PV System Control using Power Electronic Converters

[1]M Suneel, [2]P Chaithanya Kumar

[1]PG Scholar, Dept. of EEE, [2]Assistant Professor, Dept. of EEE

Gokula Krishna College of Engineering, Sullurpet

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Abstract - **The power electronic converters plays crucial role in conversion and control of the electrical power. The production of solar energy is based on the idea of converting a type of energy mostly solar energy into electrical energy. The most appealing renewable energy source is photovoltaic which transform the solar energy into DC electrical energy. Power electronics converters are used to control frequency and magnitude of the current resultant from the conversion between energies. The objective of this paper is to model and control of transformer-less grid connected PV system with Hysteresis controller which can be used to supply the electric power to utility grid. This system uses two stage conversion process. DC to DC stage which utilizes MPPT technique to extract the maximum power. DC to AC which used to control inverter output by using hysteresis Current controller. The problem of maximum power transferring is enhanced by using Incremental conductance algorithm and phase locked loops are utilized in conjunction to make supply in synchronization with the grid which reduces the two problems described. The studied system is modeled and simulated in the MATLAB/SIMULINK environment.**

keywords - **PV Grid, Solar Power Systems, Solar Cells, Power Electronic Converters**

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I. INTRODUCTION

The worldwide electrical energy consumption is increasing exponentially. To meet this rising demand, it is necessary to install more power plants. But, since fossil fuels reserves are finite and it's just a matter of time before they will run out, needless to mention their contribution in global warming, many countries are now examining their national energy policies and looking to embrace other alternatives. Renewable energies are among the energy sources that offer another way to avoid this fossil energy deadline. They are also expected to play an important role as a clean electricity power source in the future energy demands.

Energy from a source that is not depleted when used is known as renewable energy source. Such as solar or wind power. One major advantage of renewable energy is that it is sustainable and will never run out. They provide clean energy because they are non-pollutant and non-contributor to greenhouse effects and global warming. Renewable energy facilitates generally require less maintenances than traditional facilities generators. Their fuel being derived from natural and available resources reduces the costs of operation. Renewable energy produces little or no waste products such as carbon dioxide or other chemical pollutants, so have a minimal impact on the environment. Renewable energy projects can also bring economic benefits to many regional areas, as most projects are located away from large urban center and suburbs of the capital cities. These economic benefits may be from the increased use of local services.

Among this various renewable energy sources, PV power generation systems which are the most used. One of the most important applications is the Grid Connected PV system. A typical solution would be to develop a residential PV power supply system within the consumer reach. This system can also contribute in the power system stability and power quality. A grid-connected photovoltaic power system or grid-connected PV power system is an electricity generating solar PV power system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment as shown in Fig. 1. They range from small residential and commercial roof top systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, to the utility grid.
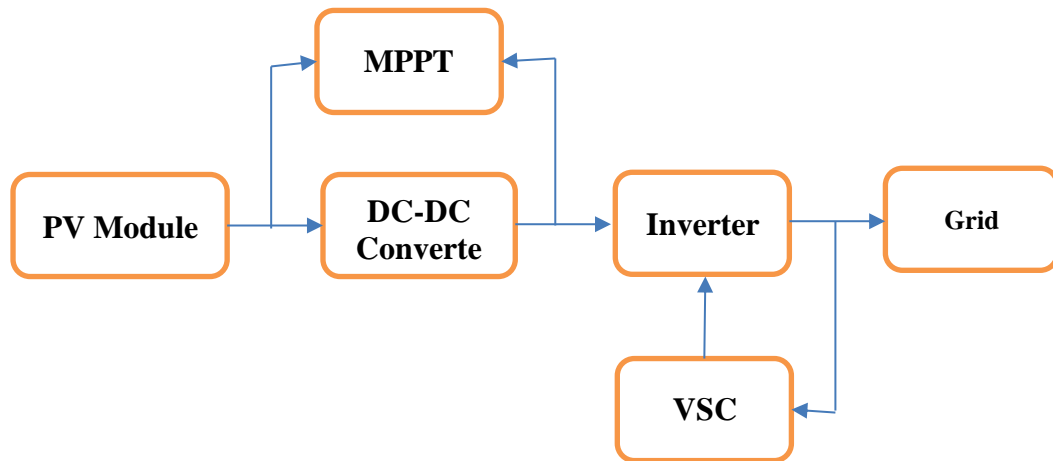
Fig. 1 Block diagram of Basic Grid connected PV system

II. GRID CONNECTED PV SYSTEM

The grid-connected PV application presents generally two problems,

- The first problem is the achieving the MPPT controller in order to maximize the delivered power regardless of the climatic conditions or the load variation.
- The second problem is the synchronization with the utility grid.

