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A GRID CONNECTED PHOTOVOLTAIC SYSTEM WITH MPPT

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Abstract- Due to inaccessibility of fossil fuels, renewable energy sources are playing a vital role for generation of electric power. In near future around world 45% required energy is being produced by photovoltaic system. Moreover, due to non-linear characteristics of PV system, output power depends on irradiance level and temperature. Therefore maximum power point tracking is required to make the produced energy more effective. In recent year various MPPT algorithms are discussed for grid connected PV systems. In this paper a P&O method of MPPT is employed for maximum extraction of power from the PV system. Regardless of the variable irradiance the P&O method is very fast for maximum extraction of power from the PV system. In present work the boost converter is working as a MPPT and a three phase voltage source inverter (VSI) are connected to the grid. Space vector pulse width modulation (SVPWM) is proposed for generation of gating pulses for voltage source inverter. The control of inverter regulates the injected current magnitude to the function of generated power. The performance of proposed control is verified using MATLAB/simulink environment. Tracking efficiency is improved by fast and precise response of the proposed control. The injected active power is very close to generated power and reactive power oscillates around zero to make power factor unity.

Index Terms- Maximum Power Point Tracking (MPPT), Photo voltaic array (PV array). Space Vector Pulse Width Modulation (SVPWM), Voltage Source Inverter (VSI).

1. INTRODUCTION

Renewable energies are playing a vital role in supplying the world's required power demands. The photovoltaic power generation system keeps growing in the last few decades to produce promising source of energy. Solar energy is so enormous and free in most parts of the world has become economical source of energy in many applications. On a clear sunny day the sun's radiation reaching on the earth can be 3000 watts per square meter depending on the location. The photovoltaic process is completely solid state and self-contained and there is no moving parts and no materials are consumed. Majority of nations have installed the grid connected photovoltaic system to provide alternate source of energy of course, the main drawback of the grid connected photovoltaic system is variable irradiance and ambient temperature, so it must be supplemented by the additional technology to supply the demand curve.

1.1 Components of Grid-Connected PV Systems

The main components of a grid-connected photovoltaic system are shown in Fig. 1.1. The system basically consists of a PV array.The AC power generated is injected into the electric grid and utilized by the local loads [1].

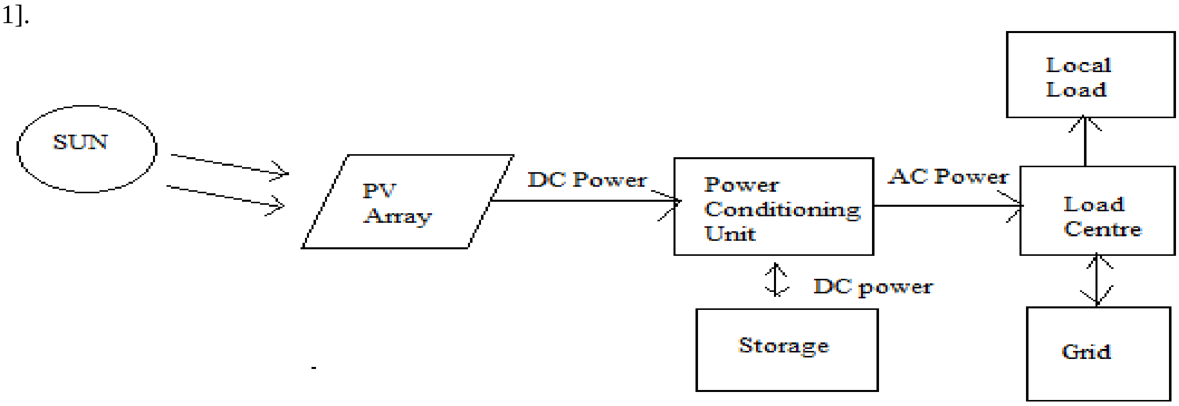

Fig. 1.1 Main Components of Grid-Connected Photovoltaic Systems

The availability of the power generated by the PV system is provided by the storage devices in some cases.

1.2 Grid Connected PV Inverter Topologies

The grid-connected inverters are used as a power transfer interface between the photovoltaic source and the electrical utility grid. The efficient processing of the power extracted from PV array is injected into the electric grid. Depending upon PV modules connection to the inverter, there are different inverter topologies. The main topologies are discussed below [2].

- Centralized PV Inverter Structure
- String Inverter Structure

- Multi string Inverter Structure
- AC Module Inverter Structure

1.3 Necessity of GRID Connected PV System

In general, grid-connected PV inverters are not able to control the reactive power and harmonic currents tired from non-linear load. The improved grid connected PV system has been proposed to compensate the reactive and harmonic current as well as injecting active power to the grid. A multi-functional grid connected system with MPPT has been developed. This developed system demonstrates the multi-functionality, harmonic & reactive power compensation ability together with the connection capability during the low voltage condition.

1.4 Proposed grid Connected PV System

The proposed grid integrated PV system integrates mostly three functions maximum-power-point-tracking, buck-boost DC-side voltage and output grid-connected current [6]. The Integrated inverter control has the main aim:

- control the active power injected into the grid;
- control and compensate the reactive power;
- ensure high quality of the injected current by Reducing the current harmonic distortion

