

## PV Cell Based Five Level Inverter Using Multicarrier PWM

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### Abstract

This paper investigates the performance of a PV cell connected Multi Level Inverter topology. These MLI's are suitable in high voltage & high power application due to their ability to synthesize waveforms with better harmonic spectrum. This paper presents, a proposed scheme adopting the Multi carrier Pulse width modulation concept. The MCPWM Cascaded Multilevel inverter strategy enhances the fundamental output voltage and reduced Total harmonic distortion. The Multilevel inverter circuit analysis and selection of proper references discussed based on the formulation switching patterns. A Single phase five level cascaded inverter is used to explain the methods. The method can be easily extended to an m-level inverter. The cascaded inverter is subjected to a new modulation scheme, which uses multiple modulating signals with a single carrier. In order to justify the merits of the proposed modulation scheme, harmonic analysis for and measured THD and output voltages are compared and discussed

**Key Words:** Multilevel inverter, Multicarrier Pulse width modulation, Total harmonic distortion, PV Cell, Switching frequency optimal PWM, Sub harmonic PWM modulation index

### I INTRODUCTION

Photovoltaic (PV) power generation is very desirable since it is renewable and does not contribute to pollution or Global climate change. PV is especially attractive for applications in where sunshine is available for most of the time. This paper presents a PV array connected to Cascaded H-Bridge type multi-level inverter to achieve sinusoidal voltage waveform and output sinusoidal current to the utility grid with a simple and cost effective power electronic solution. The topologies of multilevel inverters are classified in to three types the Flying capacitor inverter, the Diode clamped inverter and the Cascaded bridge inverter [1][2]. The proposed scheme of multilevel inverter is the multi carrier sub-harmonic pulse width modulation (MC-SH PWM) [4][5]. The MC-SH PWM cascaded multilevel inverter strategy reduced total harmonic [6]

### II MATHEMATICAL MODEL OF THE PV ARRAY

#### 2.1 Simplified Equivalent Circuit

A solar cell basically is a p-n semiconductor junction. When exposed to light, a current proportional to solar irradiance is generated. The circuit model of PV cell is illustrated in Fig. 1. Standard simulation tools utilize the approximate diode equivalent circuit shown in Fig. 2 in order to simulate all electric circuits that contain diodes. The model is based on two-segment piecewise linear approximation. The circuit consists of  $R_{on}$  in series with voltage source  $V_{on}$

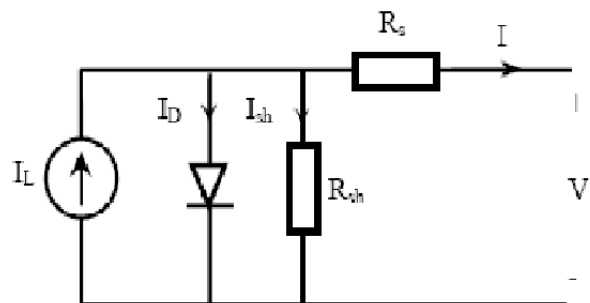


Fig. 1 Circuit model of PV solar cell

#### 2.2. Theoretical Mathematical Model:

The equation [7] that describe I-V characteristics of the solar cell based on simple equivalent circuit shown in Fig. 1, are given below;

$$I_D = I_0 \left[ e^{\frac{q(V+I R_s)}{K T}} - 1 \right] \dots \dots \dots (1)$$

$$I = I_L - I_0 \left[ e^{\frac{q(V+I R_s)}{K T}} - 1 \right] - \frac{V+I R_s}{R_{sh}} \dots \dots \dots (2)$$

Where:

I is the cell current (A).  
 q is the charge of electron =  $1.6 \times 10^{-19}$  (coul).  
 K is the Boltzman constant (j/K).  
 T is the cell temperature (K).  
 IL is the light generated current (A).  
 Io is the diode saturation current.  
 Rs , Rsh are cell series and shunt resistance (ohms).  
 V is the cell output voltage (V).

