



# **Analysis of PWM Strategies for a Single-Phase Multilevel Inverter with Reduced Number of Switches for PV Application**

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**ABSTRACT:** This paper presents a new power converter topology which consists of DC/DC power converter and a seven level inverter with reduced number of switches for PV applications. The DC/DC power converter converts the dc voltage into two independent voltage sources and the seven-level inverter consist of capacitor selection circuit along with full bridge converter. The output of the DC/DC power converter is converted into three level dc voltage by using capacitor selection circuit and further full bridge converter converts the three level dc voltage into seven- level ac voltage. This proposed topology has been implemented with six switches compared with Conventional Multilevel Inverter (CMLI). This paper proposes single and dual carrier modulation strategies to improve the spectral quality of the output. Simulation studies are carried out in MATLAB/SIMULINK and the performance parameters of the proposed inverter are computed. The results are verified.

**KEYWORDS:** Multilevel inverter, Total Harmonic Distortion, Fundamental Frequency Modulation technique, Sinusoidal Pulse Width Modulation Technique.

## **I. INTRODUCTION**

Multi Level Inverter (MLI) plays an important role in the area of power electronics and it is widely used in industrial and renewable energy applications. It is not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for high power application. The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three level converter. Subsequently, several multilevel converter topologies have been developed. It is classified into a) Diode clamped multilevel inverter b) Flying capacitor multilevel inverter c) Cascaded H-bridge multi level inverter. Among these topologies, cascaded MLI is preferred as it requires minimum number of components to implement higher number of levels. This paper focuses on a seven level cascaded H-bridge inverter with reduced number of dc sources which overcomes the disadvantages of the conventional multi level inverter. The proposed inverter has reduced dc sources and power electronic switches. Moreover, this paper proposes a new hybrid modulation technique employing single and double carrier signals in order to obtain a reduced THD. The performance of the inverter is studied in terms of spectral quality of the output and it is analyzed for various modulation indices and the results are discussed. MATLAB/SIMULNK software is employed to carry out the simulation of the proposed inverter structure.

## **II. LITERATURE REVIEW**

Jinn-Chang Wu and Chia-Wei Chou (2014) have proposed a seven-level inverter with only six power electronic switches and only one power electronic switch is switched at high frequency which is suitable for solar power generation system. The proposed inverter structure generates a sinusoidal output current that is in phase with the utility voltage and is fed into the utility. N.A.Rahim, K.Chaniago, and J.Selvaraj (2011) have proposed a single phase seven level inverter for grid connected PV system with a novel PWM control scheme. This technique employs three reference signal and single triangular carrier signal to generate PWM signals for the switches. J.Pereda and J.Dixon (2011) have

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proposed Asymmetrical CHB (ACHB) inverter uses one dc supplies with different voltages, increasing the power quality (number of levels). ACHB improves the efficiency. It operate at the fundamental frequency, reducing the switching losses. Moreover, the THD is highly reduced, therefore output filters can be eliminated.

## III. PROPOSED SEVEN LEVEL INVERTER

Fig 1 shows a seven level inverter together with dc-dc power converter. The proposed system consist of new seven level inverter and DC/DC power converter. The DC/DC power converter consists of DC/DC boost converter and current fed forward converter. DC/DC power converter is used to convert the dc voltage into two independent voltage sources. The new seven-level inverter is composed of capacitor selection circuit and full bridge converter. The capacitor selection circuit and full bridge converter converts two independent three level dc voltage and the full bridge converter converts the three-level dc voltage into seven level ac voltage.

