Modelling and Simulation of 3-Phase Grid connected Solar PV System with Power Quality Analysis

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Abstract
In this study, modelling and simulation of solar PV array using MATLAB software taking the effect of irradiance and temperature are in concern. The MPPT converter is applied to take out the maximum power out of the sun while keeping bus voltage constant. 3 phase inverter is also applied to combine it to a grid. Now the performance of the active and reactive power at the load bus which is supplied by the solar PV array is analyzed. The quality analysis of currents such as inverter current, grid current and load currents are also investigated. Finally, the effect of penetration of solar PV in the grid is presented in the form of THD of the grid.

Keywords: Modeling, MPPT, Solar PV, MATLAB, THD.

Introduction

In modern era, the world is shifting towards renewable energy sources from conventional energy sources which is mainly due to its ample availability and eco-friendly nature. Out of all the renewable resources, solar energy is very promising source that produces electrical energy using photovoltaic i.e. PV process. A noteworthy benefit of photovoltaic systems is the use of the profuse and without charge energy out of the sun.

Renewable Power such as Solar PV and their users i.e. AC loads are interfaced by using power electronic devices. These devices make the renewable sources generated power appropriate for consumption. Power generation contribution in the world using solar power has been escalating quickly and price of power generated by solar PV is declining speedily. PV cell or module converts solar energy straight into dc electrical power. Electrical power is in general transmitted and utilized in the form of AC since there are many advantages of AC Electrical power. A very competent converter i.e. inverter is essential for converting the DC power into AC for best possible utilization of energy.

Solar PV systems can be mounted on the fronts and rooftops of constructional structures, on top of the shades of railway platform and parking area shades etc. and their power can be used locally or can be fed to Grid. Solar PV system can also be installed purely as a power plant that aims to add all their formed power into the grid. PV penetration levels in the Indian electricity grids are still very low. However, the Ministry of New and Renewable Energy (MNRE) is targeting to add 20 GW grid connected solar power by 2017 under Jawaharlal Nehru National Solar Mission (JNNSM). The national solar power capability goal has been decided as 100,000 MW by 2022. This will change the scenario significantly.

System Description

The given system comprises of a PV Solar array, DC to DC boost converter and a 3-phase voltage source inverter with grid synchronization control schemes.

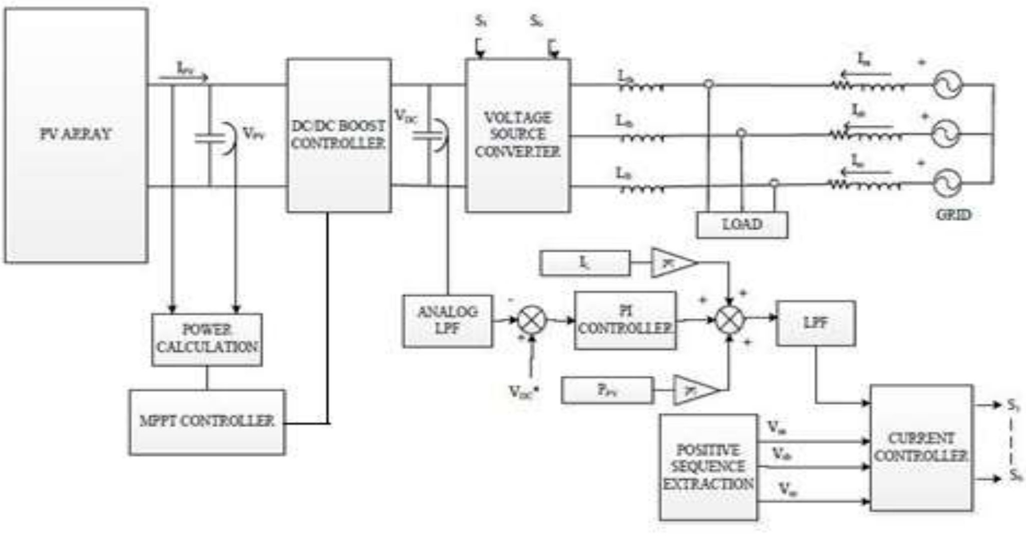

Fig. 1: System Description

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Solar PV Array: A single diode model has been considered to model the solar cell for this work. Equation based modeling of PV cell is presented as:

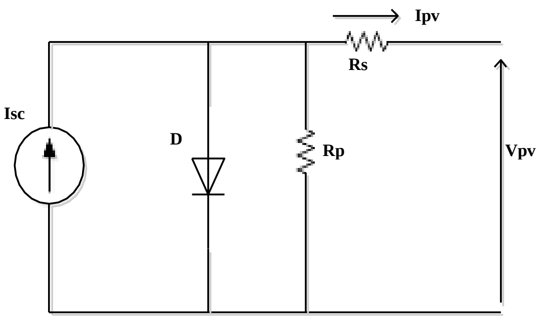

Fig. 2: Equivalent Circuit of Solar PV cell

The current-voltage characteristics of the equivalent circuit are obtained as:

$$I_{sc} - I_D - \frac{V_D}{R_p} - I_{PV} = 0 \quad (1)$$

Thus $I_{PV} = I_{sc} - I_D - \frac{V_D}{R_p}$ (2)

The I_{rs} which is reverse saturation current is written as:

$$I_{rs} = I_{scref} + \left[exp\left(\frac{qVoc}{NskAT}\right) - 1\right] \quad (3)$$

The I_0 which is module saturation current, changes with the temperature of cell are given by:

$$I_o = I_{rs}\left[\frac{\left(\frac{T}{T_{ref}}\right)^3 e^{qCg}}{Ak} * \left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \quad (4)$$

The equation which gives the PV module current output of the given single-diode model is represented by the equation:

$$I_{PV} = I_{SC}N_p - N_sI_o\left[exp\left\{\frac{q(V_{PV}+I_{PV}R_s)}{N_sAkT}\right\} - 1\right]V_{PV} + \frac{I_{PV}R_s}{R_p} \quad (5)$$

DC/DC Boost Converter: Solar PV array output is very much influenced by the parameters such as temperature and irradiance which are changing continuously. To trace the maximum power point (MPP), a control technique is required known as maximum power point tracking (MPPT).

In this study, Perturb and Observe (P and O) method for tracing the MPP of solar photovoltaic array is used. After the application of this method the output power of present perturbation cycle is matched with the output power of previous perturbation cycle. If the output power increases, then the variation of voltage and current will be continuous in same direction. If the output power decreases, then the variation in voltage and current will be in reverse direction.

Inverter Controller: Inverter in this system must only insert active component of current in the grid. To achieve this aim the difference between the real and the anticipated grid current known as steady state current error should be zero at any frequency on which grid is operated. The input voltage phase and the generated voltage phase i.e. sine and cosine components have been tracked by PLL known as phase locked loop. The high frequency harmonics has been filtered out by passing D-Q components of currents through a filter. Then the D-Q components of current are converted back to three-phase components. The gate pulses for this inverter are produced by comparing the above 3- phase components of current with the source current components and the difference between the two is to provide Hysteresis-based PWM signal generator for producing switching signals.

The terminal voltage of the system is given as:

$$V_\alpha = V_m * COS(\omega t + \emptyset) \quad (6)$$

Also current is given as:

$$i_\alpha = I_m * COS(\omega t + \theta_n) \quad (7)$$

Following equation gives:

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (8)$$

where i_d= Grid current component which is in phase; i_q= Grid current component which is reactive.

$$\begin{bmatrix} i_d = Icos(\emptyset - \theta_n) \\ i_d = -Isin(\emptyset - \theta_n) \end{bmatrix} \quad (9)$$

MATLAB Modeling

The suggested system has various components like photovoltaic array, DC-DC chopper and a three-phase voltage source converter along with control algorithm.

