CASCADED HYBRID FIVE-LEVEL INVERTER WITH DUAL CARRIER PWM CONTROL SCHEME FOR PV SYSTEM

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ABSTRACT

Cascaded Hybrid MultiLevel Inverter (CHMLI) is an attractive topology for high voltage DC-AC conversion. This paper focuses on a single-phase five-level inverter with reduced number of switches. The inverter consists of a full bridge inverter and an auxiliary circuit with four diodes and a switch. The inverter produces output voltage in five levels: zero, $+0.5V_{dc}$, $+V_{dc}$, $-0.5V_{dc}$ and $–V_{dc}$. A novel dual reference modulation technique has been proposed for the CMLI. The dual carrier modulation technique uses two identical inverted sine carrier signals each with amplitude exactly half of the amplitude of the sinusoidal reference signal to generate PWM signals for the switches. Using Perturb and Observe (P&O) algorithm, Maximum Power Point (MPPT) has been tracked for PV inverter. A Proportional Integral (PI) control algorithm is implemented to improve the dynamic response of the inverter. Performance evaluation of the proposed PWM strategy for Multilevel Inverter (MLI) has been carried out using MATLAB and it is observed that it gives reduced Total Harmonic Distortion (THD). An experimental five-level hybrid inverter test rig has been built to implement the proposed algorithm. Gating signals are generated using PIC microcontroller. The performance of the inverter has been analyzed and compared with the result obtained from theory and simulation.

KEYWORDS: *Multilevel inverter, dual carrier modulation, PI, PV and switching losses*

I. INTRODUCTION

Due to the depletion of fossil energy and environmental issues caused by conventional power generation, renewable energy such as wind and the solar have been widely used for a few decades. PV sources are used today in many applications as they have the advantage of being maintenance and pollution free, distributed through the earth. Solar electric energy demand has grown consistently by 20% - 25% per annum over the past 20 years, which is mainly due to the decreasing costs and prices. PV inverter, which is the heart of a PV system is used to convert DC power obtained from PV modules into AC power to be fed into the load .In recent years, multilevel inverters are of special interest in the distributed energy sources area because several batteries, fuel cell, solar cell and wind turbine can be connected through multilevel inverter to feed a load without voltage balance problems. There are several topologies of multilevel inverter but the one considered in this paper is the hybrid multilevel full-bridge five-level inverter employing reduced number of switches [1]. A five-level inverter is employed as it provides improved output waveforms, smaller filter size, reduced EMI and lower THD compared to the three-level PWM inverter.

This paper presents a single phase five-level PV inverter which consist of a DC-DC boost converter connected to two capacitors in series, a full bridge inverter and an auxiliary circuit with four diode and a switch as shown in Fig.1.This paper employs a dual carrier modulation technique to generate PWM signals for the switches and to produce five output voltage levels: zero, $+0.5V_{dc}$,$+V_{dc}$,$-0.5V_{dc}$ and $–V_{dc}$, where V_{dc} is the supply voltage[2]. As the number of output levels increases, the harmonic content can be reduced. The modulation technique uses two identical inverted sine carrier signals each with amplitude exactly half the amplitude of the sinusoidal reference signal.

Sinusoidal PWM is obtained by comparing the high frequency carrier with a low frequency sinusoidal reference signal [3].In this paper ,the dual carrier modulation is employed which consists of two carrier signals $V_{carrier1}$ and $V_{carrier2}$ which will take turns to be compared with the sinusoidal reference signals V_{ref} , to produce the switching signals. The inverter is used in PV system, a proportional-integral (PI) controller scheme is employed to keep the output current sinusoidal and to have a better dynamic performance.

II. CASCADED FIVE LEVEL INVERTER

The basic operational principle of five level cascaded multilevel inverter is to generate a five level output voltage i.e zero, $+0.5V_{dc}$,$+V_{dc}$,$-0.5V_{dc}$ and $-V_{dc}$, where V_{dc} is the supply voltage. The auxiliary circuit which consists of four diodes and switch S_1 is used between the DC-bus capacitor and the full bridge inverter. By proper switching of the auxiliary circuit can generate half level of the supply voltage i.e. zero, $+0.5V_{dc}$, $+V_{dc}$,$-0.5V_{dc}$ and $-V_{dc}$.. The full bridge inverter configuration together with an auxiliary circuit is shown in Fig.1. Table I illustrates the level of V_{dc} during S_1- S_5 switch on and off.

