

Article Info

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Modeling of Photovoltaic Based Grid-Tied System

Shivam Sharma* and Durgesh Kumar**

ABSTRACT

Energy consumption in world is now increasing substantially. Increasing scarcity and rising prices of fossil fuels may lead to economic instability. Continuously increasing in energy consumption will overloads the distribution grids as well as the power stations, therefore imposing a negative impact on power availability, security and quality. One of the solutions for overcoming this is use of renewable energy resources. The energy generation from PV based Grid-Tied System is highly intermittent in nature and shows wide variation because of continuous fluctuations in solar radiation intensity, temperature and unpredictable weather conditions (e.g. clouds, snow, wind, etc.). This poses a major challenge for the designers of grid connected PV systems for its applications. One of the major problems is the increase in the Total Harmonic Distortion (THD) of current injected into the grid. In this paper basic theory of grid connected photovoltaic system and proposes a new scheme for Total Harmonic Distortion (THD) improvement in grid connected Photovoltaic (PV) systems. A hysteresis current control method is introduced in this paper which is providing a PV system with reduced harmonics at the output. This Logic control can be used to improve the THD in grid connected PV systems. The whole system is modeled on MATLAB/SIMULINK. The Simulation results are given to show the overall system performance.

Keywords Photovoltaic; Harmonic Distortion; Hysteresis Current Control; Final Yield; Performance Ratio; Maximum Power Point Tracking (MPPT); Total Harmonic Distortion (THD).

1.0 Introduction

The usage of grid connected Photovoltaic (PV) systems has now become popular in many parts of the world. More numbers of grid connected PV generators that connected to a distribution network through PV inverters are potentially able to cause harmonic problems. Harmonic problem can be defined as a particular disturbance, which is created by the presence of non-linear components in the electrical system. It determines a permanent modification of the voltage and current sinusoidal wave shapes in terms of sinusoidal components at a frequency different from the fundamental. In a grid-connected photovoltaic power system, the direct current (DC) output power of the PV array should be converted into the alternating current (AC) power of the utility power system. Under this condition, an inverter to convert DC power into AC power is

required. Inverters used in the simulation circuit affect the harmonic levels. [1]. This paper completely focuses on performance of PV grid connected system. The system components and power control scheme were modeled in terms of performance behavior. The proposed models were implemented in MATLAB/Simulink. In grid connected PV system, the output from the PV system is connected to utility grid by means of PV grid tied inverter. Unlike off grid system, there is no need of batteries and charge controllers but the grid tied inverter should have special functioning capability such as anti-islanding, grid synchronization etc. The fluctuating behavior of PV output with environmental condition may degrade the power quality of inverter output which may cause to degrade the performance of utility and the consumer electrical appliances.

For reducing harmonics in grid connected PV system a new scheme is introduced. Hysteresis

*Corresponding Author: Department of Electrical Engineering, Subharti University Meerut, Uttar Pradesh, India
(E-mail: er.shivamsharma14@gmail.com)

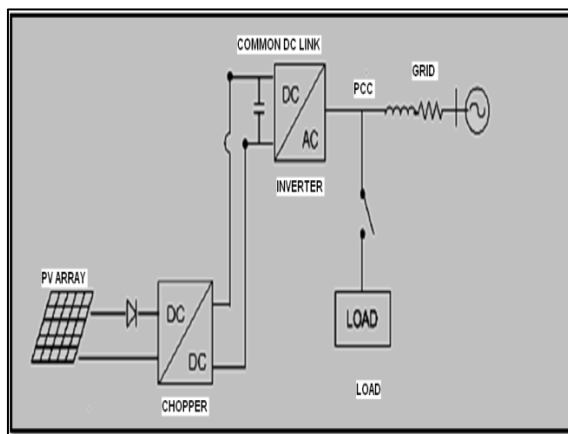
**Department of Electrical Engineering, Subharti University Meerut, Uttar Pradesh, India

current control is a method for controlling a voltage source inverter to force the grid injected current follows a reference current [4]. The line current and reference current are used to control the inverter switches.

2.0 System Modeling and Control

The proposed modern/system consists of a PV Array, DC to DC converter (chopper), a common DC capacitor, DC to AC converter (inverter), load and grid connected as shown in Fig.1. The measurements are placed at both input and output sides of the inverter, loads and at the utility grid. The connected load at point of common coupling (PCC) is a motor load. Proposed power control scheme of the PV grid connected system is modeled by using MATLAB/Simulink.

