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Performance analysis of a Grid Connected Photovoltaic Power Plant with MPPT facility

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Abstract: This paper yields a simulation model of the electrical part of a grid connected photovoltaic system. The model contains a detailed representation of the main components of the system that are the solar array, boost converter, mppt controller, inverter control circuit and utility grid. A proper control of the DC/AC inverter is developed in order to synchronize the system to the grid. The grid interface inverter transfers the energy drawn from the photovoltaic (PV) array into the grid by keeping common DC coupling voltage constant. A simulation model has been developed with the help of mathematical equations and performance is analyzed under varying irradiance level. This paper can be useful for the PV power plant designers to analyze the output of the power plant by using the simulation model. This model is a simplified approach of the system's individual modules.

I. INTRODUCTION

The basic device of the PV system is the PV cell. Cells may be grouped to form a module and modules may be used to form a PV array. More sophisticated applications require electronic converter to process the electricity from the PV device. These converters may be used to regulate the voltage and current at the load, to control the power flow in grid connected systems and mainly track the maximum power point of the device. PV devices present nonlinear I-V characteristics with several parameters that need to adjust from experimental data of practical devices. The mathematical model of the PV device is used here for analyzing a complete PV system and its component using the Matlab/Simulink simulator. Villalla et.al [4] proposed a mathematical model for photovoltaic module in which they found the parameters of non linear I-V equation by adjusting the curve at three points: open circuit, maximum power, and short circuit. They found the best I–V equation solution by an iterative process for the single-diode photovoltaic (PV) model including the effect of the series and parallel resistances, and warranties that the maximum power of the model matches with the maximum power of the real PV module. In this paper the above fallacies has been removed and a simulink model has been proposed for a real time full scale solar PV power plant . Computer Simulation of the mathematical model is done in Matlab/Simulink software.

Nowadays, PV system has been more and more attractive due to the severe environmental protection regulations and the shortage of conventional energy sources. Photovoltaic generation is the technique which uses photovoltaic cell to convert solar energy to electric energy. Photovoltaic energy is assuming increasingly importance as a renewable energy source because of its distinctive advantages, such as simple configuration, easy allocation, free of pollution, low maintenance cost, etc. However, the disadvantage is that photovoltaic generation is intermittent, depending upon weather conditions. The current contribution of solar energy to the total world's energy needs is insignificant, in the medium and long run, it is expected that solar energy, especially solar PV will form a vital component of the world's energy mix. The block diagram in figure.1 presents the proposed design for the grid interactive solar PV system.

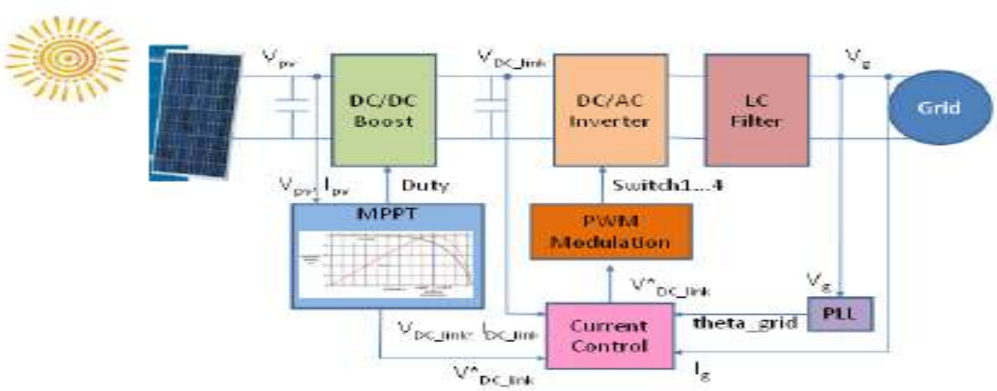


Figure. 1: Components of the grid interactive PV system

It consists of:

I. P-V array that simulates the PV voltage and current output, depending on solar irradiance,
II. A 3-phase inverter which converts the generated DC power into a 3-phase AC,
III. A filter which is an LC low pass filter reducing the harmonic distortion by cutting off the high frequency harmonics.
IV. A control unit in which a PLL synchronizes the output phase of the inverter with the phase of the grid and the PWM synchronizes the insulated gate bipolar transistor (IGBTs).

