Transistor Clamped Five Level Inverter Using Non-Inverting Double Reference Single Carrier PWM Technique for Photovoltaic Applications

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***Abstract*— This treatise deals with transistor clamped five level inverter Using Non-Inverting Double Reference Single Carrier PWM (NIDRSC PWM) Technique. Conventional or two level inverter have drawbacks like i) Requirement of fast switching devices ii) Very high dv/dt iii) High Electromagnetic Interferences (EMI) iv) Bulky filters v) Faster heating of switches and vi) Not suitable for high voltage applications. Multilevel Inverters (MLIs) are engaged to conquer the drawbacks of conventional two levels inverter. MLIs generate an AC voltage using small voltage steps obtained with the help of DC supplies or capacitor banks. To design the proposed five level inverter 5 numbers of power control switches and 8 diodes are required. The proposed inverter circuitry is investigated by using Non-Inverting Double Reference Single Carrier PWM (NIDRSC PWM) Technique in terms of harmonics content in output waveform. Under-modulation (modulation Index =0.85), unity (modulation Index =1) and over-modulation (modulation Index =1.25) PWM signal is obtained to drive control switches. Simulation results will confirm the functionality, design and operation of the proposed MLI and NIDRSC PWM Technique.**

Keywords*— *Multilevel Inverter; Photovoltaic; Non-Inverting Double Reference Single Carrier PWM; Total Harmonics Distortion.

I. INTRODUCTION

In the coming era the renewable energy has become the significant alternative for conventional power sources (Fossil Fuel). The Major concerning aspect regarding power generation systems is presence of various sources and its utilization. The conventional sources are on the way of depletion because of their over exploitation. The rapid research is on extracting energy from renewable sources such as wind, tidal, solar etc. Photovoltaic systems are more reliable and provide a viable solution to overcome the drawbacks of non-renewable sources based on fossil fuels [1]-[2]. The energy exploited from photovoltaic panels is DC in nature but in applications such as industrial adjustable speed drives, static reactive power compensators an AC supply is essential aspect [1]-[10]. Conventional or two level inverters need carrier signals with high frequency in order to obtain better output performance [1]-[20]. Conventional or two level inverter have drawbacks like i) Fast switching devices are require ii) Very high dv/dt iii) High Electromagnetic

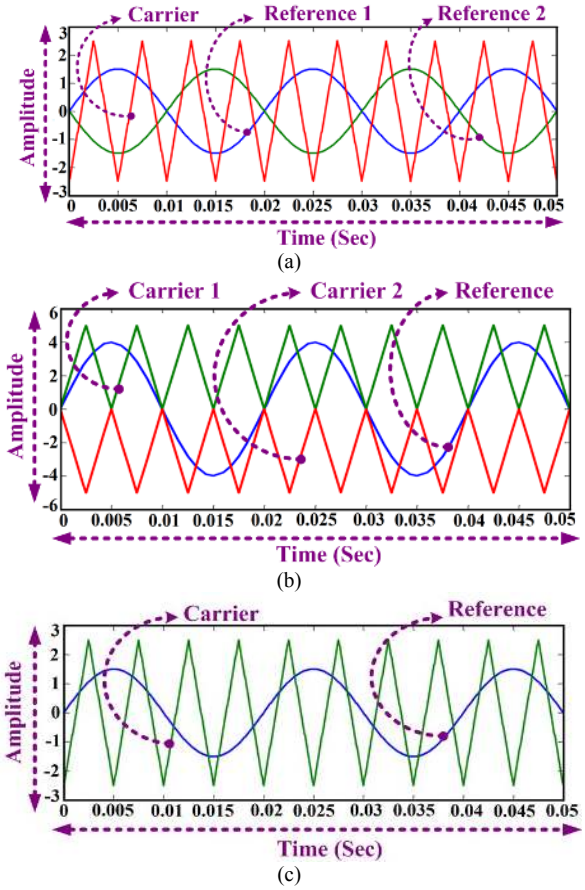


Fig. 1 Conventional Two Level Sinusoidal Modulation Techniques (a) Single carrier double reference Unipolar PWM (b) Double carrier single Reference Unipolar PWM (c) Bipolar PWM

Interferences (EMI) iv) Bulky filters v) Faster heating of switches and vi) Not suitable for high voltage applications.