MATLAB simulated model of a 3-phase grid connected system is shown in the figure 3 which incorporate a PV array connected to DC-DC converter, a DC to AC 3-phase voltage source inverter, a three phase 415 V grid with the above-mentioned load connected at PCC point.

In this paper load connected to the three-phase grid connected solar PV system is of following type:

1. Continuous connected load- A three phase balanced lagging load of 50 KVA is always connected to the system.

2. Non-linear load- A single phase diode bridge connected lagging load is also connected.

3. Discontinuous load- A three phase balanced load is connected through circuit breaker which is at times applied to the system.

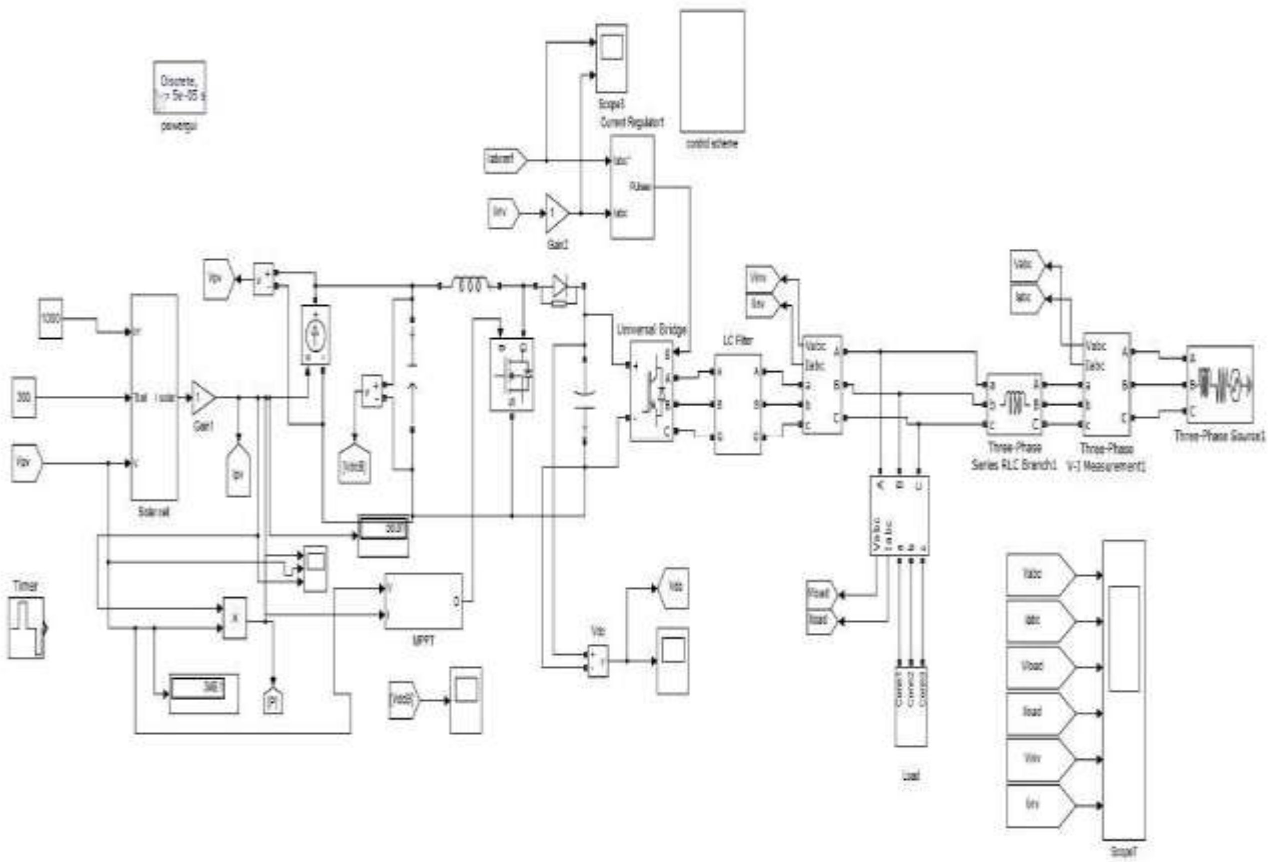