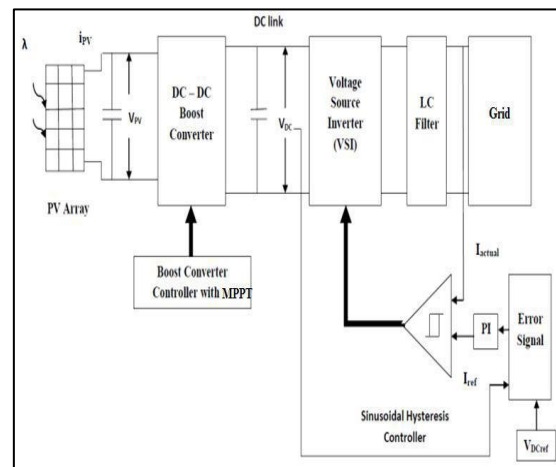
Fig 1. Block Diagram of PV Grid Connected System



The proposed complete model of Sinusoidal hysteresis band control is shown in Figure2. The proposed system consists of PV array, boost converter with MPPT controller and a voltage source inverter with hysteresis controller. The dc-dc converter is used to extract the maximum power from the PV source. As the power output of the PV array varies, the voltage across the dc link capacitor also varies. The incremental voltage change provides a measure of the change in the PV output power. A current reference is generated by comparing VDC with reference voltage feeding the error into a PI controller as shown in the figure.1. The inverter regulates VDC by facilitating the flow of power from

the PV source (through the boost converter) into the AC grid by using hysteresis control i.e. by comparing the actual grid current with the reference current and controlling the switching of its devices appropriately. Harmonics in grid connected PV system can be limited by using an appropriate control in the inverter side. Hysteresis controllers are one of the simplest controllers available for inverter control [5].

Fig 2. Block Diagram of the Proposed System



2.1 PV array

Numerous PV cells are connected in series and parallel circuits on a panel for obtaining high power, which is a PV module. A PV array is defined as a group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. Fig.3 indicates a simplified equivalent circuit model of a PV module and converter at PV system that used in the study, which consists of a current source in parallel with a diode and in series with a series resistor.

A PV cell is a simple p-n junction diode which converts the irradiation into electricity. Fig. 3 shows an equivalent circuit diagram of a PV cell which consists of a light generated current source I_L , a parallel diode, a shunt resistance R_{sh} , and a series resistance. PV modules still have relatively low conversion efficiency; therefore, controlling maximum power point tracking (MPPT) for the solar array is essential in a PV system. The amount of power generated by a PV depends on the operating voltage of the array. A PV's maximum power point (MPP) varies with solar insulation and temperature. It's V-I and V-P characteristic curves specify a

unique operating point at which maximum possible power is delivered. At the MPP, the PV operates at its highest efficiency. Therefore, many methods have been developed to determine MPPT.

$$I = I_{ph} - I_{sat} \left\{ \exp \left[\frac{q}{AKT} (V + IR_s) \right] - 1 \right\}. \quad (1)$$

Where V and I represent the output voltage and current of the PV, respectively; R_s and R_{sh} are the series and shunt resistance of the cell; q is the electronic charge; I_{sc} is the light-generated current; I_o is the reverse saturation current; n is a dimensionless factor; k is the Boltzmann constant, and KT is the temperature in $^{\circ}K$. Equation (1) was used in computer simulations to obtain the output characteristics of a solar cell, as shown in Figure 4. 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. Each curve has a MPPT, at which the solar array operates most efficiently.