The multilevel inverter concept provides a practical solution to overcome the above mentioned drawbacks of conventional inverter [1]-[20]. Harmonic content in the output waveform of MLI decreases as the number of output voltage level is increases. Multilevel inverter can synthesize the input DC into small voltage steps approximating them with a sinusoidal wave by giving proper pulses to the power control switches. As per the output performance is concerned the Multilevel Inverters (MLIs) are widely acceptable due to the minimization in Total Harmonics Distortions (THD) and

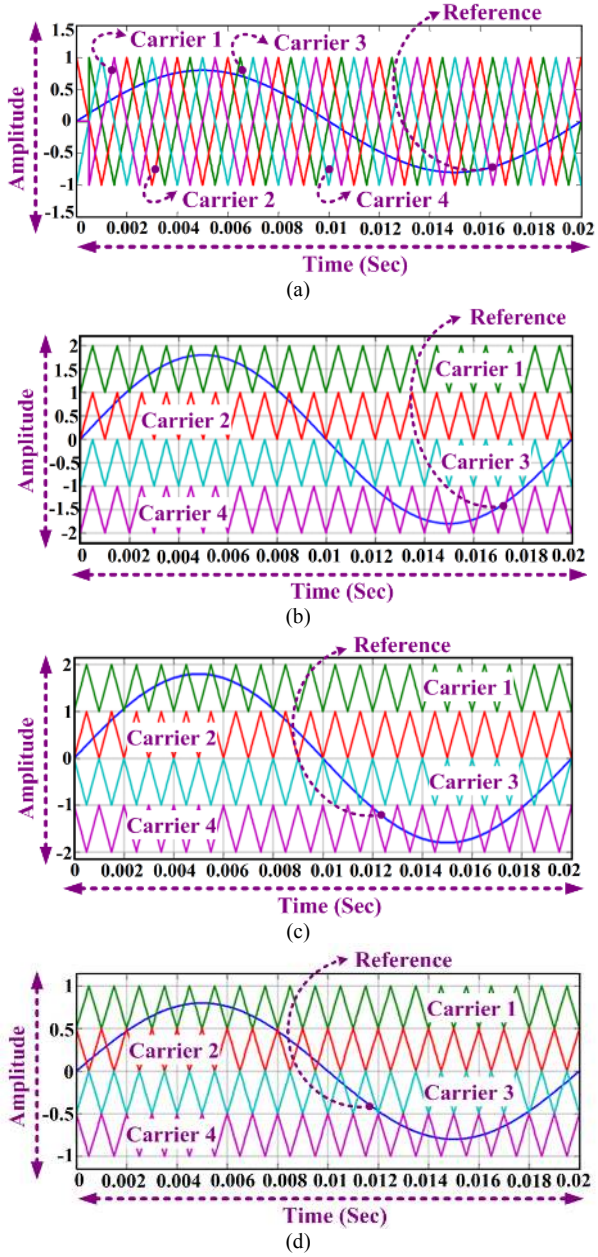


Fig. 2 Multilevel Sinusoidal Modulation Techniques (a) Phase Shifted Multicarrier Modulation (b) In Phase Disposition PWM (IPD-PWM) (c) Phase Opposition Disposition PWM (POD-PWM) (d) Alternate Phase Opposition Disposition PWM (APOD-PWM).