**2.3 PV Characteristics:**

**2.3.1 Current Vs Voltage Characteristics:**

Equation (1) was used in computer simulation to obtain the output characteristics of a solar cell, as shown in the figure 2. This curve clearly shows that the output characteristics of a solar cell are non linear and are crucially influenced by solar radiation, temperature and load condition

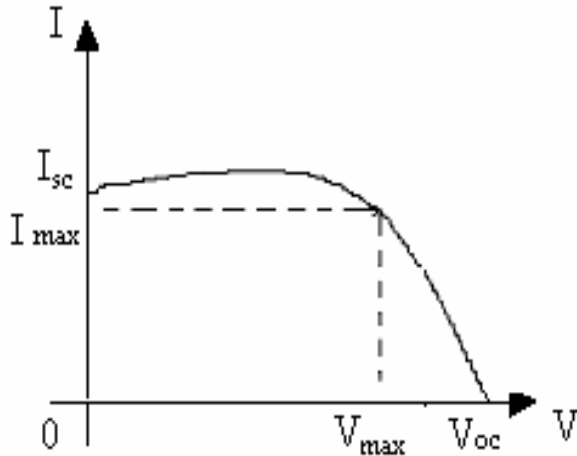


Fig 2: Output Characteristics Of Solar Cell

**2.3.2 Power Vs Voltage Characteristics:**

Figure 3 shows the typical Power versus Voltage curve of the PV array. In this figure, P is the power extracted from PV array and V is the voltage across the terminals of the PV array [2].

The characteristics have different slopes at various points. When maximum power is extracted from PV array the system is operating at MPP where slope is zero. The PV curve varies according to the current insolation and temperature. When insolation increases, the power available from PV array increases whereas when temperature increases, the power available from PV Array decreases.

**2.3.3 Variation in Available Energy due to Sun's Incident Angle:**

PV cell output with respect to sun's angle of incidence is approximated by a cosines function at sun angles from  $0^\circ$  to  $50^\circ$ . Beyond the incident angle of  $50^\circ$  the available solar energy falls off rapidly as shown in the figure 4. Therefore it is convenient and sufficient within the normal operating range to model the fluctuations in photocurrent ( $I_{ph}$ ) versus incident angle is given by Eq(3). [8].