Fig 3. Equivalent Circuit of PV Array

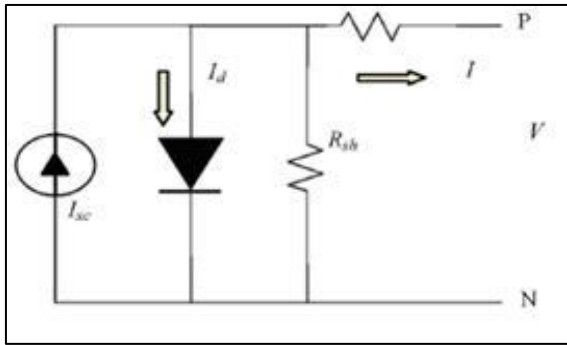


Fig 4. V-I Characteristic of a Solar Cell

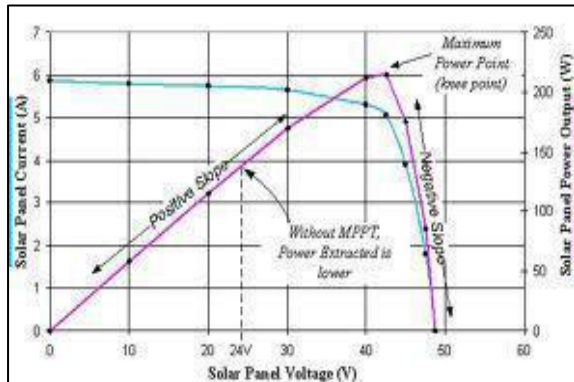
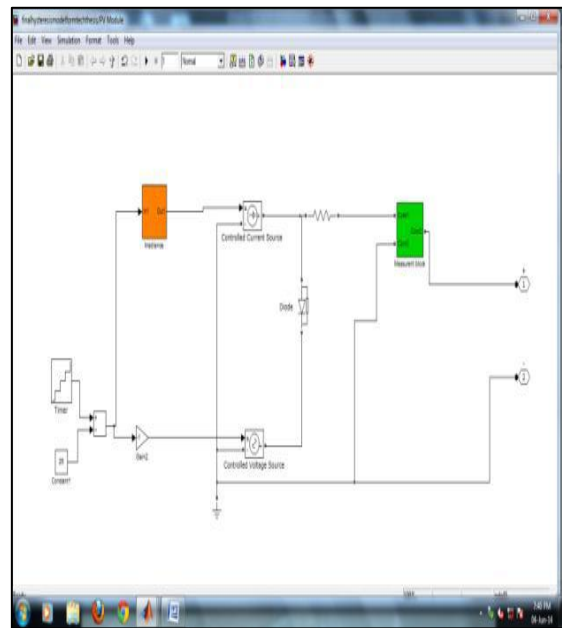


Fig. 5 shows the Simulink model of PV Module containing the constant Insolation values with its respective temperature constants forming a complete PV circuit including controlled Voltage and Current Source respectively at desired DC values. The two subsystems in orange and green background are shown in the fig. 5 containing the irradiance / insolation unit and the measurement section of the PV module.

Fig 5. Simulink Model of PV Module

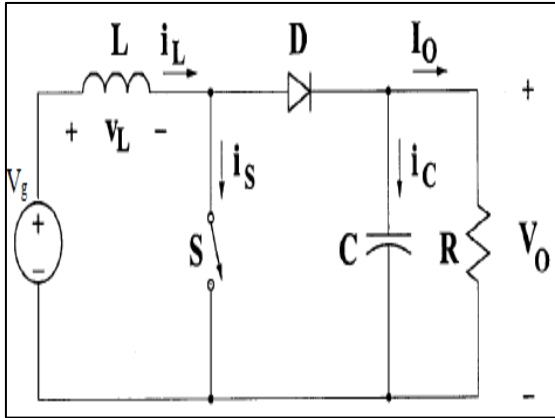


2.2 Dc – dc boost converter model (chopper)

DC-DC converters boost step-up the PV voltage to the level of the allowable maximum line voltage and to the stable required dc level without storage elements as battery. DC to DC converter is controlled to track maximum power point of the PV array.

In grid connected PV system regulated dc is maintained at the input of inverter terminals with help of boost converter. The voltage obtained from PV array can be increased with help of a boost converter.

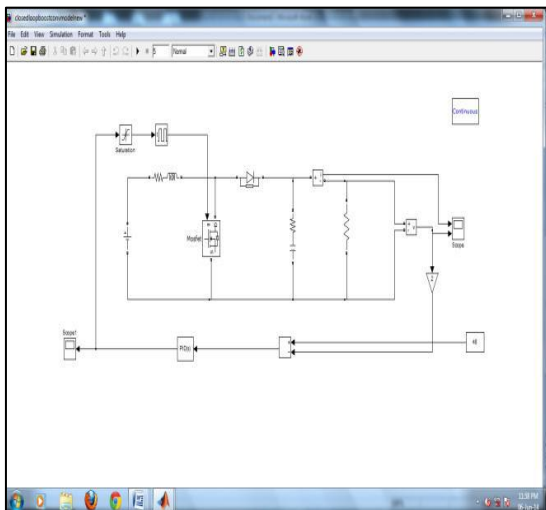
The role of the DC/DC boost converter is to increase the PV cell voltage, to control the solar power, and to regulate the voltage. The duty cycle has been varied at a high switching frequency to convert the unregulated voltage into a regulated supply. A circuit diagram of boost converter is shown in figure 5 [7].