II. BUILDING MODELING OF PV COMPONENTS

A. PV array

A photovoltaic cell is basically a semiconductor diode whose p–n junction is exposed to light [1]. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The monocrystalline and polycrystalline silicon cells are the only found at commercial scale at the present time. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited [1].

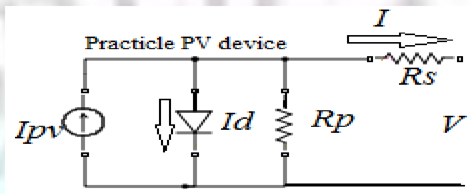


Fig.2: Single Diode Model

Figure 2 shows a single diode model of PV cell. Some authors have proposed more sophisticated models that present better accuracy and serve for different purposes. For example, in [7] & [8] an extra diode is used to represent the effect of the recombination of carriers. A three-diode model is proposed in [11] to include the influence of effects that are not considered by the previous models. For simplicity, the single diode model of figure.2 is studied in this paper. This model offers a good compromise between simplicity and accuracy [9], and has been used by several authors in previous works, sometimes with simplifications but always with the basic structure composed of a current source and a parallel diode [11], [14] and [15]. The current obtained from a photovoltaic module consisting of a number of cells (Ns) connected in series is represented by equation.(1).

$$I = I_{PV} - Io\left[\exp\left(\frac{q(V + IRs)}{akTNs}\right) - 1\right] - \frac{V + RsI}{Rp} \qquad (1)$$

I_d

I_o is the reverse saturation or leakage current of the diode, $q = 1.60217646 \times 10^{-19}$ C (the electron charge), $k = 1.3806503 \times 10^{-23}$ J/K (the Boltzmann constant), T is the temperature of the p–n junction (in Kelvin), a is the diode ideality constant, R_S is series resistance, R_P is shunt resistance. In the case of a number of modules connected in parallel (N_P), the current obtained from eq. (1) is multiplied by N_P. All PV array datasheets bring basically the following information: the nominal open-circuit voltage ($V_{oc,n}$), the nominal short-circuit current ($I_{sc,n}$), the voltage at the maximum power point (V_{mp}), the current at the maximum power point (I_{mp}), the open-circuit voltage temperature coefficient (K_V), the short circuit current temperature coefficient (K_I), and the maximum experimental peak output power ($P_{max,e}$). This information is always provided with reference to the nominal condition or standard test conditions (STCs) of temperature (25 °C) and solar irradiation (1000 W/m2). Some manufacturers provide I–V curves for several irradiation and temperature conditions. The photovoltaic module used for the calculations in this paper is the BP 380 produced by BP Solar [18]. For simplicity, the single diode model will be studied in this paper. The light-generated current of the PV cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation [9], [13]:

$$I_{PV} = \left(I_{PV,n} + K_I\,(T - T_n)\right)\frac{G}{G_n} \qquad (2)$$

$$I_{PV,n} = \left(I_{sc,n} + K_I (T - T_n)\right) \frac{G}{G_n} \qquad (3)$$

$$I_{SC} = \left(I_{sc,n} + K_I (T - T_n)\right) \frac{G}{G_n} \qquad (4)$$

Where G is irradiance on device surface; G_n = 1000 W/m2 (nominal solar radiation), T_n = 298.15 K (nominal temperature); K_I = + (0.065±0.015) % ºC, $I_{sc,n}$ = 4.8 A [18]. King et.al [12] found that there is typically less than a 5% change in the voltage coefficients over a tenfold change in irradiance from 100 W/m2 to 1000 W/m2. The temperature of the PV module can be obtained from the following equation [5]:

$$T - T_a = (219 + 832\bar{K}) \frac{NOCT - 20}{800} \qquad (5)$$

Where T_a is the ambient temperature which can be obtained from the Metrological Department; NOCT °C (nominal cell operating temperature, obtained from the BP380 module datasheet); $\bar{K}$ is the monthly clearness index. The diode saturation current I_o and its dependence on the temperature may be expressed by the following equation [14]:

$$I_o = I_{o,n} [\tfrac{T_n}{T}]^3 \exp[\tfrac{qE_g}{ak} (\tfrac{1}{T_n} - \tfrac{1}{T})] \qquad (6)$$

