

# Simulation of High Power Factor Single Phase Inverter For PV Solar Array

Anam Aziz, Mr. Vaibhav Purwar

**Abstract**— Photovoltaic (PV) systems are solar energy supply systems, which either supply power directly to an electrical equipment or feed energy into the public electricity grid focuses on the latest development of modelling and control of grid connected photovoltaic energy conversion system. This paper depicts information about DC-AC inverter used in solar inverter. We will get DC power from solar panels and this converter inverts DC to AC. This design and modulation is based on MATLAB software. In circuit, for switching purpose IGBT is used. There are many other devices also but IGBT has more advantages than others that are shown by comparison with others. The main thing is that this conversion and switching of IGBT is done using different types of PWM methods. Here we are using HCCPWM method for conversion of AC power. This method is very efficient than other methods and also it reduces harmonics to very much extent in output. The Thesis objective are, to design an inverter model by using MATLAB and making analysis on the output voltage and to study the function of PWM in single phase inverter. Its scopes are:

1. Modeling and simulation using MATLAB.
2. Using HCCPWM method for the switching operation.

**Project application:** This Project is based on solar inverter. This inverter will be used in our college for lab applications.

**Index Terms**— Simulation, Boost-Converter, Single Phase, PV Inverter, Grid connected inverter MATLAB/Simulink

## I. INTRODUCTION

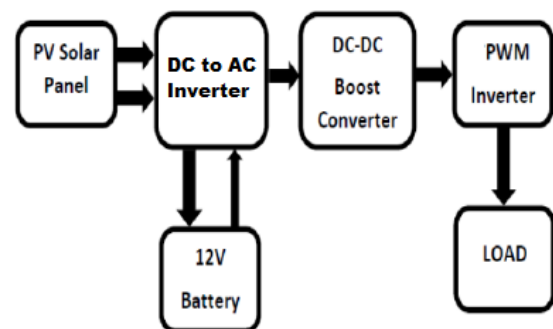
Presently world is facing too much challenges one of them is to generating the enough electrical power that will fulfill the requirements of mankind. Today generation of electrical power based on the conventional coal, gas and nuclear based. World population is increasing day by day so the requirement of them also increased and hence generation of electrical power is also increased. Basically there are two types of power generation sources:

1. Conventional
2. Non-conventional.

Today most of generation of electrical power based on Conventional sources such as coal, gas and nuclear etc. Conventional sources are no more after some of the years and which are not sufficient to fulfill the requirement of the mankind. Nuclear energy is not much preferable because its radiation effect. Therefore some part of energy should be generated based on non-conventional sources. There are also problems of increasing pollution and energy demands and hence the exploitation of solar has received more and more attentions. This project is also focus on modeling and

simulation of single-phase solar inverter by Pulse Width Modulation. A Pulse Width Modulation is a technique that use as a way to decrease total harmonic distortion in inverter circuit. The model is implemented using MATLAB software with the SIMPOWER SYSTEM block set based on computer simulation. Computer simulation plays an important role in the design, analysis, and evaluation of power electronic converter and their controller. MATLAB is an effective tool to analyze a PWM inverter. Advantages of using MATLAB are the following:

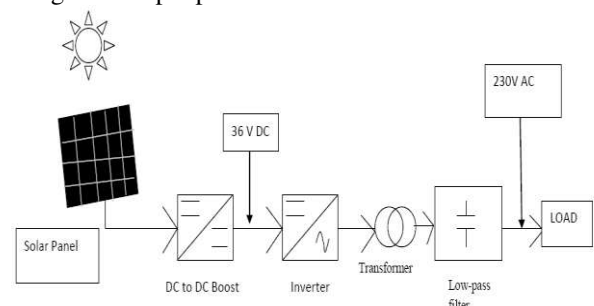
1. Faster response
2. Availability of various simulation tools
3. Various functional blocks, etc.



**Figure 1** General Diagram of Solar Inverter System

## II. BLOCK DIAGRAM

Block diagram of single phase solar inverter is shown in Fig 2. Solar panel output is 24volt. Dc to dc boost converter converts 24-volt dc voltage to 36-volt dc. This dc voltage is converted to ac voltage using inverter. Inverter output is sine coded PWM pulses. These sine-coded pulses are stepped up using step up transformer. These sine coded PWM pulses are converted into sine wave using low-pass filter. This sine wave ac voltage is fed to the load. The ac output is 220volt 50Hz. For design the output power of solar inverter is taken 250VA.



**Figure 2** Block diagram of single phase PV solar Array

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## III. SOLAR ENERGY

Solar energy is a non-conventional type of energy. Solar energy has been harnessed by humans since ancient times using a variety of technologies. Solar radiation, along with secondary solar-powered resources such as wave and wind power, hydroelectricity and biomass, account for most of the available non-conventional type of energy on earth. Only a small fraction of the available solar energy is used.