Fig 5: DC – DC Converter Model

Voltage conversion ratio is given by

$$\frac{V_o}{V_s} = 1 - D \quad (2)$$

Fig 6 shows the MATLAB/Simulink model of the boost converter which is providing the output by boosting the PV output as per the required DC level, so that the MPPT (maximum power point) should be achieved to provide the better output response.

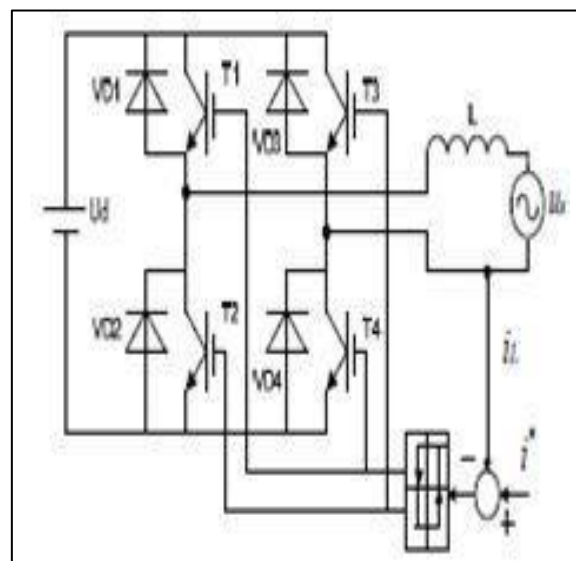
Fig 6: MATLAB/Simulink Model of DC-DC Boost Converter

2.3 Single Phase Inverter model

Hysteresis inverters are used in many low and medium voltage utility applications when the inverter line current is required to track a sinusoidal reference within a specified error margin. Hysteresis

current control is a method for controlling a voltage source inverter to force the grid injected current follows a reference current. A block diagram of a hysteresis controller is shown in figure 4. The line current and reference current are used to control the inverter switches. Lower and upper hysteresis band limitations are related to the minimum and maximum error directly (e_{min} , e_{max}). When the reference current is changed, line current has to stay within these limits. The range of the error signal ($e_{min} - e_{max}$) directly controls the amount of ripples in the output current from the inverter which is called the hysteresis band. The principle of hysteresis current control is that reference current i^* , which is synchronous with grid voltage u_s , compares with inductors actual output current i_L , and then the deviation ($i^* - i_L$) put into hysteresis comparator. When $|i^* - i_L| > H$ (H is half hysteresis band width), switching status is changed. At every switching cycle T , which is composed of current rise time t_{ir} and current fall time t_{if} , inductor current error i_L changes from H to $-H$ and then comes back. These kinds of controllers not only are robustness and simple but also have a good transient response [9][10].

The mathematical analysis of single-phase grid connected inverter is adopted as example. The inverter consists of the DC source u_d , power electronic devices T_1 , T_2 , T_3 , T_4 , freewheeling diodes VD_1 , VD_2 , VD_3 , VD_4 , inductor L and grid voltage u_s , shown as figure 5.

Fig 7: Single-Phase Grid-Connected Inverter

In Fixed-band hysteresis control the hysteresis bands are fixed throughout the fundamental period. The algorithm for this scheme is given as

$$I_{ref} = i_{max} \sin \omega t \quad (3)$$

$$\text{Upper band: } i_u = i_{ref} + \Delta i \quad (4)$$

$$\text{(Lower band: } i_l = i_{ref} - \Delta i \quad (5)$$

Δi = Hysteresis band limit

$$\text{If } i_a > i_u, V_o = -V_d \quad (6)$$

$$\text{If } i_a < i_l, V_o = V_d$$

In Sinusoidal Band Control the hysteresis bands vary sinusoidally over a fundamental period [11]. The upper and lower bands are given as:

$$i_{ref} = i_a^* = i_{max} \sin \omega t \quad (7)$$

$$i_u = (i_{max} + \Delta i) \sin \omega t \quad (8)$$

$$i_l = (i_{max} - \Delta i) \sin \omega t$$

Algorithm:

For $i_{ref} > 0$

$$\text{If } i_a > i_u, V_o = -V_d \quad (9)$$

$$\text{If } i_a < i_l, V_o = V_d$$

For $i_{ref} < 0$

$$\text{If } i_a < i_l, V_o = V_d \quad (10)$$

$$\text{If } i_a > i_u, V_o = -V_d$$

In order to tie a PV system with the utility grid, the DC output power of the DC-DC converter should be converted into a single phase AC power using a single phase inverter.