Where E_g is the band gap energy of the semiconductor = 1.12 eV.The nominal saturation current $I_{o,n}$ is obtained by evaluating eq. (1) at the nominal open-circuit condition, with V = $V_{oc,n}$, I= 0, and $I_{PV} \approx I_{sc,n.}$

$$I_{o,n} = \frac{I_{sc,n}}{exp\left[\frac{V_{oc,n}}{aV_{t,n}}\right] - 1} \qquad (7)$$

Where $V_{t,n} = \frac{kT_n}{a}$

The value of a is stated by Tsai et.al [12] for different types of PV depending on the PV technology. The value of R_p can be obtained as:

R_p =

$$\frac{V_{mp}\left(V_{mp} + I_{mp} R_S\right)}{\left[V_{mp} I_{PV} - V_{mp} I_o\, exp\left[\frac{V_{mp} + I_{mp} R_S}{N_s a} \frac{a}{kT}\right] + V_{mp} I_o - P_{max,e}\right]} \qquad (8)$$

B. MPPT and Boost Converter

For extraction of maximum energy it is reasonable to have MPPT facility. The boost topology is able to raise the input voltage to intermediate DC link voltage with the only drawback because of efficiency drop at low voltage.
The DC- DC boost converter shown in figure has very important relation with with following equations:-

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D}$$

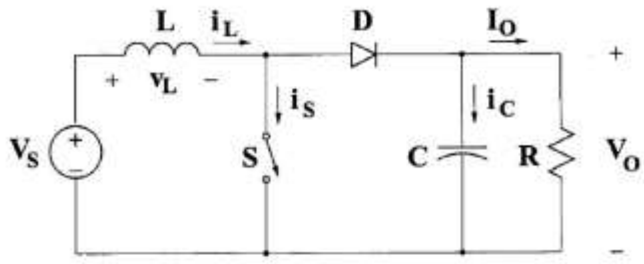
$$D = 1 - \frac{V_{in}}{V_{out}}$$

Where D is the duty cycle of switching device,V_{out} is the DC lik output voltage and V_{in} is the input voltage. For continous current mode, the boundary condition in boost converter is found by

$$L_b = (1-D)^2 * (1-D) * T$$

The minimum value for the capacitor can be found by

$$C_{min} = D * \frac{V_0}{V_r * f * R}$$



For getting the maximum power point on the VI curve a simple Perturb and Observe algorithm is selected. The Instantaneous output voltage and current at PV panel is tracked by this controller in such a way to identify the direction of maximum power point.
The tracking of the MPP is obtained by a feedback control of the average output terminal voltage of the panel.

