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THREE-LEVEL COMMON-EMITTER CURRENT-SOURCE POWER INVERTER WITH SIMPLIFIED DC CURRENT-SOURCE GENERATION

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Abstract

A diverse circuit of a three-level common-emitter current-source power inverter with simplified DC current source generation circuits was developed and presented in this paper. The required power devices to construct the inverter can be reduced by using the proposed circuit. The power supplies of gate drive circuits are much more modest than the traditionary three-level H-bridge current source power inverter. In this new inverter circuits, nearly all controlled semiconductor switching components are coupled at a common emitter configuration. Thereunto, using the proposed inverter circuits, a perfect modified sine-wave and pulse-width modulation operations can be attained. To examine the basic operations of inverter circuits, computer simulations were done. The simulation tests were conducted by utilizing power electronic design software PSIM. The test results showed that the proposed inverter circuits worked well delivering a three-level current, both pulse-width modulation and staircase waveforms, which attest the basic operation of the proposed inverter.

Keywords: Current sensor, Power inverter, Pulse-width modulation.

1. Introduction

Voltage-Source Power Inverter (VSPI) such as half-bridge, H-bridge and three-level diode clamped or Neutral Point Clamped (NPC) inverters have been widely applied as a Photovoltaic (PV) power converter either standalone or grid-connected operation [1-3]. According to Noguchi and Soroso [4, 5], these converters, however, have some problems when applied in high-speed switching-frequency operation due to Electromagnetic Interference (EMI) induced by high-gradient voltage or voltage change during switching operation. Alternatively, a Current-Source Power Inverter (CSPI) offers benefits in contrast with VSPI, e.g., natural short-circuit current protection, the better life time of inductors as energy buffer compared to energy buffer in a VSPI, which employing capacitors [6, 7]. Moreover, Barbosa et al. [8] and Suroso et al. [9] predetermined AC output current waveform and no need of a link inductor when operated as a grid-connected inverter are other merits of a CSPI.

Recently, the overall achievements of the power electronics field have improved extraordinarily. One reason is that of the advanced development in power semiconductor technologies operating at a higher speed switching operation for higher power capability such as IGBTs and power MOSFETs [10, 11]. In addition, it is also supported by the intense research in power converter topology.

In particular, multilevel power inverters are appealing a great interest since their features to minimize the harmonic components of inverter's output voltage and current effectively [12, 13]. The technology of multilevel power inverters is interesting in the power processing applications of eco-friendly energy resources such as the solar power system, hydropower plant, geothermal, sea-wave, fuel-cell and wind energy systems. The multilevel power inverters possess the ability to output higher power with a reduced gradient of voltage and current change than the traditional two-level power inverter. The multilevel inverter is capable to generate a higher quality output waveform, lower EMI noise and minimize power filter size [14-16]. In order to support a wider application of renewable energy sources and to overcome some issues of power inverter circuits, innovative power converter circuits for renewable energy sources such as a Photovoltaic (PV) power generation must be developed for standalone or grid connected operations.

Antunes et al. [17] commented that a generalized circuit topology of multilevel CSPI has been discussed. This topology used three-level H-bridge CSPI as the basic circuit configuration. Iwaya and Noguchi [18] reported a multilevel CSPI circuit of which, gate terminals of semiconductor-controlled switches could be supplied by only one power supply. However, the controlled power switches of the DC current generator, still involve three isolated gate drive power supplies in total. Suroso and Noguchi [19] presented a circuit of three-level CSPI of which, all semiconductor-controlled switches are fully connected at a common-emitter connection or at a same potential value. In this inverter topology, the circuits require two DC inductors, two DC current detectors and two free-wheeling diodes to construct the DC current generator circuits. Nevertheless, the modified sine-wave and PWM operations could not be achieved properly by using this topology because of the unwanted free-wheeling diode current during the inductor charging mode.