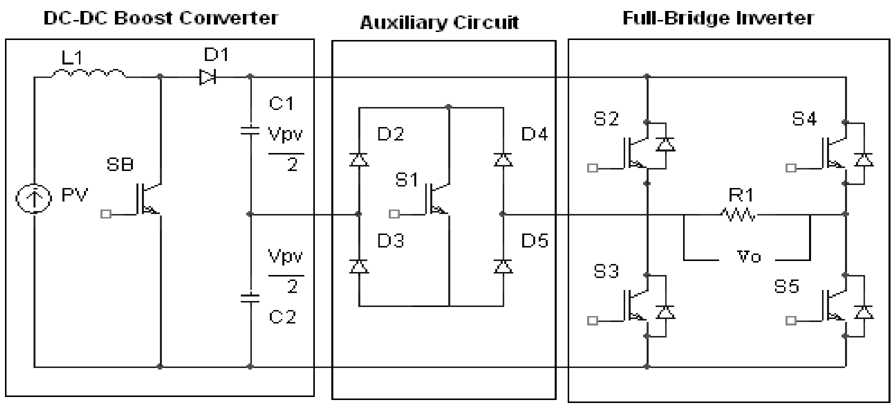


Fig.1.Full-bridge inverter configuration together with an auxiliary circuit

The circuit operation is explained as follows: The switches S_1 ,S_2 and S_3 will be switching at the rate of the carrier signal frequency while S_4 and S_5 will operate at a frequency equivalent to the fundamental frequency. The circuit operation is divided into four modes:

Mode 1: In this mode switches S_1 and S_5 conduct and the diodes D_1 and D_4 are forward biased. The output voltage equals to $+0.5V_{dc}$.

Mode 2: In this mode switches S_2 and S_5 conduct. The output voltage equals to $+V_{dc}$.

Mode 3: In this mode switches S_1 and S_4 conduct and the diodes D_2 and D_3 are forward biased. The output voltage equals to $-0.5V_{dc}$.

Mode 4: In this mode switches S_3 and S_4 conduct. The output voltage equals to $-V_{dc}$.

Table I: Conduction sequence of switches

S_1	S_2	S_3	S_4	S_5	V_{inv}
ON	OFF	OFF	OFF	ON	$+0.5V_{dc}$
OFF	ON	OFF	OFF	ON	$+V_{dc}$
OFF	OFF	ON	ON	ON	0
ON	OFF	OFF	ON	OFF	$-0.5V_{dc}$
OFF	OFF	ON	ON	OFF	$-V_{dc}$

III. DUAL CARRIER MODULATION OF MLI

There are many control techniques employed for cascaded five level inverter [4]. This paper presents the dual carrier inverted sine modulation technique. The inverted sine PWM has a better spectral quality and a higher fundamental voltage compared to the triangular based PWM. Two carrier signal

$V_{carrier1}$ and $V_{carrier2}$ each with amplitude exactly half of the amplitude of the sinusoidal reference signal are considered as shown in Fig.2. $V_{carrier2}$ is compared with the sinusoidal reference signal and pulses are generated whenever the amplitude of the reference signal is greater than the amplitude of carrier signal. If V_{ref} exceeds the peak amplitude of the $V_{carrier2}$, then $V_{carrier1}$ will be compared with the V_{ref}. This will lead to the switching pattern as shown in Fig 3.The switches S_2 and S_3 will be switching at the rate of the carrier signal frequency while the switches S_4 and S_5 will operate at frequency equivalent to the fundamental frequency.

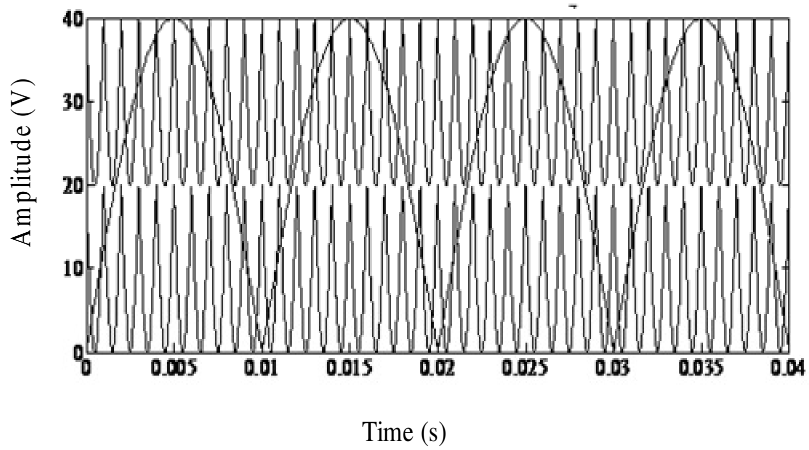
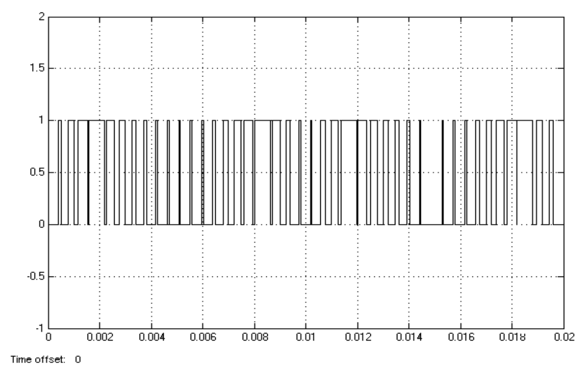
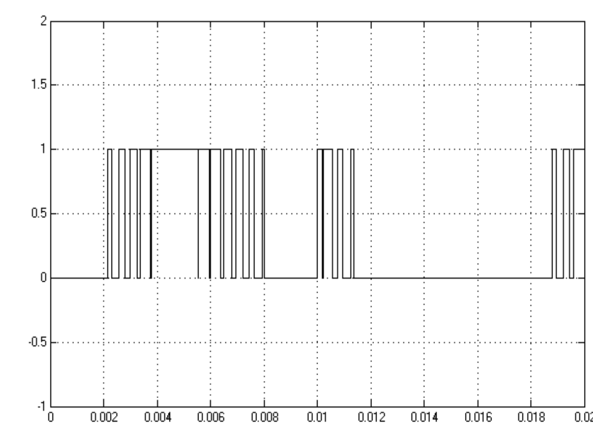


