

# Photovoltaic (PV) model Evaluation with Maximum Power Point Tracking (MPPT)

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**Abstract:** Solar energy is widespread this is due to increase in its demand across the world. This is because this form of energy can supply steady, stable, regular and clean energy. Evaluation of PV (photovoltaic) model with maximum power point tracking (MPPT) using matlab/simulink cell model for estimating the I-V characteristic curves of photovoltaic panel with respect to changes on environmental parameters (temperature and irradiance) and cell parameters (parasitic resistance and ideality factor) were evaluated. The PV model equations were modelled and simulated using MATLAB/SIMULINK Approach. This paper confirmed the usefulness of MATLAB/SIMULINK in the development of MPPT (maximum power point tracking) algorithm. Using a Shockley diode equation, an accurate simulink PV panel model was developed. The variables which affected the performance of a PV panel were studied thoroughly and every manufacturer intends to produce their PV panel in the ideal condition.

**Keywords:** Photovoltaic, diode, energy, model, temperature, irradiance

## 1.0 Introduction

In order to create low power remote and independent electronic devices it is necessary to collect and convert energy directly from the environment. This is very important in order to maintain a continuous operation. A good solution is the use of a photovoltaic device [1]

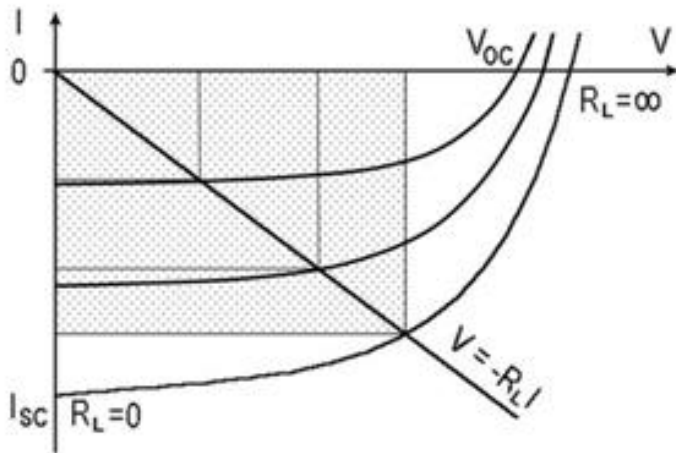
Renewable energy resources have become the major attention in the power sector, there is a growing awareness that renewable energy such as photovoltaic system. Solar arrays are used in many terrestrial and space applications [2]. For best utilisation, the photovoltaic cells must be operated at their maximum power point (MPP). However, the MPP varies with illumination, temperature, solar radiation and other ageing effects. The energy radiated by the sun on a bright sunny day is approximately  $1\text{kw/m}^2$  attempts have been made to make use of this energy in raising steam which may be used in driving the prime movers for the purpose of generation of electrical energy [3]. However on account of large space clouds, winds, haze etc., there is limited application of this source in the generation of electric power.

In this paper, Modelling and simulation were implemented using MATLAB/SIMULINK with the aim of verifying the effectiveness.

## 2.0 PV cell model

Modelling is basic tool of the real system simulation. For modelling, it is necessary to analyze the influence of different factors on the photovoltaic cells and take into consideration the characteristics given by the producers [4]. The mathematical models for photovoltaic cells are based on the theoretical equations that described the operation of the photovoltaic cells and can be developed using the equivalent circuit of the photovoltaic cells. The empirical models rely on different values extracted from the I-V characteristic of the photovoltaic cells and they approximate the characteristic equation of the solar panels using an analytical function [5].

The photovoltaic panel is a power source whose parameters depend on some external factors like incident light angle, shading, ambient temperature etc. Some of these factors are unpredictable and, for this reason, so is the evolution of cell parameters. The most known parameters of the photovoltaic panel are the open circuit voltage ( $V_{oc}$ ) and short circuit current ( $I_{sc}$ ). These values define the points where the I(V) graph curve of the panel intersects the two axes (I and V), like in Fig. 1.