voltage rating of power switches. Diode clamped, flying capacitors, cascaded H-bridge are the three basic circuitry of Multilevel Inverter (MLIs) [11]-[13]. Out of this circuitry more reliable solutions are obtained by cascaded multilevel inverter due to modularity, robustness, compactness and less component count needed than diode clamped and flying capacitor. The modulation strategies to control power switches are mostly based on sinusoidal and triangular waves due to simplicity and provides a viable solution to minimize the THD content in the output waveform of inverter. Power switches of conventional two level inverters are control by using unipolar and bipolar sinusoidal pulse width modulation. The unipolar modulation normally requires single carrier and two sinusoidal reference waves. In unipolar modulation technique sinusoidal reference waves have same magnitude, same frequency and phase shift of 180 degree to generate symmetrical waveform as shown in fig. 1(a). The switching pulses can also generated by comparing two 180 degree phase shifted carrier with single reference signals as shown in Fig. 1(b). In bipolar modulation technique the gate pulses are obtained by comparing a sinusoidal modulating signal or reference signal with a high frequency carrier signal as shown in Fig. 1(c). Carrier based SPWM technique for MLI are broadly classified into two types i) Phase Shifted Multicarrier Modulation (single sinusoidal reference wave and N-1 carrier with proper phase shift is required to design N level Inverter) ii) Level shifted Multicarrier Modulation (single sinusoidal reference wave and N-1 carrier with proper level shift is required to design N level Inverter) [12]-[20]. Fig. 2(a) shows the pattern of Phase Shifted Multicarrier Modulation technique with four carriers. Depending upon the disposition of the carrier waves, level shifted SPWM technique can be classified as i) IPD-PWM (In Phase Disposition PWM) ii) POD-PWM (Phase Opposition Disposition PWM) and iii) APOD-PWM (Alternate Phase Opposition Disposition PWM). The pattern of IPD-PWM, POD-PWM and APOD-PWM is shown in fig. 2(b)-(d) respectively. In this treatise transistor clamped five-level inverter is presented for photovoltaic applications. A new modulation technique Non-Inverting Double Reference Single Carrier PWM (NIDRSC PWM) is adopted to control the power switches. The proposed inverter circuitry is investigated in terms of harmonics content in output waveform. Under-modulation (modulation Index =0.85), unity modulation (modulation Index =1) and over-modulation (modulation Index =1.25) PWM signal is obtained to drive control switches. Simulation results will confirm the functionality, design and operation of the proposed MLI and NIDRSC PWM Technique.

The paper is arranged in such a manner that section-II provides the details of transistor clamped inverter and proposed modulation scheme. In section-III simulation results are discussed in detail. Finally, conclusion is provided in section-IV.