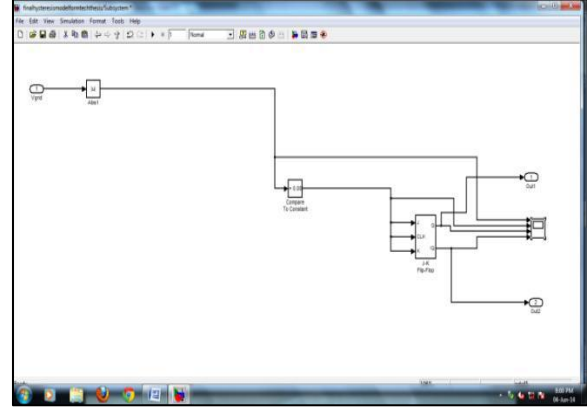
It is part of inverters' task to keep the DC voltage across its input (DC-DC converter's output) at a constant value.

In this simulink model, the single phase inverter, a firing pulse is generated by generating a absolute values of AC voltage with the help of mathematical logic operations by using Boolean function.

For obtaining the same, the Boolean operation of the input signal is sent on to the JK flip-flop which converts the generated pulse into two halves, viz. negative and positive halves cycles.

Fig.8. Shows the simulink model of the pulse generation through the applied absolute values of the AC voltage, which helps the thyristor gate to turn-on respectively during the two half cycles as per provided pulses.

Fig 8: Simulink Model of Pulse Generation Through Absolute Square Pulse Conversion of Grid Voltage



2.4 Total harmonic distortion (THD)

Harmonics are sinusoidal components of a periodic wave having a frequency that is a multiple of the fundamental frequency. Harmonics in PV systems are generated by the converters which use switching techniques that generate signals that are not perfect sinusoidal. Connecting PV systems to the utility grid, which is already being injected with harmonics by the non-linear loads connected to the power network, will add a stress on the power quality of the grid.

In order to maintain acceptable levels of grid power quality, standards that regulate the effects of PV systems on the utility grid should be developed. One such standard is IEEE Std 929-2000 "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems" which ensures compatible operation of photovoltaic (PV) systems that are connected in parallel with the electric utility. It is recommended by the previous standard that the harmonic distortion at the Point of Common Coupling (PCC), which is the point at which the PV system is tied with the grid.

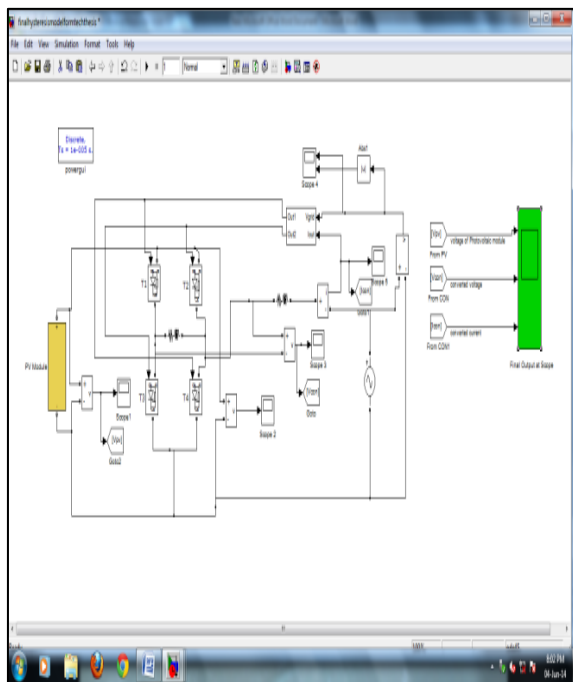
Total harmonic current distortion shall be less than 5% of the fundamental frequency current at rated inverter output. The main criterion for assessing the quality of the voltage delivered by an inverter is the Total Harmonic Distortion (THD). The goal is to see if the low order harmonics amplitude will decrease when the number of level increases.