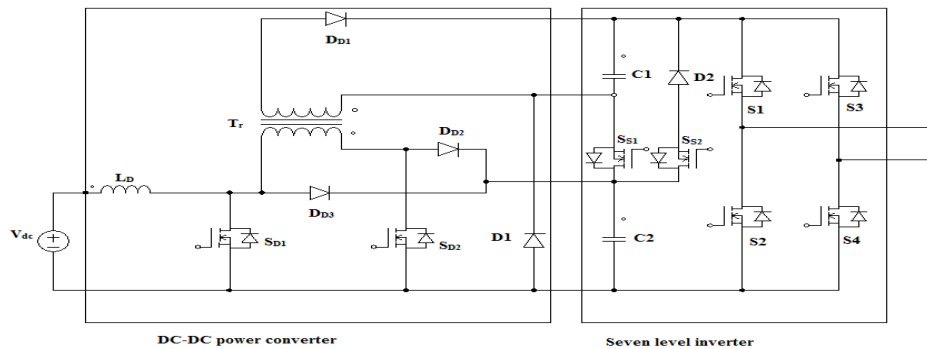


Fig 1. Seven level inverter together with DC-DC power converter

DC-DC power converter is composed of boost converter and current fed forward converter with turns-ratio of 2:1. Fig 2 shows the operation of DC-DC power converter. When switch  $S_{D1}$  is turned ON, boost converter charges the capacitor  $C_2$  of the new seven level inverter. When switch  $S_{D1}$  is turned OFF and  $S_{D2}$  is turned ON, the current fed forward converter charges the  $C_1$  of the new seven level inverter. The voltage across the  $C_2$  is

$$V_{c2} = \frac{1}{1-D} V_s \quad \text{eq.(1)}$$

$V_s$  is supply voltage and  $D$  is duty ratio of  $S_{D1}$ . The voltage across the  $C_1$  is

$$V_{c1} = \frac{1}{2(1-D)} V_s \quad \text{eq.(2)}$$

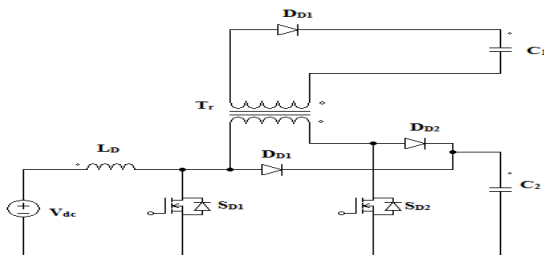


Fig 2. operating circuit of DC-DC power converter

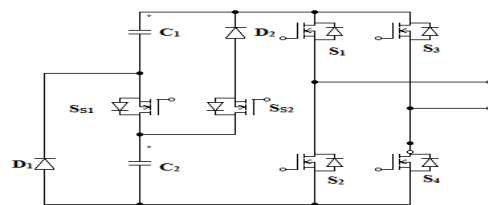


Fig 3. operating circuit of new seven level inverter

Fig 3 shows operating circuit of new seven level inverter (Zero,  $V_{dc}/3$ ,  $2V_{dc}/3$ ,  $V_{dc}$ ,  $-2V_{dc}/3$ ,  $-V_{dc}/3$ ,  $-V_{dc}$ ). The voltage across  $C_1$  and  $C_2$  are constant and equal to  $V_{dc}/3$  and  $2V_{dc}/3$ . i.e. the input voltage is 70, the voltage of the capacitor  $C_1$  is 70V and voltage of the capacitor  $C_2$  is 140V. All switches are operated in fundamental frequency. The circuit operation is explained as follows. The circuit operation of seven level inverter classified as 8 modes. Positive half cycle have 4 modes and negative half cycle have 4 modes.

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*Mode 1:* In this mode, switches  $S_1$  and  $S_4$  conducts, switches  $S_{S1}$  and  $S_{S2}$  are turned off. The capacitor  $C_1$  discharges through the diode  $D_1$ , so the output voltage of the inverter is  $V_{dc}/3$ .

*Mode 2:* In this mode, switches  $S_{S2}$ ,  $S_1$  and  $S_4$  conducts, switch  $S_{S1}$  is turned off. The capacitor  $C_2$  discharges through the diode  $D_2$ , so the output voltage of the inverter is  $2V_{dc}/3$ .

*Mode 3:* In this mode, switches  $S_{S1}$ ,  $S_{S2}$ ,  $S_1$  and  $S_4$  conducts, both the capacitors  $C_1$  and  $C_2$  discharges through the diode  $D_1$  and  $D_2$  so the output voltage of the inverter is  $V_{dc}$ .

*Mode 4:* In this mode, switches  $S_2$  and  $S_4$  conducts, other switches are turned off, so the output voltage of the inverter is zero.