Solar powered electrical generation relies on photovoltaic system and heat engines. Solar energy's uses are limited only by human creativity. To harvest the solar energy, the most common way is to use photovoltaic panels which will receive photon energy from sun and convert to electrical energy. Solar technologies are broadly classified as either passive solar or active solar depending on the way they detain, convert and distribute solar energy. Active solar techniques include the use of PV panels and solar thermal collectors to strap up the energy. Passive solar techniques include orienting a building to the Sun, selecting materials with favorable thermal mass or light dispersing properties and design spaces that naturally circulate air. Solar energy has a vast area of application such as electricity generation for distribution, heating water, lightening building, crop drying etc.

## IV. SYSTEM COMPONENTS

### A. Modelling Of Photovoltaic Module/Array

The photovoltaic module is the result of associating a group of photovoltaic cells in series and parallel, with their protection devices, and it represents the conversion unit in this generation system. The manufacturer supply PV cells in modules, consisting of NPM parallel branches, each with NSM solar cells in series shown in Figure 3

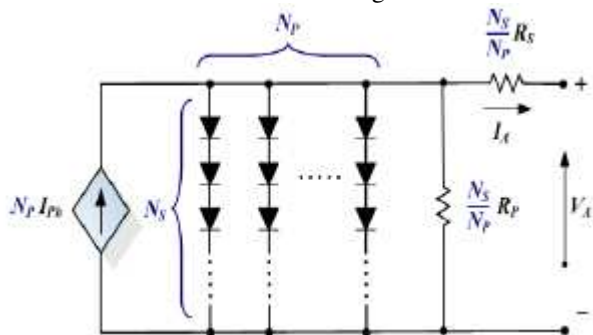


Figure 3 Equivalent circuit of a PV array.

Although the mathematical and simulation photovoltaic modules development began time ago, improvements of these models are analyzed and presented continually. One of the objectives of this study is a review of those existing methods and models.

$$I_A = N_P I_{Ph} - N_P I_{RS} \left\{ \exp \left[ \frac{q}{A k T_C} \left( \frac{V_A + I_A R_S}{N_S} \right) \right] - 1 \right\} - \frac{N_P}{R_P} \left( \frac{V_A + I_A R_S}{N_S} \right)$$

Where:  $I_A$ : PV array output current

$V_A$ : PV array output voltage

$I_{Ph}$ : Solar cell photocurrent

$I_{RS}$ : Solar cell reverse saturation current (aka dark current)

$q$ : Electron charge,  $1.60217733 \times 10^{-19}$  Cb

$A$ : P-N junction ideality factor, between 1 and 5

$k$ : Boltzmann's constant,  $1.380658 \times 10^{-23}$  J/K

$T_C$ : Solar cell absolute operating temperature, K

$R_S$ : Cell intrinsic series resistance

$R_P$ : Cell intrinsic shunt or parallel resistance

The photocurrent  $I_{Ph}$  for any operating conditions of the PV array is assumed to be related to the photocurrent at standard test conditions (STC) as given in equation (2).

$$I_{Ph} = f_{AM_a} f_{IA} \left[ I_{SC} + \alpha_{Isc} (T_C - T_R) \right] \frac{S}{S_R}$$

### B. DC to DC Boost Converter

DC to DC Converters are used for converting one level of DC voltage (usually unregulated) to another level of DC voltage (regulated). This transformation is done with the help of a network consisting of storage elements like inductor and capacitor [1].

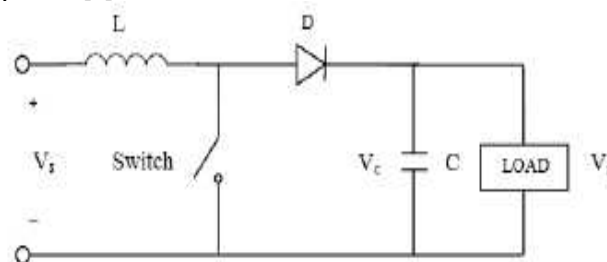


Figure 4 Boost Converter

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost converter is shown in Fig. 4. Here, IGBT is used as a switch. When the switch is turned-ON, the current flows through the inductor and energy is stored in it. When the switch is turned-OFF, the stored energy in the inductor tends to collapse and its polarity changes such that it adds to the input voltage. Thus, the voltage across the inductor and the input voltage are in series and together charge the output capacitor to a voltage higher than the input voltage.

### C. Control of DC to DC converter

The output voltage of DC to DC converter is controlled or regulated by switching ON and OFF the switch, in a periodic manner. The regulation is normally achieved by HCC Pulse Width Modulation (PWM) technique at a fixed frequency. The constant switching frequency  $f_t$  is given by [1],

$$f_t = \frac{1}{T_t}$$

Where  $T_t$  is the time period of switching device and it is nothing but the addition of ON and OFF time of a switching device which is given by

$$T_t = T_{on} + T_{off}$$

As the ratio  $T_{on}/T_t$  is duty ratio and as this duty ratio varies, the output voltage also varies. This is called constant frequency, variable duty ratio control [1].