$$I_{ph} = I_{max} \cos \theta \dots\dots\dots (3)$$

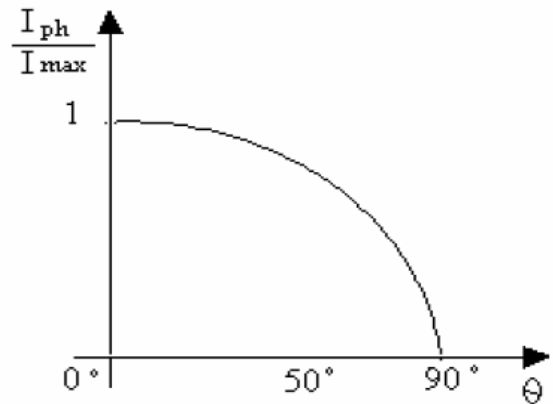


Fig 3: Power Vs Voltage

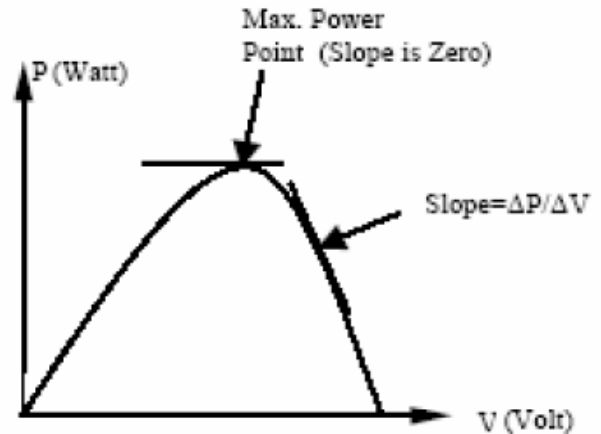


Fig 4: Variation In Available Energy Due Sun's Incident Angle Variation

### III CASCADED MULTILEVEL INVERTER

A single-phase structure of an m-level cascaded inverter is illustrated in Figure 5. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs,  $+V_{dc}$ , 0, and  $-V_{dc}$  by connecting the dc source to the ac output by different combinations of the four switches,  $S_1$ ,  $S_2$ ,  $S_3$ , and  $S_4$ . To obtain  $+V_{dc}$ , switches  $S_1$  and  $S_4$  are turned on, whereas  $-V_{dc}$  can be obtained by turning on switches  $S_2$  and  $S_3$ . By turning on  $S_1$  and  $S_2$  or  $S_3$  and  $S_4$ , the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by  $m = 2s+1$ , where s is the number of separate dc sources. An example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 6. The phase voltage

$$V_{AM} = V_{A1} + V_{A2} + V_{A3} + V_{A4} + V_{A5}$$

For a stepped waveform such as the one depicted in Figure 6 with s steps, the Fourier Transform for this waveform follows [9, 13]:

$$V(\omega t) = \left(\frac{4V_{DC}}{\pi}\right) \sum [\cos(n\theta_1) + \cos(n\theta_2) + \dots] \quad (4)$$

From (4), the magnitudes of the Fourier coefficients when normalized with respect to  $V_{dc}$  are as follows

$$H(n) = \frac{4}{\pi n} [\cos(n\theta_1) + \cos(n\theta_2) + \dots + \cos(n\theta_s)] \quad (5)$$

The conducting angles,  $\theta_1, \theta_2, \dots, \theta_s$ , can be chosen such that the voltage total harmonic distortion is a minimum. Generally, these angles are chosen so that predominant lower frequency harmonics, 5th, 7th, 11th, and 13th, harmonics are eliminated [14].

Multilevel cascaded inverters have been proposed for such applications as static var generation, an interface with renewable energy sources, and for battery-based applications. Cascaded inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaic's or fuel cells

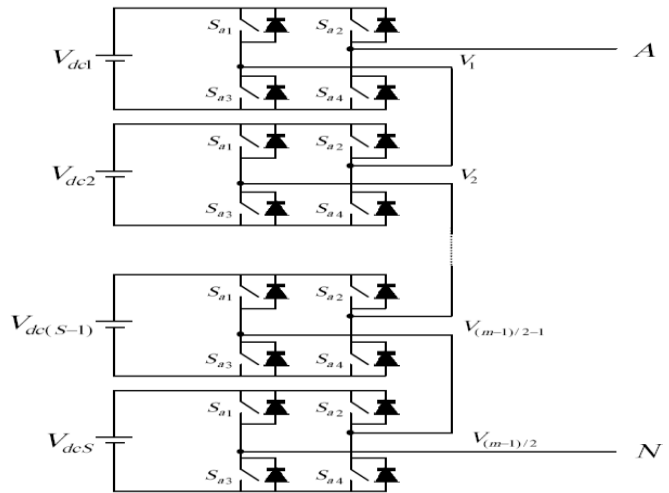


Fig 5 Single-phase structure of a m level multilevel cascaded H bridge inverter

Cascaded inverters have also been proposed for use as the main traction drive in electric vehicles, where several batteries or ultracapacitors are well suited to serve as SDCSs [15, 16]. The cascaded inverter could also serve as a rectifier/charger for the batteries of an electric vehicle while the vehicle was connected to an ac supply.

