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Modeling and Simulation of Photovoltaic System using Boost Converter with MPPT and Connected to Grid

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Abstract: *The recent upsurge in the demand of the PV system is due to the fact that they produce electrical power without hampering the environment by directly converting the solar radiation into electric power. However, the solar radiation never remains constant, it keeps on varying throughout the day. The need of the hour is to deliver the constant voltage to the grid irrespective of variation in solar insulation and temperature.*

This paper represents the analysis of modeling and simulation of photovoltaic system with MPPT and connected to grid. It also describes a maximum power point tracker for a photovoltaic system using MATLAB software. The maximum power available from PV system is strongly dependent on weather conditions. So, in order to maximize the efficiency and reliability, it is desirable to predict the maximum power available from PV system. The maximum power point tracker along with the PV module and DC-DC boost converter has been simulated. The simulation results show that the system is capable of predicting the maximum power point correctly under different environmental conditions. Then we coupled the PV array with the boost converter in such a way that with variation in load, the varying input current and voltage to the converter follows the open circuit characteristic of the PV array closely. At various insulation levels, the load is varied and the corresponding variation in the input voltage and current to the boost converter is noted. The power is supplied to the different types of A.C. loads that are termed as standalone by the series and parallel combination of single cell module after that PV module is connected to the grid.

Keywords: *dc-dc boost Converter, Maximum Power Point (MPP), Maximum Power Point Tracking (MPPT), Photovoltaic (PV).*

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Introduction :

The 21st century has brought focus on energy crises. Due to this, many researchers are moving towards developing renewable energy. Renewable energy is a source of pollution-free and green energy. Among all renewable energy sources, solar and wind energy are considered to be good sources. The biggest challenge in developing a photovoltaic system is to track maximum power point (MPP) in the shading condition and dynamic atmospheric conditions because MPP varies with change in variation of parameters like temperature and irradiance. To track maximum power point, there are many maximum power point tracking techniques (MPPT) available. In literature, many MPPT techniques in which main focus is towards to track MPP and operate PV system in global maximum power point. Incremental conductance (INC) and Perturb and observer (P&O) are two most common methods used because of their easy implementation and effective tracking. Boost converter is used as intermediate converter to perform fast switching and regulated output. By many literatures it has been proved that boost converter has more efficient working over the buck converter. The power capacity range of a single PV panel is about 100W to 300W and the maximum power point (MPP) voltage range is from 15V to 40V. The grid connected PV system stage uses a full-bridge inverter in this system employing a high step-up dc–dc converter in the front of the inverter which improves power-conversion efficiency and provides a stable dc link to the inverter. The dc–dc converter is used for large step-up conversion from the panel's low voltage to the voltage level of the application. The high step-up dc–dc converters for these applications posses the following common features:

- High step-up voltage gain. Generally, about a step-up gain is required.
- High efficiency.
- No isolation is required.

A DC-AC inverter used is double and controls the DC-link capacitor voltage and control output current to be in-phase with the grid voltage. It is synchronized to grid using the Phase Locked Loop (PLL).

Model Validations of PV System :

Photovoltaic cell models have long been a source for the description of photovoltaic cell behaviour for researchers and professionals. The most common model used to predict energy production in photovoltaic cell modeling is the single diode circuit model. The ideal photovoltaic module consists of a single diode connected in parallel with a light generated current source as shown in Fig. 2.

A single diode electrical equivalent circuit of a solar module, as shown in the Fig. 1, consists of a current source, diode, series resistance and a parallel resistance. The current source generates the photo-current (IPH) which is a function of the incident solar irradiation and temperature. The diode represents the p–n junction of a solar cell. For real solar cells, the voltage loss on the way to the external contacts is expressed by a series resistance (RS) and the leakage current due to the manufacturing defects is accounted by a parallel resistance (RSH).

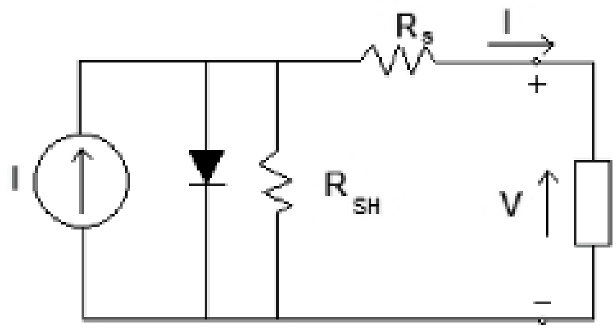


Fig. 1. Circuit diagram of a PV model

Equations

Equations for the Extended I–V curve is derived as follows:

$$I_{rr} = I_{SCR} / [\exp(qV_{oc}/N_s KAT) - 1] \quad 1.1$$

$$I_d = I_{rr} \left(\frac{T_{rak}}{T}\right)^3 \exp\left[\frac{q E_g}{A k}\left(\frac{1}{T_{rak}} - \frac{1}{T}\right)\right] \quad 2.2$$

$$I_{PV} = [I_{scr} + K_i \ (T-298)] * \ I / 1000 \quad 3.3$$

$$I_o = N_P I_{PV} - N_p I_p \{-1\} - \exp\left[\frac{q(V+IR_s)}{A k_s T}\right] \quad 4.4$$

Where,

- Io is the output of the PV module.
- Vo is the output of the PV module.
- Trk is the reference temperature in Kelvin.
- T_{ak} is the module operating temperature in Kelvin.
- I is the PV module illumination (W/cm2).
- q is electron charge 1.6*10-19 C.
- A = 1.3 is an ideality factor.
- K is Boltzman constant 1.3805*10-23 J/K.
- Eg is the band gap of Si 1.12 eV.
- I_{scr} is the the PV module short circuit current at 25C & I =1000 W/cm2.
- N_s is the number of cells connected in series.
- N_p is the number of cells connected in parallel.

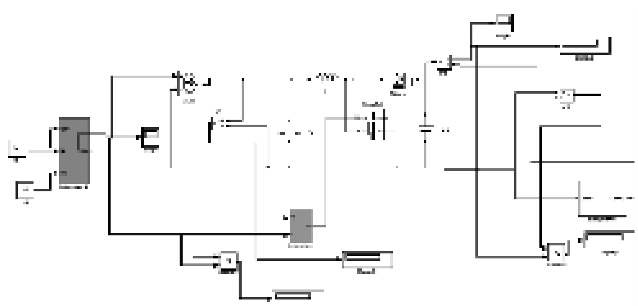
- K_i is the short circuit temperature coefficient at Iscr 0.0013 A/0C.
- R_s is the series resistance of PV module.
- I_{pv} is the light generated current of PV module.
- I_d is the PV module saturation current.

The MATLAB / Simulink model of the PV module is designed by implementing the equations (1.1),(1.2),(1.3), (1.4) are as above:

Based on the above equations and using the electrical specifications presented in Table 1, the PV system model has been developed using MATLAB/Simulink as shown in Fig. 4.

Table 1. Parameter specification of ICO-SPC 100w PV Module [9]

Parameter specification of ICO-SPC 100w PV Module [9]		
Parameter	Variable	Value
Maximum Power	Pm	100W
Maximum Voltage	Vm	17.89V
Current at Max Power	Im	5.79A
Open Circuit Voltage	Voc	20.76V
Short Circuit Current	Isc	6.87
Total No. of cells in series	Ns	36
Total No. of cells in parallel	Np	1



Effect of Temperature :

Like all other semiconductor devices, solar cells are also sensitive to temperature. The electrical efficiency of the photovoltaic panel depends on temperature and is inversely proportional to the temperature. Increase in temperature reduces the band gap of a semiconductor, which effects most of the semiconductor material parameters. The band gap decreases with increasing temperature [23, 24] can be viewed as increasing the energy of the electrons in the material. A small energy is therefore required to break the bond. In the bond model of a semiconductor band gap, due to reduction in the bond energy also reduces the band gap.

Therefore increasing the temperature reduces the band gap which leads to an increase in photocurrent. The parameter most affected by an increase in temperature is the open-circuit voltage. In a solar cell, the dark saturation current of the PV cell increases which leads to a decrease in open circuit voltage. The impact of increasing temperature is shown by the figure 1[25].

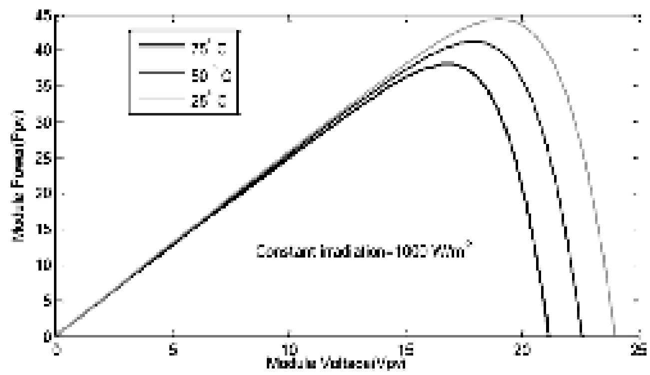


Fig. 3. P-V characteristics with different temperature

Effect of Irradiance :

Current is directly proportional to Irradiance and Voltage has a logarithmic dependence on irradiance. A direct linear relationship is observed by the study of solar flux and efficiency.