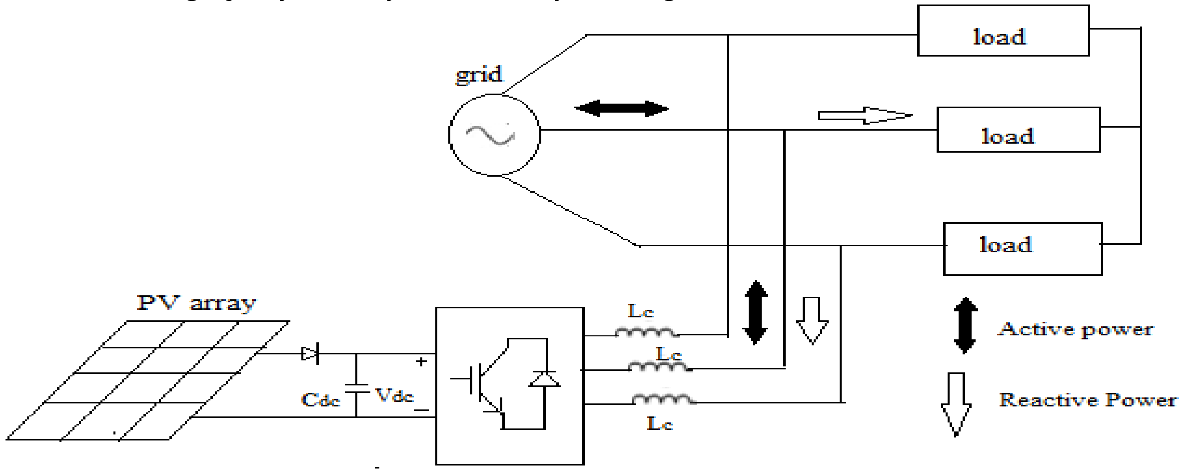

Fig. 1.2 Grid connected Photovoltaic System

2. MATERIALS AND METHODOLOGY

2.1. Maximum Power Tracking (MPPT)

To implement a system that has the ability to track the maximum power point, it is necessary that the system has components including PV array, DC/DC converter and a programmable controller to apply algorithms of MPPT[5].

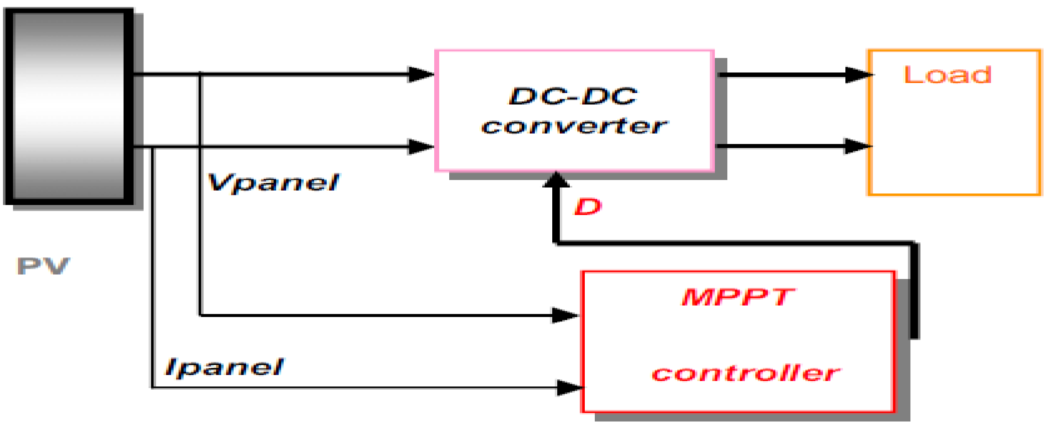

Fig. 2.1 Block Diagram MPPT Controller

Output voltage of PV arrays with series-parallel connection is comparatively low. So it is necessary to have multiplier DC/DC converters with high efficiency in order to convert low voltage of PV arrays to high voltage such as 380 volt for full bridge converters or 760 volts for half bridge converters in 220 volts network systems. Conventional boost converters are used widely in renewable energy application due to simple circuit structure [15].

In Fig. 2.2, a single-phase and single-switch boost converter is shown.

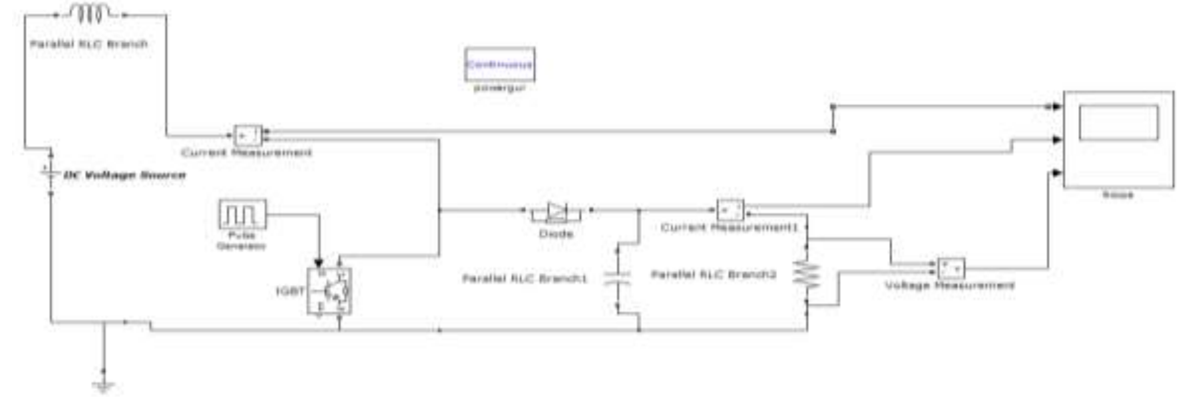

Fig. 2.2 MATLAB Simulation Model of the Boost Converter

2.2 Mathematical Modeling of Boost Converter

The boost converter is used to get maximum efficiency of PV cell by tracking MPP (Maximum power point).The circuit diagram of the Boost converter is shown in Fig.2.3

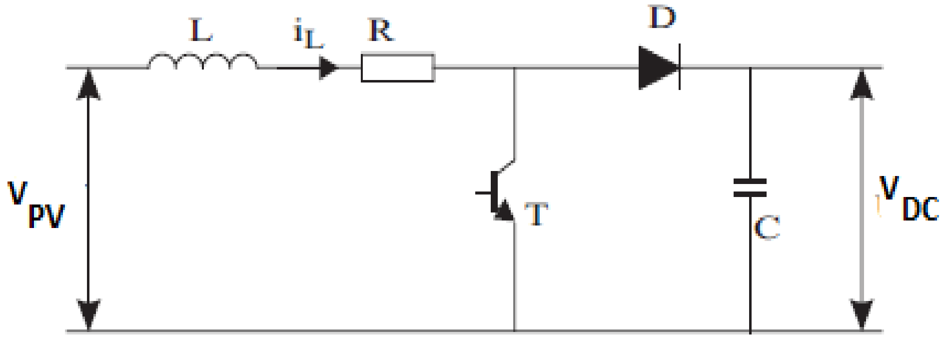

Fig. 2.3 Boost Converter

The output PV cell voltage i.e. input voltage of the boost converter is denoted by V_{PV} .Also the boost converter output voltage is denoted by V_{DC}. It is the dc link voltage connecting boost converter and inverter connected to the grid. Mathematical modeling of the boost converter is explained with two modes of operation [2]. When transistor is turned ON:

$$V_{PV} - L\frac{di_L}{dt} - Ri_L - V_t = 0 \tag{2.1}$$

From equation (2.1), the inductor current is

$$\frac{di_L}{dt} = \frac{(V_{PV} - Ri_L - V_t)}{L} \tag{2.2}$$

When transistor is turned OFF:

$$V_{PV} - L\frac{di_L}{dt} - Ri_L - V_D - V_{DC} = 0 \tag{2.3}$$

From equation (2.4), the inductor current is

$$\frac{di_L}{dt} = \frac{(V_{PV} - Ri_L - V_D - V_{DC})}{L} \tag{2.4}$$

The Average model of the boost converter can be calculated using the fact that in steady state the sum of the currents when transistor is turned on and off is zero:

$$\Delta i_{L(Ton)} + \Delta i_{L(Toff)} = 0 \tag{2.5}$$

When transistor is turned on, the following approximation is used:

$$\frac{di_L}{dt} = \frac{\Delta i_{L(Ton)}}{DT} = 0 \tag{2.6}$$

Where T is a period and D is a duty ratio while transistor is on.

$$\Delta i_{L(Ton)} = DT\frac{Upu - Ri_L - U_T}{L} \tag{2.7}$$

Similarly, when transistor is turned off, the following approximation is used:

$$\frac{di_L}{dt} = \frac{\Delta i_{L(Toff)}}{(1-D)T} \tag{2.8}$$

Using (2.4) and (2.8) we have:

$$\Delta i_{L(Toff)} = (1-D)T\frac{Upu - Ri_L - U_D - Udc}{L} \tag{2.9}$$

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Applying (2.7) and (2.9) to (2.5), the output voltage of the boost converter is given by:

$$U_{dc} = \frac{Upu - Ri_L - U_D + DU_D - DU_T}{1-D} \quad (2.10)$$

If we neglect Rs, U_D and U_T, the average model of the average output voltage of the boost converter is given with:

$$U_{dc} = \frac{U_{pu}}{1-D} \quad (2.11)$$

2.3 Control of the Boost Converter with MPPT Controller

From the characteristic I-V and P-V curves of photovoltaic modules, it is shown that there was a unique point for the maximum power (PMPP). This point is defined as the maximum power point (MPP) with the optimal voltage V_{mpp} and the optimal current I_{mpp}. At this point, the entire PV system should operate with the maximum efficiency and produce its maximum output power [16].

Perturb and observe are used: reduced perturbation step size, variable step size, three points weights comparison methods and optimized sampling rate.

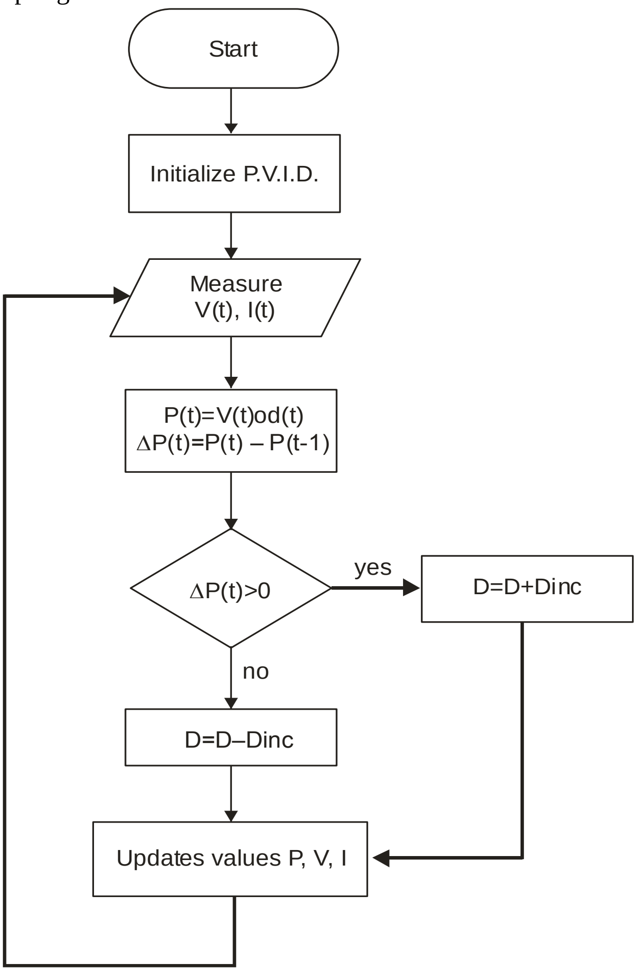

Fig. 2.4 Flow Chart for P&O

3.4 Mathematical Modeling of Three Phase Inverter

The mathematical modeling of three phases VSI is expressed using power circuit as shown in Fig. 2.5

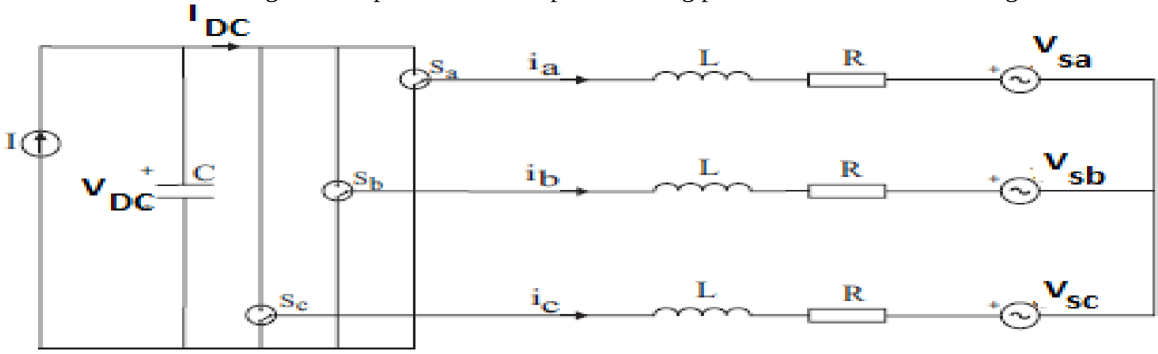

Fig. 2.5 : Power Circuit of Three Phase VSI

The mathematical modeling of three phase VSI is expressed as:

Mathematical model of the VSI is given by:

$$C\frac{dU_{dc}}{dt} + i_{dc} = I \quad (2.12)$$

$$L\frac{d[i]_{abc}}{dt} + Ri = \Delta[u]_{abc} \quad (2.13)$$

$$i_a + i_b + i_c = 0 \quad (2.14)$$

Where $\Delta[u]_{abc} = [u]_{abc} - [u_s]_{abc}$. Applying the transformation method from three-phase system *abc* to rotating frame *dq*:

$$\begin{bmatrix} x_d \\ x_q \end{bmatrix} = \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \cos\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t - \frac{2\pi}{3}\right) \\ \cos\left(\omega t + \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \quad (2.15)$$

To the current $[i]_{abc}$ we have:

$$I_{d=}\left[i_a\cos\omega t + i_b\cos\left(\omega t - \frac{2\pi}{3}\right) + i_c\cos\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (2.16)$$

$$I_{q=} -\left[i_a\sin\omega t + i_b\sin\left(\omega t - \frac{2\pi}{3}\right) + i_c\sin\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (2.17)$$

And similarly to the voltage [□$_u$]abc we have:

$$\Delta U_{d=}\left[\Delta u_a\cos\omega t + \Delta u_b\cos\left(\omega t - \frac{2\pi}{3}\right) + \Delta u_c\cos\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (2.18)$$

$$\Delta U_q = -\left[\Delta u_a\sin\omega t + \Delta u_b\sin\left(\omega t - \frac{2\pi}{3}\right) + \Delta u_c\sin\left(\omega t + \frac{2\pi}{3}\right)\right] \quad (2.19)$$

If we have apply the derivative to (2.16):

$$\frac{dI_d}{dt} = \left[\frac{di_a}{dt}\cos\omega t + \frac{di_b}{dt}\cos\left(\omega t - \frac{2\pi}{3}\right) + \frac{di_c}{dt}\cos\left(\omega t + \frac{2\pi}{3}\right)\right. \quad (2.20)$$

$$\left. -\omega\left[i_a\sin\omega t + i_b\sin\left(\omega t - \frac{2\pi}{3}\right) + i_c\sin\left(\omega t + \frac{2\pi}{3}\right)\right]\right]$$

Using (2.13), (2.16), (2.17) and (2.18), (2.20) can be rewritten as:

$$\frac{dI_d}{dt} = \omega I_q - \frac{R}{L}I_d + \frac{1}{L}\Delta U_d \quad (2.21)$$

Similarly, for current I_q we have:

$$\frac{dI_q}{dt} = -\omega I_d - \frac{R}{L}I_q + \frac{1}{L}\Delta U_q \quad (2.22)$$

Equation (27) and (28) cab be transformed in the Laplace domain (S-domain) as:

$$(sL + R)I_{d=}\Delta U_d + \omega L I_q \quad (2.23)$$

$$(sL + R)I_{q=}\Delta U_q - \omega L I_d \quad (2.24)$$

Multiplying (2.24) with the complex number j and adding it to (2.23) we have:

$$(sL + R)(I_d + jI_q) = \Delta U_d + j\Delta U_q + \omega L(I_q - jI_d) \quad (2.25)$$

This can be written as:

$$\left(\frac{sL}{R}/j\omega L\right)\vec{I} = \Delta\vec{U} \quad (2.26)$$

Similarly, for current I_q we have:

$$\frac{di_q}{dt} = -\omega I_d - \frac{R}{L}I_q + \frac{1}{L}\Delta U_q \quad (2.27)$$

Equation (2.23) and (2.24) can be transformed in the Laplace domain (s- domain) as:

$$(sL + R)I_d = \Delta U_d + \omega L I_q \quad (2.28)$$

$$(sL + R)I_q = \Delta U_q + \omega L I_d \quad (2.29)$$

Multiplying (2.29) with the complex number j and adding it to (2.28) we have:

$$(sL + R)(I_d + jI_q) = \Delta U_d + j\Delta U_q + \omega L(I_q - jI_d) \quad (2.30)$$

which can be rewritten as:

$$(sL + R + j\omega L)\vec{I} = \Delta\vec{U} \quad (2.31)$$

Where $\vec{I} = I_d + jI_q$ and $\Delta\ \vec{U} = \Delta U_d + j\Delta U_q$

The transfer function G(s) of the circuit is given with:

$$G(s) = \frac{\vec{I}}{\Delta\vec{U}} = \frac{1}{sL + R + j\omega L} \quad (3.32)$$

3.5 SVPWM Modulation Strategy

The three-phase power inverter is the same represented in Fig.2.5.There are six power switchesS1 to S6. Each of them are controlled by individual switching variables which are obtained from the principles of space vector PWM. The three-phase voltage in abc reference frame should be represented in dq reference frame for the Space vector PWM. The output voltages can be represented in the space as set of vectors. These vectors correspond to switching combinations for the inverter switches [18].