*Mode 5:* In this mode, switches  $S_2$  and  $S_3$  conducts, switches  $S_{S1}$  and  $S_{S2}$  are turned off. The capacitor  $C_1$  discharges through the diode  $D_1$ , so the output voltage of the inverter is  $-V_{dc}/3$ .

*Mode 6:* In this mode, switches  $S_{S2}$ ,  $S_2$  and  $S_3$  conducts, switch  $S_{S1}$  is turned off. The capacitor  $C_2$  discharges through the diode  $D_2$ , so the output voltage of the inverter is  $-2V_{dc}/3$ .

*Mode 7:* In this mode, switches  $S_{S1}$ ,  $S_{S2}$ ,  $S_2$  and  $S_3$  conducts, both the capacitors  $C_1$  and  $C_2$  discharges through the diode  $D_1$  and  $D_2$ , so the output voltage of the inverter is  $-V_{dc}$ .

*Mode 8:* In this mode, switches  $S_2$  and  $S_4$  conducts, other switches are turned off. So the output voltage of the inverter is zero.

Table1. Conduction sequence of switches for fundamental frequency modulation Technique

$S_{S1}$	$S_{S2}$	$S_1$	$S_2$	$S_3$	$S_4$	$V_0$
0	0	1	0	0	1	$V_{dc}/3$
0	1	1	0	0	1	$2V_{dc}/3$
1	1	1	0	0	1	$V_{dc}$
0	0	0	1	1	0	$-V_{dc}/3$
0	1	0	1	1	0	$-2V_{dc}/3$
1	1	0	1	1	0	$-V_{dc}$

## IV. PWM TECHNIQUES

In MLI, seven-level output voltage is obtained by different combination of conduction state of six switches. The gating pulse for these switches are given by using hybrid modulation which is the combination of fundamental frequency modulation (FPWM) and sinusoidal PWM. In the sinusoidal PWM, two methods are employed namely:

- Single Carrier Modulation of MLI
- Dual Carrier Modulation of MLI

The output is obtained with reduction in switching loss from FPWM and good harmonic reduction from SPWM.

### A) Single and Dual Carrier Modulation for MLI

The triangular signal is compared with sinusoidal reference signal and pulses are generated whenever the amplitude of the reference signal is higher than the carrier signal. Switches  $S_{D1}, S_{D2}$  will be switched at fundamental frequency and switches  $S_{S1}, S_{S2}, S_1, S_2, S_3, S_4$  are switched at high carrier frequency. The amplitude and frequency modulation ratio is defined as :

Amplitude modulation ( $m_a$ ) ratio is expressed as,

$$m_a = \frac{\text{Amplitude of } V_{ref}}{\text{Amplitude of } V_{carrier}} \quad \text{eq.(3)}$$

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Frequency modulation ratio ( $m_f$ ) can be expressed as,

$$m_f = \frac{f_s}{f_1} \quad \text{eq.(4)}$$

where,  $f_s$  is PWM frequency and  $f_1$  is fundamental frequency.  $m_f$  should be an odd integer, otherwise DC component may exist and even harmonics will be present at the output voltage.  $m_f$  should be a multiple of three for three-phase inverter. Fig 4.shows a carrier and reference waveform for single carrier modulation technique. Fig 5. shows the carrier and reference waveform for dual carrier modulation technique.