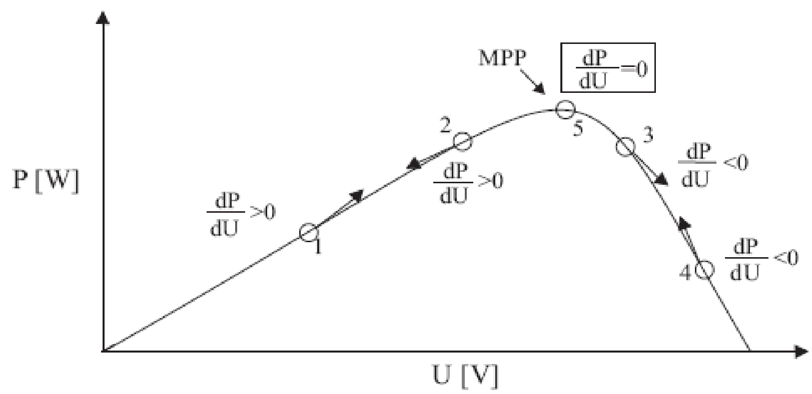


Figure – PV characterstick and tracking of MPPT operating point

Flow chart of the P & O algorithm is shown in figure

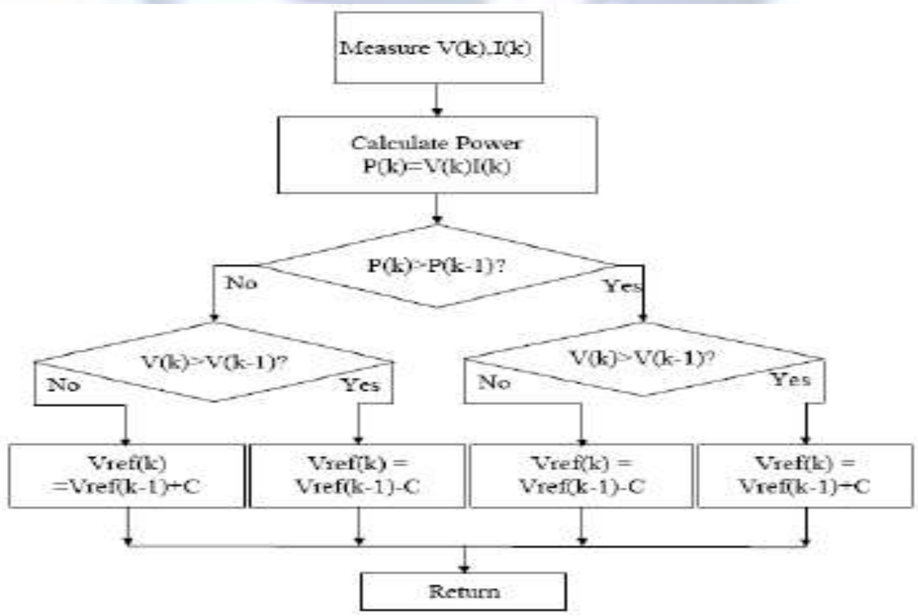


Figure P & O flowchart

Operating strategy is described as follows:

$$1.dV(k) > 0 \,\&\, dP(k) > 0 \Rightarrow D(k+1) = D(k) - c$$
$$2.dV(k) < 0 \,\&\, dP(k) < 0 \Rightarrow D(k+1) = D(k) - c$$
$$3.dV(k) > 0 \,\&\, dP(k) < 0 \Rightarrow D(k+1) = D(k) + c$$
$$4.dV(k) < 0 \,\&\, dP(k) > 0 \Rightarrow D(k+1) = D(k) + c$$

Where a particular number identify the respective point in fig. and c is a constant parameter. This boost converter boosts the voltage from 270 V to 500 V at standard test conditions. The MPPT controller varies automatically the duty cycle in such a way to generate required voltage for maximum power extraction.

B. Voltage Source Converter

Grid-connected converters are necessary for dc–ac and vice versa conversion. To avoid the distortions to the power grid, the generated currents from these converters are required to have low harmonics and high power factor. For conversion of dc-ac in grid connected PV system, there are several types of topologies and converter designs are used in existing installations [2]. There are still some subjects as yet unproven. Reliability, life span, and maintenance needs should be certified through long-term operation of a PV system. Further inverter designs are used in existing installations [2]. The main circuit is the part where the DC electric power is converted to AC in inverter mode and vice versa in converter mode. Voltage source converter here used is a three level VSC, which regulates the DC link voltage at 500 V and keeps unity power factor. This voltage source converter converts 500 V DC link voltage into 260 V AC and tends to keep unity power factor. The control structure for this converter consists of two control loops. The function of the external control loop is to regulate the DC link voltage at 500 V. An internal loop controls the I_d and I_q components and regulates them.

Control scheme for VSC is shown in figure.
I_{d_ref} is obtained from the output of DC voltage control external loop. I_q component of current is set to zero in such a way to keep power factor unity. V_d and V_q components of

IV. SIMULATION RESULTS AND DISCUSSION

This paper analysis the behavior of a grid connected PV system with MPPT facility under varying solar irradiance level. A computer simulation is performed using Matlab/Simulink software. The Manufacturer data of PV module used in this simulation is shown in Table I.