Power = VI (Watts)

Efficiency = (Output power of solar panel / (Area of solar panel x 1000W/m^2))×100 %

Solar flux is directly proportional to output current and efficiency, this means that output current is directly proportional to efficiency; therefore output current and solar flux directly determines the efficiency of panel.

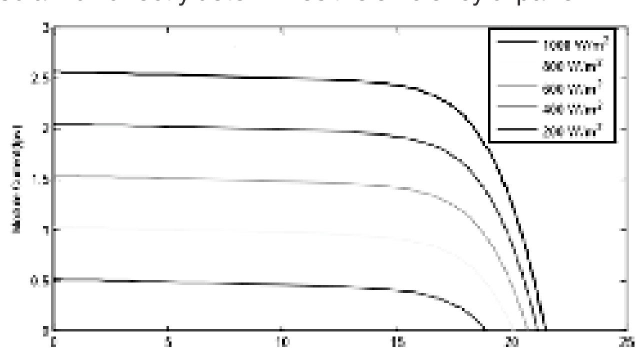


Fig. 4. V-I characteristics with different irrandiance

Boost Converter :

The maximum power point tracking is consisting a load matching problem. For changing the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required. It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, then for a buck-boost converter and minimum for a boost converter but as we intend to use our system either for tying to a grid or for a water pumping system which requires 230V at the output end, so we use a boost converter for such type of applications.

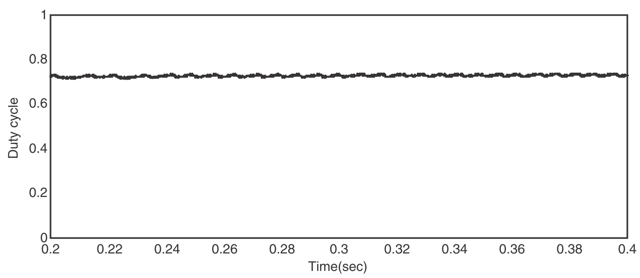


Fig. 5. Duty cycle for boost convertor

MPPT in Photovoltaic Systems:

A typical solar panel converts only 30 to 40 per cent of the incident solar irradiation int electrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem [15], the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. In the source side we are using a boost convertor connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like motor load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance. Under varying irradiance and cell temperature levels, the maximum power point (MPP) and corresponding operate voltage of a PV cell continuously changes. Consequently, autonomous tracking of the MPP [3, 4] is essential to any PV power system to provide maximum energy harvesting at all times. In the proposed PV system, maximum energy harvesting of the PV plant is provided by sub-dividing the plant into smaller, parallel-connected PV arrays, and providing local MPPT of each array via the resonant boost converter interface. Many MPPT algorithms have been proposed, varying in complexity, accuracy, convergence speed and cost. A good summary of offline and online MPPT methods is 45 Maximum Power Point Tracking Control System 46 provided in [19]. The most widely applied algorithms are the hill-climbing and perturb and observe (P&O) methods. Both methods involve the perturbation of either the duty ratio (hill climbing) or the input voltage reference (P&O) of the power converter and measuring the change in power due to the perturbation. Figure 4.1 shows the P-V characteristic of a PV panel and how the P&O algorithm adjusts the operating point on the curve. A voltage increment _V (decrement) to the left of the maximum power point voltage VMPP results in an increase (decrease) in the power produced by the PV panel. Therefore if the algorithm determines that the perturbation has resulted in a positive (negative) change in power P, the following perturbation is maintained (reversed), and until the maximum power point PMPP has been reached.

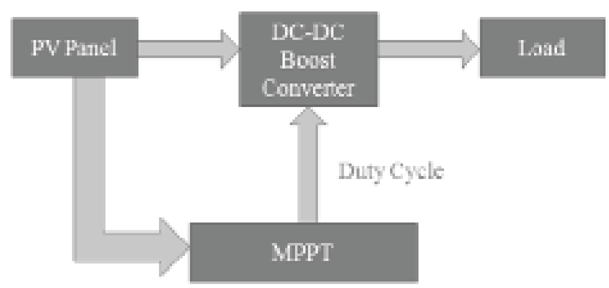


Fig. 6. An Overview of Maximum Power Point Tracking

Perturb and Observe (Hill Climbing Method)

In this method the controller adjusts the voltage by small amount from the array and measures power, if the power increases further adjustments in that direction are tried until power no longer increases. This is called the Perturb and Observe method. Like the P&O algorithm, incremental conductance algorithm can produce oscillation in power output and can perform erratically under rapidly changing atmospheric condition. This method computes the maximum power point by comparison of the incremental conductance to array conductance, when these two are the same; the output voltage is the MPP voltage. The simulation of perturb and observe MPPT are shown in above figure.