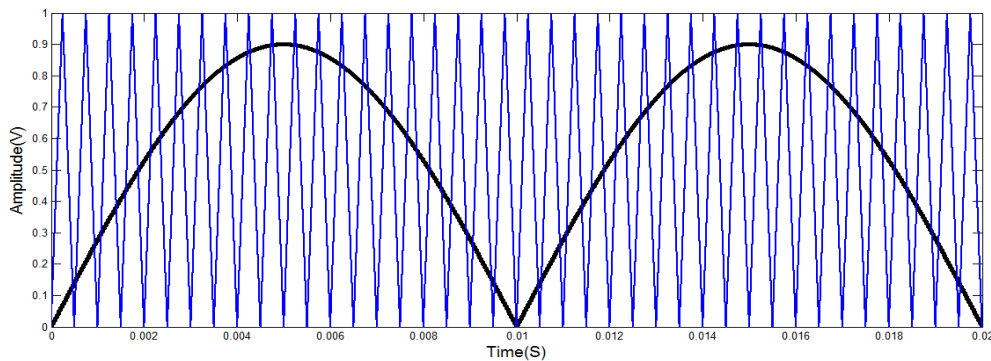


Fig 4. Carrier and reference waveform for single carrier modulation technique

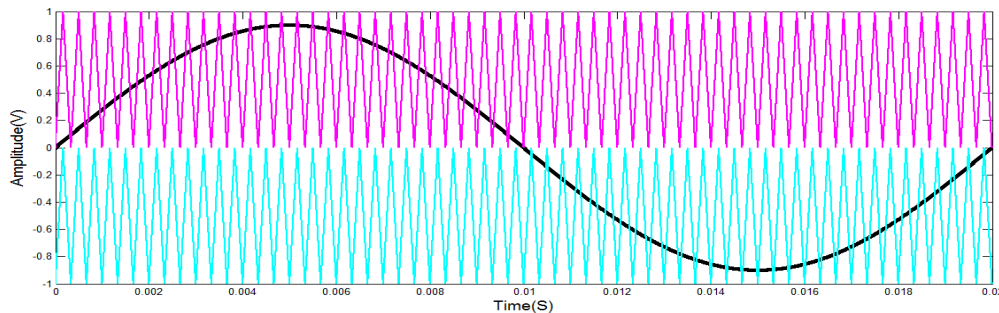


Fig 5. Carrier and reference waveform for Dual carrier modulation technique

By comparing different PWM Techniques based on THD values, dual carrier PWM technique has reduced THD and produces better quality output.

## V. SIMULATION RESULTS

The single-phase seven-level inverter topology for the proposed modulation strategies namely single carrier and dual carrier PWM was simulated in MATLAB and is shown below. The simulation was carried out with an input voltage of 70V and switching frequency is 15150Hz. The other simulation parameters are shown in Table 2.

Table 2 simulation parameters

DC-DC POWER CONVERTER	
PARAMETERS	SPECIFICATION
Input Voltage( $V_{dc}$ )	70 V
Inductor( $L_D$ )	1mH
$f_s$	50Hz

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## SEVEN LEVEL INVERTER

PARAMETERS	SPECIFICATION
Capacitor C1,C2	500mF
Resistor r1,r2	0.01Ω
Load(R)	50Ω

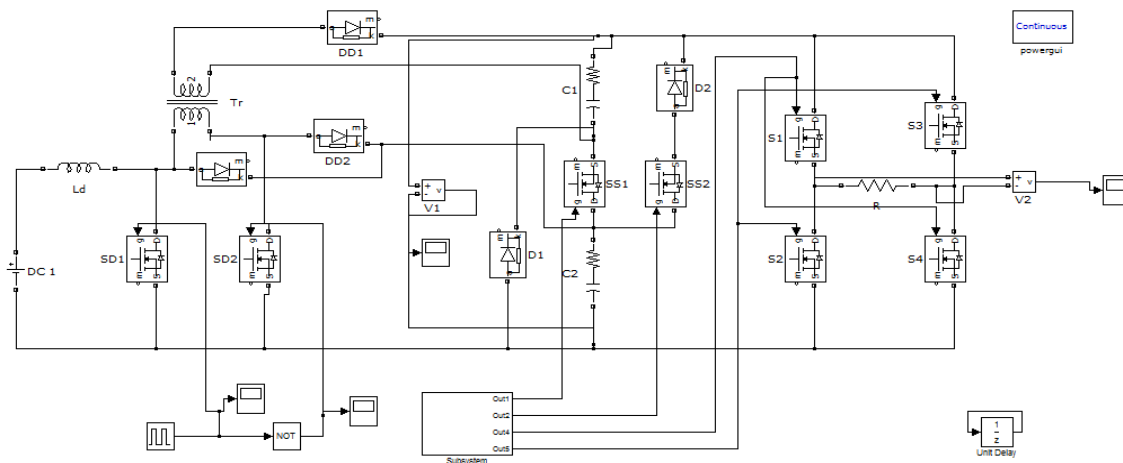


Fig 6. SIMULINK model of the single-phase seven level inverter

The simulink model is shown in Fig.6. The output voltage and THD have been compared so as find out the best suitable strategy for seven level inverter. Figs.7 & 8 show the output load voltage waveforms for single carrier PWM and dual carrier PWM.