In this research manuscript, a different circuit of three-level common-emitter CSPI with simplified DC current generator circuits was designed and investigated. The new inverter circuits can reduce the current sensor count and free-wheeling

power diodes into only one for both sensor and power diode. The proposed three-level inverter circuits are also able to operate in both stair-case and PWM waveform operations. The principle work and performance of the simplified three-level common-emitter CSPI were tested and verified by using computer simulations test.

2. Proposed Circuit Configuration

2.1. Outline of inverter circuit

Figure 1 denotes a circuit of three-level common-emitter CSPI circuits wherein two DC currents are used as input currents. A unique point of this power inverter is that all controlled semiconductor switches are connected at an exactly equal potential value. In other word, all of the sources or emitter terminals of the IGBTs or power MOSFET switches are commonly connected [18-21].

Figure 2 is a circuit diagram of three-level common-emitter CSPI with conventional DC current generation circuits. Two DC power inductors, two controlled switches Q_{c1} and Q_{c2} and two free-wheeling power diodes are used in this circuit. In this DC current generation circuits, the switches Q_{c1} and Q_{c2} need two isolated gate drive circuits. Figure 3 is the proposed three-level common-emitter CSPI circuits. A simplified DC current source generation is applied in this circuit. It needs only one DC current sensor, a free-wheeling diode and a controlled switch QC.

Using the simplified inverter circuits, some merits can be acquired:

- Because of its common-emitter configuration, the Electromagnetic Interference (EMI) noise problem can be lowered.
- Furthermore, the inverter circuit is more appropriate to be run at a higher switching rate, so it can increase the power density and improve quality waveform of the inverter.
- In the proposed inverter circuit, the count of DC current sensor is can be lessened to be one sensor only.
- The unidirectional power switches and power diodes of the DC current sources generator circuit are also decreased into one, in each. In consequence, circuit components can be minimized [15].

Figure 4 shows a complete operation mode of the inverter circuits. The inductors experience three basic operations, specifically are circulating, charging and discharging current stages.

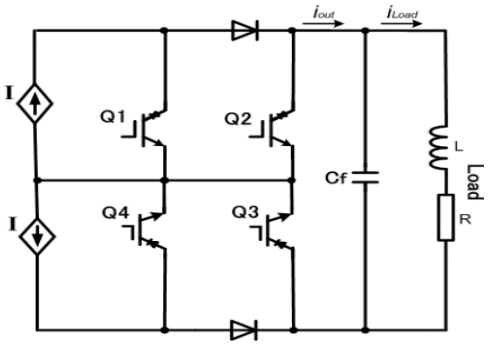


Fig. 1. Three-level common-emitter CSPI [18-21].

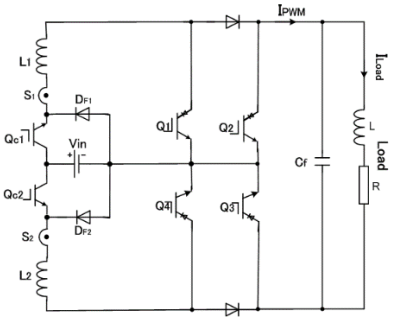


Fig. 2. Traditional three-level common-emitter CSPI [18].

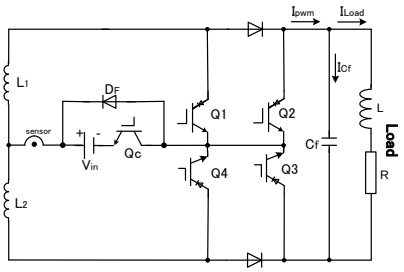
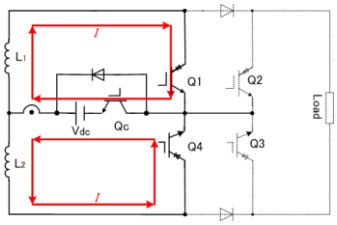
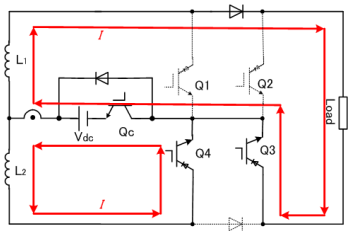


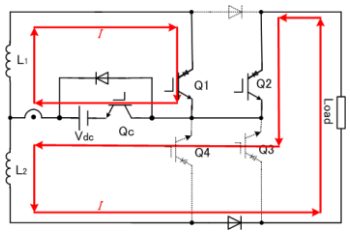
Fig. 3. Proposed three-level CSPI circuits [15].



