

Modeling and Simulation of a PV System using DC-DC Converter

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Abstract- In this era of efficient use of energy and cost cutting, solar energy comes into prominence. Conversion of this freely available energy into useable form will reduce the burden on other resources; while at the same time expand our energy reserve. In this paper, an attempt has been made to model and simulate a photovoltaic cell. PV cell works at its efficient best when it is operating at its maximum power point. The energy derived from the cell is used to power the load. A DC-DC converter is used as an interface between the cell and the load. A buck-boost converter is implemented as it serves our purpose over the entire operating range of the PV cell. The duty cycle of the converter is varied to ensure impedance matching between the cell output and the load while the “Perturb and Observe” algorithm tracks the maximum power point of the cell. The set-up is studied under different conditions and for different values of the load. An inverter can be used at this stage for a load that works on ac voltage. The whole circuit is simulated using MATLAB SIMULINK. The idea is to ensure maximum performance of the set-up irrespective of the changes in the physical conditions.

I. Introduction

Solar energy is the primary source of energy. It is renewable and eternal. The need for converting solar energy to usable form arises due to the exhaustion of fossil fuels. A solar cell serves this purpose. This paper aims at the modeling and simulation of a PV system using a DC-DC converter in MATLAB/ SIMULINK. A PV cell is used to convert solar energy into electrical energy by photovoltaic effect. A photovoltaic cell is made up of two layers: n layer and p layer respectively. The p-layer which is thinner than the n-layer is exposed to sunlight. The photons from the sunlight are absorbed by the semiconducting material thereby exciting the free electrons to travel from n-layer to p-layer. Hence there is a flow of current in the circuit. Thus, a PV cell outputs a short circuit current depending on the irradiance and temperature.

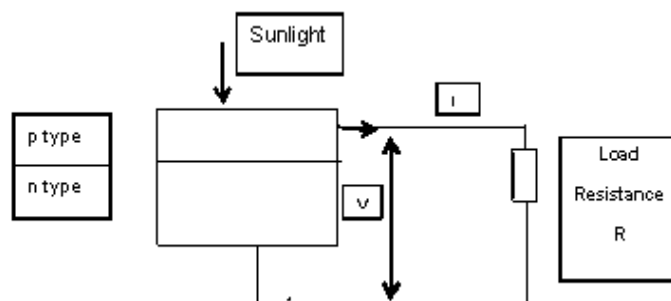


Figure 1: The basic model of a PV cell.

The output of the PV system is not very efficient due to the varying atmospheric conditions such as temperature and irradiance. Hence, to improve the performance of the PV system, a MPPT system and a DC-DC converter are employed. The MPPT system is responsible to track the maximum power point of the PV system and transfer it to the load. The DC-DC converter is used to improve the strength of the source voltage.

II. Materials and Methods

Characteristics of the PV module:

To study the performance of the PV module under various atmospheric conditions, it is required to estimate IV and PV characteristics.

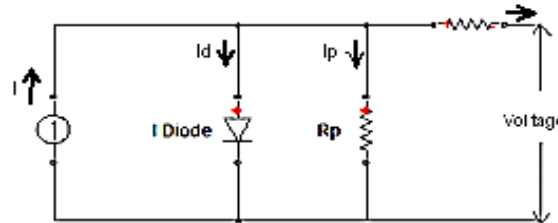


Figure 2: The equivalent one diode model for PV.

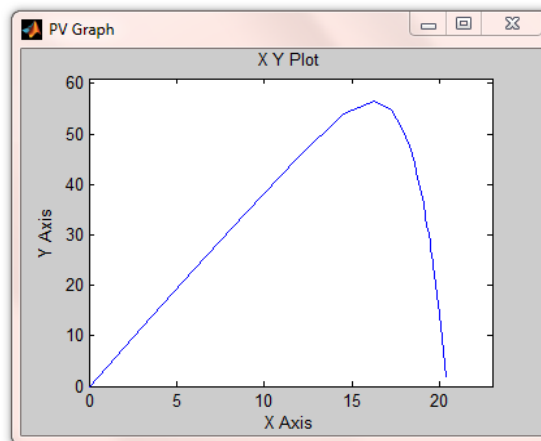
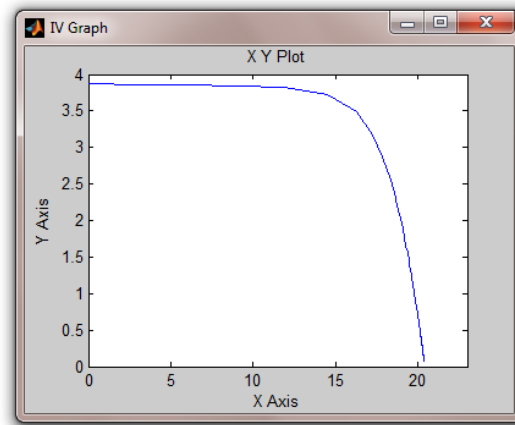