Considerable efforts have been made into the control of these systems. The most common control strategies structures applied to this decentralized power generator is based on Power-Angle Control (PAC) which is also called Voltage-Angle Control (VAC), Voltage Oriented Control, P-Q Control, or Decoupled Current Control. Another Active Power Control using a robust nonlinear adaptive back stepping approach. But, these researches have been done using PEC regardless of their models type (detailed or averaged). The switching model (detailed model) is modelled with IGBT/diode pairs controlled by pulses, produced by a Pulse Width Modulation (PWM) generator. This model provides the most accurate simulation results, but takes a long simulation time. Further, it cannot give satisfaction for the analysis of small-signal due to its discrete behaviour.

While, average value modelling further simplifies PEC representation by neglecting the switching effects. Indeed, the average model is modelled using a switching function (SF) directly controlled by reference voltage (u_{ref}) or by duty cycle (d) ($0 < d < 1$). Therefore, in average model case, there is no need to implement a PWM generator block that requires high switching frequency (f). That's why this model provides faster simulations than the detailed. In addition, these models are also useful to predict converter steady-state characteristics and small-signal dynamics in discontinuous conduction mode (DCM). Also, and in spite of its disadvantages, the average model remains often useful before the final control design. It is considered a good compromise between complexity, computation time and acceptable accuracy for system simulation. Due to these advantages, the average models of the both PEC are used in this paper in order to accelerate the simulation.

III. VOLTAGE SOURCE INVERTER

Inverters are static power converters that produce an AC output waveform from a DC power supply. They are applied in adjustable AC speed drives, Uninterruptible Power Supplies (UPS), shunt active power filter, etc. For sinusoidal AC outputs, the magnitude, frequency, and phase should be controllable. If a DC input is a voltage source, then the inverter is called a Voltage Source Inverter (VSI). According to a number of phases, inverters are classified into two types.

1. Single Phase Voltage Source Inverter
2. Three Phase Voltage Source Inverter

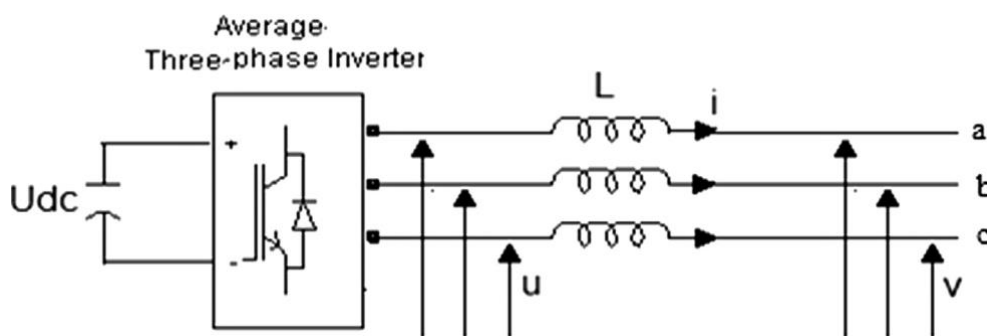The typical three-phase VSI topology is shown in Fig. 2.

Fig. 2 VSI Power Topology.