Pmp= 305.2
Vmp= 54.70
Imp= 5.58;
Voc= 64.20;
Isc= 5.96;
TempC_Pmp= -1.154e+000;
TempC_Vmp= -1.860e-001;
TempC_Imp= -2.120e-003;
TempC_Voc= -1.770e-001;
TempC_Isc= 3.516e-003;
Rs= 0.037998;
Rp= 993.51;
Isat= 1.1753e-08;
Iph= 5.9602;
Qd= 1.3;

voltage are converted to three modulating signal which operates the PWM three level pulse generator.

C. Filter, Load, and Grid

Grid utility is simulated using a three phase source from simpower system library. Instead of this Grid utility can also be simulated using impedance estimation. Such values have been experimentally measured in [6]. The Grid utility is not presented in this contribution. The idea to have a simulation that will work for each day and give us data for such a system has been studied and will be fulfilled at the future. filters are used to reduce harmonics. A 10 kvar capacitor bank is used for filtration of harmonics generated by VSC. Utility grid is modeled using a 25 kV distribution feeder and 120 kV transmission line. Simulated PV plant is connected to the feeder via a three phase coupling transformer. A 30 MW and 2 MVA load is connected to grid.

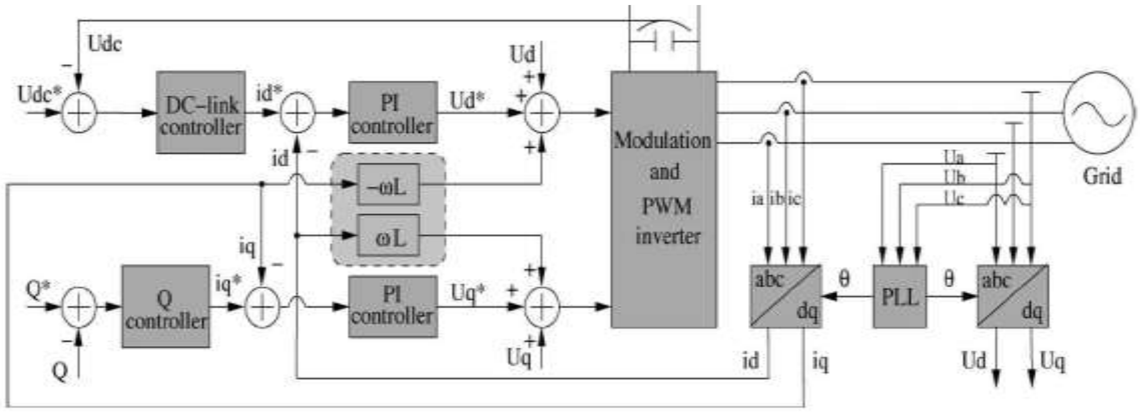


Figure 3 General structure for inverter control unit

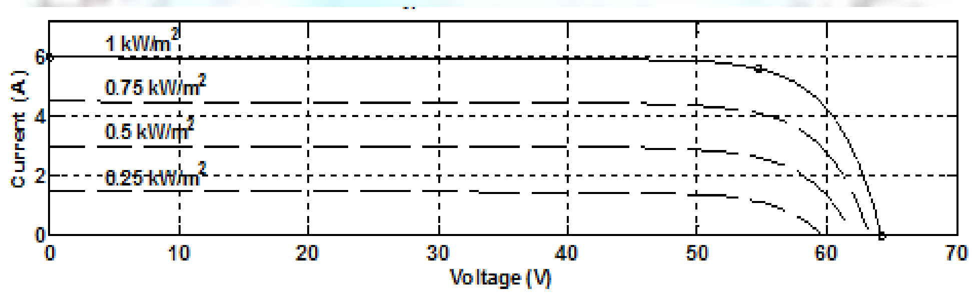


Figure:-IV characteristics of SPR-305

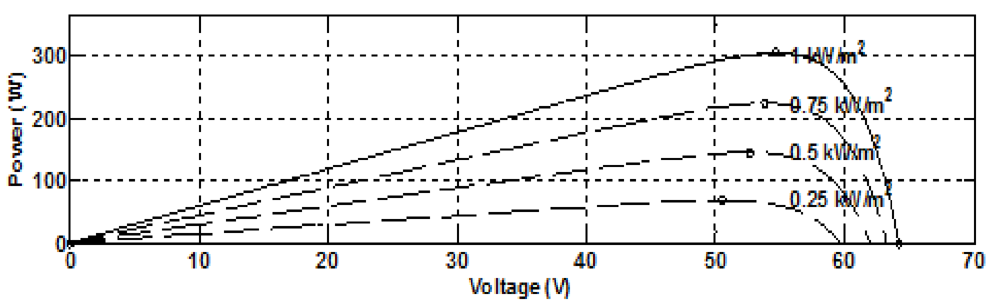
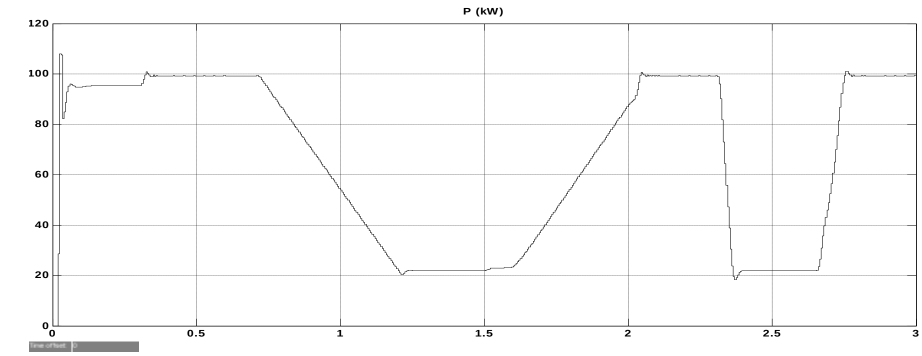
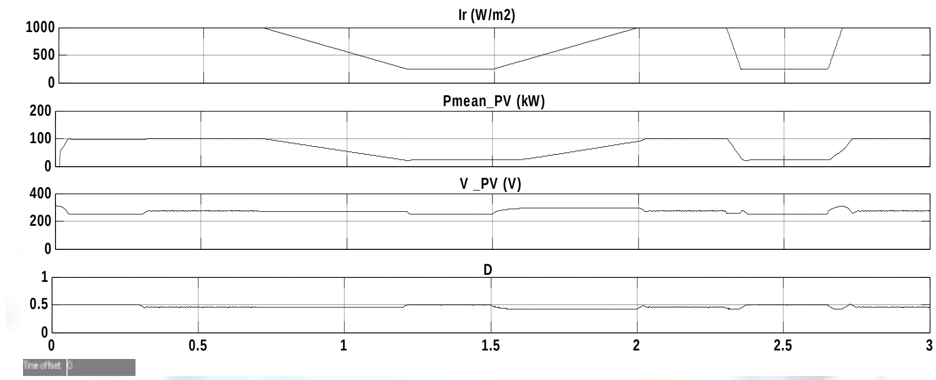


Figure:- PV characteristics of SPR-305

IV and PV curve of a SPR-305 module is shown in figures Under different irradiance level.

For analyzing the behavior of PV system and MPPT solar irradiance is varied using signal builder. Figure shows the change in power output as per change in solar irradiance.
After 0.3 s the MPPT controller is enabled which tracks the maximum V and I on points on IV curve and provide duty cycle to the boost converter. This facility find the optimum duty cycle ratio.





Above figure shows the change in mean power,change in generated PV output voltage as per change in irradiance level. Figure also validate the change in duty cycle with irradiance level.