Figure 3: I-V and P-V characteristic curves of a PV module.

When no load is connected to the module, there is no current flow in the circuit. Hence, the voltage across the PV reaches its maximum. This voltage is the Open circuit voltage. When a load is connected there is an increase in the current which results in the decrease in the voltage. This current is called the Short circuit current. This short circuit current is directly proportional to the irradiation. The PV cell operates in two different regions: constant voltage and constant current. The slope of the characteristics in constant current region is decided by R_p and that in constant voltage region is decided by R_s .

On applying Kirchhoff's current law to the node 'A' :

$$I_{ph} = I_d + I_{rp} + I$$

$$I = I_{ph} - I_d - I_{rp}$$

$$I = I_{ph} - I_o [\exp((V + I.R_s)/V_t) - 1] - [(V + I.R_s)/R_p] \text{ ----- equation 1}$$

Where:

I_{ph} : Insolation current

I_o : Reverse saturation current

I : Cell current

V : Cell voltage

R_s : Series resistance

R_p : Parallel resistance

V_t : Thermal voltage = KT/q

K : Boltzmann constant

T : Temperature in Kelvin

q : charge of an electron

Substituting $V = 0$ in equation 1;

$$I_{sc} = I_{ph} - I_o [\exp((I_{sc}.R_s)/V_t) - 1] - [(I_{sc}.R_s)/R_p]$$

I_{sc} : Short circuit current

Substituting $I = 0$ in equation 1;

$$V_{oc} = V_t \cdot \ln ((I_{ph} / I_o) - (V_{oc} / I \cdot R) + 1)$$

V_{oc} : Open circuit voltage.

Modeling of the PV system:

This paper deals with the modeling of a PV system in MATLAB / SIMULINK based on the mathematical equations. The PV module consists of 36 cells which are interconnected, each with a power rating of 1.36W. The module voltage is calculated by multiplying the individual cell voltage by the number of cells.

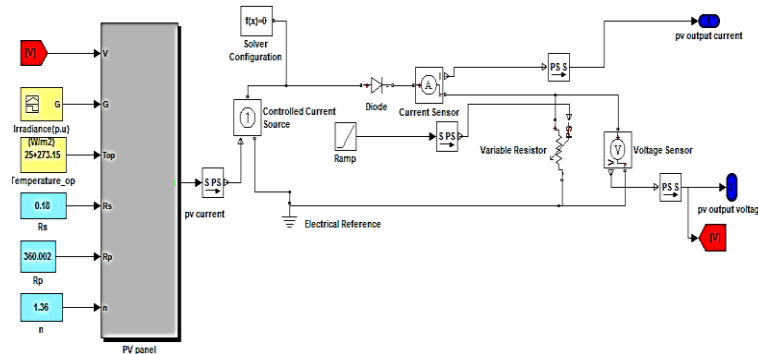


Figure 4: The Simscape model of the PV module.

Buck Boost Converter:

The DC-DC converter acts as an interface between the system and the load. A buck boost converter (step up / step down) is implemented here; it extracts the maximum power point regardless of the temperature difference, irradiance and load conditions. On changing the duty cycle of the converter the source impedance can be matched with the load impedance to maximize the power efficiency. This converter either bucks or boosts the output voltage with respect to the input voltage. The buck boost converter is designed based on the following formulas:

The output voltage of the converter,

$$V_o = V_s(D / (1 - D)) \text{ where } V_s = V_{pv}$$

The inductance L is given by,

$$L = (1 - D)^2 R / (2 \cdot f)$$

Where R is the load resistance and f is the switching frequency.