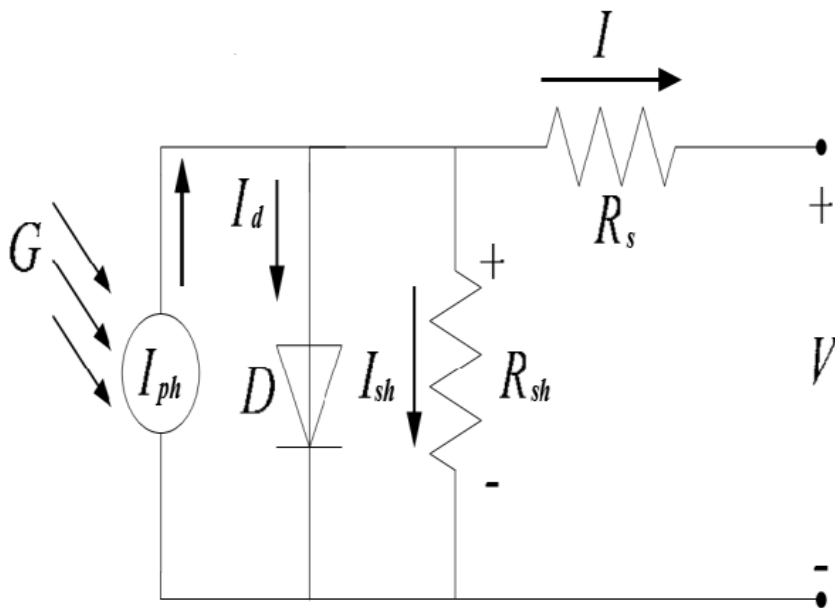


**Fig. 1. Some  $I(V)$  characteristics of a photovoltaic panel under different work conditions**

Every point on the  $I(V)$  curve has specific values of  $V_i$  and  $I_i$ , defining the power as  $P_i = V_i \cdot I_i$ . For a specific  $I(V)$  curve there is only one point corresponding to the maximum power. This is called maximum power point or MPP. For any power source it is always good to supply electrical consumers at this value or close to it. For a specific resistive load,  $R_L$ , the  $I(V)$  load characteristic is a line given by the equation  $I = -V/R_L$ . This line intersects the panel characteristic in a point which is near or far from MPP (Fig. 1.). According to this position, the power transferred to the load can only be a fraction of the power that panel can supply at MPP. To correct this unbalance and prevent the associated loss of usefully power, some methods, generically named MPPT (Maximum Power Point Tracking) are used.

A simplest equivalent circuit of a solar cell is a current source in parallel with a diode. The output of the current source is directly proportional to the solar energy (photons) that hits on the solar cell (photocurrent  $I_{ph}$ ).

During darkness, the solar cell will not be an active device; it works as a diode, i.e. a p-n junction. It produces neither a current nor a voltage. However, if it is allowed to connect to an external source (large voltage) it generates a current  $I_d$ , called diode (D) current or dark current. The diode determines the  $I(V)$  characteristics of the cell.



**Figure 2: Circuit diagram of a PV cell [6].**

The circuit diagram of a PV cell showed above in figure 2 was the accurate simulation obtained after considering the following parameters:

- Temperature dependence of the diode reserved saturation current  $I_s$ .

- Temperature dependence of the photo current  $I_{ph}$ .
- Series resistance  $R_s$  [9] (internal losses due to the current flow) which gives a more accurate shape between the maximum power point and the open circuit voltage.
- Shunt resistance  $R_{sh}$  [9], in parallel with the diode, this corresponds to the leakage current to the ground. Equations which defined the model of a PV cell were given below in equations (1- 5) [9], [10]:

$$V_t = \frac{kT_{op}}{q} \dots\dots\dots(1)$$

$$V_{oc} = V_t \ln \left( \frac{I_{ph}}{I_s} \right) \dots\dots\dots(2)$$

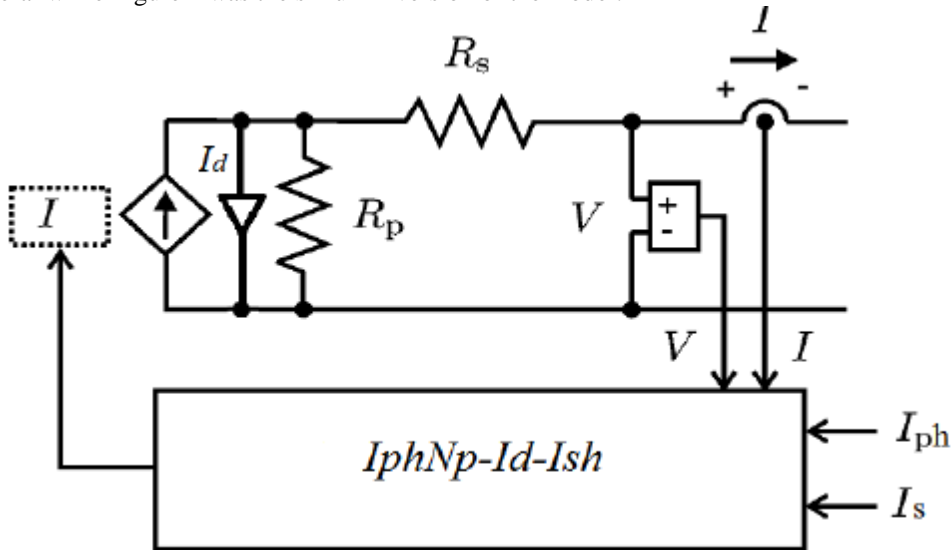
$$I_d = \left[ e^{\left( \frac{V+IR_s}{nV_tCN_s} \right)} - 1 \right] I_s N_p \dots\dots\dots(3)$$

$$I_{ph} = G_R [I_{SC} + k_i (T_{op} T_{ref})] \dots\dots\dots(4)$$

$$I = I_{ph} N_p - I_d - I_{sh} \dots\dots\dots(5)$$

**3.0 Method of Study**

Considering the environmental and cell parameters, a PV cell simulation set up model based on equations (1)-(5) and Tables 1 was developed in MATLAB/SIMLINK with a variable load resistance at the output. Fig. 3 depicted the PV cell simulation set up in general while Figure 4 was the simulink version of the model.



