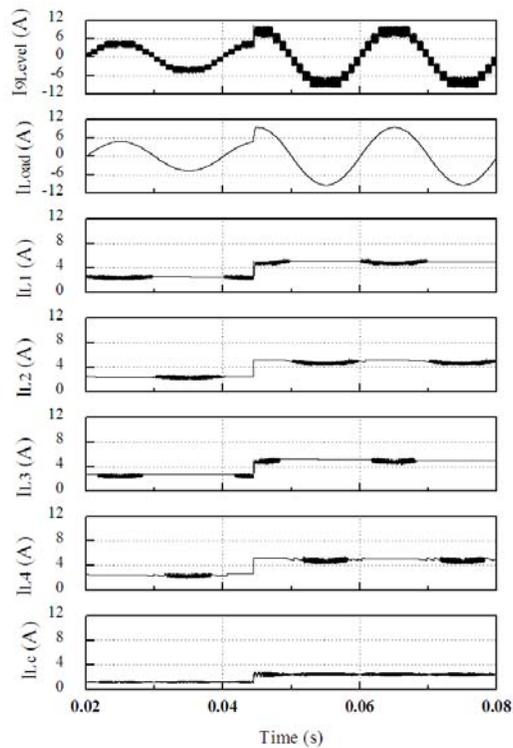


Figure 10. Transient current waveforms

4. CONCLUSION

A nine-level current-source power inverter circuits using common-emitter inverter and inductor-cell circuits was presented and examined in this research paper. The new inverter circuit produced a nine level PWM output current waveform from the dc input currents with low harmonic components. Using small capacitor filter, a sinusoidal load current was obtained. Proportional current controller worked regulating a stable inductor cell current to generate a balanced intermediate levels of nine-level current waveform. A simpler nine-level inverter circuit and more stable inductor currents can be achieved in this new inverter.

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