The voltage ripple of the buck boost converter is computed from,

$$\Delta V / V = D / R \cdot C \cdot f$$

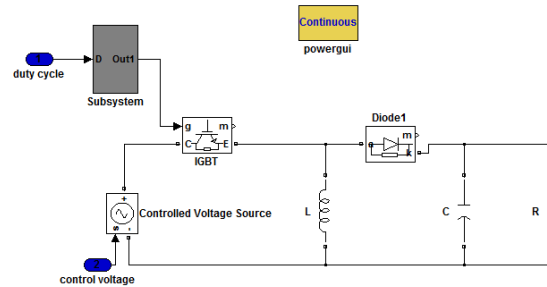


Figure 5: Buck boost converter.

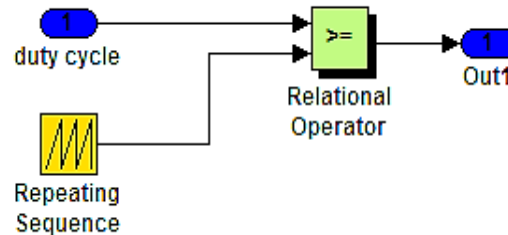


Figure 6: Generation of PWM signal.

The figure shows the buck boost converter. The duty cycle is generated by the MPPT system and it is compared with a repeating sequence to produce a PWM signal as shown in the figure. The PWM signal is used to control the ON and OFF time of the IGBT in the converter. As long as the IGBT is ON, the capacitor charges and the input voltage of the converter i.e. the PV voltage is reproduced at the output. If the duty cycle $D > 0.5$ then the output voltage of the converter is larger than the input voltage and if $D < 0.5$ the output voltage is smaller than the input voltage.

Maximum Power Point Tracking system:

Since the output of the PV is less efficient, a MPPT system is adopted to enhance the PV power. This paper emphasizes on the Perturb and Observe algorithm to optimize the performance. This is achieved by varying the duty cycle of the buck boost converter so that the source impedance can be matched with load impedance. Each time the output power of the buck boost converter is compared with the previous power of the module and the duty cycle of the converter is adjusted accordingly to track maximum power point. This process continues until the power of the PV reaches the maximum value (close to MPP).

Perturb and Observe method:

In this algorithm, the PV voltage $V(k)$ and the current $I(k)$ are the inputs. The power of the PV is calculated accordingly. The power and the voltage of the PV are delayed by $(k-1)$ instant. The present value of P and V are compared with the previous values and their difference is noted.

$$\Delta P = P(k) - P(k-1)$$

$$\Delta V = V(k) - V(k-1)$$

If ΔP and ΔV are positive then the duty cycle is decreased i.e.; $D = D - \Delta D$.

And if ΔP is positive and ΔV is negative duty cycle is increased i.e.; $D = D + \Delta D$.

On doing this repeatedly, the maximum power point is tracked and the output power of the PV system is maximized.

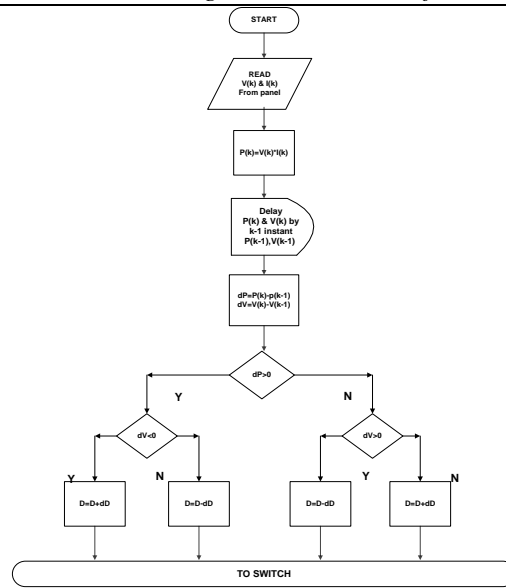


Figure 7: Flowchart for the MPPT.