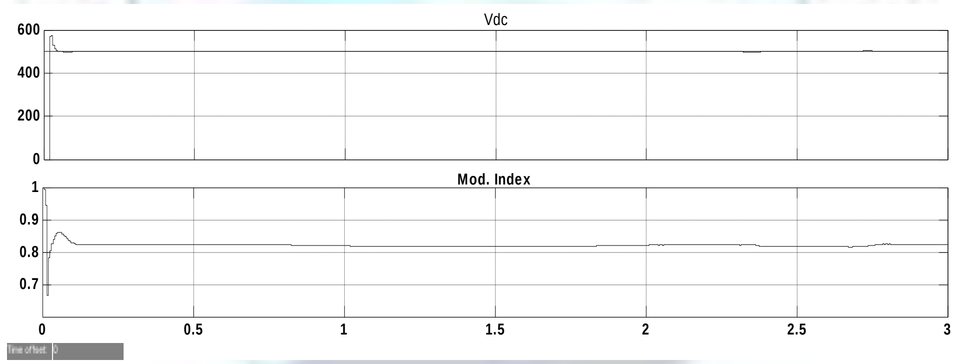


Figure verify that the Dc link voltage is kept constant at 500 V DC. Figure also shows the change in modulation index.

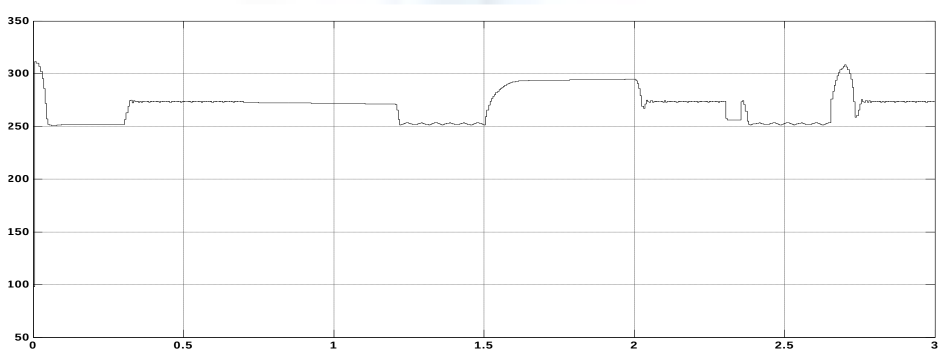


Figure give an idea how the terminal voltage change with irradiace.