**Figure 3: A PV cell simulation set up [13]**

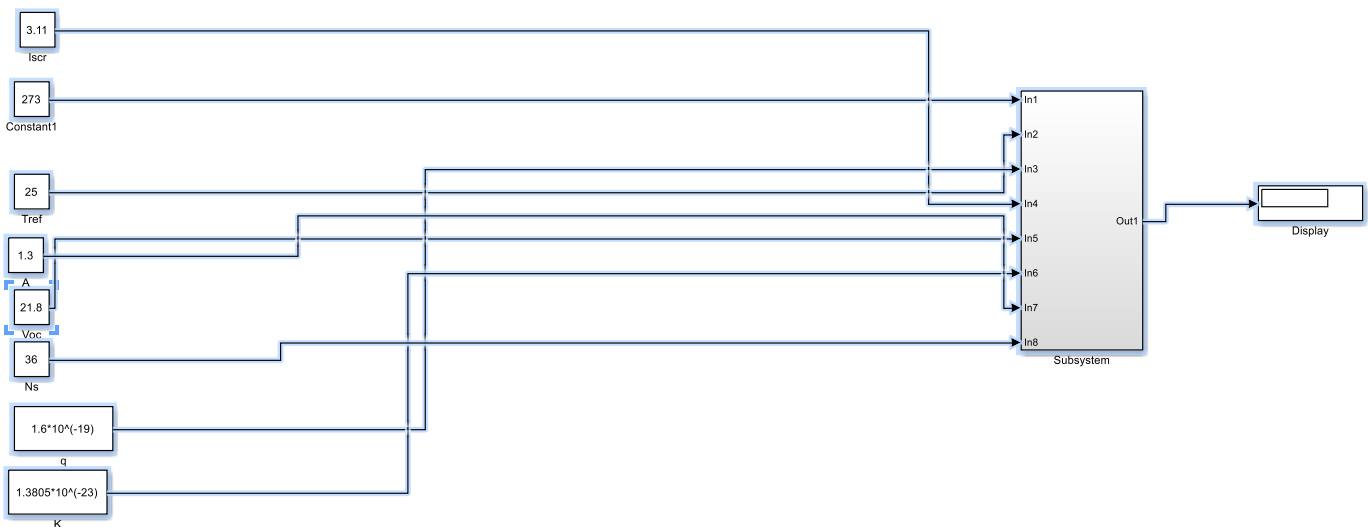


Figure 4: A PV cell SIMULINK set up

After changing  $G, T_{op}, R_s, R_p$  and  $n$  different results are obtained. Prior to simulation, some predefined specification are obtained for Solarex MSX-60 from [13] and is shown in Table.1

Table 1: PV panel parameters

Attribute	Value
Voc (open circuit voltage )	21.8V
Isc (Short Current Voltage)	3.11A
Vmp (Voltage at MPP)	17.44V
Imp(Current at MPP)	2.86A
Pmp (Power at MPP)	50W

4.0 Results and Discussions

4.1 Results

Table 1.0 show the calculated data from the simulated model [8] at standard temperature conditions. Table 1 is used for evaluating the simulation results.

Figures. 5, 6, 7, 8 shows the Current-Voltage (*IV*), Power-Voltage (*PV*), Power-Current(*PI*), Power-Temperature(*PT*) curves at different irradiance  $G$  ( $W/m^2$ ) with constant  $T_{op}=25$

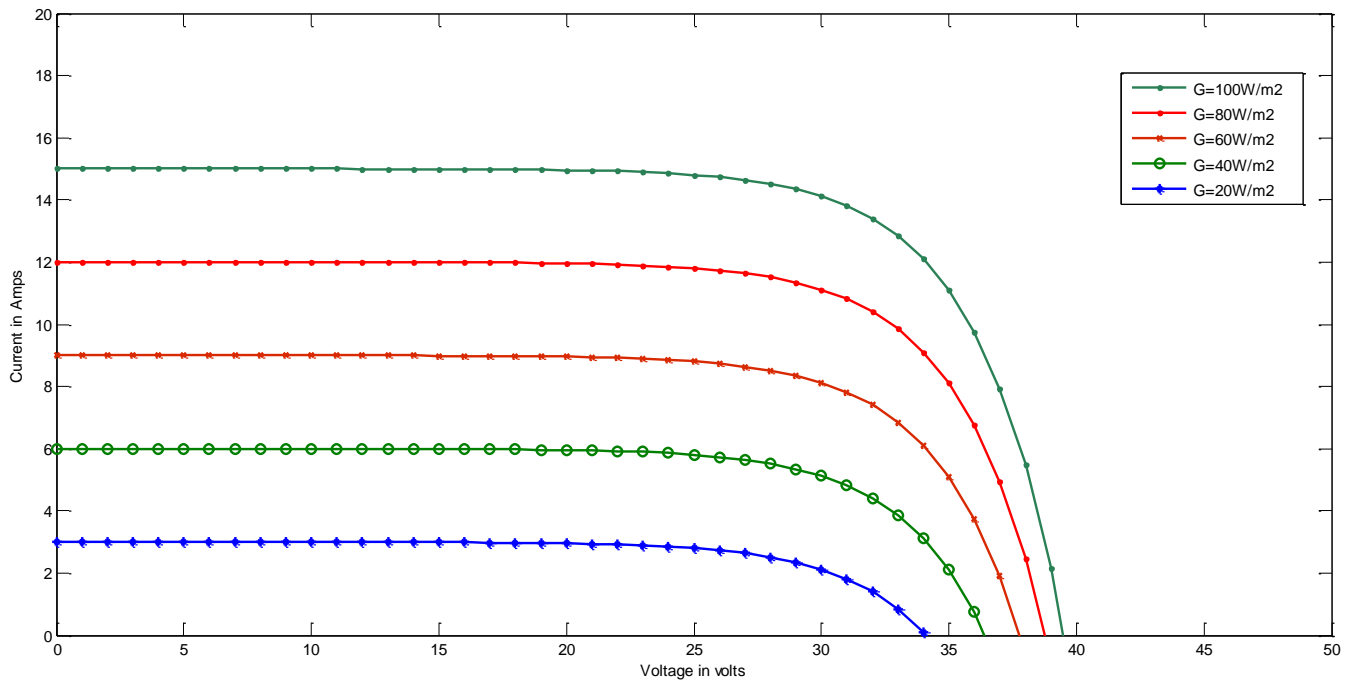


Figure 5: Current-Voltage curves at different Irradiance (G)