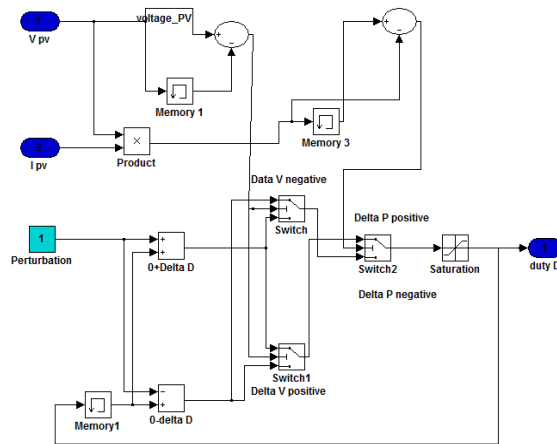


Figure 8: Perturb and Observe MPPT design in Simulink.

The whole system:

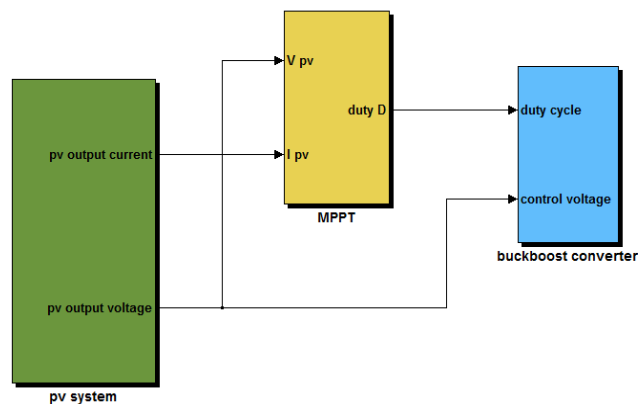


Figure 9: Whole system.

The whole system is an interface between the PV system and a converter with a MPPT block. The PV module is implemented in MATLAB/Simscape, the MPPT is developed in MATLAB/Simulink and the converter in SimpowerSystems. The output current and voltage from the PV is given to the MPPT which is used to generate duty cycle. The MPPT system will change the duty cycle of the converter depending on the atmospheric variations. The other input to the converter is the PV voltage which is coupled using a controlled voltage source (which is an interface between Simscape and Simpower Systems).

III. Results and discussions

The proposed PV module in MATLAB/Simscape is shown in the figure 4. The I-V and P-V plot for different irradiances at constant temperature $T=25\text{ }^\circ\text{C}$ are shown in figure 10 and 11 respectively.

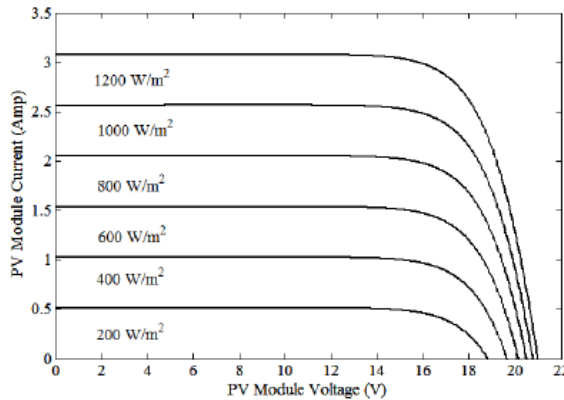


Figure 10: I-V characteristics curves of the PV system for different irradiances.

When the irradiance decreases the output photo current of the PV system also decreases thereby decreasing the load voltage.

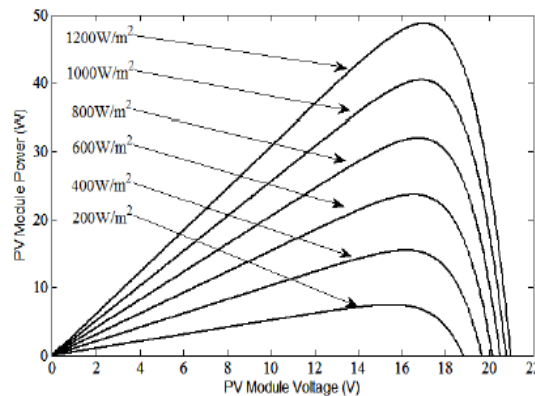


Figure 11: P-V characteristics curves of the PV system for different irradiances.