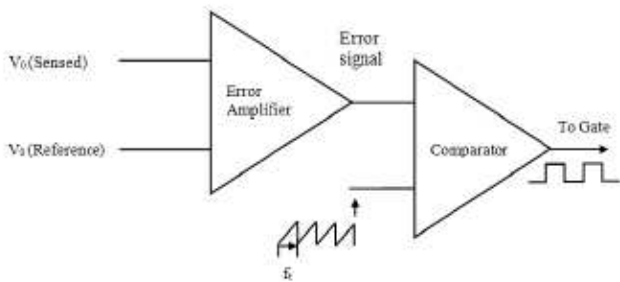


Figure 5 Control circuit of boost converter

Control circuit of boost converter is shown in Fig.3. For regulation purpose, output voltage is continuously sensed  $V_o$  (sensed) and compared with a reference voltage  $V_o$  (reference). The resulting error signal is compared with a saw tooth waveform having frequency  $f_t$ . The output of a comparator is fed to the switch or fed into the gate of a power IGBT [1]. Usually, frequency in kilohertz is selected so as to maximize the efficiency of a converter.

#### D. Voltage Controller

In general using electrolytic capacitors are less desirable for their short operational lifetime. Hence Long lifetime film capacitors serve as a substitute, however their high prices limit the size that can be used in PV inverters. This causes a significant double line frequency ripple on the DC link voltage which may further couple through the control loop. Therefore a band stop filter is placed on the dc voltage feedback loop to attenuate the ripple. Fig. 6 shows the block diagram of the outer voltage control loop. A simple PI controller is used as a voltage controller  $G_v(s)$  to regulate the dc link voltage.

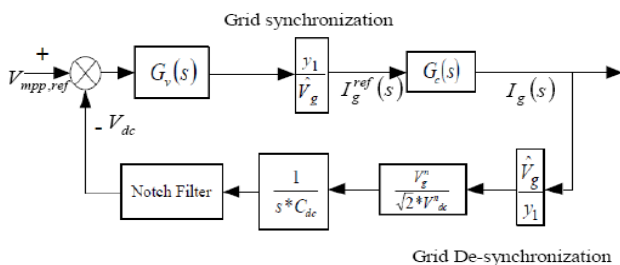


Figure 6 Block diagram of outer voltage loop.

### V. PULSE WIDTH MODULATION

Pulse-width modulation is the internal control of converter. By using this control technique the output voltage of the converter can be controlled. Pulse-width modulation is the most efficient method among all the methods of controlling the output voltage of the inverter.

In this method of control, the ON and OFF periods of the inverter component is adjusted and hence, a controlled AC output voltage is obtained by giving a constant DC voltage at the input PWM control are very useful in industrial applications. The amplitude of the pulses are constant but the width of these pulses are varying according to the modulating signal. The width is varied to reduce its harmonics component [2].

PWM have a wide field of applications such as motor speed control, converters, communication, etc. For example PWM

is used to control the switches of inverter to control the power supplied to the motor. By controlling the ON-OFF time of the switches we can control the speed of the motor. When we need more speed we increase the ON time of the switches similarly when we need to slow down the motor we decreases the OFF time of the switches. Higher switching frequency for the switches so that the power losses is insignificant as compare to the power supplied by the source.

#### A. Sinusoidal Pulse Width Modulation

This type of pulse-width modulation is almost similar to that of multiple-pulse width. The width of the pulses in the former one is constant but here in SPWM, the width of the pulses varies according to the amplitude of the reference (sinusoidal) signal.

In SPWM, the frequency of carrier is very high and this signal is compared with the sinusoidal reference signal of the desired frequency. The carrier signal and the reference signal are compared together using a comparator. When the amplitude of the reference wave is higher than the carrier then only the output of the comparator is high otherwise it remains low.

In a SPWM, we compare the sinusoidal control signals ( $V_a$ ,  $V_b$  and  $V_c$ ), which are 120 degree apart with each other with a triangular voltage signal ( $V_T$ ). Intersection of triangular signal with each phase of the sinusoidal control signal produces switching signal for each phases of the inverter.

An inverter has six switching devices  $S_1$  to  $S_6$  with output of each phase is connected to the centre of each inverter leg as shown in figure 7. There are two switch in each leg of the inverter and ON and OFF in a complementary fashion. That is, only one switch will conduct at any instant of time in one leg of inverter. The pole output voltage of the inverter varies between  $V_{dc}/2$  to  $-V_{dc}/2$  where  $V_{dc}$  be total DC voltage [4].