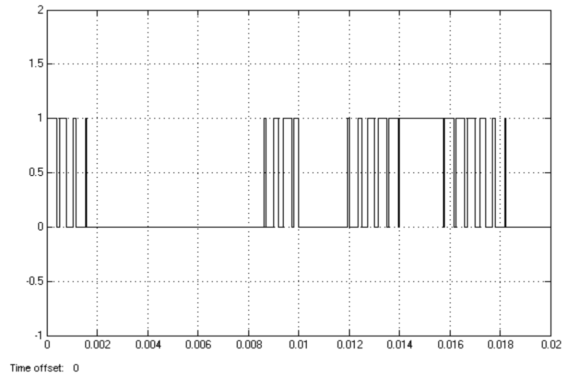
Fig.2. Carrier and reference sine waveform for dual carrier modulation technique



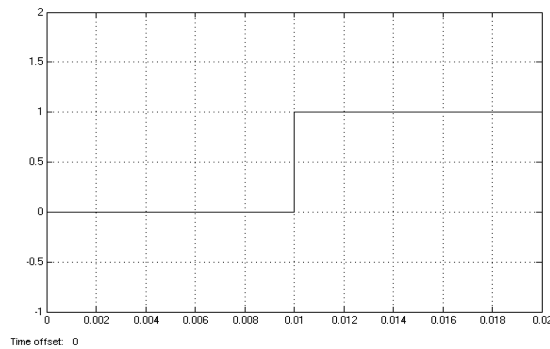
(a)PWM switching signals for S_1



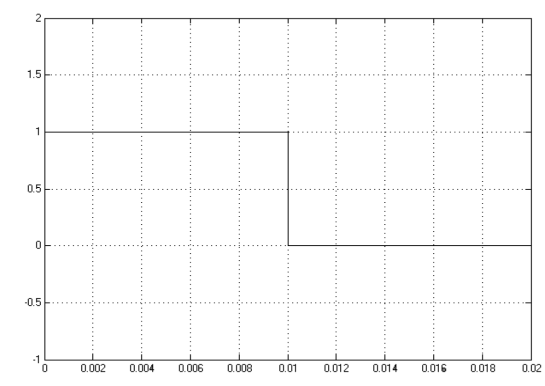
(b)PWM switching signals for S_2



(c)PWM switching signals for S_3



(d)PWM switching signals for S_4



(e)PWM switching signals for S_5

Fig.3.Switching pattern for single phase five level inverter

IV. PV MODELLING

Recently Photo Voltaic (PV) system is recognized to be in the forefront in renewable electric power generation. PV module represents the fundamental power conversion unit of a PV generator system. The output characteristic of a PV module depends on the solar insulation, the cell temperature and the output voltage of the PV module. Since PV module has non-linear characteristics, it is necessary to model it for the design and simulation of Maximum Power Point Tracking (MPPT) for PV system applications.[5,6] Equivalent circuit of a PV cell is shown in Fig.4.The current source I_{ph} represent the cell photo current. R_{sh} and R_s are the shunt and series resistances of the cell respectively. The simulink model of PV module is shown in Fig.5

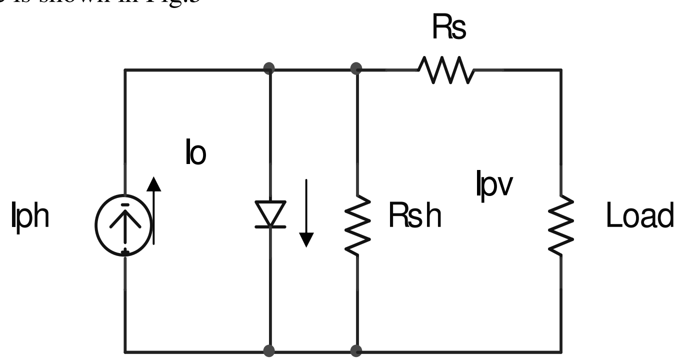


Fig.4.Equivalent circuit of PV cell

The current output of PV module is

$$I_{pv}= N_p * I_{ph} - N_p*I_o[\exp(q*(V_{pv} + I_{pv}R_s)/N_sAkT) -1] \qquad (1)$$