(a) Energy charging stage of inductor L_1 and L_2.



(b) Energy charging stage of inductor L_1 and L_2.



(c) Energy discharging stage of inductor L_2, circulating current stage of inductor L_1.

Fig. 4. Operation stages of the proposed inverter circuits.

2.2. DC current controller and modulation strategy

In a current-source type inverter, DC current source is required instead of DC voltage source. The power inductors are used in order to create DC current sources together with DC voltage source. In this inverter circuits, two power inductors L_1 and L_2 are utilized, however, this circuits need a single current sensor only. A proportional integral current controller and a triangular signal waveform were applied to regulate the inductor's currents as shown in Fig. 5. In this controller, the amplitude of current reference I_{ref} determines the amplitude of the DC currents in the inductors. The current I_1 is the current detected by the current sensor. The current I_1 will naturally divide flow into the inductor L_1 and L_2. The triangular carrier will specify the ON and OFF frequency of the controlled switch Q_1.

For many applications, a pure sinusoidal current and voltage wave shapes are the ideal shape for mostly electrical power load. However, in actual practice, the voltage and current outputs of a power inverter contain harmonics components. This can be caused by many causes such as voltage reduction in power semiconductor devices and improper operation of inverter's control circuits. Suroso et al. [15] explained that the Pulse Width Modulation (PWM) strategy is employed to obtain a lower distortion of inverter's output voltage and current waveform. The proposed inverter used a carrier-based level-phase shifted sinusoidal PWM strategy with two triangular carrier waveforms. The comparator circuits produce PWM control signals for the controlled power switch of inverter circuits. The modulation strategy is shown in Fig. 6. In this method, the two triangular carriers have phase difference 180 degrees. The frequency of carriers is identical, which is the switching speed of inverter's semiconductor switches [19-21]. A sinusoidal modulating signal is used to generate a sinusoidal current and voltage waveforms. The frequency of modulating signal gives the fundamental frequency of output current.

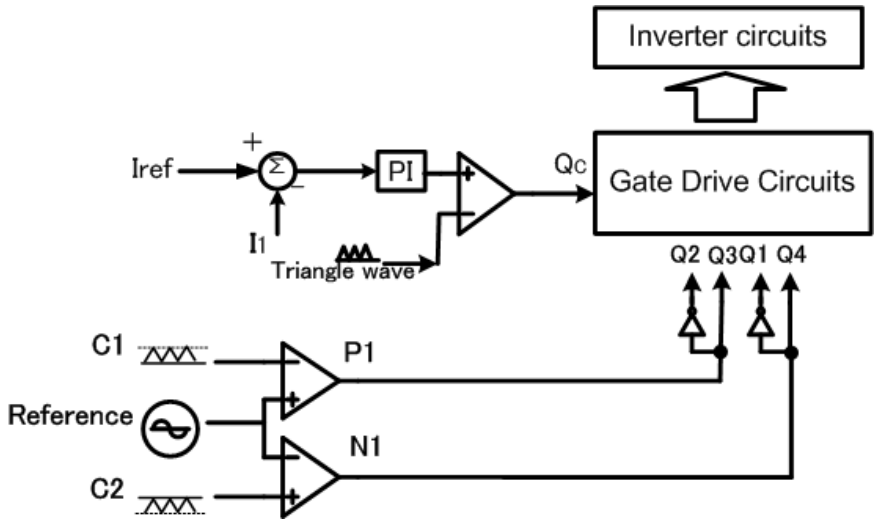


Fig. 5. Inductor current controller and modulation technique [19, 20].