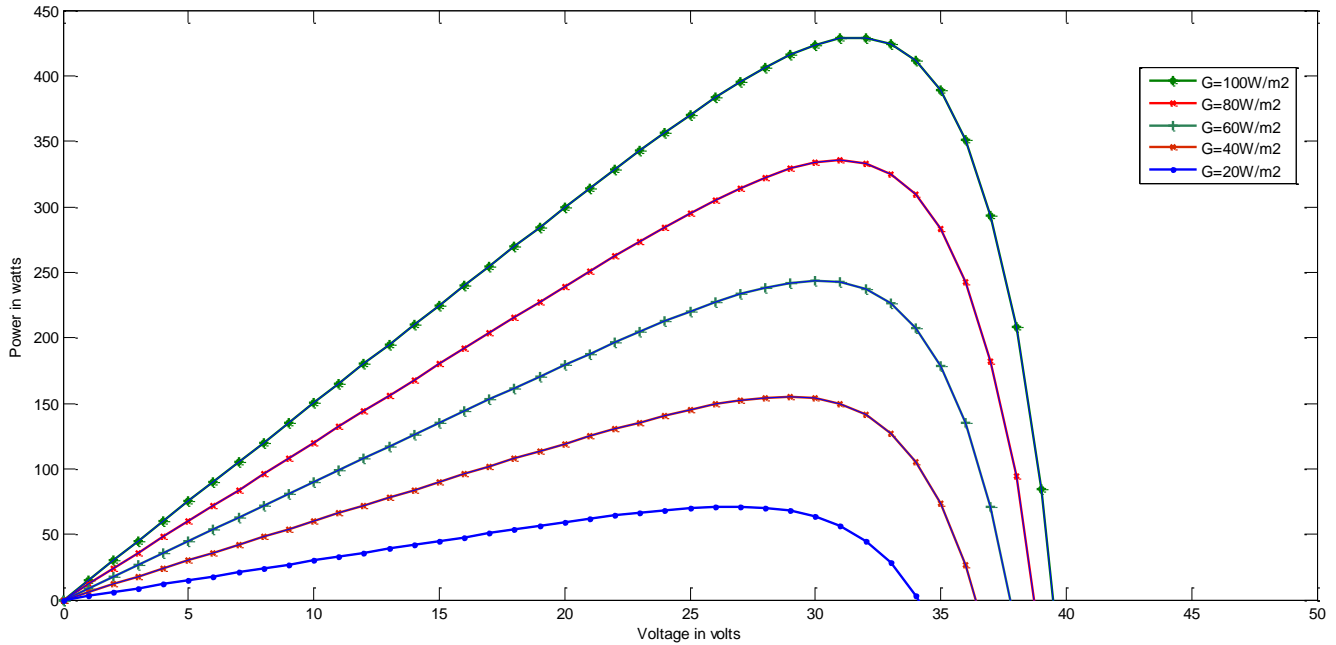


Figure 6: Power-Voltage curves at different Irradiance (G)