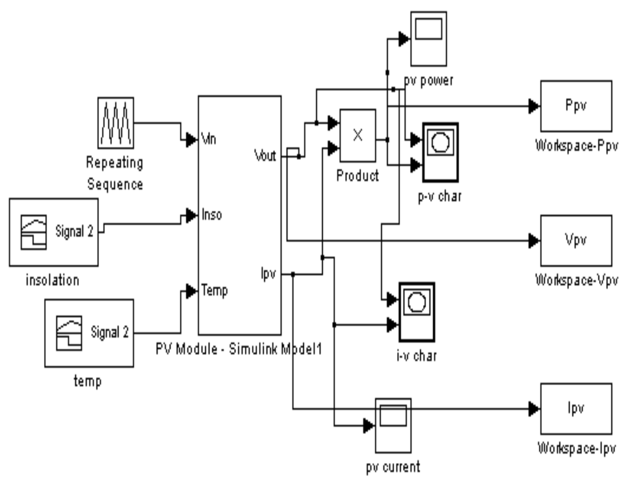


Fig.5 Simulink model of PV module

The I-V output a characteristic of PV module at 1000W/m2 irradiation is shown in Fig.6 and the P-V characteristics of PV module at 25°C is shown in Fig.7.

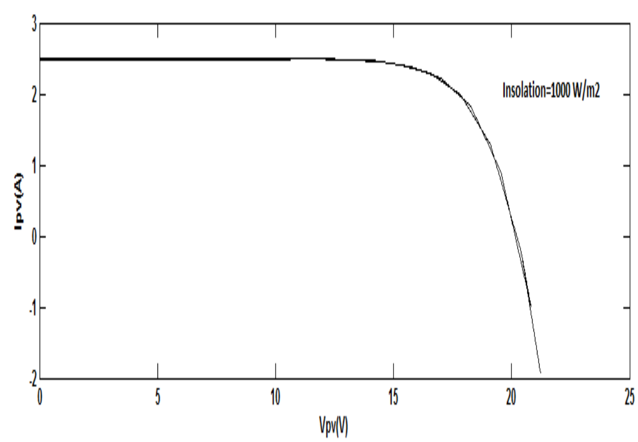


Fig.6.I-V Characteristics of PV module

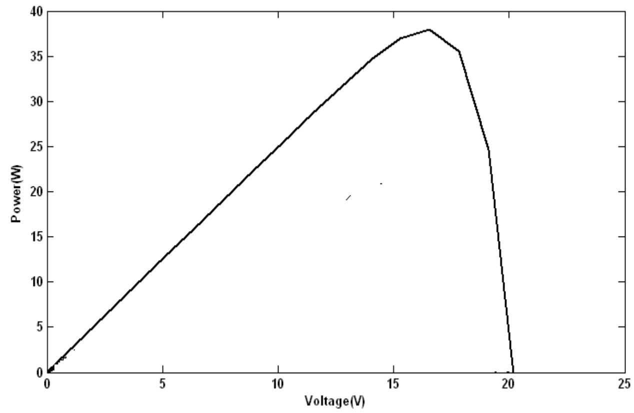


Fig.7.P-V Characteristics of PV module

As the irradiance level is inconsistent throughout the day, the amount of electric power generated by the solar module is always changing with weather conditions. To overcome this problem, Maximum Power Point Tracking (MPPT) algorithm is used [7]. It tracks the operating point of the I-V curve to its maximum value. Therefore, the MPPT algorithm will ensure maximum power is delivered from the solar modules at any particular weather conditions. In this proposed inverter, Perturb & Observe (P & O) algorithm is used to extract maximum power from the modules [8]. The flowchart for MPPT is shown in Fig.8 and the simulink model for P&O is shown in Fig.9.