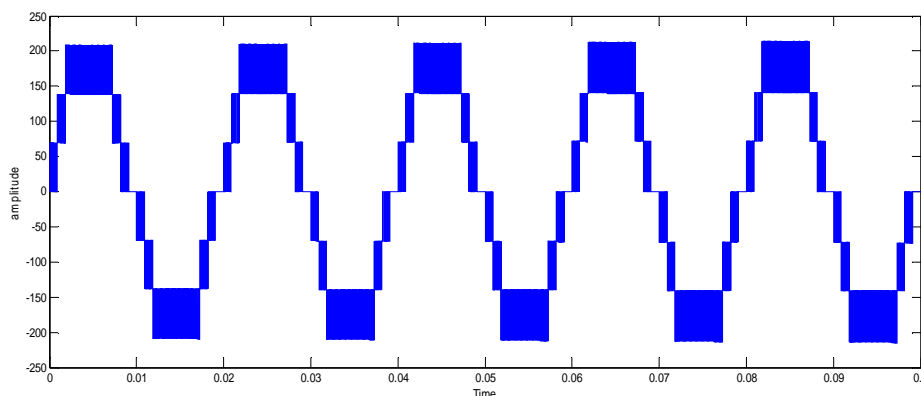


Fig.7 Output Voltage waveform for MLI with single carrier PWM

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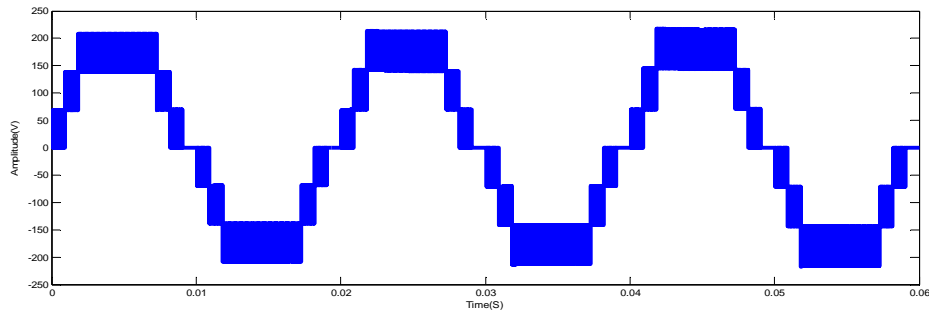


Fig.8 Output Voltage waveform for MLI with dual carrier PWM

Figs 9 & 10 show the FFT spectrum of the output voltage of the seven-level inverter for single and dual carrier PWM techniques. Fig.11 &12 shows the THD Vs  $m_a$  and THD Vs switching frequency for dual carrier PWM method.