For modulating index less than one peak of triangular carrier signal is always greater than the peak of sinusoidal control signal. When the carrier signal is less than the sinusoidal signal, the upper devices are conducting and the lower devices are OFF. Similarly, when the triangular signal is less than the sinusoidal signal, the upper devices is OFF and the lower devices are conducting. The switches in each leg of the inverter are controlled together and the control signal is:

$S_{11}$  is ON when  $V_a > V_T$

$S_{12}$  is ON when  $V_a < V_T$

$S_{21}$  is ON when  $V_b > V_T$

$S_{22}$  is ON when  $V_b < V_T$

$S_{31}$  is ON when  $V_c > V_T$

$S_{32}$  is ON when  $V_c < V_T$

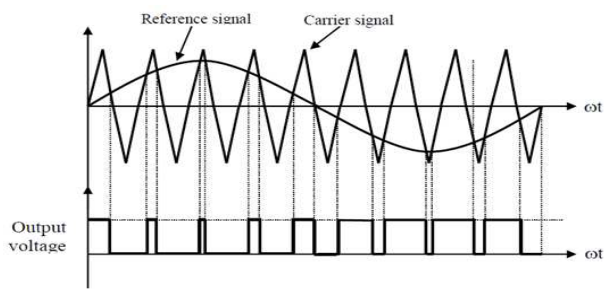
$V_a$ ,  $V_b$  and  $V_c$  are the amplitude of reference and  $V_T$  is amplitude of carrier.

The inverter line-to-line is obtained from the pole voltages as:

$V_{ab} = V_{ao} - V_{bo}$

$V_{bc} = V_{bo} - V_{co}$

$V_{ca} = V_{co} - V_{ao}$



**Figure 7** SPWM Signal

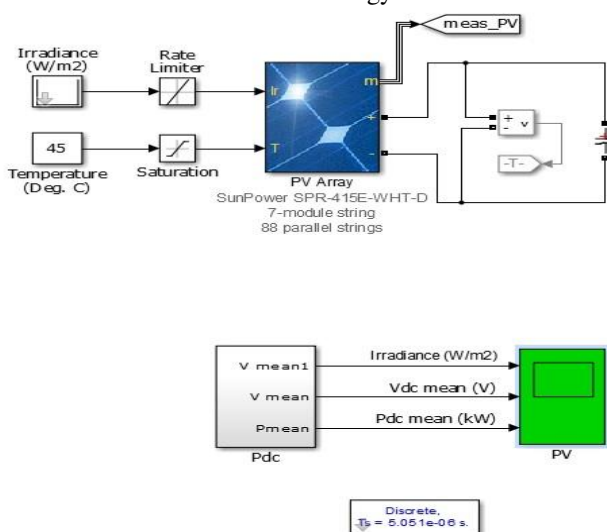
## B. Hysteresis current control Pulse Width Modulation

The Hysteresis current control PWM (HCC-PWM) is the most widely used inverter switching mechanism for Single-phase inverter. It achieves the voltage vector control by adjusting the timing and duty ratio of the eight switching states of the single-phase inverter. Assuming that stator coils in the single phase are identical, each switching state of the single-phase inverter corresponds to a voltage vector in the single-phase stator coil frame.

The result of comparator output signal is used to control converter switches to make it ON/OFF. Thus the operation of converter switches force input current to follow the desired reference. Space vector pulse width modulation control technique is simple, accurate, and robust and provides fast dynamic response hence advantages. The HCCPWM can be implemented by using wither sector selection algorithm or by using a carrier based space vector algorithm. Other pulse width modulation schemes suffer from the drawbacks of random switching and excessively large switching frequency under large load conditions. This technique has two excellent features: its maximum output voltage is 15% greater and the controller utilizes the zero vectors also along with the nonzero and this result in reducing the switching frequency and reduced harmonics distortions [4].

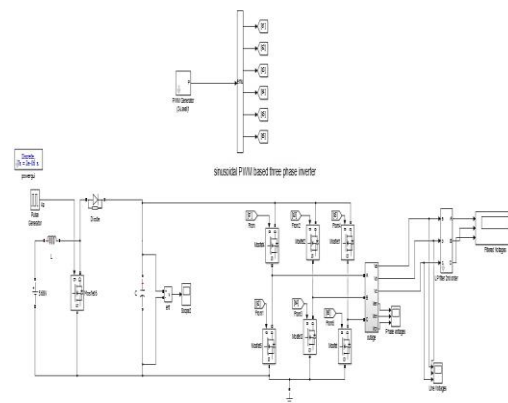
## VI. SIMULINK MODEL

Figure 8 is a simulation of a photovoltaic array producing power extracted from the solar energy.

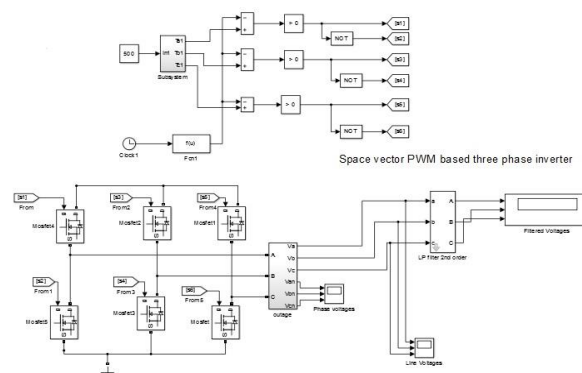


**Figure 8** Simulation diagram of proposed converter

Figure 9 is a simulation diagram of sinusoidal PWM based single phase inverter with boost dc-dc converter used at the start for a significant increase in the dc output of the PV array. Simulink block is used here to get desirable output.