Both P&O and Incremental conductance method that can find the local maximum of power curve for the operating condition of PV array, and so finally provide a true maximum power point As we analyze the graph of the current Vs voltage we get that the maximum power is obtained at somewhat less than short circuit current termed at maximum current .and the below open circuit voltage that is termed as open circuit voltage. A standalone photovoltaic pumping system (PVPS) is one of the most promising applications of photovoltaic (PV) systems, specifically in the remote areas, that have an important insulation and have no access to an electric grid. To operate in the power point (MPP) of the PV panel, and improve the efficiency of the system, we use the technique of tracking of the MPP.

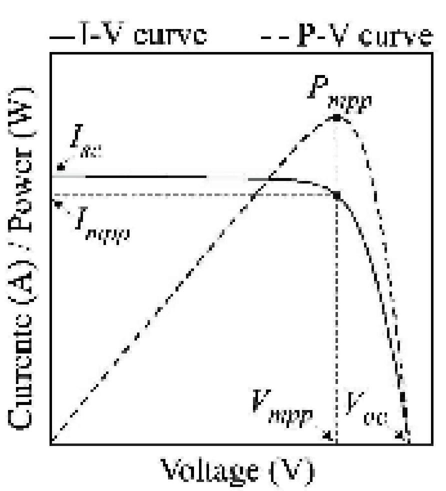


Fig. 7. IV PV curve

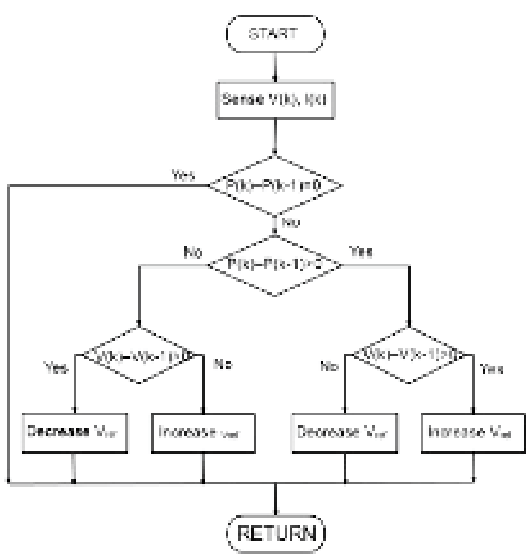


Fig. 8. Perturb and observe (hill climbing method)

Simulation Results and Analysis :