The inverter is usually followed by a low pass filter since higher frequency harmonics are easy to filter. This means that the performance of multilevel inverters can be improved by cancelling or

reducing lower order harmonics. Lower order harmonics generate the most important currents when an inductive load is used.

To analyzed THD hysteresis current controlled model of PV based grid tied system is designed in fig 9, which makes it possible to reduce the THD at desirable values shown in Table 1 and Table 2 respectively.

Fig 9: Simulink Model of PV Based Grid-Tied System



The THD is a ratio between the Root Mean Square (RMS) of the harmonics and the fundamental signal. For an inverter that has a fundamental output voltage V_1 and harmonics V_2, V_3, \dots , we define the THD as follows

$$THD = \frac{\sqrt{\sum_{k=2}^N V_k^2}}{V_1}$$

The inverter, whose normalized harmonic spectrum and Total Harmonic Distortion values are given in Table 1, is used in the simulated circuit. Moreover, in the grid, there are not any other

harmonic sources except the inverters of PV systems. In addition, it is assumed that inverters used in simulated circuit have the same harmonic values.

Table 1: Inverter Current Harmonics (Normalized to Fundamental) and its THD Value

Harmonic order (n)	% (I_n / I_1)
1	100
3	1,5
5	0,6
7	0,3
9	0,4
11	0,21
13	0,2
THD	1,7

Table 2: Inverter Current Harmonics

Harmonic order (n)	I_n (A)
1	9
3	0,135
5	0,054
7	0,027
9	0,036
11	0,019
13	0,018

This value is adjusted to Table 1 and the result is shown in Table 2. Using the values in Table 2, each harmonic of the inverter is modeled as a current source. Thus, an inverter consists of seven current sources in the simulation circuit.

3.0 Simulation Results

The performance of the proposed structure is assessed by a computer simulation that uses MATLAB Software. Hysteresis current control scheme is analyzed in this paper work. A flexible and simple simulation model of PV cell, boost converter with MPPT controller, single phase inverter with hysteresis current control is developed. The PV array has been designed by considering the irradiance, isolation and temperature respectively. The simulation results and PV Characteristics of the PV model at temperature-28°C and irradiance - 1000mW/cm² are plotted and is shown in Fig. 10. For two-stage PV generation system, boost chopper circuit is always used as the DC-DC converter. Since the output voltage of PV cell is low, the use of boost circuit will enable low-voltage PV array to be used, as a result, the total cost will be reduced. The Fig.11 and Fig.12 shows the simulation result of the PV

array fed boost converter and output voltage of proposed system.