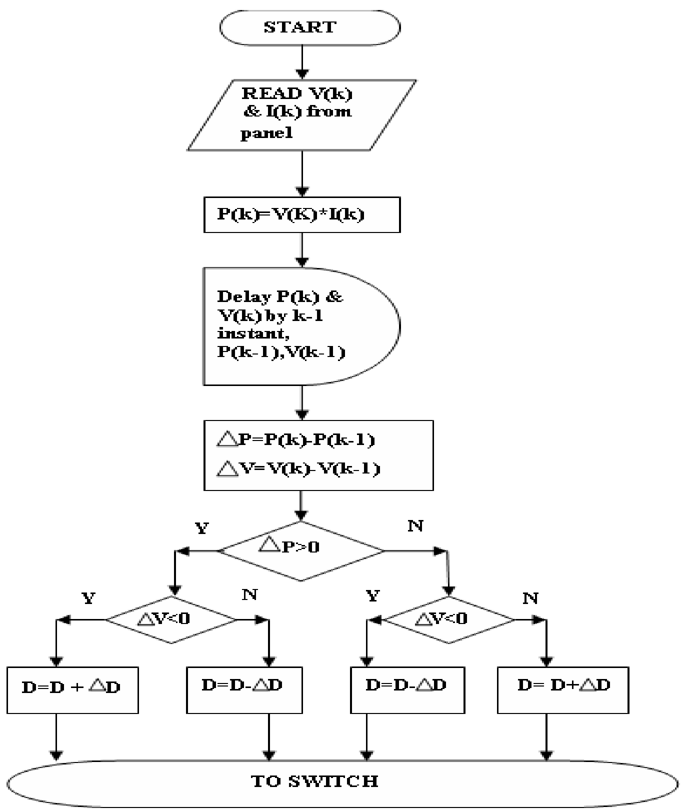


Fig.8.Flowchart for Perturb and Observe method

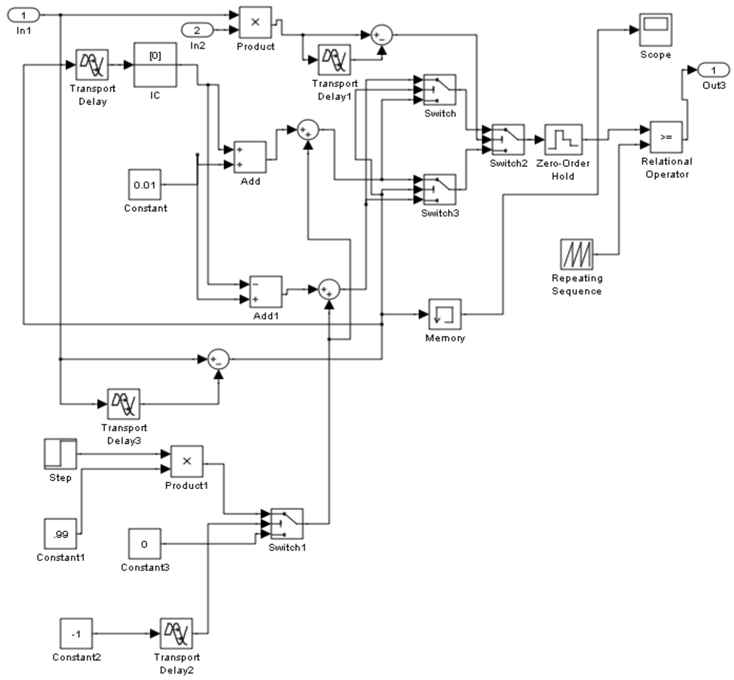


Fig.9.Simulink model for MPPT

V. CONTROLLER DESIGN

The feedback controller used in this algorithm utilizes the PI controller. As shown in Fig.11, for a grid connected system, the current injected into the load, also known as the load current I_L, is sensed and fed back to a comparator which compares it with the reference current I_{ref}. I_{ref} is obtained from constant m which is derived from MPPT algorithm [9]. The instantaneous current error is fed to a PI controller. The PI controller is tuned using Ziegler-Nichols tuning method [10]. Ziegler and Nichols (refer Fig.10) proposed rules for determining values of proportional gain k_p and integral time T_i based on the transient response characteristics of the given plant. There are two methods available. The first method of Ziegler- Nichols of tuning rules is as follows:

For PI controller:

$K_p=0.9\frac{T}{L}$, $T_i=\frac{L}{0.3}$

Where T and L are Time constant and delay time respectively.

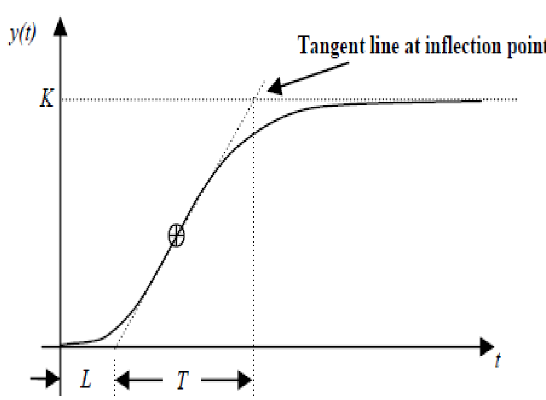


Fig.10 Ziegler- Nichols first method

Using Zeiglers method, the proportional gain K_p is set at 0.89 and the integral gain K_i is set at 88. The integral term in the PI controller improves the tracking by reducing the instantaneous error between the reference and the actual current. The resulting error signal u, form the sinusoidal reference signal which is compared with two carrier signal $V_{carrier1}$ and Vcarrier2 to produce PWM signals for the inverter switches.