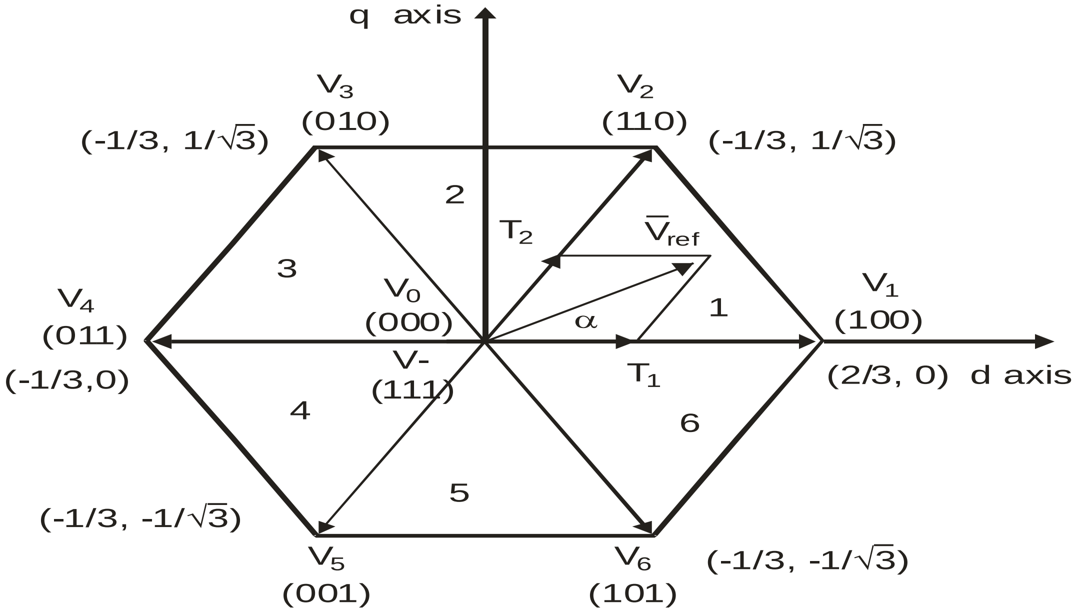

Fig. 2.6 Switching Vectors and the 6 Sectors

The principle of space vector PWM technique is that the voltage vector command is calculated by estimation via three adjacent vectors base. It is necessary to decompose the space voltage vector $V_{ref[\alpha,\beta]}$ into directions of the sector base vectors. For instance, if Vref is located in sector 1 (Fig.2.6), the base vectors are V_1, V_2 and V_0 (V_7 can also be used because it gives the same output voltage), if V_{ref} is located in sectors 2, the base vector surrounding V_{ref} are V_2, V_3 and V_0.

Table-2.1 Switching States of the Inverter Switches

Voltage Vectors	Switching Vectors			Line to Neutral Voltage x V_{dc}			Line to line Voltage x V_{dc}		
	a	b	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

The time span of every vector for the voltage is taken by calculations in sector 1 where

$T_z V_{ref} = T_1 V_1 + T_2 V_2 + T_0 V_0$

$T_Z = T_1 + T_2 + T_0$

Where V_1, V_2 and V_0 basically outline the triangular area in which V_{ref} are found. T_1, T_2 and T_0 are the matching vector periods and T_z is the sampling time

V_1 (100) is applied for a period of T_1

V_2 (110) is applied for period T_2

V_0 (000) or V_7 (111) is applied for period of T_0 for this sector.

3. RESULTS AND DISCUSSION

Simulation results of developed grid connected PV system under different conditions i.e. under different temperature, irradiation level are presented to validate the developed controls and MPPT for the proposed model. The boost converter acts as a MPPT tracker is developed. Maximum power tracking for different environmental conditions is confirmed by the optimal power extracted from the PV array and low ripple content in the PV power output around MPP. Fig 3.1 shows the grid connected PV system model using MATLAB/Simulink environment.

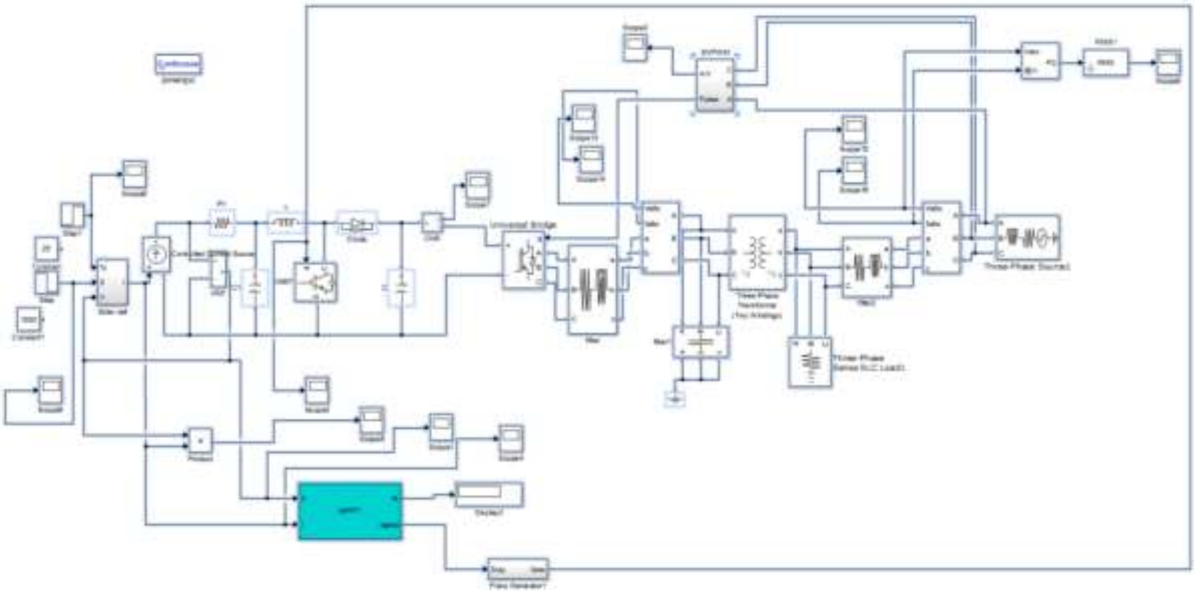

Fig. 3.1 : Proposed Grid Connected PV System

3.1 Steady State Operation of Grid Connected PV System

In this case the performance of grid connected PV system is investigated under constant solar irradiance G = 1000 W/m^2, T=25° C with MPPT algorithm. The PV array is operated at maximum voltage of 25V, maximum current of 8A, thus, has a maximum output power of 2,00W. When the system is in steady state, the solar isolation is 1000 W/m^2, and the environmental temperature is 25º C.