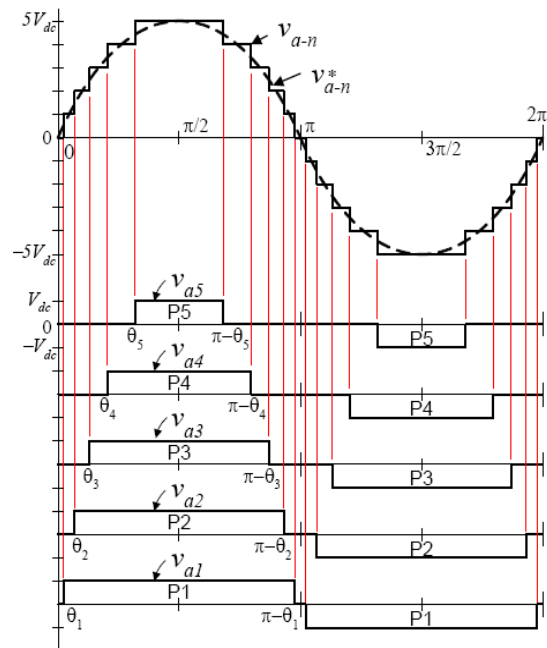


Fig 6. Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources

Additionally, the cascade inverter can act as a rectifier in a vehicle that uses regenerative braking

#### IV MULTICARRIER PULSE WIDTH MODULATION

##### MULTICARRIER SUB HARMONIC PULSE WIDTH MODULATION (MC-SH PWM)

Fig.7 shows Multicarrier sub harmonic pulse width modulation (MC-SH PWM) modulating signal generation. Fig.4 shows a m-level inverter, m-1 carriers with the same frequency  $f_c$  and the same amplitude  $A_c$  are disposed such that the bands they occupy are contiguous

The reference wave form has peak to peak amplitude  $A_m$ , the frequency  $f_m$ , and its zero centered in the middle of the carrier set. The reference is continuously compared with each of the carrier signals. If the reference is greater than s carrier signal, then they active device corresponding to that carrier is switched off.

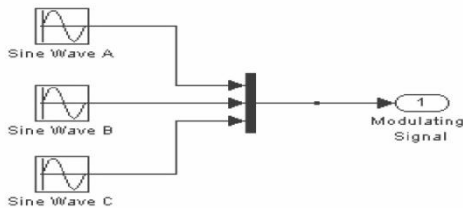


Fig. 7: Multicarrier sub harmonic PWM modulating signal generation

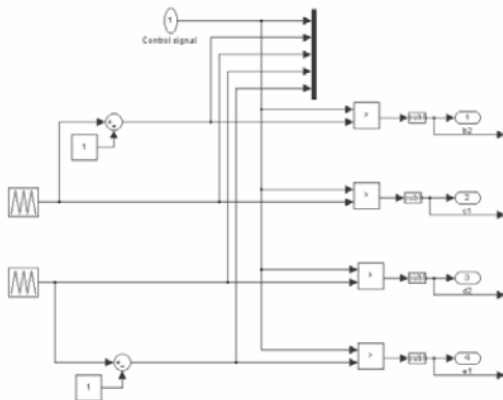


Fig. 8: Multicarrier sub harmonic PWM signal generation

In multilevel inverters, the amplitude modulation index  $m_a$  and the frequency ratio  $m_f$  are defined as

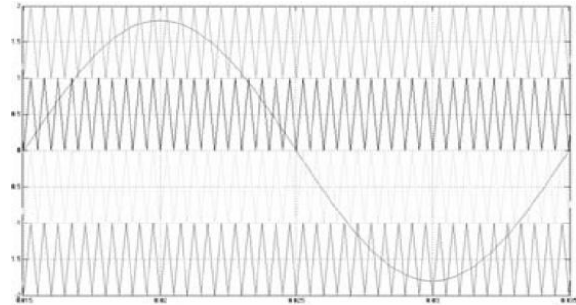


Fig. 9: Multicarrier sub harmonic pulse width modulation.

$$m_a = \frac{A_m}{(m-1)A_c} \dots\dots\dots (6)$$

$$m_f = f_c / f_m \dots\dots\dots (7)$$

Using MC-SH PWM THD value can be reduced with reduction in output voltage. In this Paper, When input voltage  $V_{dc} = 230V$  the THD value 8.35% and its output voltage  $V_{ac} = 9$  volts.