From the loop equation for voltages in the circuit described in Fig. 2. Let U be the inverter output voltages and V be the grid voltages then, the 3- phase voltages are given as

$$\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} - L\frac{d}{dt}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$C\frac{dv_c}{dt} + i_{dc} = I$$

$$L\frac{di_{(abc)}}{dt} + Ri = \Delta[U]_{abc}$$

$$i_a + i_b + i_c = 0$$

where

$$\Delta[U]_{abc} = \Delta[V]_{abc} - \Delta[U]_{abc}$$

Applying the transformation method from three phase system abc to rotating frame dq

$$\begin{bmatrix} X_d \\ X_q \end{bmatrix} = \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \cos[\omega t - \frac{2\pi}{3}] & -\sin[\omega t - \frac{2\pi}{3}] \\ \cos[\omega t + \frac{2\pi}{3}] & -\sin[\omega t + \frac{2\pi}{3}] \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix}$$

To the current [i]abc , the equations are given as follows

$$I_d = \left[i_q \cos\omega t + i_b \cos\left(\omega t - \frac{2\pi}{3}\right) + i_C \cos\left(\omega t + \frac{2\pi}{3}\right) \right]$$

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

And similarly to the voltage [ΔUabc],the equations are given follows

$$\Delta U_d = -\left[\Delta U_d \sin\omega t + \Delta U_b \sin\left(\omega t - \frac{2\pi}{3}\right) + \Delta U_C \cos\left(\omega t + \frac{2\pi}{3}\right) \right]$$

$$\Delta U_q = -\left[\Delta U_a \sin\omega t + \Delta U_b \sin\left(\omega t - \frac{2\pi}{3}\right) + \Delta U_C \cos\left(\omega t + \frac{2\pi}{3}\right) \right]$$

If we apply the derivative to (3.)

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

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

Using above equations,

$$\frac{dI_d}{dt} = \omega I_q - \frac{R}{L}I_d + \frac{1}{L}\Delta U_q$$

IV. SIMULINK MODEL OF BOOST CONVERTER

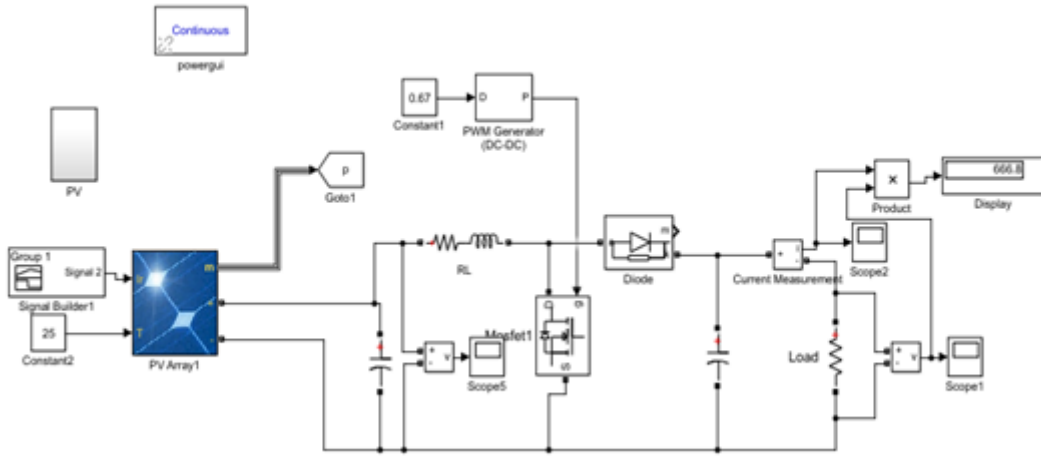The Fig. 3 shows the boost converter design in Simulink and corresponding waveforms are shown in Fig. 4.