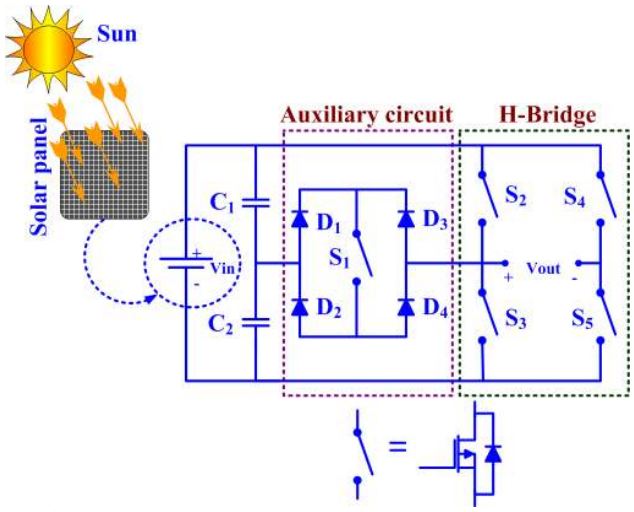


Fig.3 Power circuitry of Transistor Clamped Five Level Inverter

II. Transistor Clamped Five Level Inverter And Non-Inverting Double Reference Single Carrier PWM Technique

A. Power Circuit of Transistor Clamped Five Level Inverter

Transistor clamped five level inverter topology is shown in fig. 3. In this topology a power MOSFET is attached to the conventional H-Bridge inverter. The circuit employing fast diodes and MOSFET (S_1) are termed as auxiliary circuits. The capacitors network used in power circuit is acts as voltage divider. Capacitors network split the input side voltage into two equal voltages (*Vin/2*). The transistor clamped five level inverter generates output levels *Vin, Vin/2, 0, –Vin/2,* and *–Vin* by giving proper PWM signals to control switches. Proposed MLI needs only five control switches to generate five levels in output voltage of inverter. The auxiliary circuit is responsible for generating the output voltage levels *Vin/2* and *–Vin/2*.

B. Working Modes of Transistor Clamped Five Level Inverter

The operating modes of transistor clamped five level inverter are explained in this section. Fig. 4(a) depicts the equivalent power circuitry of proposed inverter to attain the output voltage level *Vin*. Power control switches S_5 and S_2 are in ON state to attain output voltage level *Vin.* Fig. 4(b) depicts the equivalent power circuitry of proposed inverter to attain the output voltage level *Vin/2*. Control switches S_5 and S_1 are in ON state to attain *Vin/2* voltage level. Fig. 4(c) depicts the equivalent power circuitry of proposed inverter to attain the output voltage level zero. Control switches S_4 and S_2 are in ON state to attain zero level. Fig. 4(d) depicts another possibility to attain the zero voltage level. Control switches S_5 and S_3 are in ON state to attain the zero level. Fig. 4(e) shows the equivalent circuitry of proposed inverter to attain output voltage level *-Vin/2*. Control switches S_4 and S_1 are in ON state to attain *-Vin/2* voltage level. Fig. 4(f) shows the equivalent circuitry of proposed inverter to attain output voltage level *-Vin*. Control switches S_4 and S_3 are in ON state to attain *-Vin* voltage level. Table I shows the switching sequence of transistor clamped five level inverter and it is observed that only two switches are turn ON to attain any voltage level.

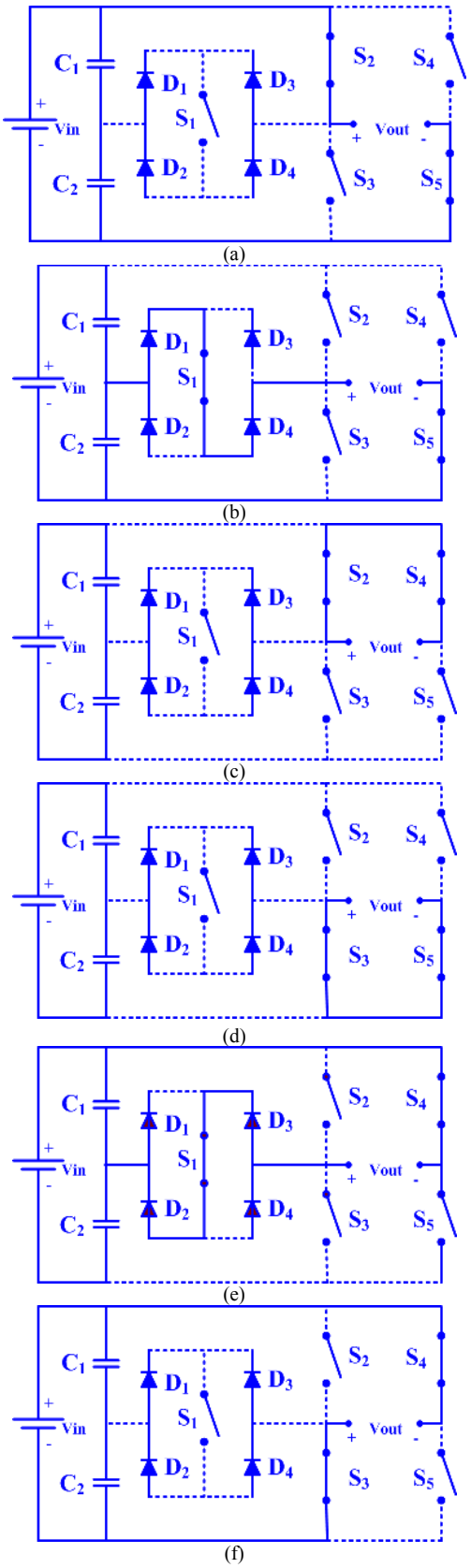
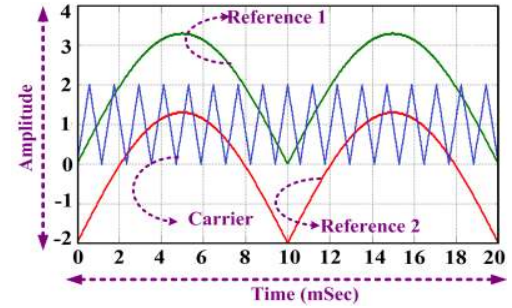