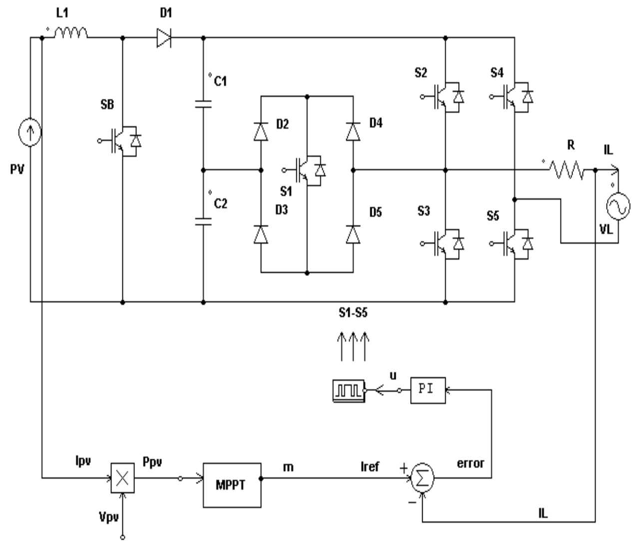


Fig.11.Five level inverter with control algorithm

VI. SIMULATION RESULTS

Simulation was performed by using MATLAB SIMULINK to verify that the proposed inverter can be practically implemented in a PV system. It helps to confirm the PWM switching strategy for the five level inverter. It consists of two carrier signals and a reference signal. Both the carrier signals are compared with the reference signal to produce PWM switching signals for switches. The DC-DC boost converter output waveform and the five level PV inverter output are shown in Fig.12 and Fig.13. Table II shows the specifications of inverter, boost converter, PI controller.

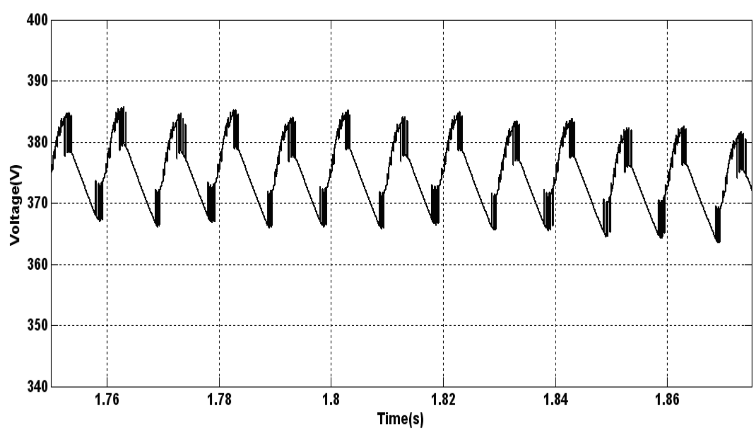


Fig.12.Output voltage ripple waveform of boost converter

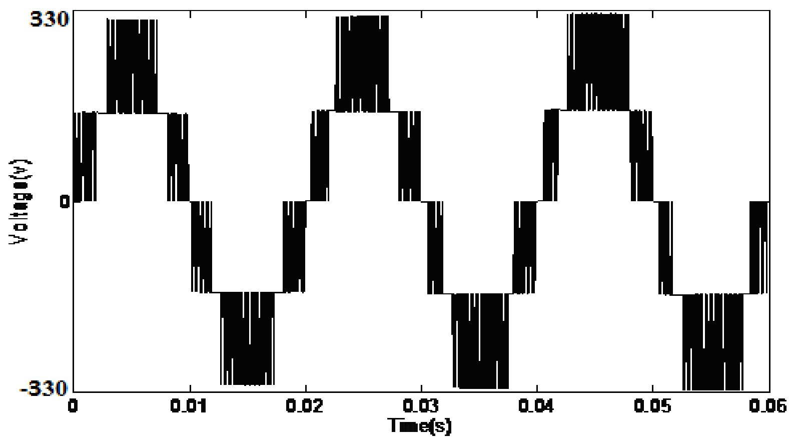


Fig.13.Five level output of PV inverter under open-loop condition

The inverter voltage and grid voltage are in phase and this is shown in Fig.14.