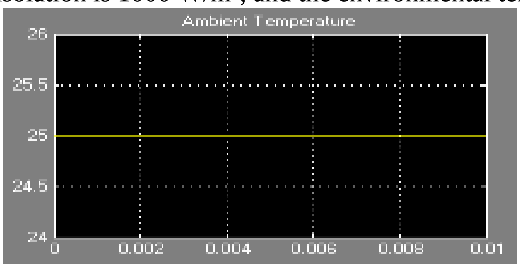

Fig. 3.2 : Ambient Temperature at steady state

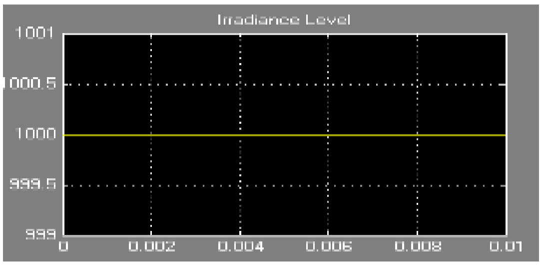

Fig. 3.3 : Irradiance Level at Steady State

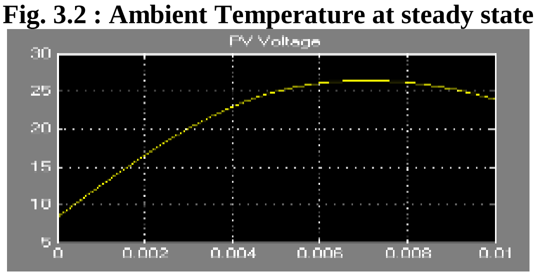

Fig. 3.4 : PV Voltage at Steady State

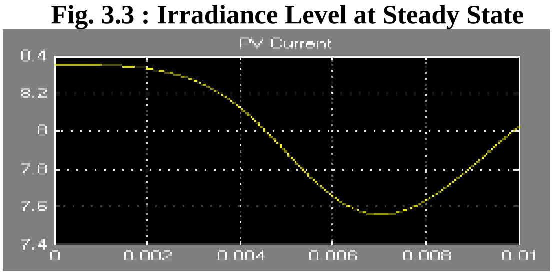

Fig. 3.5 : PV Current at Steady State

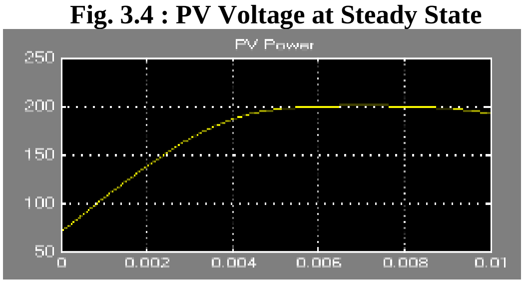

Fig. 3.6 : PV Power at Steady State

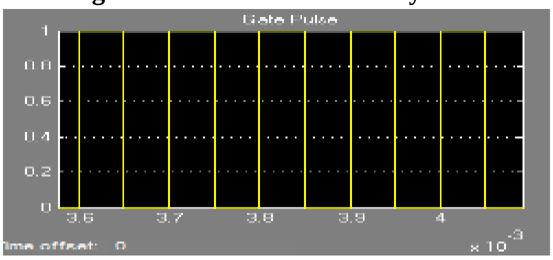

Fig. 3.7 : Gate Pulse for IGBT of Boost Converter

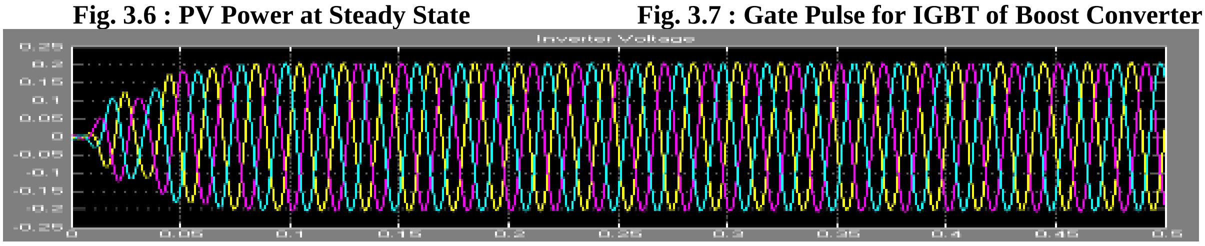

Fig. 3.8 Inverter Voltage at Steady State

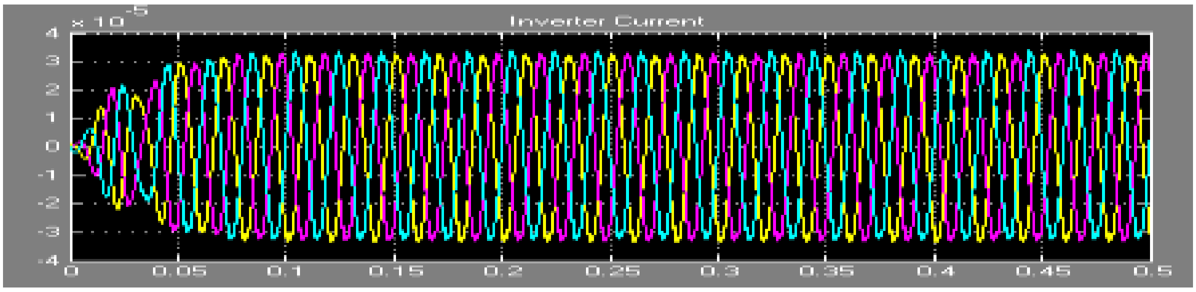

Fig. 3.9 Inverter Current at Steady State

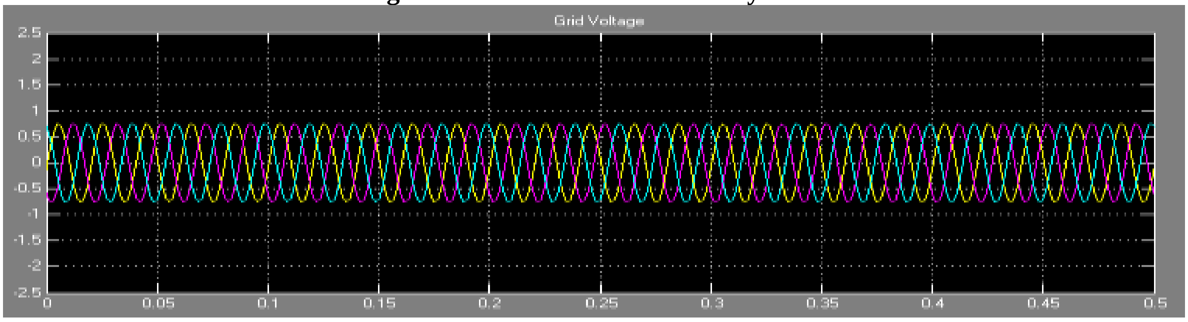

Fig. 3.10 Grid Voltage at Steady State