Fig. 3 Simulink Model of Boost Converter without MPPT

Table. 1 Parameters of a Boost Converter

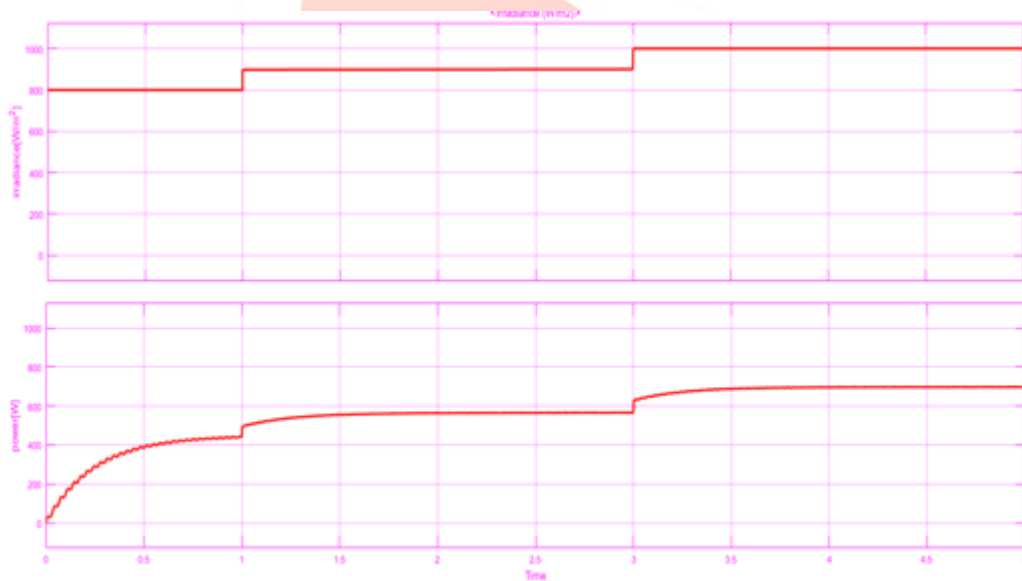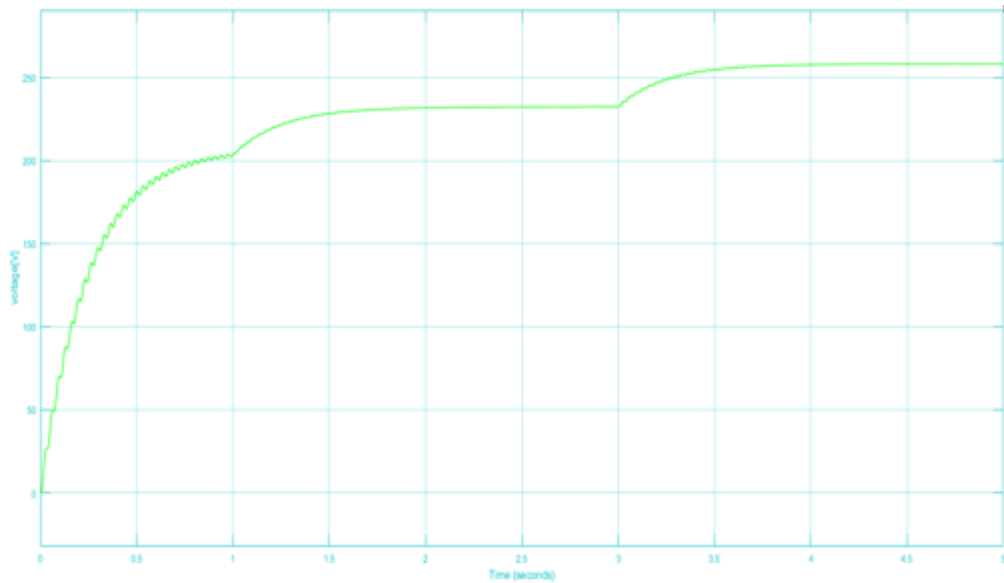| S. No.	Parameters	Values
1.	Output voltage	500 V
2.	Input voltage	263 V
3.	Inductor	15 Mh
4.	Capacitor	1500 µH
5.	Load	100Ω

Fig. 4 Irradiance and Power Characteristics without MPPT.

Fig. 5 Output Voltage of Boost Converter without MPPT.