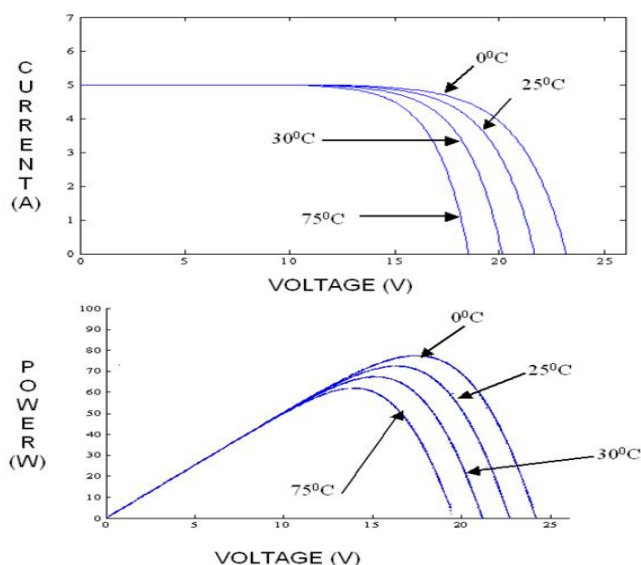
**Figure9** Simulink diagram of sinusoidal PWM Single phase inverter



**Figure 10** Simulation model of hysteresis current control PWM based single-phase inverter

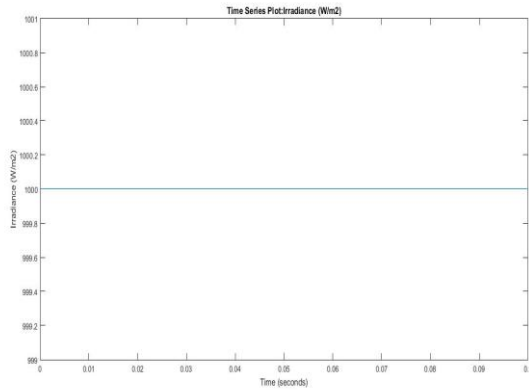
## VII. RESULTS

A photovoltaic array used for the production of power from the solar energy consist of several photovoltaic cells arranged in combination of series and parallel. The I-V and P-V characteristics of the photovoltaic array module is shown in figure 11.



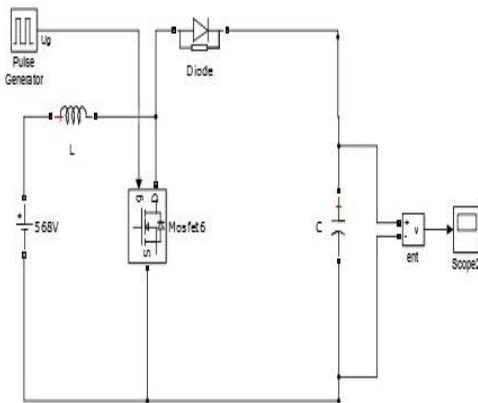
**Figure 11** I-V and P-V characteristics of PV module

The output power and voltage produced from the photovoltaic array with the above parameters are given below in figure 12.



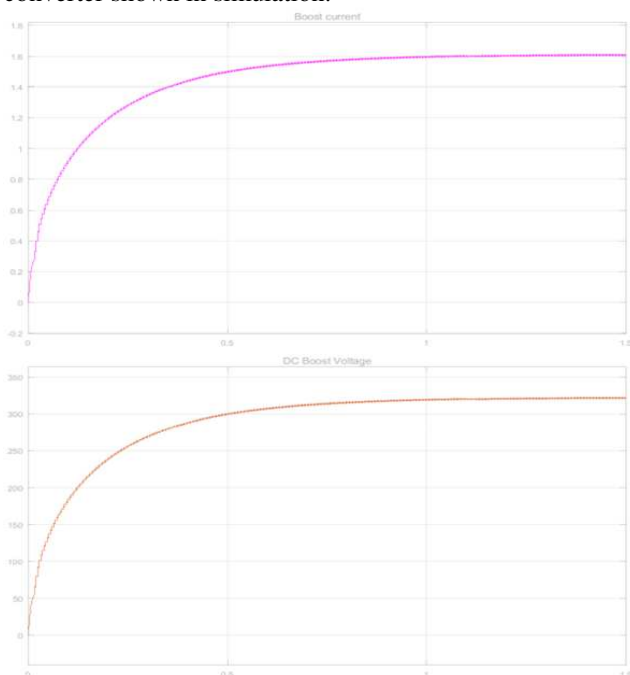
**Figure 12** Output waveform of PV array Irradiance  $\text{W/m}^2$