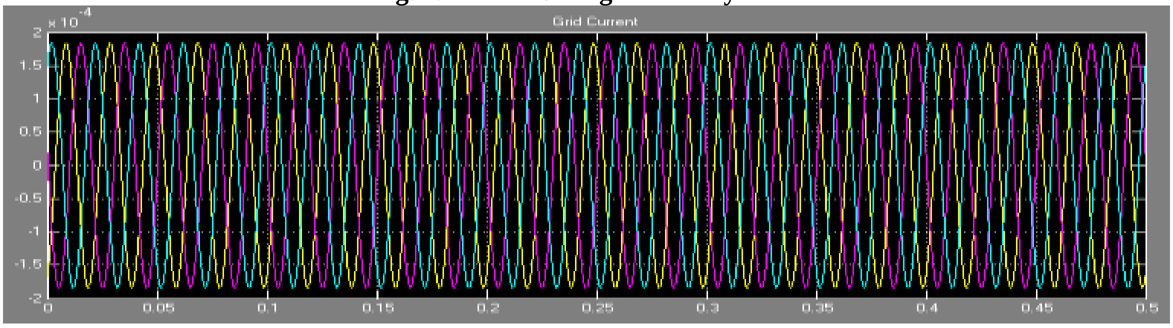

Fig. 3.11 Grid Current at Steady State

Fig. 3.12 Active and Reactive Power at Steady State

3.2 Dynamic Operation of Grid Connected PV System

In this case the performance of the grid connected PV system is investigated under variable solar irradiance and ambient temperature. The solar panel was subjected to sudden change in isolation level from 1000 to 200 W/m^2. An immediate effect on solar current and solar voltage due to the sudden change in isolation level at 0.005 sec has shown in Fig.

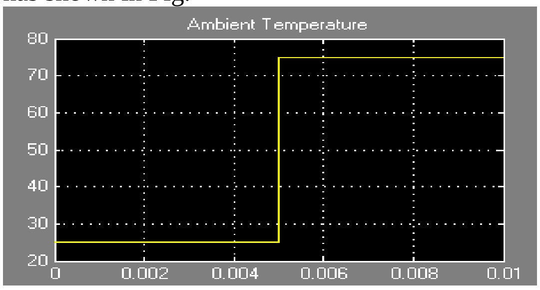

Fig. 3.13 Variable Ambient Temperature

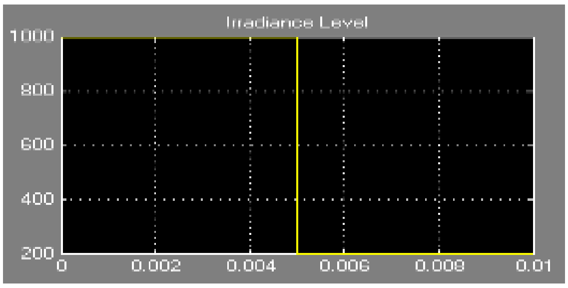

Fig. 3.14 Variable Irradiance Level

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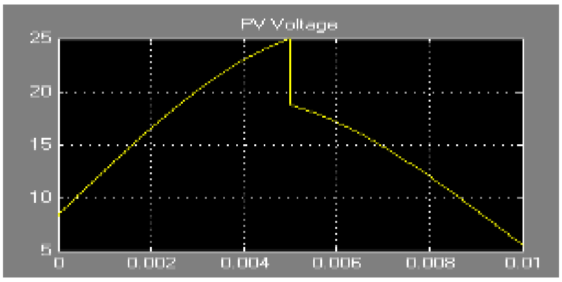