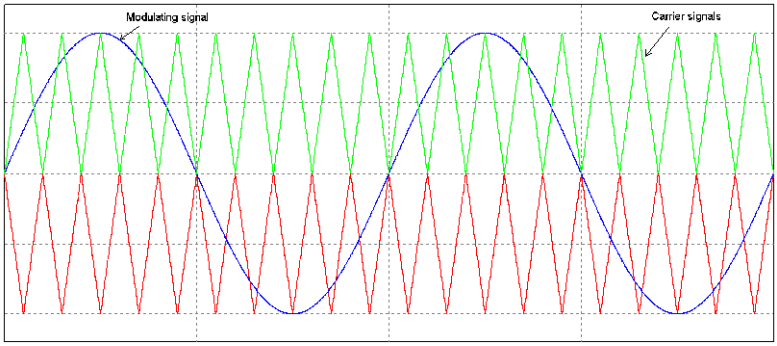


Fig. 6. The triangular carrier and modulating signals [15].

3. Results and Analysis

The developed CSPI circuits were tested by means of computer simulation with Power SIM Software. The computer simulations are used to examine and analyse the principal operation of the developed inverter. The tested inverter circuit is described in Fig. 3. The inverter circuit parameters are detailed in Table 1. An inductive power load with power resistor 5 Ω and power inductor 5 mH are connected to inverter's output terminal. The frequency of the triangular carrier and sinusoidal modulating signal are 21 kHz and 50 Hz, successively. A 120-volt DC-voltage source is applied in the DC current source generation circuits.

Table 1. Test parameters.

DC power supply	120 V
DC input inductor, L_1	100 mH
DC input inductor, L_2	100 mH
Triangular carrier frequency	21 kHz
Modulating signal frequency	50 Hz
Capacitor output filter, C_f	100 µF
Power load	R = 5 Ω, L = 5 mH
Modulation index	1

Figure 7 presents the three-level PWM current and load voltage waveshapes generated by the proposed inverter circuits. It proved that a three-level PWM current wave shape was produced by the proposed inverter. Furthermore, a sinusoidal load voltage waveform, V_{Load}, was yielded by the inverter. Figure 8 is the enlarged figure of PWM output current and voltage waveforms displaying the PWM pattern of current and voltage output wave shapes. Figure 9 shows the harmonics spectrum of three-level PWM current against frequency range 0-50 kHz. The switching harmonics components and its sideband emerge about 21 kHz and 42 kHz. Figure 10 is the low-frequency harmonics of PWM current. The amplitude of low harmonic orders is less than 2%, compared to the fundamental component. Figure 11 presents the harmonic analysis result of the load voltage waveform generated by the inverter. In this figure, the frequency range is 0-50 kHz. There is no high-frequency component in the load voltage waveform. Moreover, Fig. 12 presents the low frequency of harmonics of the load voltage waveform. The third harmonic order is the harmonic component that still exists in the load voltage waveform.

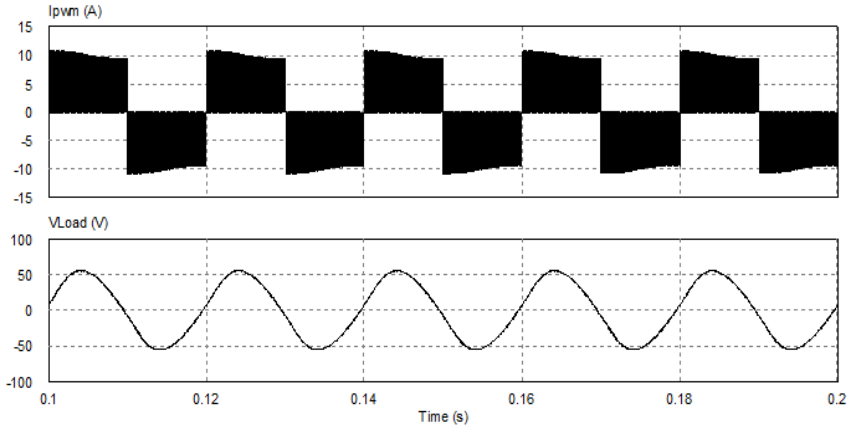


Fig. 7. Three-level PWM current and load voltage wave shapes.