V. SIMULINK MODEL OF MPPT ALGORITHM

The MPPT Algorithm used in this model is incremental conductance. This model is mostly used due to its higher tracking ability and can operate at different climatic conditions efficiently.
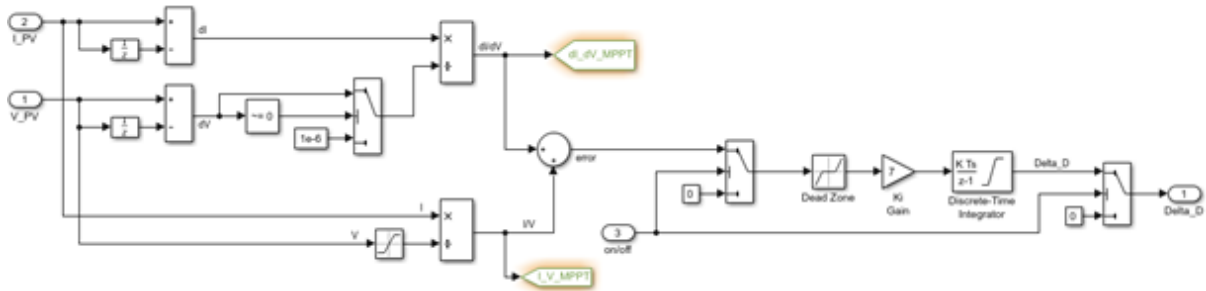

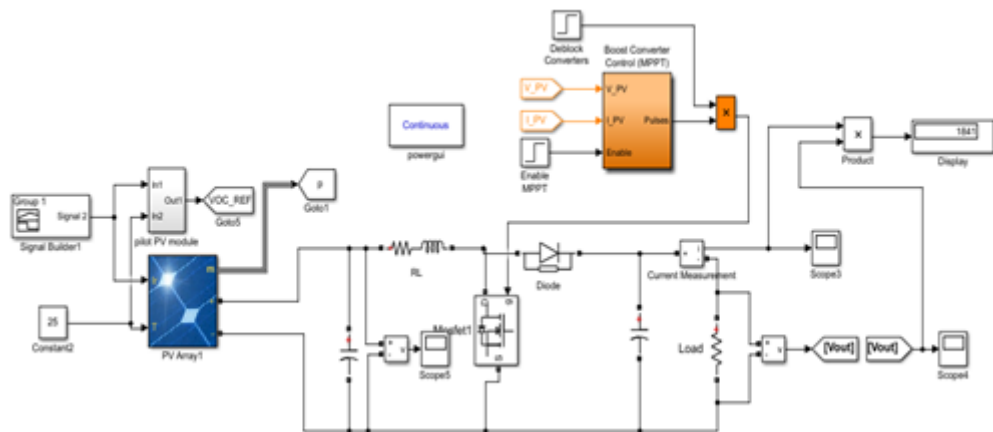Fig. 6 Design of MPPT Algorithm in Matlab/Simulink.

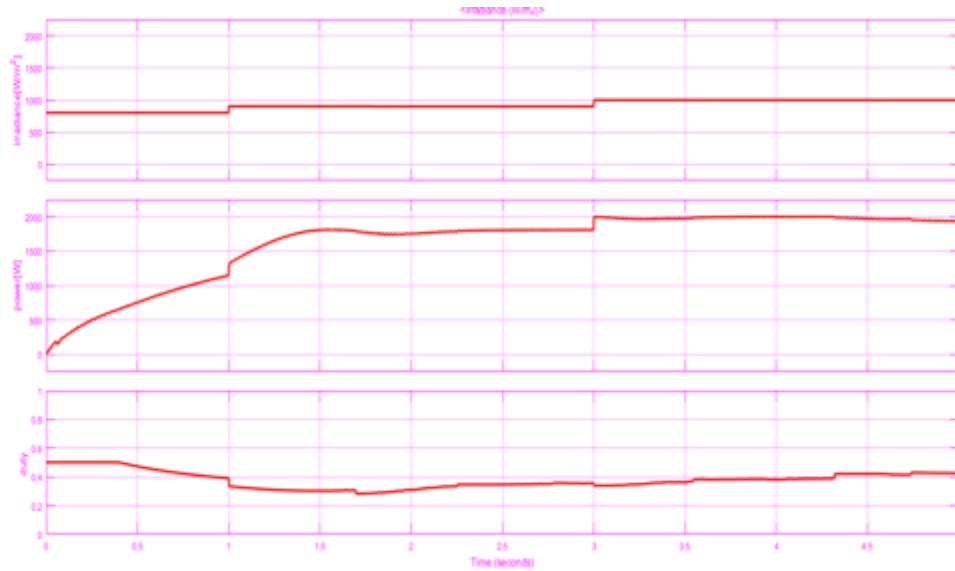Fig. 7 Simulink Model of Boost Converter with MPPT Algorithm.