Fig. 3: MATLAB Simulation of Grid Connected Solar PV

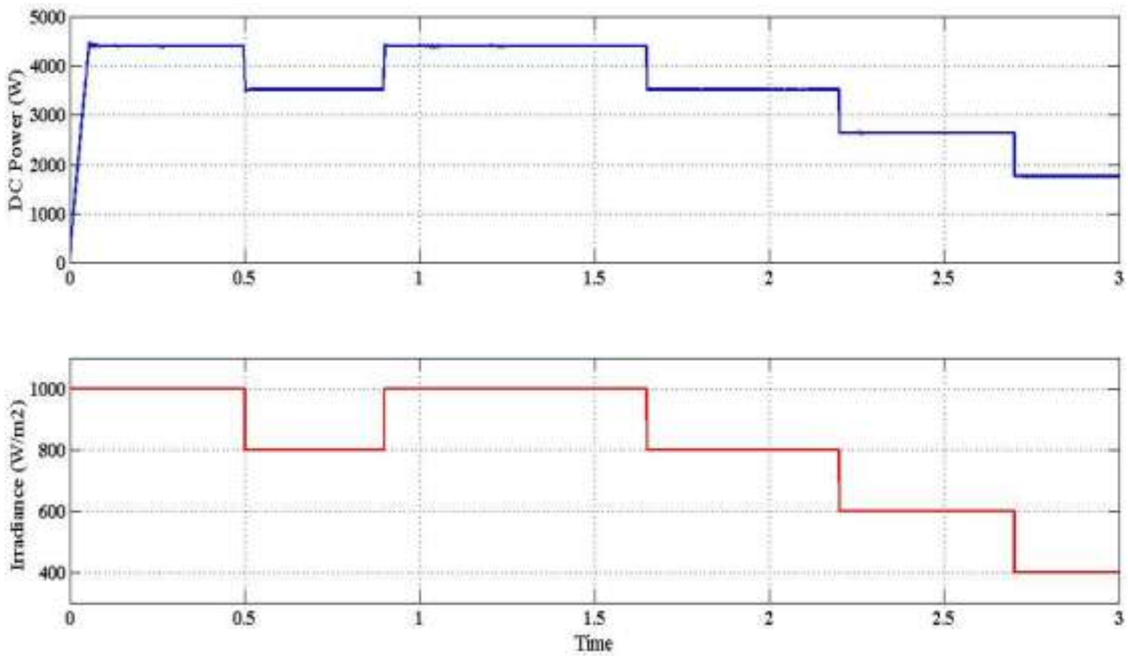

Fig. 4: DC Power of Solar Photovoltaic System at changing irradiance

Results

DC Power Supplied by the Solar PV System: Power supplied by solar PV system is dependent on the voltage and the current of solar panel which in turn are dependent on the irradiance and temperature. At constant ambient temperature, DC power supplied by solar PV panel follows the irradiance pattern.

PV Voltage and Current: Solar PV current and voltage are most important parameters for the working of solar photovoltaic system. These are the parameters which are used as response to MPPT controller which then produces pulses for the DC boost chopper.