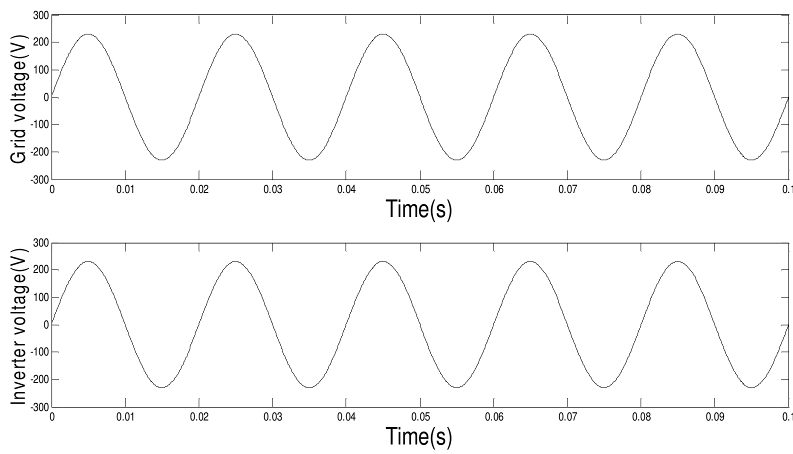


Fig .14 Grid voltage and Inverter voltage in phase

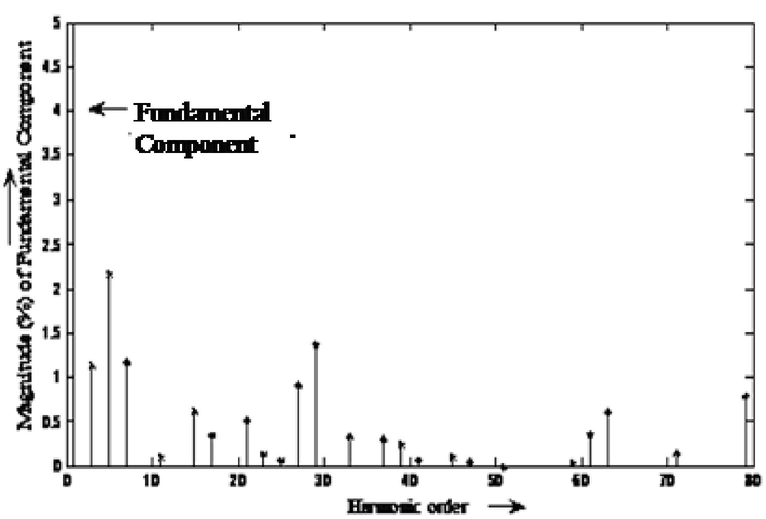


Fig.15 FFT analysis of load voltage of five level inverter (closed loop, THD = 5.45 %)

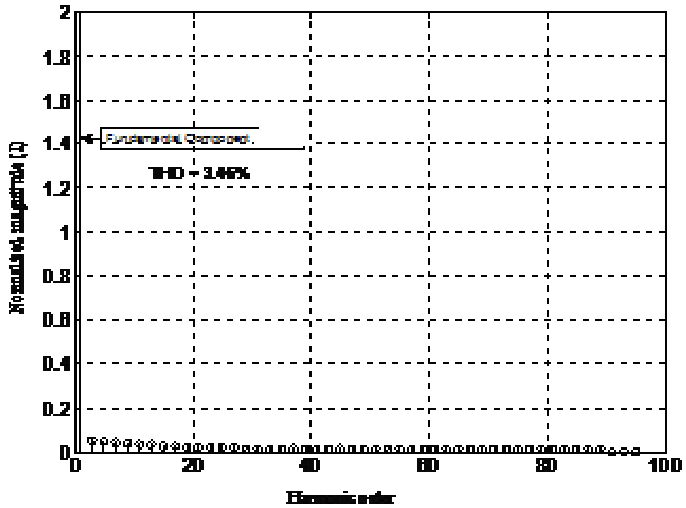


Fig.16 FFT analysis of load current of five level inverter (closed loop, THD = 3.46 %)

TABLE II : Specifications of PV Module, Boost Converter, and Inverter

PV MODULE	
Rated Power	: 37.08 W
Voltage at Maximum Power(Vmp)	:16.56 V
Current at Maximum Power(Imp)	: 2.25 A
Open circuit voltage(Voc)	: 21.24 V
Short circuit current(Ioc)	2.55 A
Total number of cells in series(Ns)	: 36
Total number of cells in parallel(Np)	: 1
MULTI-LEVEL INVERTER	
C_1-C_2	: 1000 uF
Switching frequency	: 2250 Hz

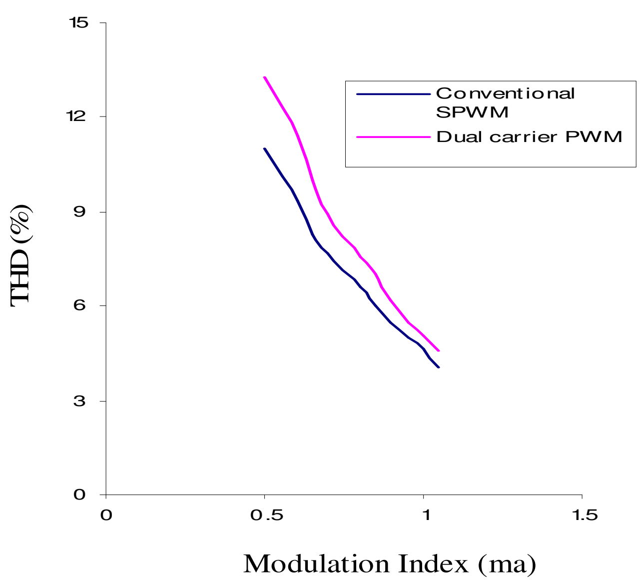


Fig.17 THD Vs ma graph for conventional SPWM & Dual carrier PWM Technique

VII. EXPERIMENTAL RESULTS

To experimentally validate the hybrid cascaded MLI using the proposed modulation, a prototype five-level inverter has been built using FGA25N120 Si IGBT for the full bridge inverter as shown in Fig.1. The gating signals are generated using PIC18F4550 microcontroller. The hardware implementation of hybrid MLI is shown in Fig.18.