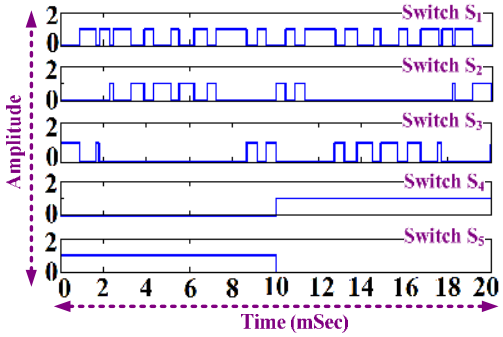
Fig. 4 Working Modes of Transistor Clamped Five Levell Inverter (a) Level V_{in} (b) Level $V_{in}/2$ (c) Level Zero (d) Level Zero (e) Level $-V_{in}/2$ (f) Level $-V_{in}$

TABLE I. Switching states of the Transistor Clamped Five Level Inverter

S_5	S_4	S_3	S_2	S_1	V_o
ON	OFF	OFF	ON	OFF	V_{in}
ON	OFF	OFF	OFF	ON	$V_{in}/2$
ON	OFF	ON	OFF	OFF	0
OFF	ON	OFF	ON	ON	0
OFF	ON	OFF	OFF	OFF	$-V_{in}/2$
OFF	ON	ON	OFF	ON	$-V_{in}$



(a)



(b)

Fig.5 (a) Non-Inverted Double Reference Single Carrier Pulse Width Modulation (IDRSCPWM) Technique (b) Gate pulses for control switches of Transistor Clamped Five Level Inverter

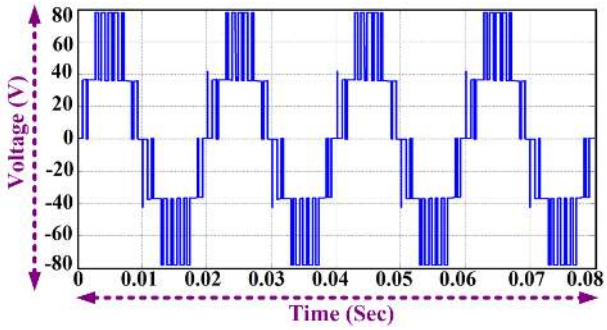
TABLE II. Simulation Parameters of Proposed Inverter

Parameters	Value
DC Supply (for 0.85)	78V
DC Supply (for 1)	67V
DC Supply (for 1.25)	60V
Carrier Frequency	1000Hz
C_1-C_2	2200uF
LOAD, Power	50Ω,12mH, 40W