Fig. 8 Tracking characteristics of Incremental Conductance.

The Fig. 8 shows the adjusting of duty cycle with accordance to irradiance. From 0 to 1 seconds the irradiance (G) is 600 w/m^2 and Temperature is 25 ^0C, Maximum Power is 1218W and Maximum Voltage is 280V. From 1 to 3 seconds, G = 800 w/m^2, Temperature (T) =25^{0}C, Maximum Power is 1615W and Maximum Voltage is 410V. From 3 to 5 seconds, G = 1000 w/m^2, T = 25^{0}C and Maximum Power =2001W and Maximum Voltage is 440V.
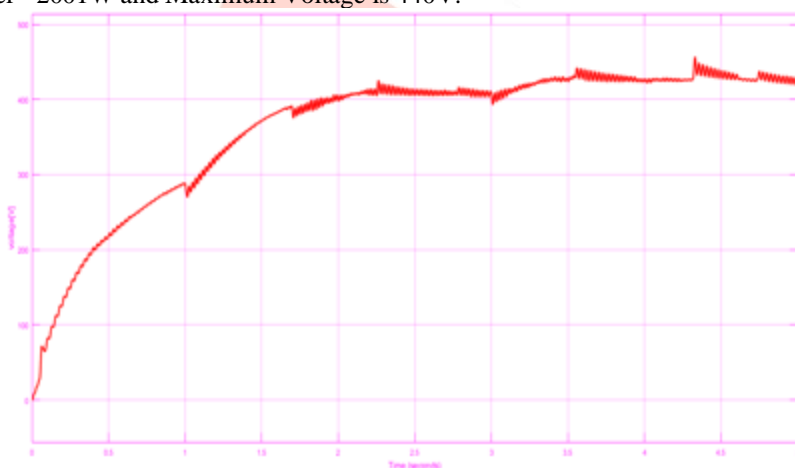

Fig. 9 Output Voltage of Boost Converter with MPPT Algorithm.

Table. 2 Comparison of boost converter with & without MPPT

Parameters	Irradiance(w/m2)	Power(W)	Voltage(V)
Boost Converter with MPPT	600	1218	263
	800	1615	264.5
	1000	2001	265.8
Boost Converter without MPPT	600	450	200
	800	550	230
	1000	650	260

From the above table it is clear that boost converter with MPPT gives more Power than the boost converter without MPPT.

VI. SIMULINK MODEL OF 2KW GRID CONNECTED PV SYSTEM

Fig. 10 shows the study PV system, composed by:
- KC200GT PV modules which the parameters are shown in Table 3.
- Boost converter and transformer less 3-ph VSI.
- Output self-filter,
- Two controllers blocks that are used respectively for tracking the MPP and to control the amplitude and frequency requirements of the utility AC grid, the line to line grid RMS Voltage VLL=380 V and grid frequency f=50 Hz.