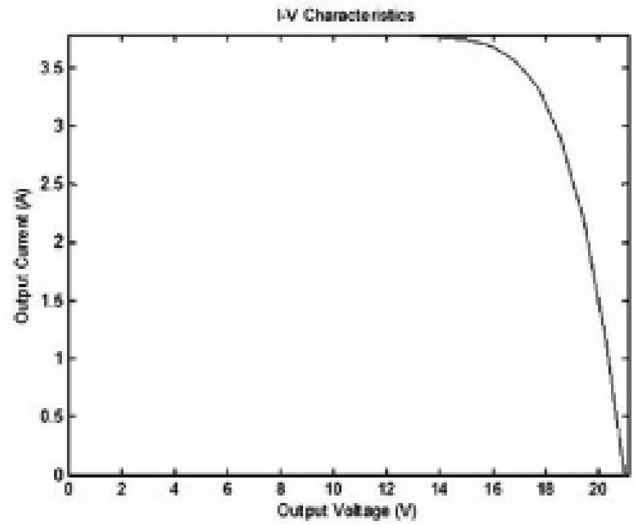


Fig. 9. IV curve of PV

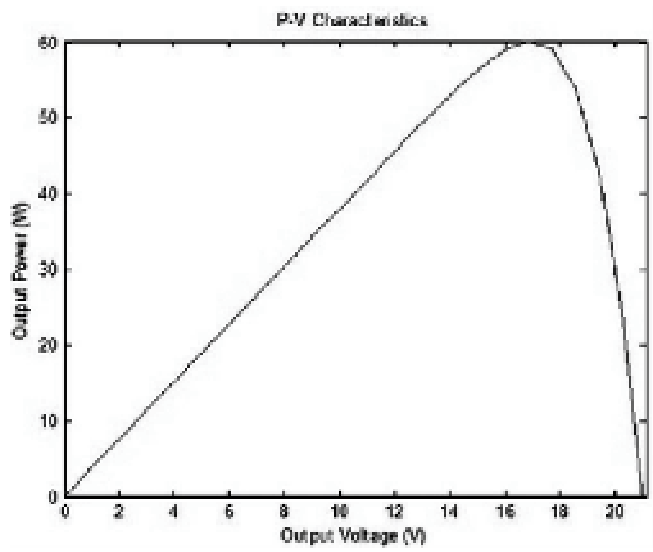


Fig. 10. pv curve of PV

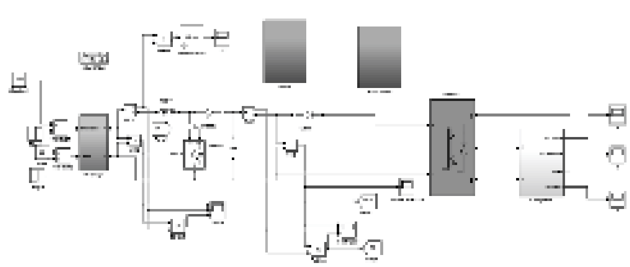


Fig. 11. Simulation of Grid connected PV system using Boost Converter and Maximum Power Point Tracking (MPPT)

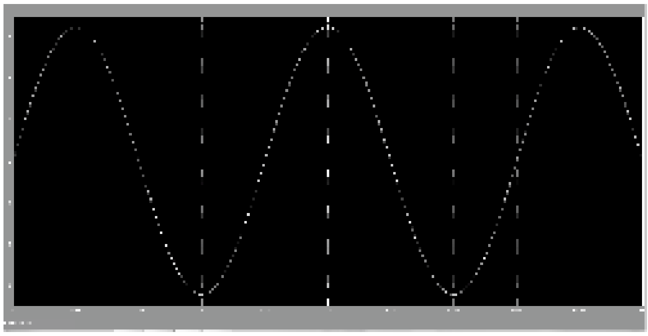


Fig. 12. Grid synchronization current

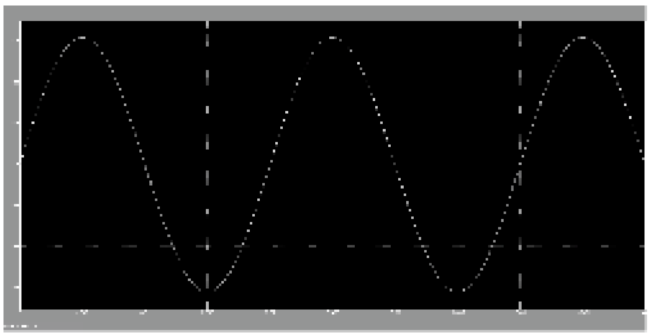


Fig. 13. Grid synchronization voltage

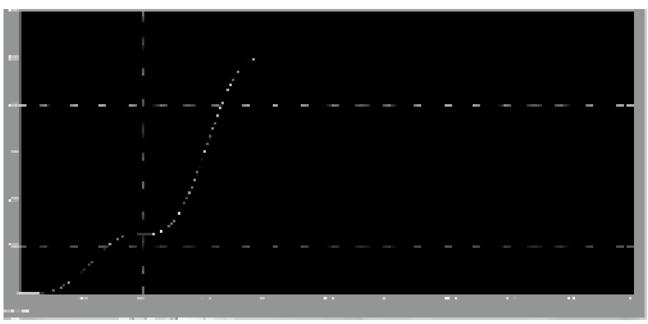


Fig. 14. Active power of grid

Conclusions :

This paper describes a detailed analysis of the effect of solar irradiance and temperature on the I-V and P-V curve of photovoltaic module SOLAREX MSX-60, by MATLAB simulation. In order to track the maximum power point under different irradiance and temperature conditions, an MPPT is designed which employed Perturb and Observe Algorithm. Further, a DC-DC boost converter is specifically designed for SOLAREX MSX-60 module which successfully stabilized the operating point of PV system that in turn facilitated the task of MPPT. The entire model is capable of tracking the MPP with good efficiency, faster response and satisfactory power output. After that by applying the voltage source inverter and voltage control scheme it can be capable to supply power to ac loads so by increasing the no of series and parallel connected PV module total power has been increased and supplied to standstill load connected to the PV array.

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