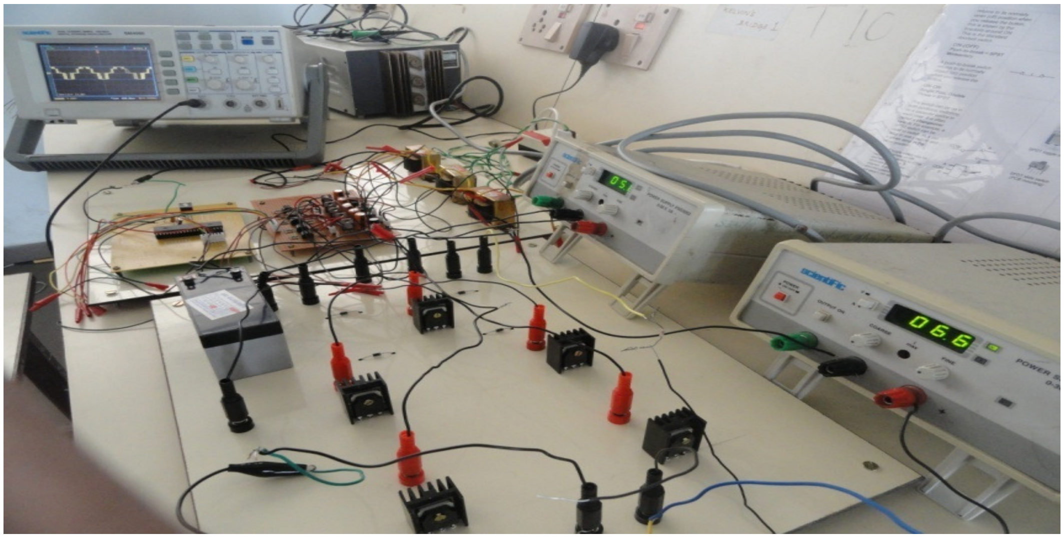


Fig.18 Photograph for hardware implementation of Hybrid MLI

The experimental load voltage of five-level inverter for R-load (R= 30 ohms) is shown in Fig.19

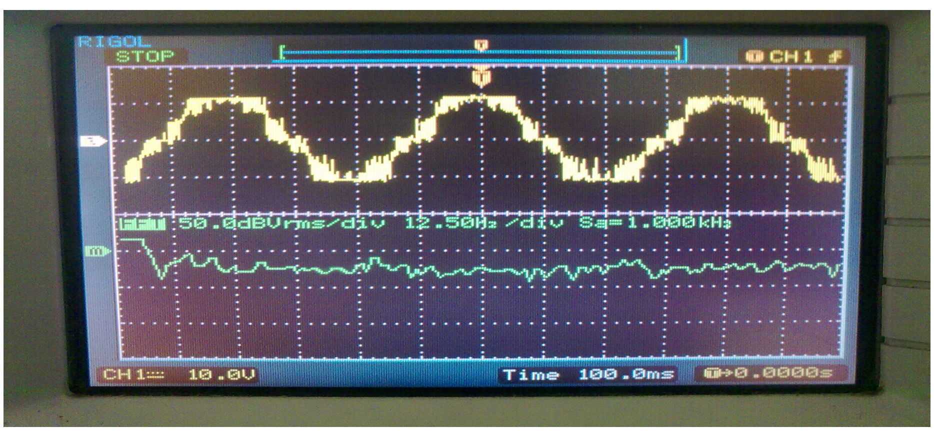


Fig .19 Five-level voltage of hybrid MLI

VIII. CONCLUSION

This paper has presented a single phase multilevel inverter for PV application. A dual carrier modulation technique has been proposed for the multilevel inverter. The circuit topology, modulation strategy and the operating principle of the proposed inverter has been analyzed. It is found that dual carrier modulation gives a reduced THD compared to dual reference modulation as reported in the literature. The inverter has been simulated using PV as a source. Using P&O algorithm, maximum power point has been tracked. A PI current control algorithm is implemented to optimize the performance of the inverter. The proposed strategy has been verified through MATLAB simulation. By employing this technique, the Total Harmonic Distortion is reduced.

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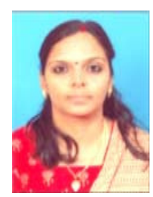
BIOGRAPHY



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