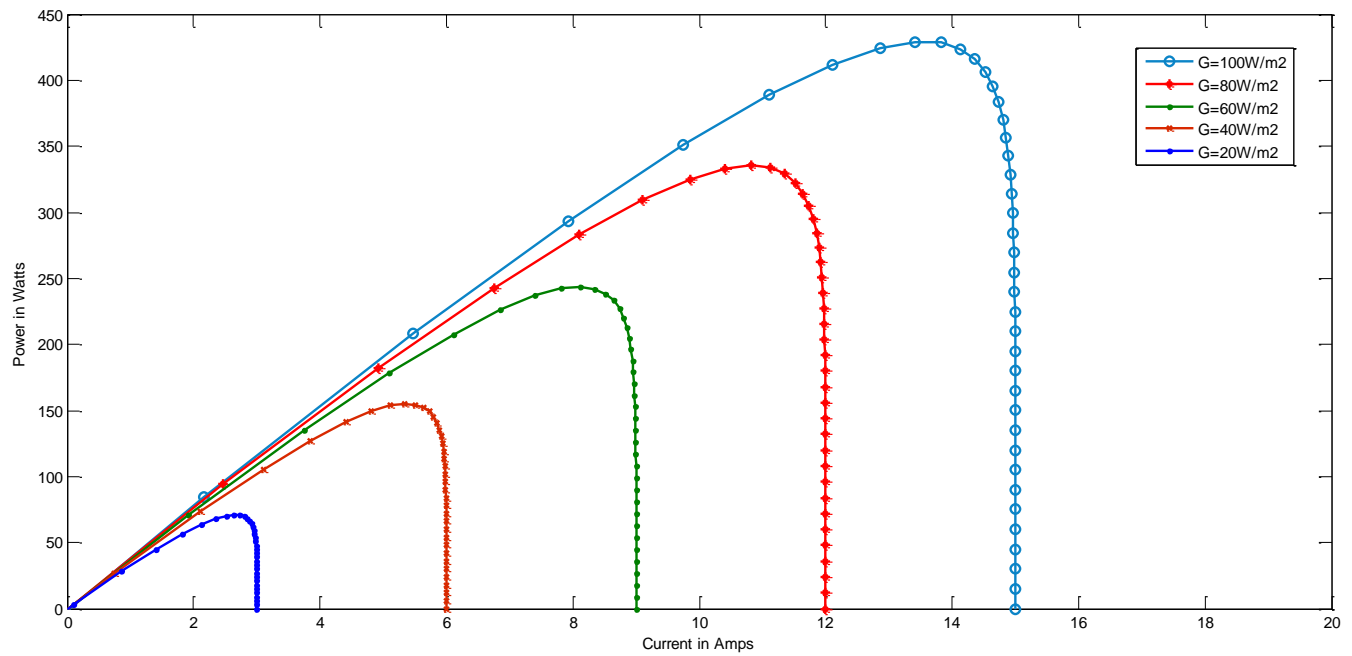


Figure 7: Power-Current curves at different Irradiance (G)