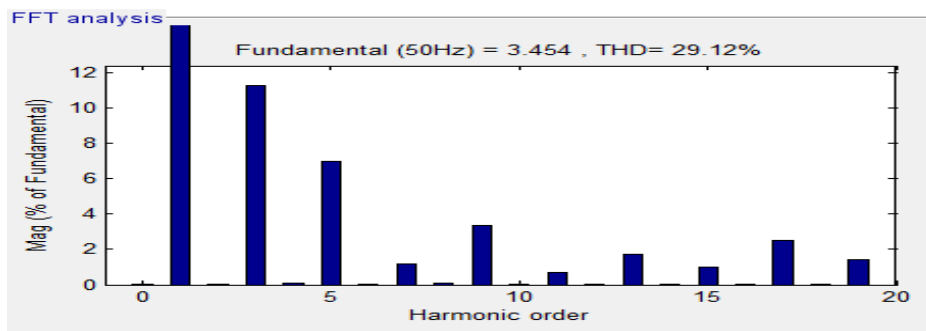


Fig 9 FFT analysis for single carrier modulation of MLI

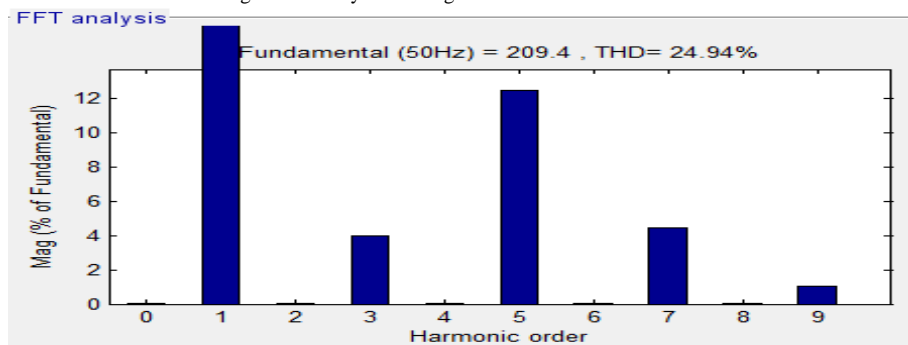


Fig 10 FFT analysis for Dual carrier modulation of MLI

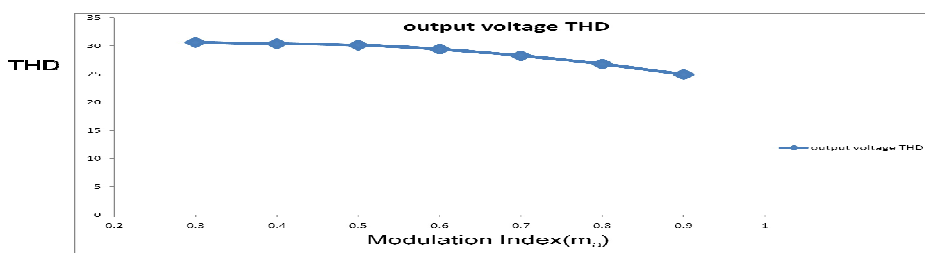


Fig 11. THD Vs  $m_a$  graph for Dual carrier modulation of MLI

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The THD values for the seven level inverter with dual carrier PWM was around 24.94% when the modulation index was equal to 0.9. The Modulation index decreased to 0.8 as the inverter output voltage THD was equal to 26.72%. i.e when the modulation index increases it reduces the THD values.

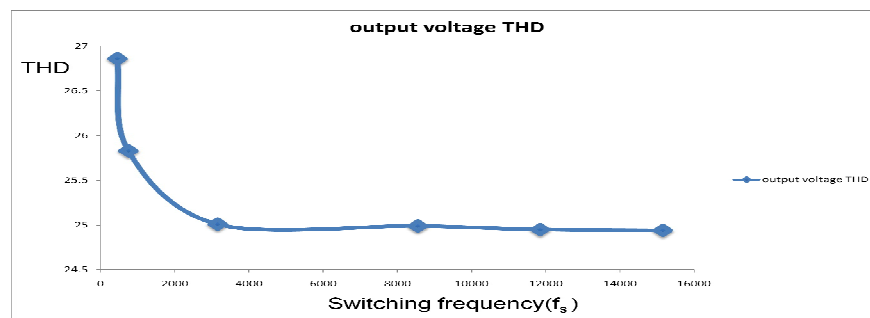


Fig 12. THD Vs switching frequency graph for Dual carrier modulation of MLI

The THD values for the seven level inverter with dual carrier PWM was around 24.94% when the switching frequency was equal to 15150Hz, as shown in Fig12. The switching frequency decreased to 3150Hz as the inverter output voltage THD was equal to 25.01% i.e when the switching frequency increases it reduces the THD values. From the simulation results, it is inferred that the dual carrier PWM technique provides a reduced THD compared to single carrier one. Therefore, dual carrier PWM method is found to be suitable for the proposed MLI for PV applications.

## VI. CONCLUSION

This paper has presented a single-phase seven level inverter with reduced number of switches. A single and dual carrier modulation method have been proposed. It is found that dual carrier modulation gives a reduced THD compared to single carrier modulation and it gives a better quality output. Therefore, PV is recommended for the proposed inverter with reduced number of switches. Hence, seven-level inverter with reduced component along with dual carrier PWM technique will enhance the quality of the output and provides a better efficiency for suited for PV applications.

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