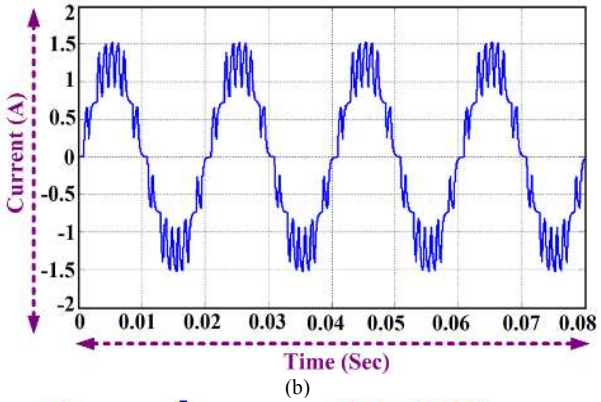
C. *Non-Inverting Double Reference Single Carrier PWM (NIDRSC PWM) Technique*

Fig. 5(a) shows the logic of Non-Inverting Double Reference Single Carrier Pulse Width Modulation (NIDRSC PWM) technique for five levels. Two absolute Non-Inverting sine waves with equal amplitude and one with an offset value are compared with a high frequency triangular carrier to attain pulses for control switches S_1, S_2 and S_3. Offset value is equal to amplitude of carrier wave. Complementary pulses of fundamental frequency are used for control switches S_4 and S_5. The modulation index is given by the equation (1). Where amplitude of the reference wave is equal to 'A_m' and amplitude of the triangular carrier wave is equal to 'A_c'. The gate pulses for control switches are depicts in fig. 5(b).

$$m=\frac{A_m}{2A_c} \tag{1}$$



(a)



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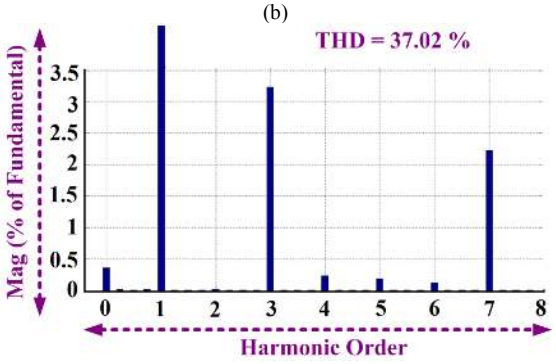

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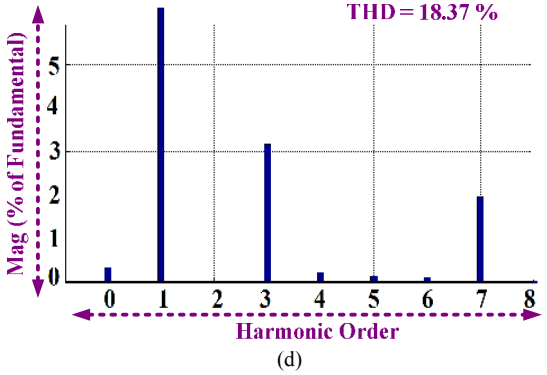

(d)

Fig. 6 Simulation Result with 0.85 modulation Index (a) Output voltage (b) Output current (c) Total Harmonics Distortion of output voltage waveform (d) Total Harmonics Distortion of output current waveform