Figure 13 shows the simulation of boost dc-dc converter



**Figure 13** Simulation model of boost dc-dc converter

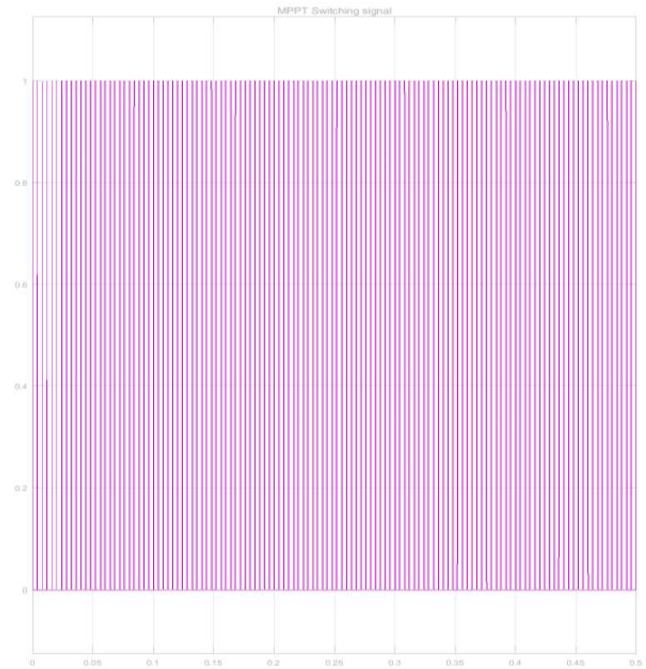
Figure 14 shows the output waveform of boost dc-dc converter shown in simulation.



**Figure 14** Output waveform of boost dc-dc converter

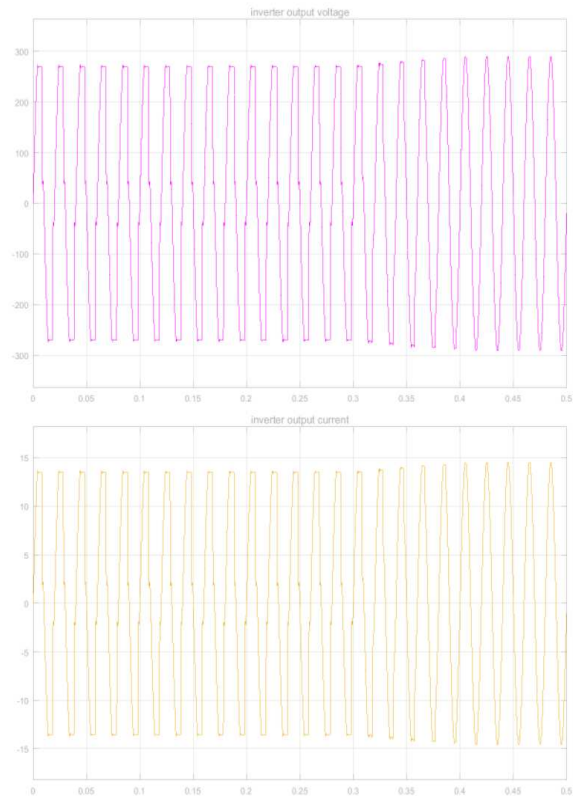
## HYSTERESIS CURRENT CONTROL PWM BASED SINGLE PHASE INVERTER

The MPPT technique perturbs & observer has been used here to generate the switching signal for maximum power tracking that shown in figure



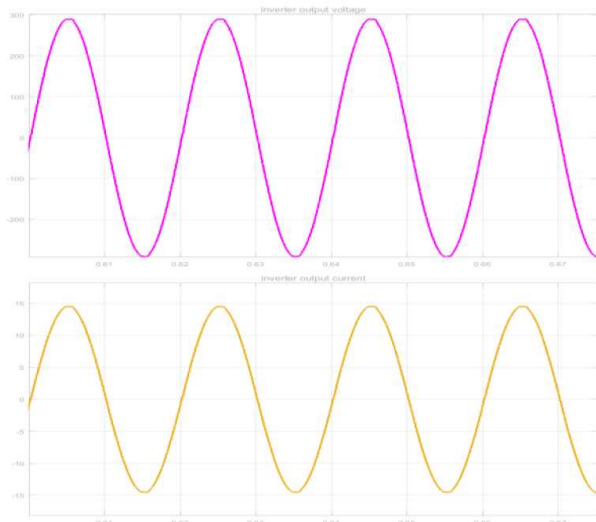
**Figure 15** MPPT switching signal

The inverter output current and voltage are shown in fig 16 in normal and zoom state. The time period = 0.02, then calculated frequency = 50 Hz



**(a)** Inverter output voltage & current in normal state

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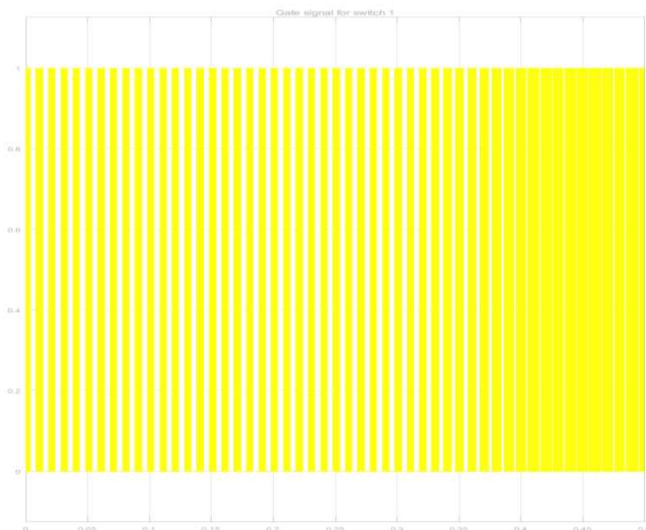
(b) Inverter output voltage & current in zoom state



(c) Gate signal for switch no 3

**Figure 16** Inverter output voltage & current

The Gate signals for four switches are shown in figure 17.