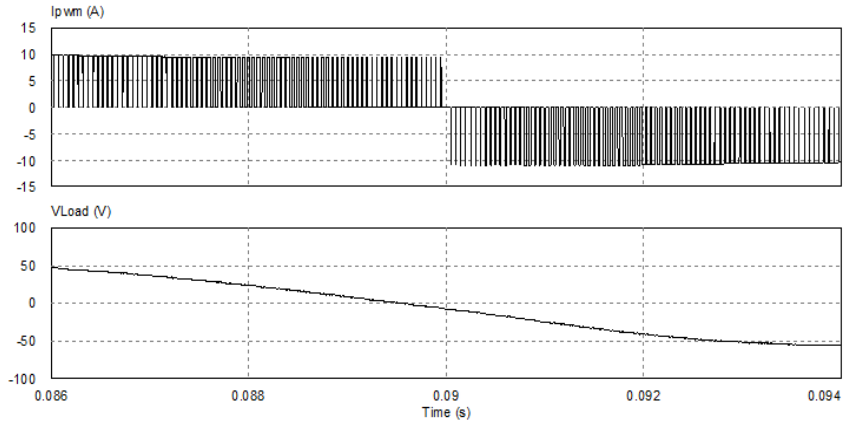


Fig. 8. Enlarged figure of three-level PWM and load current wave shapes.

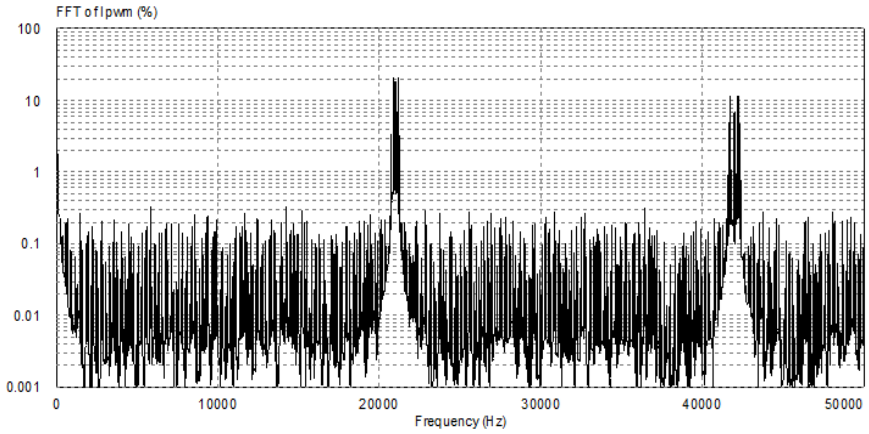


Fig. 9. Harmonic spectrum of three-level PWM current with frequency range 0-50000 Hz.

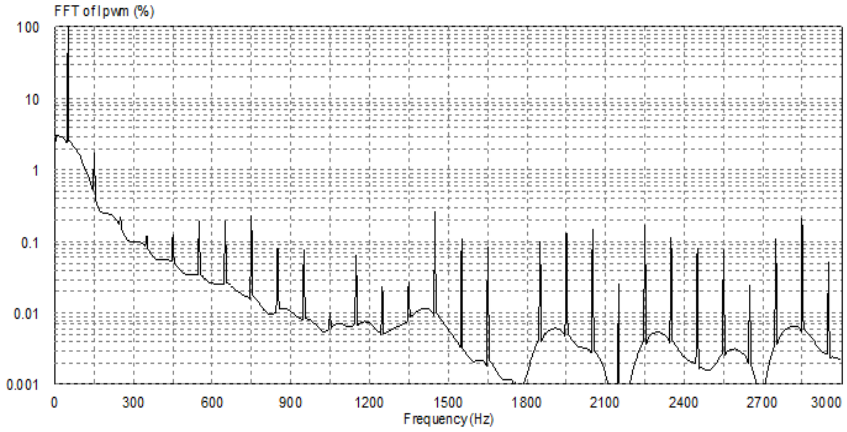


Fig. 10. Harmonic spectra of three-level PWM current with frequency range 0-3000 Hz.