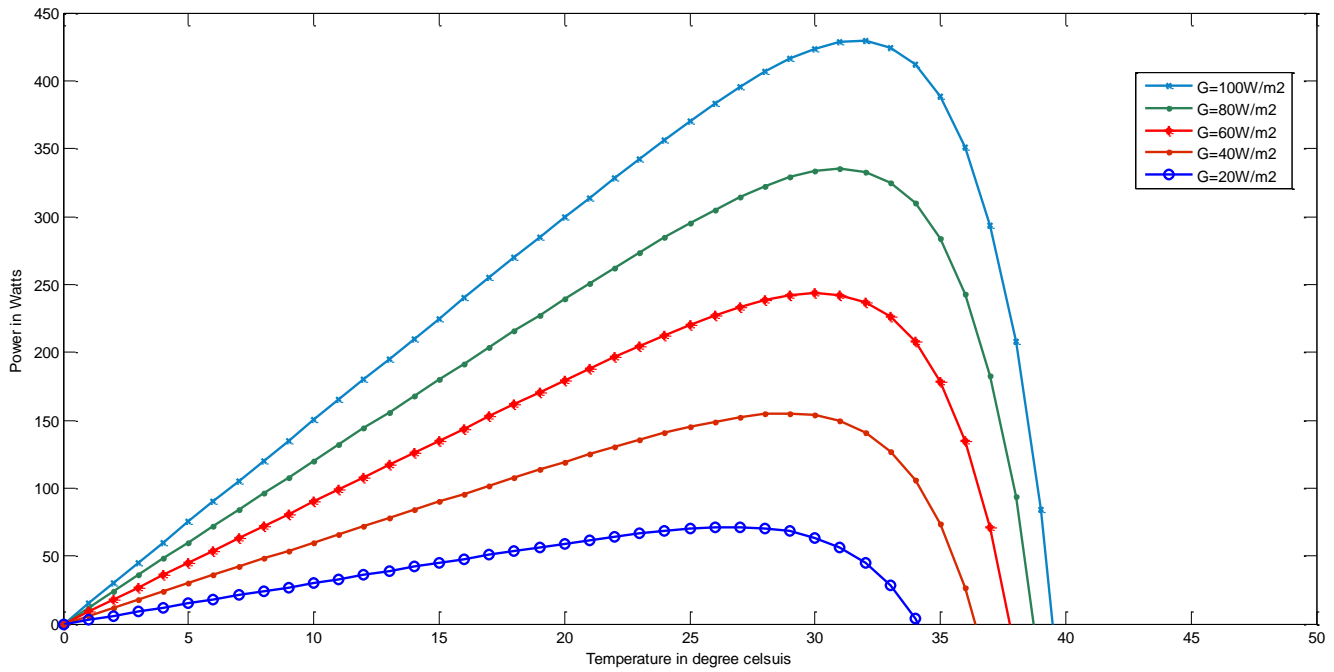


Figure 8: Power-Temperature curves at different Irradiance (G)