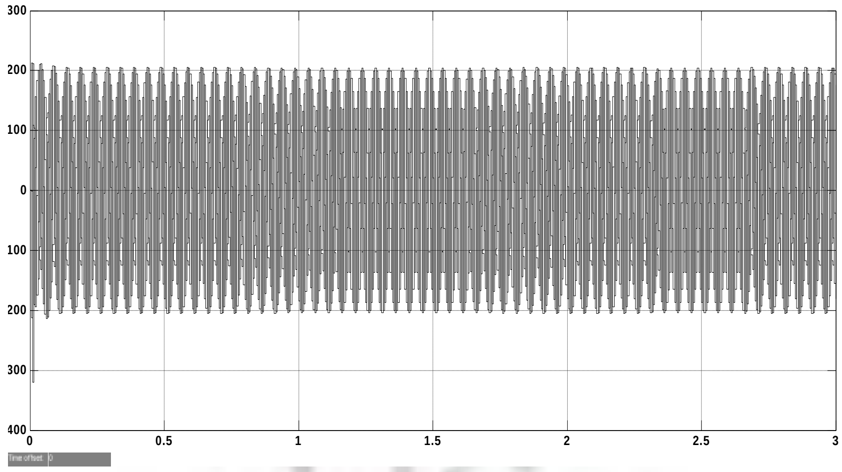
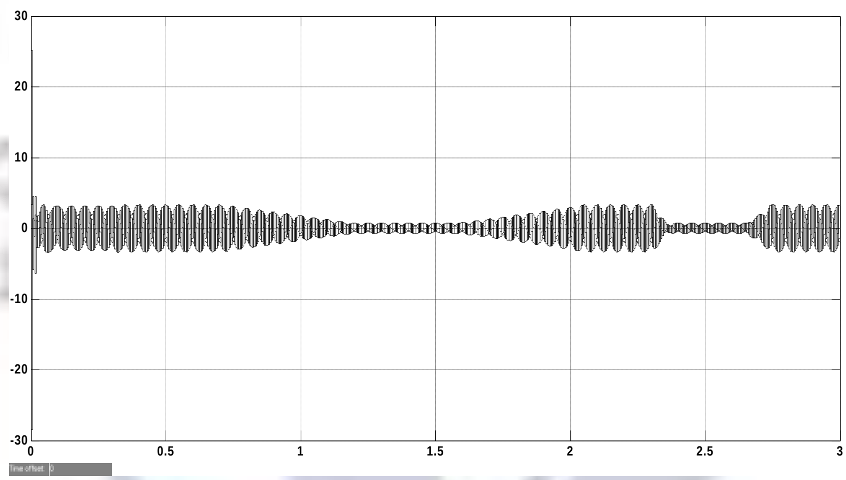
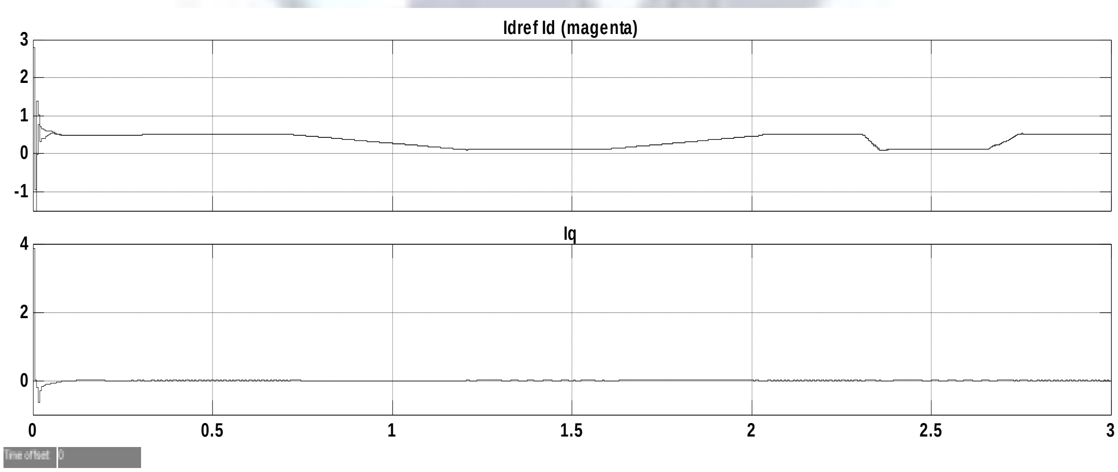


Figure output of VSC

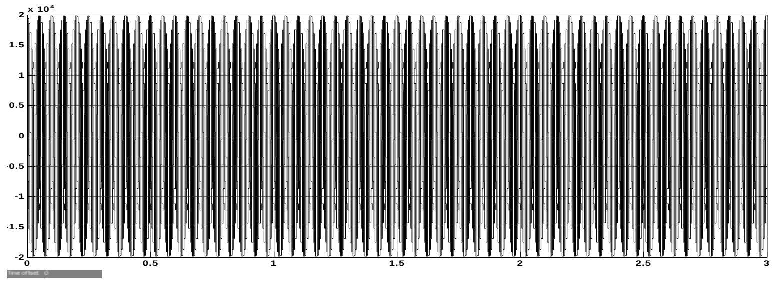
Figure grid side three phase voltage



Three phase current



Id and Iq components



V. Conclusion

This paper presents the model and simulation of a grid connected PV plant with mppt facility and analyzes its electrical performance for different operating conditions. Overall system is built by integrating individual models of a PV array, interfaces, and load. Simulation results show that the overall simulink model of the grid interactive PV plant performs well to reflect the system behavior for different operating scenarios. This model does't requires storage of the PV module characteristics as data storage but calculates the power generated and energy delivered by the PV module at different environmental conditions. This PV model gives properly the I-V and P-V characteristics of a photovoltaic module. This system is able to take into account the variations in the environmental conditions such as temperature and irradiance. This model analyzes the impact of different technologies on the PV system. By this multicrystalline technology is proven higher than amorphous silicon technology. Thus in assortment of the best PV technology actually it depends on the usage and also niche area on where the PV system would be applied. Finally through verification using the real time system, the grid connected model can be used for energy output prediction.

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