#### V PRAPOSED PROTOTYPE

The Cascaded Multilevel Converters are simply a number of conventional two-level bridges, whose AC terminals are simply connected in series to synthesize the output waveforms. Fig. 10 shows the power circuit for a five-level inverter with two cascaded cells. The Cascaded Multilevel Converters needs several independent DC sources which may be obtained from batteries, fuel cells or solar cells and in this solar cells are used

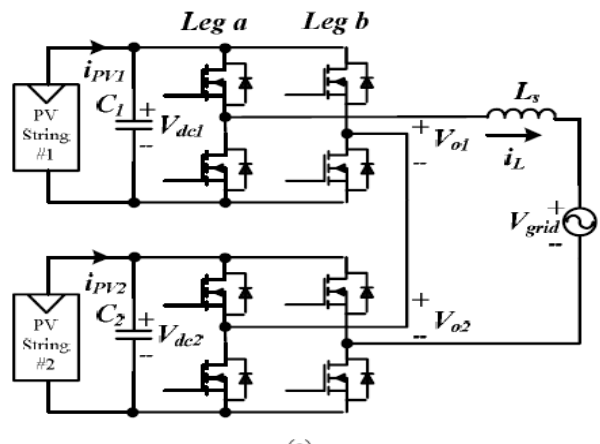


Fig 10 Proposed power circuit for a five-level inverter with two cascaded cells.

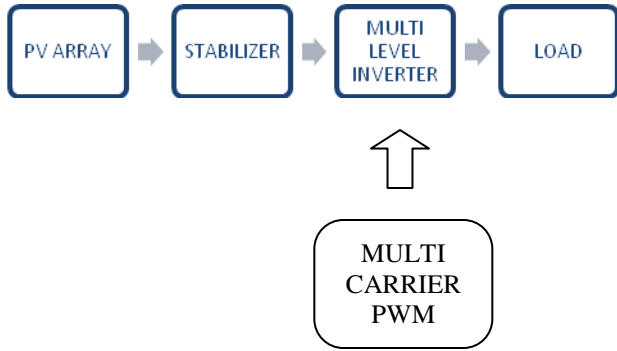


Fig. 11 Block diagram of proposed Multi level inverter

**VI SIMULATION RESULTS**

Fig 10 shows complete PV generation system based on the proposed multilevel converter has been implemented in a prototype and the proposed block diagram as shown in the figure 11. It is worth mentioning that the output voltage of the PV string arrays should be chosen based on the grid nominal voltage and the minimum desired operating power of each cell. If the power generated by all strings is equal, the output voltage of all cells will be equal. Simulations have been carried out in MATLAB–Simulink to study the performance of the proposed control and modulation scheme. The particular system shown in Fig. 12 is modeled Two PVAs are connected to a passive load through a Five-level cascaded H bridge inverter. Fig 13 shows a PV Array contains six series-

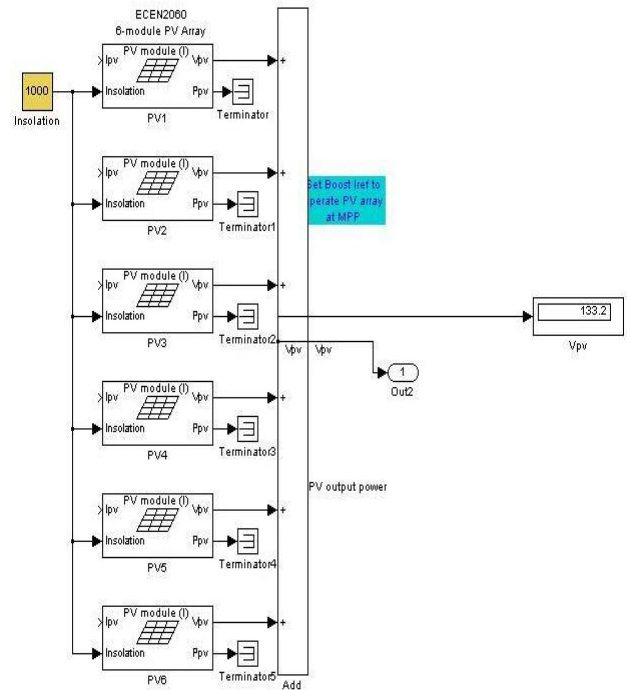
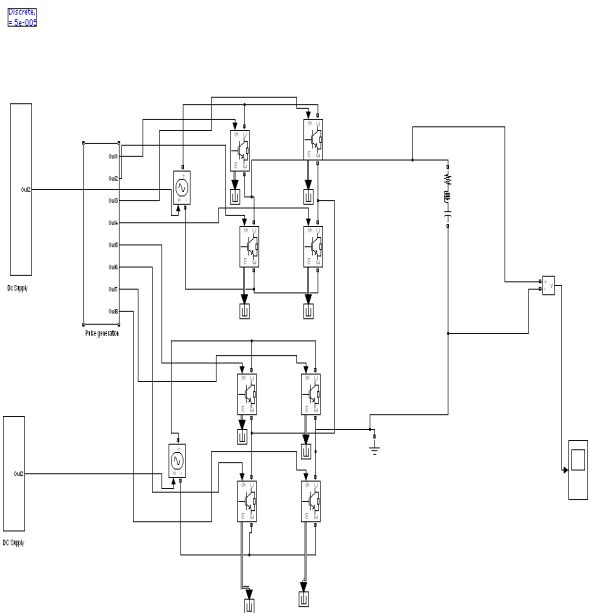