Two loads, with:
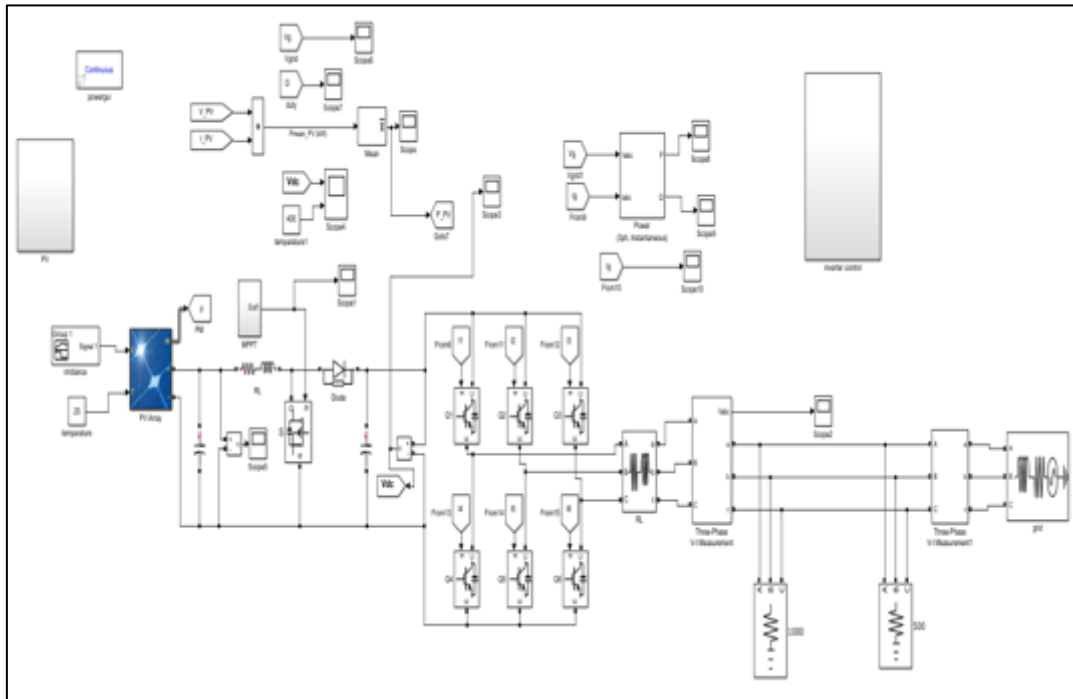Load1=1000W. Load2=500W.

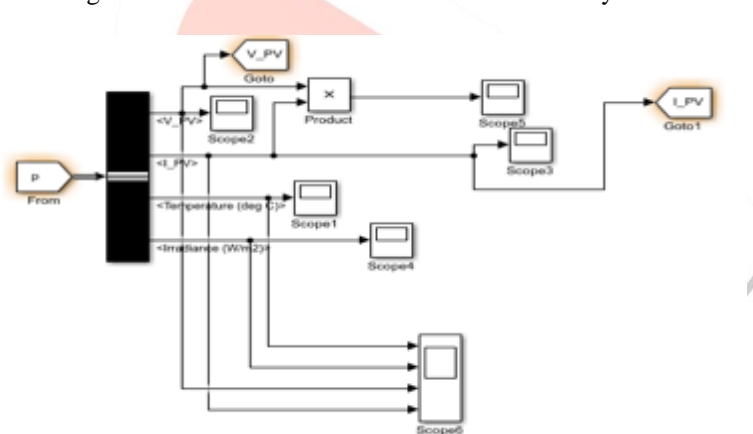Fig. 10 Simulink Model of a Grid Connected PV System.

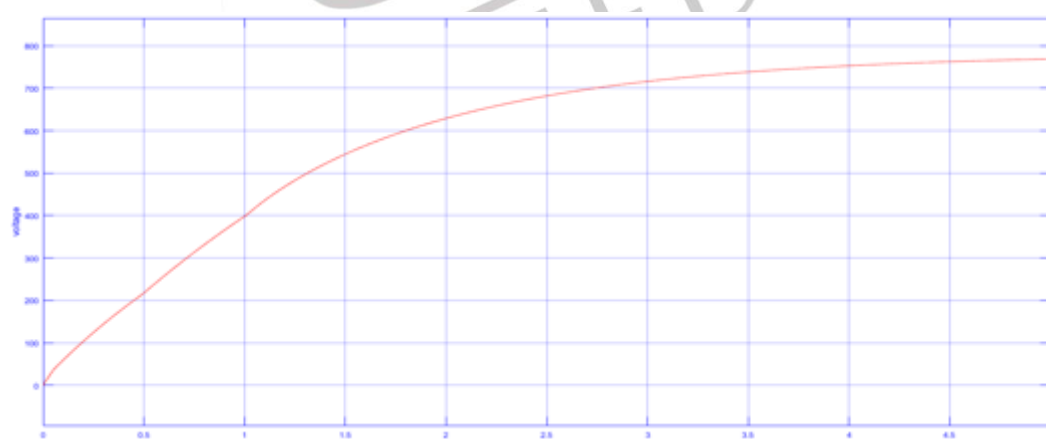Fig. 11 Simulink Model of a PV measurement subsystem.