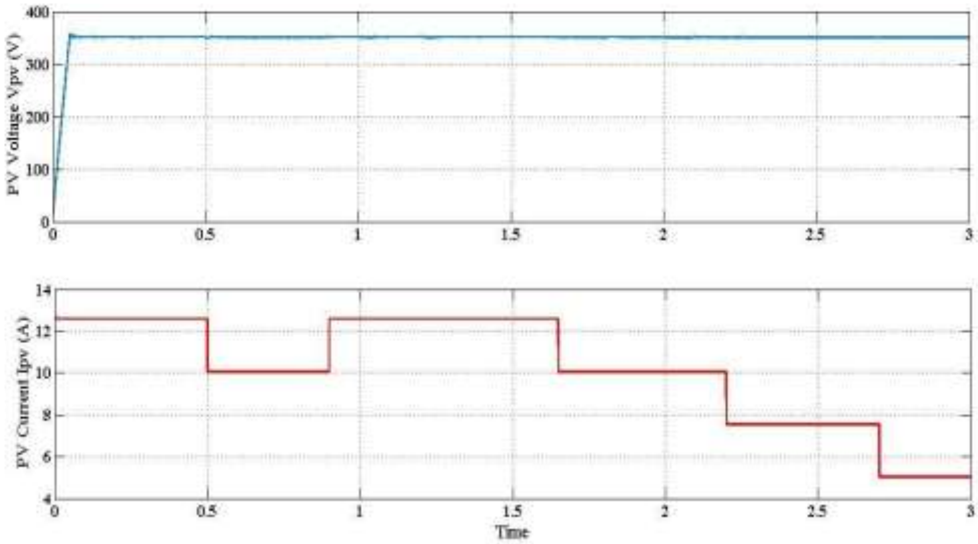

Fig. 5: PV Voltage and Current

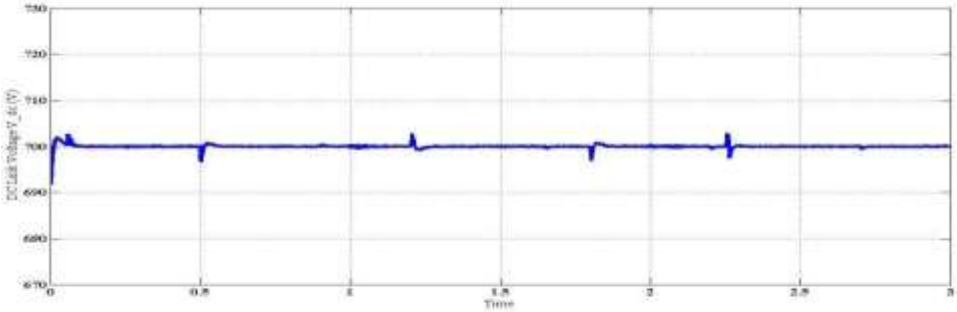

Fig. 6: DC link voltage

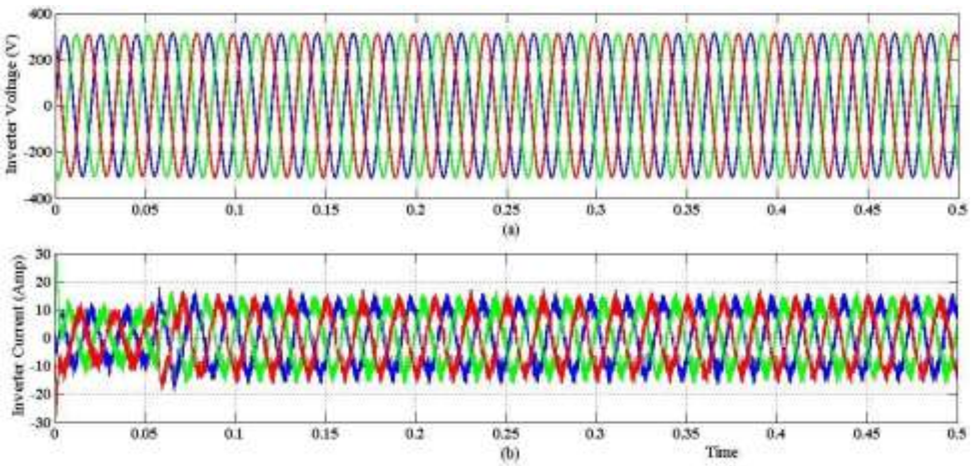

Fig. 7: Inverter (a) voltage (b) Current

DC Link Voltage: The voltage which is applied to the inverter input is known as DC link voltage. For maintaining a desired value of DC link voltage, a DC-DC chopper is used. To sustain a constant DC link voltage, a large value of capacitor is utilized. An almost constant 700 V DC link is obtained from boost converter.