Fig 13 PV Array



connected 130-V 1000-Wp PV panels.

Fig 12 Five Level Inverter with PV Cell

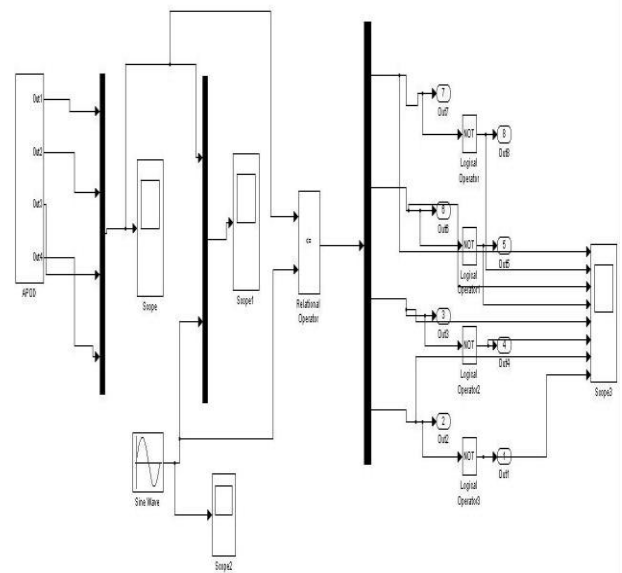


Fig. 14 Pulse Generator with Multi Carrier PWM

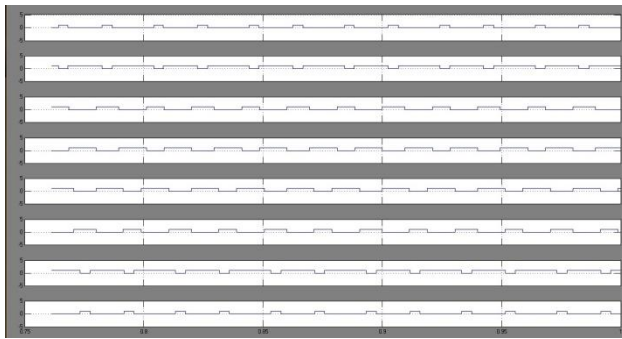


Fig. 15 Genrated Gate pulses

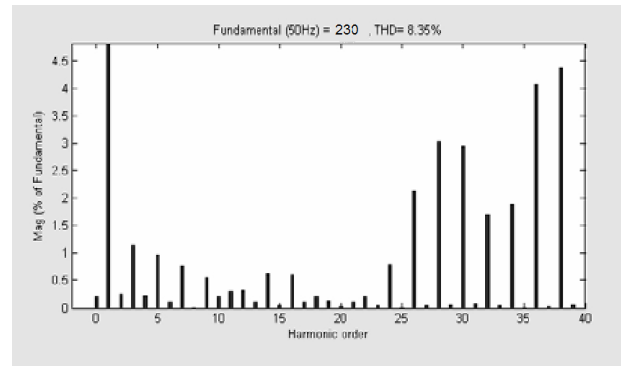


Fig 19 Harmonic spectrum of the simulated output

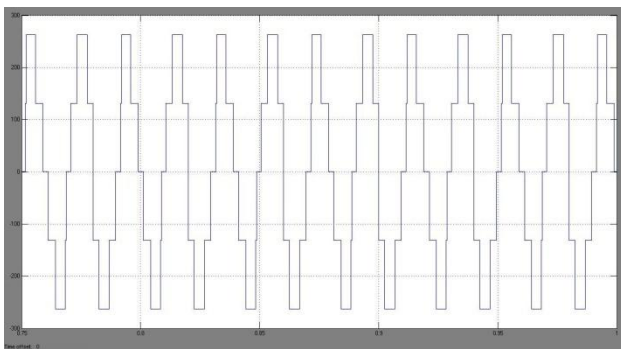


Fig. 16 Output Voltage of Five Level Inverte

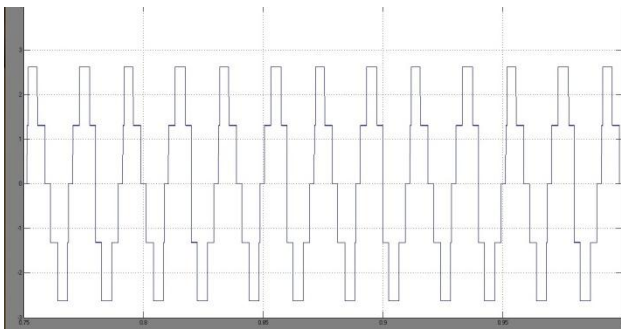
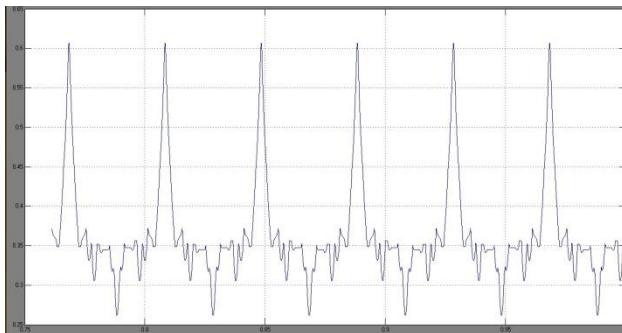


Fig. 17 Output Current of Five Level Inverter



18 THD

In this model APOD technique is used. The generated output pulses from the Multi carrier PWM block as shown in the Fig. 14 and those pulses generated are in eight numbers which is required to drive the devices in to ON state with the aid of Muti carrier pulse converter blocks as shown in figure 15. The output voltage and output current are as shown in fig. 16 and fig 17 respectively

The switching patterns adopted are applied at the cascaded multilevel inverter switches to generate five output voltage levels at 0.9 modulation index. The THD of inverter output voltage and Harmonic spectrum of the simulation system is as shown in the fig.18 and Fig 19 respectively, which shows the results are well within the specified limits of IEEE standards. The experimental and simulated results are show satisfactory results in term of total harmonic distortion and output voltage and current waveform shapes To verify the validity of the proposed PV Cell Based Five Level Inverter using multicarrier PWM The results of both output voltage and FFT analysis are verified by simulating the main circuit using MATLAB

## CONCLUSION

This paper presented an five-level cascade H-bridge Inverter, which uses MC PWM and PV system with separate solar panels as DC sources to interact with the power grid. The MC PWM strategy reduces the THD and this strategy enhances the fundamental output voltage. When Modulation Index is equal to 0.9 by adopting MC PWM strategy the THD value is 6.35. Those schemes confirmed by simulation results. This proposed prototype can be extended to m-level inverter.



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