We see that the power of the system increases with the increase in voltage. Once the power reaches its maximum value, with further increase in voltage the power decreases. The maximum power is transferred when the resistance of the load matches with the source resistance

An irradiance of 200 W/m^2 has obtained a maximum power of almost 10 W and an irradiance of 1200 W/m^2 has a maximum power of 50 W.

The current and voltage outputs of the buck boost converter are shown in the figure 12.

The input voltage to the converter is 20.6V and the output voltage of the converter is 18.4 V. The buck boost converter is controlled by applying duty cycle to the IGBT. This is calculated using the formulae $V_o = V_s \cdot (D/1-D)$. So the duty cycle is 0.533. For a buck boost converter, if $D = 0.5$ the output voltage either decreases or increases with respect to the input voltage. In this system, the output voltage is decreased. Hence it acts as a buck converter.

The system power is 73 W. The figure 13 shows the output power of the system.

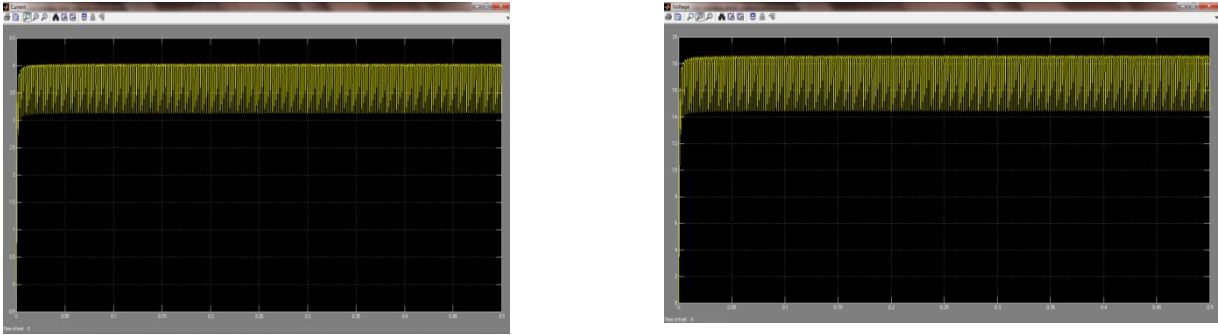


Figure 12: The output Voltage and Current of the converter.

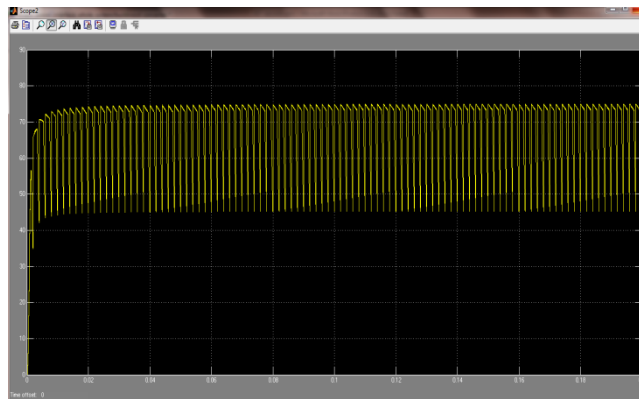


Figure 13: The system power.

The Perturb and Observe method works efficiently and provides duty cycle to the converter.

IV. Applications

The output of the PV system is a DC voltage. Therefore, it can be used to charge a battery. An inverter converts DC voltage into AC, which can power which work on AC like television and other home appliances.

V. Conclusion

This paper analyzes and studies the performance of a PV system implemented using MATLAB/Simulink. The simulation result implies that the Perturb and Observe algorithm tracks the maximum power point. We conclude that the MPPT system adjusts the duty cycle of the buck boost converter in varying irradiances and temperature to extract the maximum power from the system and deliver it to the load. The buck boost converter will either increase or decrease the output voltage with respect to the input voltage based on the duty cycle. The I-V and P-V characteristics of PV module is studied under various irradiances and it is found that the generated photo current has only a very little effect on the short circuit current and also, on increasing the temperature the efficiency of the PV module decreases.

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VII. References

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