Fig. 12 Output Voltage at DC link.

The output voltage at the DC link is shown in the Fig. 13. The reference voltage is taken as 700V. From the graph the voltage is 750V.
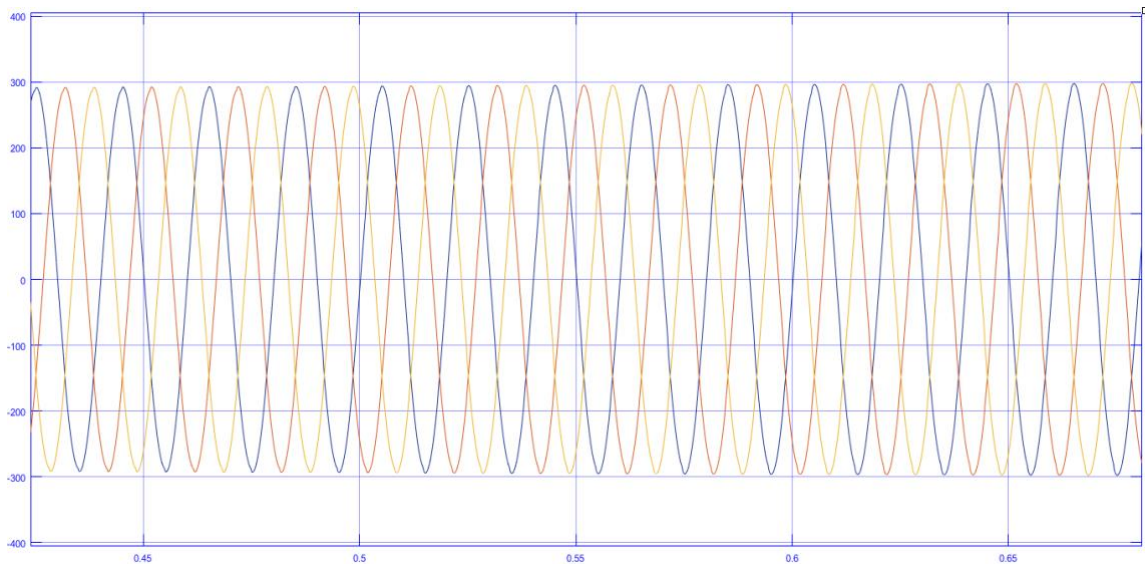
Fig. 13 Output Voltage at Grid.

- ➢ The line to line voltage of the grid is taken as 380 V (RMS).
- ➢ From 0 to 0.5 sec the applied irradiance is 600W/m*2, 25_0 C, the voltage at the load is reduced because at 600W/m*2 PV array able to 1180W but the connected load is 2000W.

From 0.5 sec to 5 sec the applied irradiance is 1000W/m*2, 25_0C, the voltage at the load increases gradually as increase of the PV power.

VII. CONCLUSION

In this paper simulation is done to study behaviour of the grid-connected residential PV System in order to convert efficiently the solar energy. The simulated model and the results obtained for various operating conditions, show the robustness control approach as well to maintain a constant DC bus voltage. They also demonstrate the tracking accuracy and the fast response with low oscillations of the proposed modified IC algorithm as MPPT technique. PLL is used to make the rotating frame synchronous with grid voltage by extracting the grid angle. It managed to synchronize the system as expected. On the other hand, the transformer-less grid-connected PV system, without storage facilities, using a simple and cheap MPPT controller, can be considered a very interesting topology for residential applications. Indeed, the PV chain devices number is reduced, which mean, less cost and less installation complexity. So, it can make their easy and cheap facilities more attractive in developing countries. The simulation results also indicate that the proposed system provides power to the local loads, regardless of climatic conditions or loads variation. The grid takes care to provide the additional power required by those loads when the PVG cannot supply enough energy. Otherwise, any PVG extra power is injected to the grid. Thus, this proposed residential PV system can be a typical solution to meet an energy demand part and improve the electrical distribution grid.

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