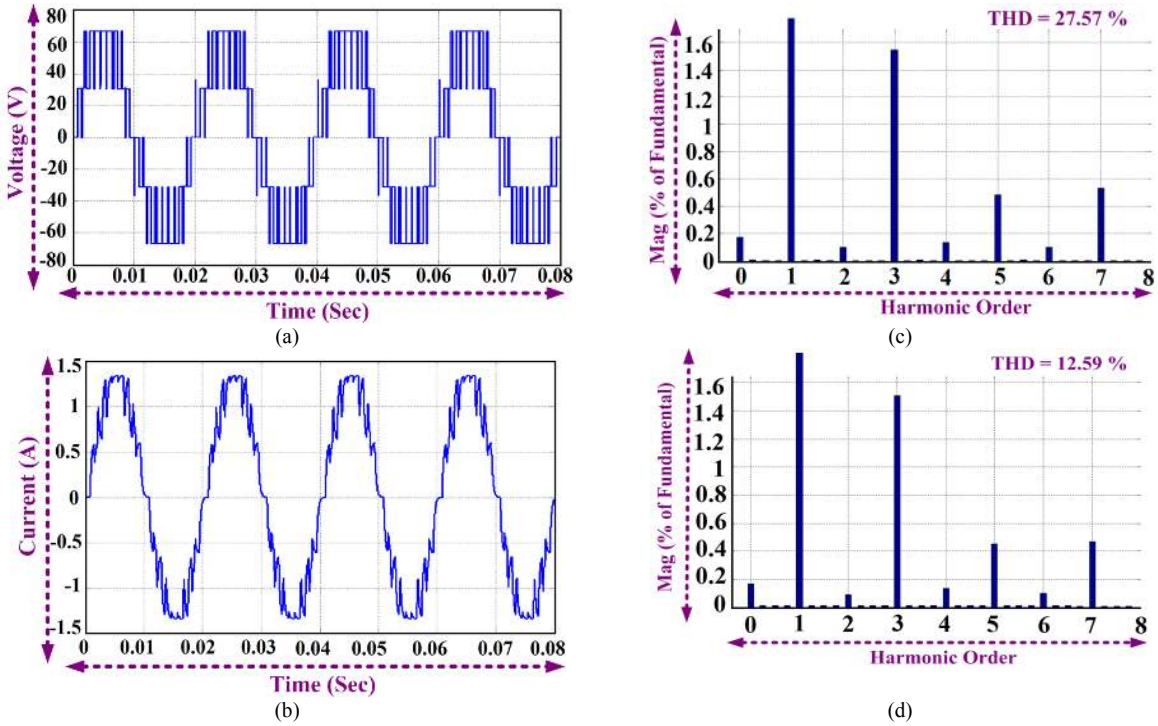

Fig. 7 Simulation Result with unity modulation Index (a) Output Voltage (b) Output current (c) Total Harmonics Distortion of output voltage waveform (d) Total Harmonics Distortion of output current waveform