Fig 10: P-V Characteristics of the PV Model

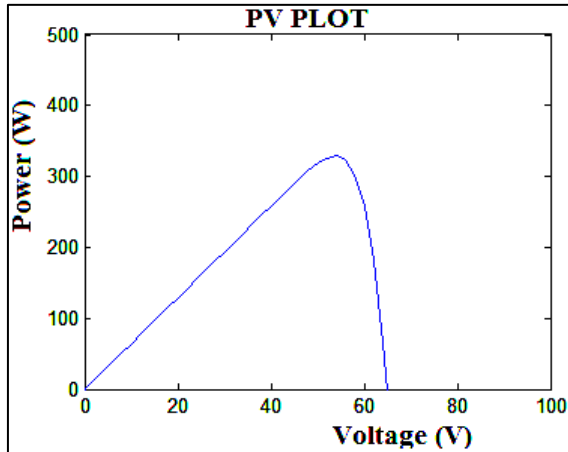


Fig 11: Output Responses of Boost Converter of Current and Voltage

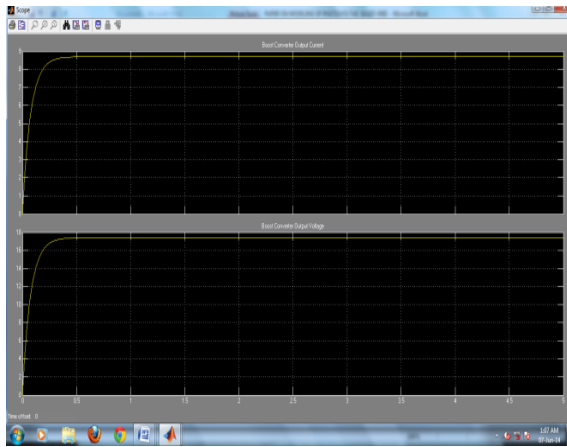


Fig 12: Inverter Output Current at the Scope

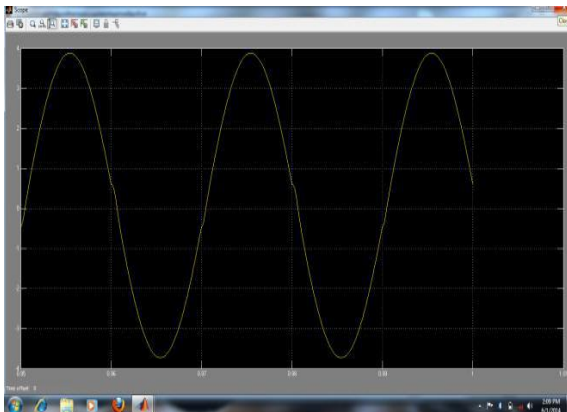


Fig 13: Inverter Output Voltage at the Scope

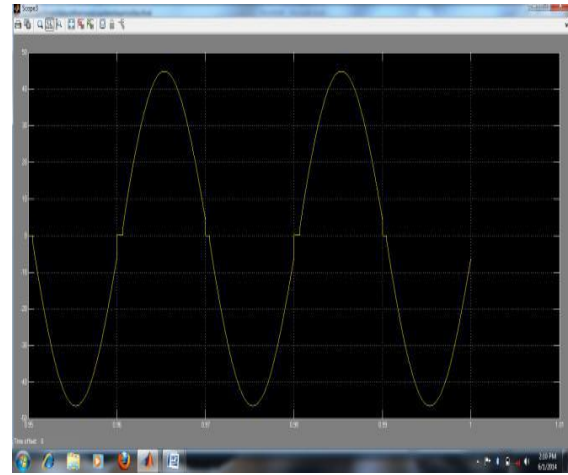
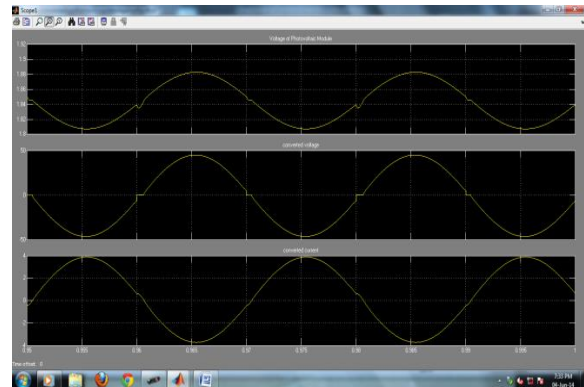


Fig 14: Final Response Obtained Through PV Based Grid-Tied System



4.0 Conclusion

Photovoltaic (PV) sources are used nowadays in many applications as they own the advantage of being maintenance and pollution free. A major application of PV is in the area of distributed or dispersed generation. Regarding practical problems associated with the interaction of the PV system with the grid.

One of the major problems is the increase in the Total Harmonic Distortion (THD) of current injected into the grid during low solar radiation periods. The simulation results show the excellent performance on THD in PV grid connected system. The THD of PV grid-connected system has been analyzed under influence of load conditions. The inverter of harmonic currents is affected not only by the grid conditions but also by using of electronic

components. The simulation shows the different THD for voltage and current.

A review of conventional methods for THD reduction for grid connected PV system is done. This paper described a new scheme for controlling the line current THD in grid connected PV systems. Grid tied inverters convert DC power to AC power with an efficiency of 90% or more most of the time. Inverters can even work to some extent when irradiance levels up to 200W/m^2 , but performance starts to drop off dramatically when irradiance levels falls below it. The harmonics generated in the PV power converting systems greatly vary with the solar irradiance. The odd harmonics have greater impacts on power quality than even harmonics as they have higher magnitude. The current THD is more sensitive on the fluctuation of solar irradiance than the respective voltage THD. Current THD greatly decreases with the increase in the solar irradiance while voltage THD slightly increases with increase in solar irradiance.

In this paper, Simulation of Grid-Tied Photovoltaic system has been completely performed. Simulation results are obtained with better performance which makes it easy to develop a large grid-tied PV system which will surely fulfils the needs to develop large amount of power by using renewable energy resource.

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