Fig. 3.15 PV Voltage at Dynamic State Operation

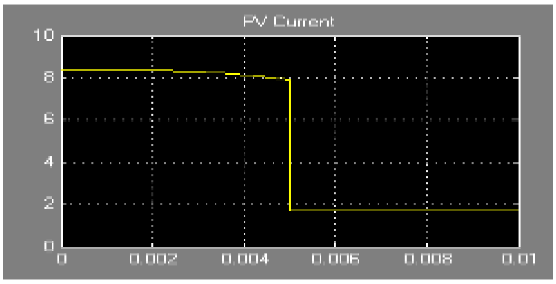

Fig. 3.16 PV Current at Dynamic State Operation

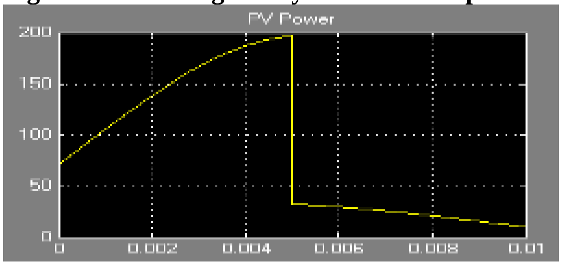

Fig. 3.17 PV Power at Dynamic State

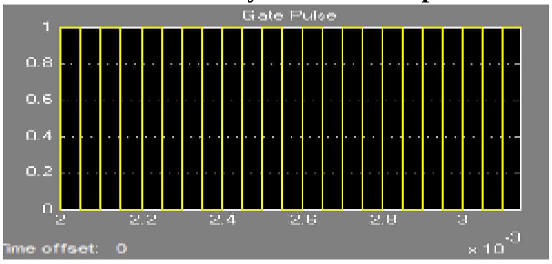

Fig. 3.18 Gate Pulse for IGBT of Boost Converter

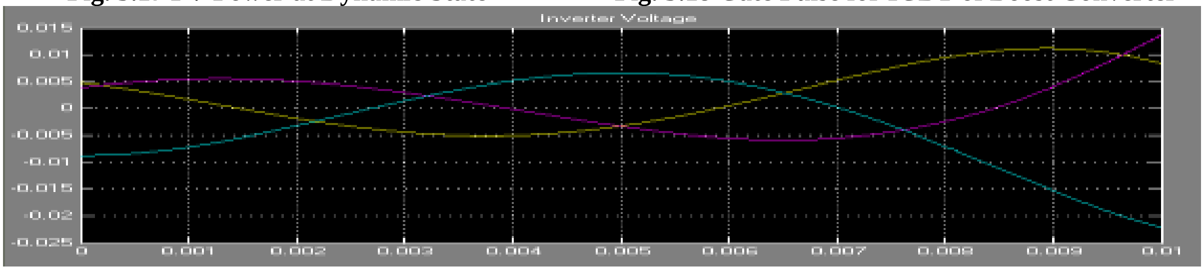

Fig. 3.19 Inverter Voltage at Dynamic State

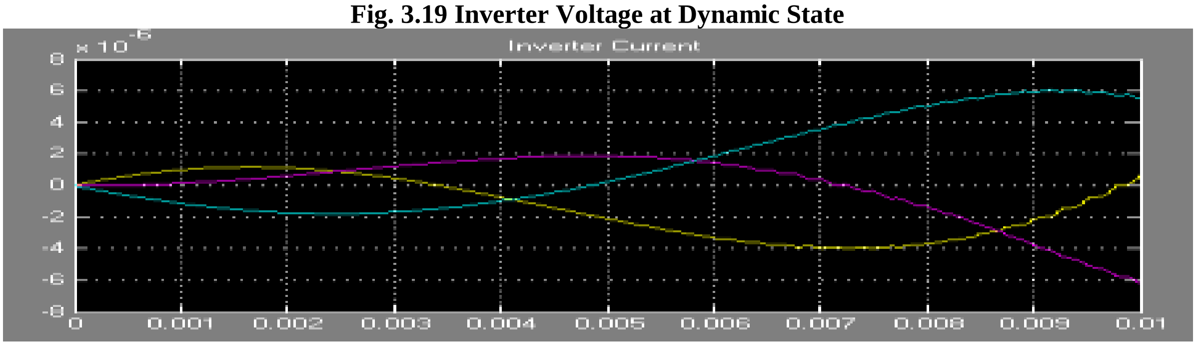

Fig. 3.20 Inverter Current at Dynamic State

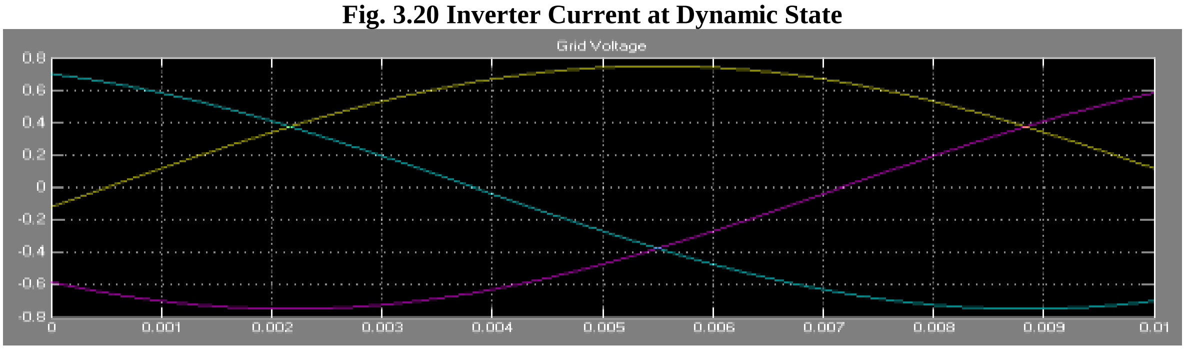

Fig. 3.21 Grid Voltage at Dynamic State

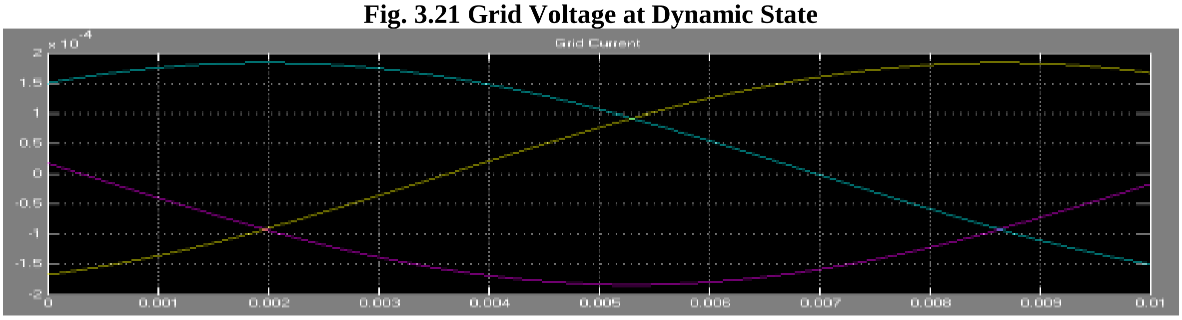

Fig. 3.22 Grid Current at Dynamic State

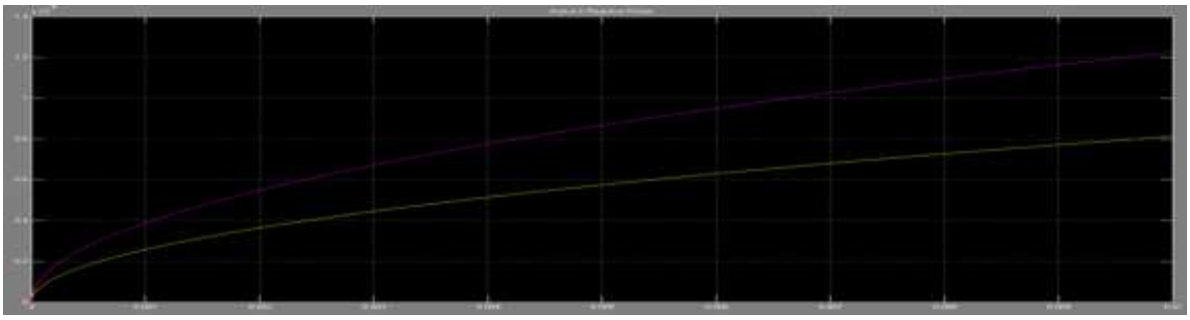

Fig. 3.23 Active and Reactive Power at Dynamic State

4. CONCLUSION

The performance of the proposed grid connected PV system has been analyzed using MATLAB/SIMULINK environment. The proposed grid connected photovoltaic system works efficiently at variable irradiance level and ambient temperature. The P&O method for MPPT and SVPWM method for generation of gating pulses for three phase voltage source inverter are used. Using proper controller design the grid connected PV system can track maximum power from the PV array and supply purely sinusoidal current to the grid. During changing weather conditions the P&O method tracks peak power from the PV array. The SVPWM method for generation of gating pulses for inverter gives better dynamic response in abrupt weather conditions. Hence the voltage source inverter allows the power transfer from PV panel to the utility grid at unity power factor operation.

5. FUTURE SCOPE

To extend the work presented in this thesis, one can focus on following issues such as:

- This work can be extended to micro grid for non-linear and unbalanced load.
- Distributed generation modeling and control is still area of research. It can be extended to smart grid.
- This work can be extended to intelligent device like programmable logic controller (PLC) for maximum efficiency.

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