Inverter Voltage and Current: Inverter (VSI) produces a three phase ac voltage output to supply the three phase load at PCC point. A three-phase universal bridge utilizing IGBT switch is used in MATLAB simulation work to convert DC link voltage to three phase ac. Pulse for IGBT switches is produced by inverter control block. The three-phase balanced voltage and current supplied by inverter are shown in fig. 7.

Power Supplied to Grid: Active power and reactive power both are supplied by the system. As shown in the figure the active power is reliant on the irradiance parameter, but the reactive power is more or less constant irrespective of the variation in meteorological parameter. Solar PV system supplies only a partial portion of reactive power requirement.

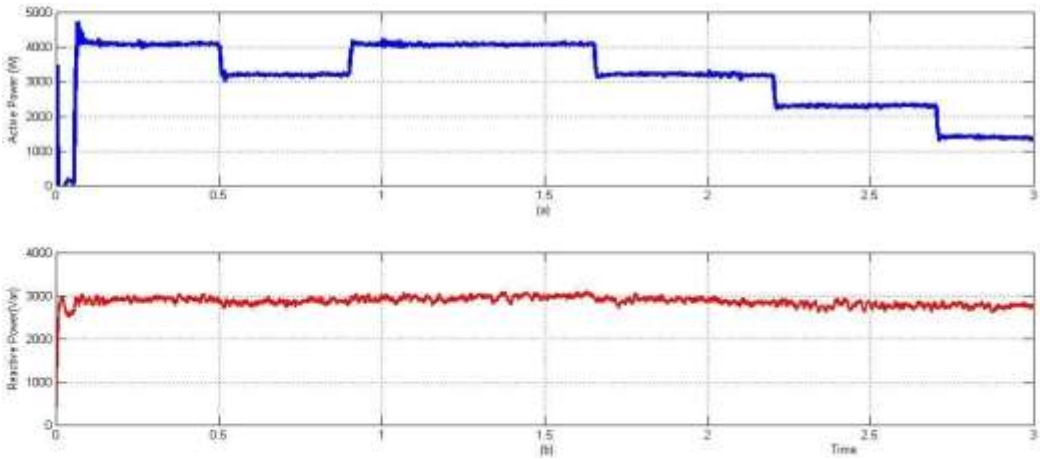

Fig. 8: a) Active power b) Reactive power supplied to Grid at Changing Irradiance

Power quality analysis of system: Power quality analysis of three phase grid connected system is presented when the percentage penetration of solar PV increased from 10% to 30% on the basis of harmonic distortion in the current of grid and voltage at the PCC point. The same comparison is given in the table 1.

Table 1
Comparison of power quality at different percentage penetration

% Penetration of SPV	% Current THD of Grid	% Voltage THD of PCC Point
0	0.5	0.2
10	3.52	1.5
15	4.33	1.4
20	4.54	1.31
25	4.78	1.27
30	5.18	1.22

Conclusion

Analysis of the performance of 3-phase grid connected system with P and O MPPT technique and inverter control scheme bases on synchronous reference frame theory is carried out. The performance of solar PV system is analyzed for constant and different levels of irradiance on the basis of Vpv, Ipv, Vdc, power supplied by solar panel and active and reactive power supplied by the inverter. Further power quality three phase grid connected system is analyzed on the basis of variation of PCC point voltage at the discontinuous load and total harmonic distortion (THD) analysis of the grid current for increasing percentage penetration of Solar PV in the existing grid.

As distribution grid is weak grid i.e. high R/X ratio PCC point voltage is affected by sudden load change or change in irradiance which directly affects the active power supplied by the Solar PV. Also, to connect solar PV system with grid many power electronic switches is used which produces harmonics, hence THD level of grid current goes on increases from 3.52% to 5.18% as the percentage penetration increases from 10% to 30%.

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