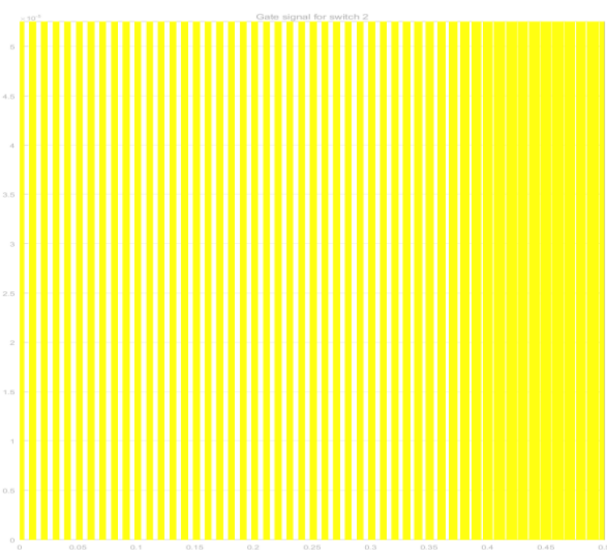
(a) Gate signal for switch no 1



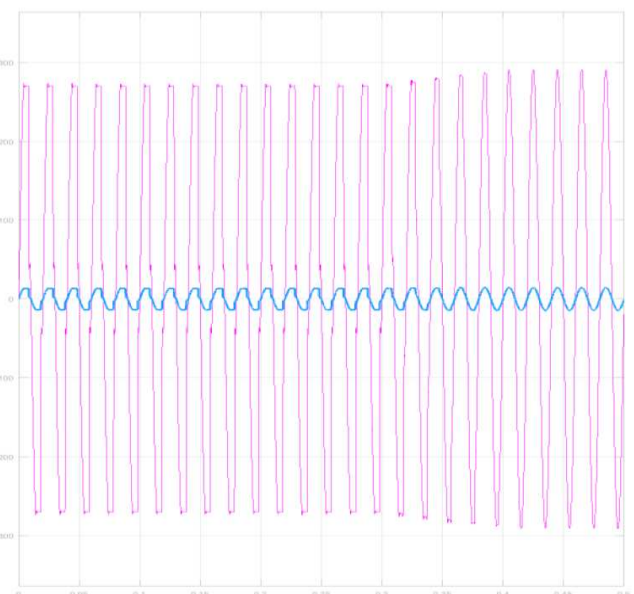
(d) Gate signal for switch no 4

**Figure 16** Gate signals for switches

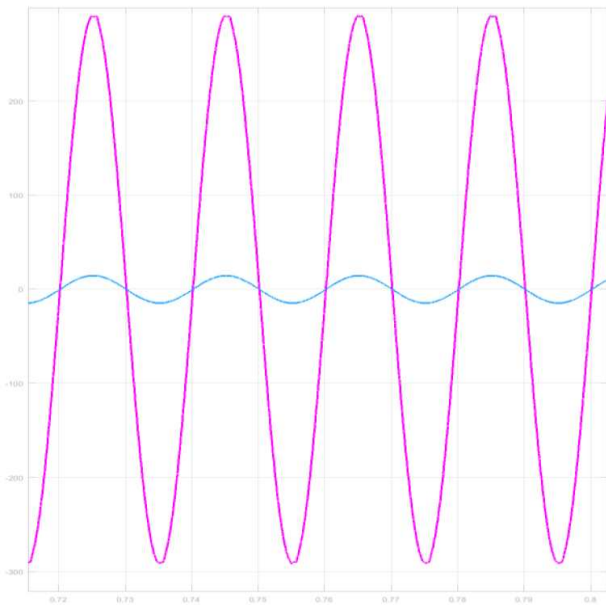
The unity power factor is shown in figure 18 as below. It can be seen in the figure that the phase angle between two waveforms is zero. Hence the power factor is unity.



(b) Gate signal for switch no 2



**Figure 18** Unity power factor in normal state



(b) Unity power factor in zoom state

Figure 18 Unity power factor

## THD ANALYSIS

The Total Harmonic Distortion is calculated in the following figure 19.