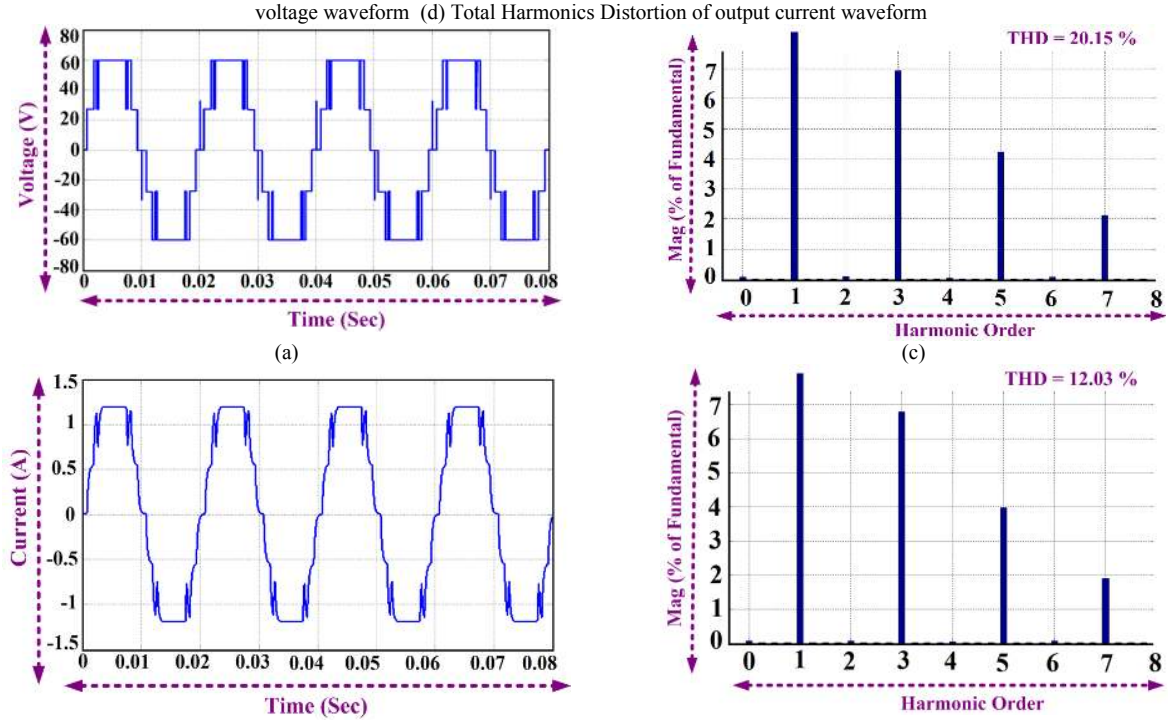

Fig. 8 Simulation Result with modulation Index 1.25 (a) Output Voltage (b) Output current (c) Total Harmonics Distortion of output voltage waveform (d) Total Harmonics Distortion of output current waveform.

III. Simulation Results And Discussion

Proposed inverter circuit is simulated in MATLAB to verify the functionality inverter circuit. Non Inverting Double Reference Single Carrier PWM (NIDRSC PWM) Technique is used with modulation index 0.85 (under modulation), 1 (Unity Modulation) and 1.25 (Over modulation) to control the switches. The simulation parameter is given in Table II.

A. Under Modulation Non Inverting Double Reference Single Carrier PWM Technique (NIDRC PWM)

Fig. 6(a) shows the output voltage waveform of proposed inverter for modulation index 0.85. The 48V RMS output

voltage is obtained by applying a DC voltage of 78V. Fig6 (b) shows the output current waveform. Due to inductive load the current waveform got a nearly sinusoidal shape and it is observed that the RMS value of current is 0.91A. Fig. 6(c) and 6(d) shows the harmonic spectrum of voltage and current respectively. From the harmonic spectrum it is found that the total harmonic distortion in the output voltage is 37.02% and for output current it is 18.37%.

B. Unity Modulation Non Inverting Double Reference Single Carrier PWM Technique (NIDRC PWM)

Fig. 7(a) shows the output voltage waveform of inverter for modulation index 1. The 48V RMS output voltage is obtained by applying a DC voltage of 67V. The output current is waveform is shown in Fig. 7(b). Due to inductive load the current waveform got a nearly sinusoidal shape and it is observed that the RMS value of current is 0.93A. Fig. 7(c) and 7(d) shows the harmonic spectrum of voltage and current respectively. From the harmonic spectrum it is observed that the total harmonic distortion of output voltage and current is 27.57% and 12.59% respectively.

C. Over Modulation Non Inverting Double Reference Single Carrier PWM Technique (NIDRC PWM)

Fig. 8(a) shows the output voltage waveform of inverter with a modulation index of 1.25. The 48V RMS output voltage is obtained by applying a DC voltage of 60V. The output current waveform is depicted in Fig. 8(b). Due to inductive load the current waveform got a nearly sinusoidal shape and it is observed that the RMS value of current is 0.94A. Fig. 8(c) and 8(d) shows the harmonic spectrum of voltage and current respectively and it is observed that the total harmonic distortion of output voltage and current is 20.15% and 12.03%.

IV. CONCLUSION

Transistor clamped five level inverter is presented for photovoltaic application and Non Inverting Double Reference Single Carrier Pulse Width Modulation (NIDRSC PWM) technique is used to generate five levels. Simulation of proposed inverter is carried out for modulation index 0.85 (Under Modulation), 1 (Unity Modulation), 1.25 (Over Modulation) and harmonics content is analyzed. Simulation results confirm the functionality, design of the proposed inverter and NIDRSC PWM Technique.

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