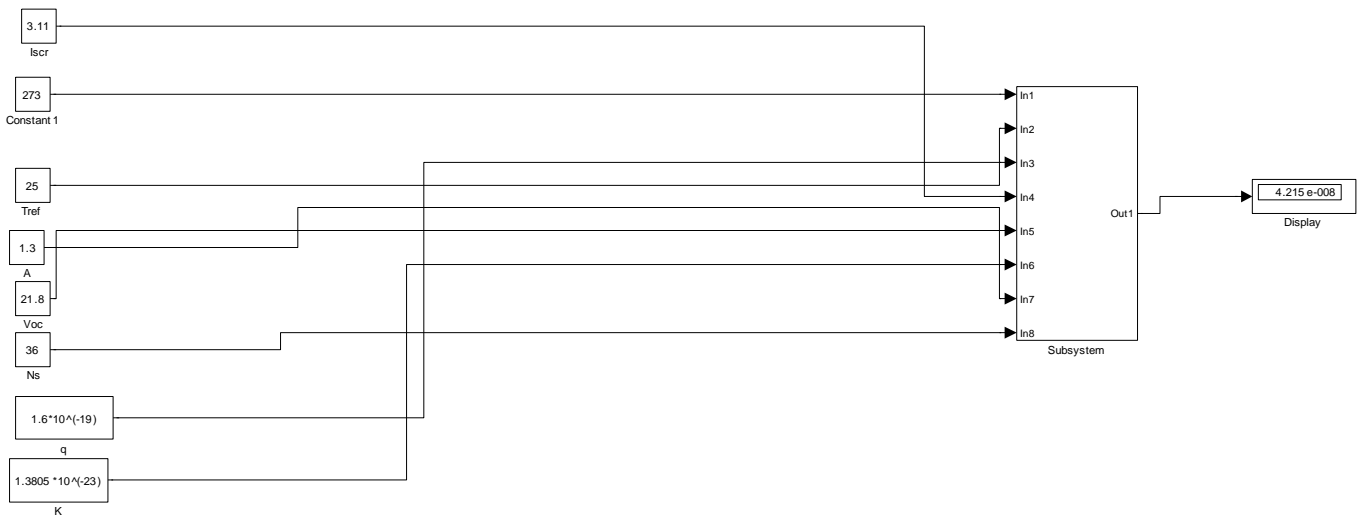


Figure 9: A PV cell simulation with result displayed

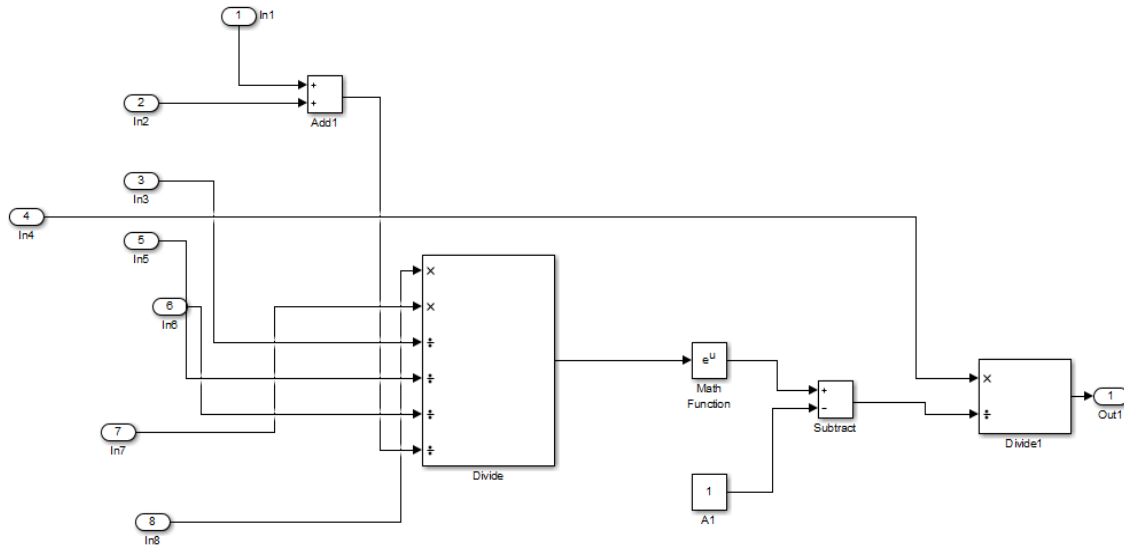


Figure 10: Subsystem embedded in the PV model in simulink

### Discussions

Figures 5 to 8 show that the irradiance increases with power as shown the plots. The Voltage against Power characteristics and Voltage against Current characteristics of a solar cell mainly depends upon the solar irradiation as showed in Figure 5 and 6. The solar irradiation level changes with variation in environmental conditions which can result into different maximum power. Therefore the maximum power point tracking algorithm can only be used to maintain the maximum power constant when there is unstable solar irradiation level. If the solar irradiation level is higher, then more input to the solar cell is needed which would yield a higher magnitude of the power with the same voltage value. When there is increase in the solar irradiation the open circuit voltage increases. Because, when there is more incident radiation of solar light when it falls on the solar cell, as a result of higher excitation energy, more electrons will be supplied, they therefore increase the mobility level of electron resulting in more power is generation.

### 5. Conclusion

From the simulation results which are depicted in figures (5)-(10), the variables  $G$ ,  $T_{ak}$ ,  $R_s$ ,  $R_p$  and  $n$  which affected the performance of a PV panel was studied thoroughly. In addition to it, these results could be used to develop the MPPT algorithm by understanding how these variables work. The ideal condition for obtaining the maximum power from the PV panel are  $T_{op} = 25^\circ\text{C}$ , A.M = 1.5,  $R_s = 0.18 \text{ ohm}$ ,  $R_p = 360 \text{ ohm}$  and  $n = 1.36$  which is shown in Figure 5 with legend  $G = 1000 \text{ W/m}^2$  (blue colour). This ideal condition was also specified in the Solarex MSX-60 datasheet [9]. Every manufacturer intends to produce their PV panel in the ideal condition as mentioned above and the nomenclature is given below.

#### Nomenclature

STC: Standard Test Condition,  $G = 1\text{kW/m}^2$  at spectral distribution of AM=1.5,  $T_{ak} = 25^\circ\text{C}$

$V_0$  = Output voltage of the PV module

$n$  : Diode ideality factor, 1.36

$N_s, N_p$  : No of PV panel in series & parallel

$E_g$ : Band-gap energy of the cell, 1.12eV

A.M : Air mass coefficient [12]

$I_{scr}$ : the PV module short circuit

$T_{rk}$ : reference temperature in Kelvin

$T_{ak}$ : module operating temperature in Kelvin

$q$ : electric charge  $1.6 \times 10^{-19}$

$V$ : Thermal Voltage, V

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