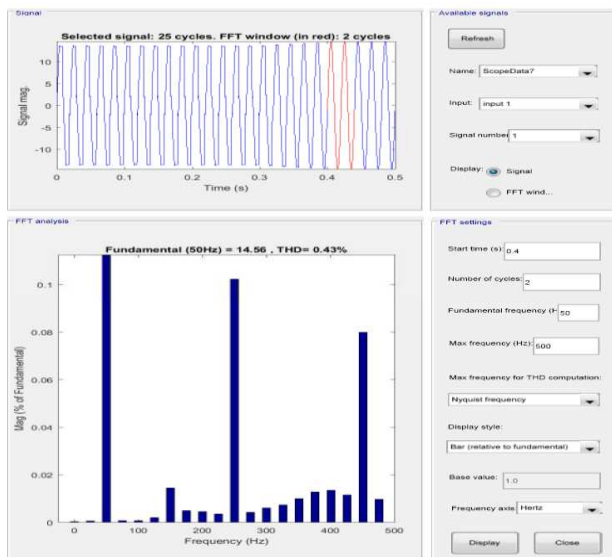


Figure 19 THD Analysis

On a comparative analysis with the reference paper Ref [6] the total harmonic distortion which was coming out to be 1.75% is now efficiently reduced to 0.43% shown in the figure 19.

## VIII. CONCLUSION

Designing of single-phase grid connected solar PV system is carried out in this work. System parameters are calculated and from these parameters model is formulated and simulation results are presented. Modeling of the PV cells is one of the mature areas in the field. There are a variety of models available in the literature and can be divided into two main categories; detailed and simplified models. Detailed models attempt to represent the physics of the PV cell and are usually

suitable for studies that require the detailed cell information such as implementation of maximum power techniques and analysis of the effect of change in irradiance and temperature on the performance of the PV cell. On the other hand, simplified models usually provide a direct estimate of the maximum power generated from the PV cell at certain operating conditions. This highlights HCC-PWM switching scheme for the proposed multilevel inverter. It utilizes three reference signals and a triangular carrier signal to generate PWM switching signals. The behavior of the proposed multilevel inverter was analyzed in detail. By controlling the modulation index, the desired number of levels of the inverter's output voltage can be achieved.

## REFERENCES

- [1]Chetan Singh Solanki, Solar Photovoltaics Fundamentals, Technologies and Applications, PHI learning private limited, 2009, New Delhi
- [2]Control, vol. 6, no. 1, pp. 2–20, 2000.Mohseni And M. Islam:” New Vector-Based Scheme For Three-Phase PWM Voltage-Source Inverters,” IEEE Transactions On Power Electronics, Vol. 25, No. 9, Sept. 2010
- [3]J. S. Siva Prasad and B. G. Fernandes\_ “Active Commutated Thyristors CSI for Grid Connected Photovoltaic Applications”. The 4m International Conference on Power Electronics and Motion Control. Vol. 3, pp: 1767-1771. 2004.
- [4]Anastasios Ch. Kyritsis. Nikolaos P. Papanikolaou. “Design and control of a current source fly-back inverter for decentralized grid connected photovoltaic systems.” European Conference on Power Electronics and Applications. pp: p.1-p.10, 2005.
- [5]P. Verdelho, “Voltage type inverter control methods in unbalanced and non-sinusoidal conditions,” in Conf. Rec. 24th IEEE-IES Annu. Meeting, , pp. 479–484. 1998.
- [6]Juan Jose Negroni. Carlos Meza. Domingo Biel. “Control of a Buck Inverter for Grid- Connected PV Systems: a Digital and Sliding Mode Control Approach ”.IEEE International Symposium on Industrial Electronic. Vol. 2. pp: 739-744. 2005.
- [7]Rangy Sunny, Robins Anto “Harmonics Control and Performance Analysis of a Grid Connected Photovoltaic System” International Conference on Advanced Computing and Communication Systems (ICACCS -2013), Dec. 19 – 21, 2013, Coimbatore, INDIA. 201. IEEE Standard Definitions of Terms for Solar Cells,1969.
- [8][http://en.wikipedia.org/wiki/Solar\\_panel](http://en.wikipedia.org/wiki/Solar_panel)
- [9]Oliva Mah NSPRI, "Fundamentals of Photovoltaic Materials", National Solar power institute, Inc. 12/21/98.
- [10]K.H. Hussein, I. Muta, T. Hoshino, M. Osakada, "Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions", IEE Proc.-Gener. Trans. Distrib., Vol. 142, No. 1, January 1995.
- [11]Muhammad H. Rashid, “Power Electronics Circuits, Devices and Applications”, Third Edition.
- [12]Power Electronics by Dr. P.S. Bimbhra. Khanna Publishers, New Delhi, 2003. 3rd Edition.
- [13]Control, vol. 6, no. 1, pp. 2–20, 2000.Mohseni And M. Islam:” New Vector-Based Scheme For Single-Phase PWM Voltage-Source Inverters,” IEEE Transactions On Power Electronics, Vol. 25, No. 9, Sept. 2010
- [14]J. Salmon, E. Nowicki, W. Xu, and D. Koval, “Low distortion Single phase inverters utilizing harmonic correction circuit topologies with both IGBT and thyristors switches,” in Proc. IEEE APEC, vol. 2, pp. 1100–1106. 1998

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