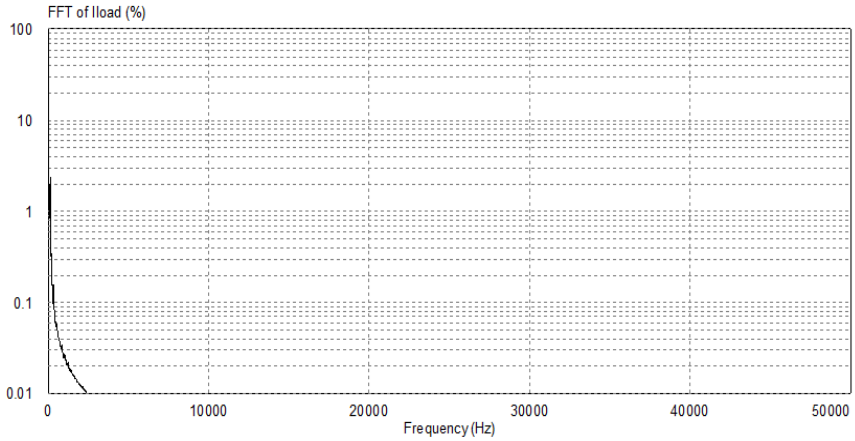


Fig. 11. Harmonic spectra of load voltage with frequency range 0-50000 Hz.

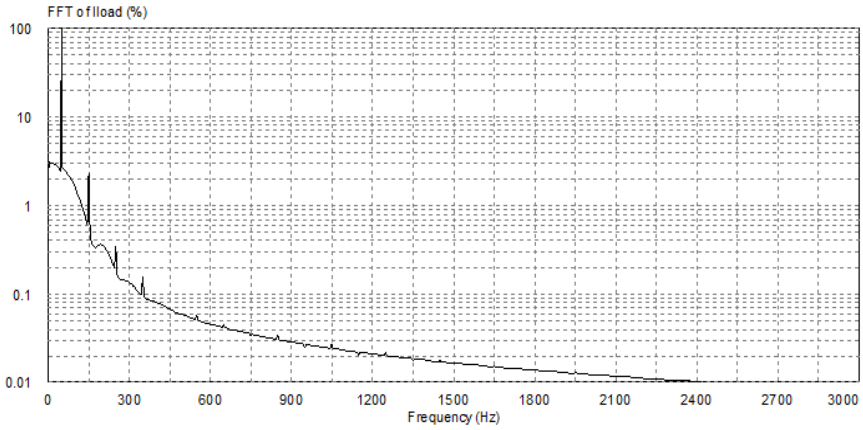


Fig. 12. Harmonic spectra of load voltage with frequency range 0-3000 Hz.

Figure 13 presents the DC inductor current waveforms, I_{L1} and I_{L2} flowing via power inductors L_1 and L_2 of the DC current source generation circuits. The average amplitude of this current is about 5 ampere with ripple value 10.51%. Finally, Fig. 14 shows the current waveform flowing through the diode D_1 and controlled switch Q_1 of the DC current generator. The current is the discontinued current pattern caused by alternately the charging and discharging operations of inductors L_1 and L_2. Furthermore, Fig. 15 represents the three-level modified sine wave of load current and voltage wave shapes of the proposed inverter circuits. The proposed inverter generated a proper three-level modified sine wave output current that could not be synthesized by the conventional inverter circuits.

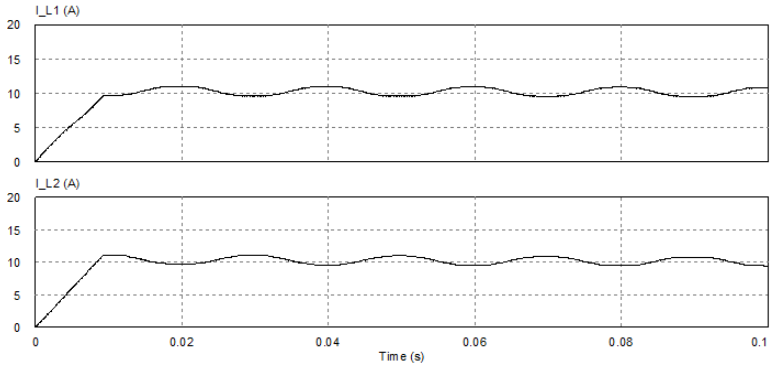


Fig. 13. Inductor current wave shapes.

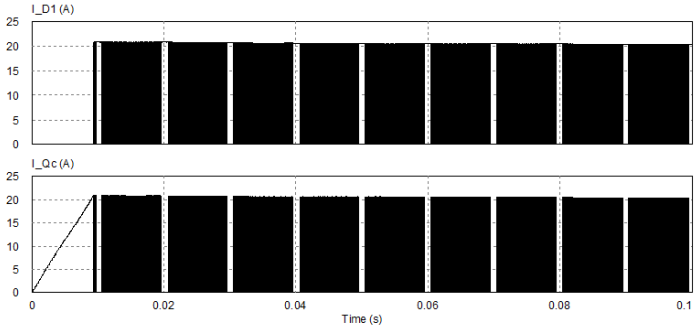


Fig. 14. The current waveforms flowing thru diode D_1 and switch Q_1.

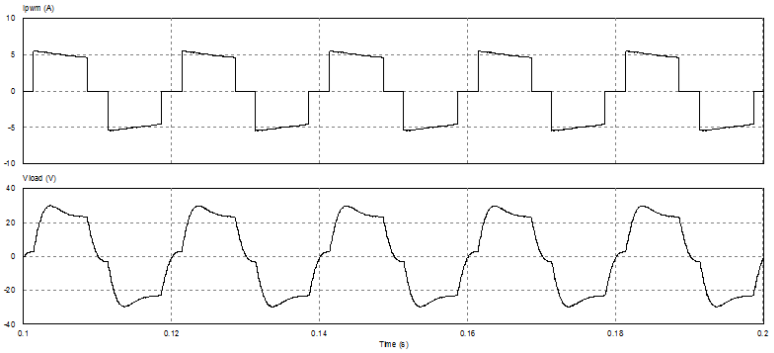


Fig. 15. Modified sine-wave output current and load voltage waveforms.

4. Conclusions

A different circuit structure of a three-level Current-Source Power Inverter (CSPI) with simplified DC current source generation circuits has been presented. The new inverter circuit can minimize the total device count. The proposed circuit entails a single DC current sensor only to regulate two different currents in inductors. The power supplies of the gate drive circuits are simpler than the traditional H-bridge CSPI because of its common-emitter configuration. Furthermore, a perfect modified sine-wave and pulse-width modulation operations can be produced by this new topology compared with the conventional circuit topology. Based on the computer simulation test results, it confirmed that the developed new simplified inverter structure worked well delivering a three-level PWM current and sinusoidal voltage waveforms with low harmonic components.

Nomenclatures

I_1	Amplitude of current source
I_{Cf}	Capacitor filter current
I_{Load}	Load current
I_{PWM}	Pulse width modulation output current
I_{Ref}	Reference current
L_1	First inductor of current source generation circuits
L_2	Second inductor of current source generation circuits
Qc	Controlled switch of current source generation circuits
Q_{c1}	First chopper-controlled switch
Q_{c2}	Second chopper-controlled switch
V_{dc}	Input voltage

Abbreviations

AC	Alternating Current
CSPI	Current Source Power Inverter
DC	Direct Current
EMI	Electromagnetic Interference
IGBT	Insulated Gate Bipolar Transistor
IGCT	Integrated Gate-Commutated Thyristor
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
PI	Proportional Integral
PV	Photovoltaic
PWM	Pulse Width Modulation
VSPI	Voltage Source Power Inverter

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