



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

R. I. Areola<sup>1</sup>, F. T. Oyediji<sup>1\*</sup> and E. A. Olajuyin<sup>2\*</sup>

<sup>1</sup>Federal Polytechnic Ile-Oluji, Ondo State, Nigeria.

<sup>2</sup>Bamidele Olumilua University of Education Science and Technology Ikere, Ekiti State, Nigeria.

## Authors' contributions

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

## Article Information

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## ABSTRACT

The use of solar energy is widespread 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. It was concluded that the MPPT is able to achieve maximum power output when there is variation in solar irradiance.

*Keywords: Photovoltaic; diode; energy; model; temperature; irradiance.*

\*Corresponding author: Email: [ibkareola@fedpolel.edu.ng](mailto:ibkareola@fedpolel.edu.ng);

## NOMENCLATURES

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 [1]
$I_{scr}$	: 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.

## 1. INTRODUCTION

In order to create 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, the use of a photovoltaic device can be adopted for constant supply of energy from the environment [2].

Renewable energy resources have become the major attention in the power sector, there is a growing awareness that renewable energies that utilises photovoltaic system has created. Solar arrays are useful in many terrestrial and space applications [3]. For best utilisation, the photovoltaic cells must operate 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  $1\text{kW/m}^2$ , several 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 [4]. 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, effectiveness of the MPPT in maintaining the maximum power supplied by a PV model is evaluated using MATLAB/SIMULINK.

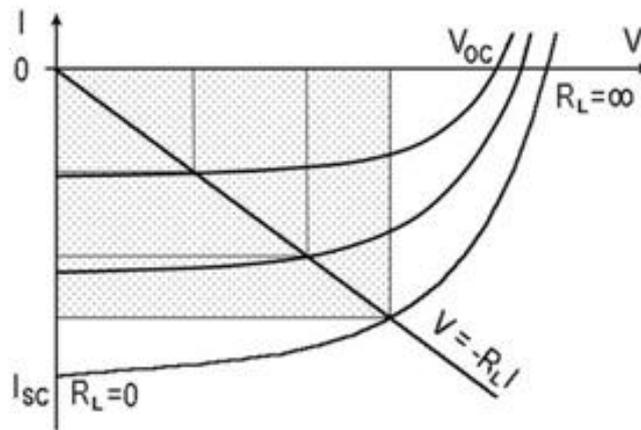
## 2. PV CELL MODEL

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 [5]. The

mathematical model for photovoltaic cells relates to the theoretical equations that describes the operation of the photovoltaic cells developed using the equivalent circuit of the photovoltaic cells. The empirical models rely on different values extracted from the I-V (Current-Voltage) characteristics of the photovoltaic cells and they approximate the characteristic equation of the solar panels using an analytical function [6].

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.

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  $I_{R_L}(V)$  load characteristic is a line given by the equation  $I_{R_L} = -I = V/R_L$ . 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, method generically named MPPT (Maximum Power Point Tracking) are used.



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

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 connects 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.

The circuit diagram of a PV cell showed above in Fig. 2 is 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  $R_s$  [8] (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  $R_{sh}$  [8], in parallel with the diode, this corresponds to the leakage current to the ground. Equations which defined the model of a PV cell are given below in equations (1- 5) [8,9]:

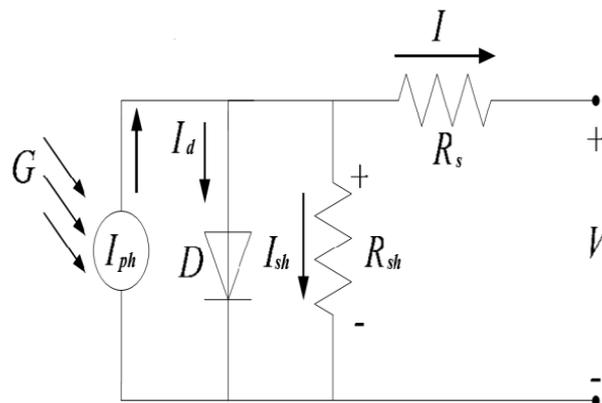
$$V_t = \frac{kT_{op}}{q} \dots\dots\dots(1)$$

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

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

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

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



**Fig. 2. Circuit diagram of a PV cell [7]**

### 3. METHOD OF STUDY

Considering the environmental and cell parameters, a PV cell simulation set up model based on equations (1) - (5) and Table 1 was developed in MATLAB/SIMULINK with a variable load resistance at the output. Fig. 3 depicts the PV cell simulation set up in general while

Fig. 4 represents the SIMULINK version of the model.

After changing  $G$ ,  $T_{op}$ ,  $R_s$ ,  $R_p$  and  $n$ , different results were obtained. Prior to simulation, some predefined specification are obtained for Solarex MSX-60 from [10] and as shown below in Table 1.

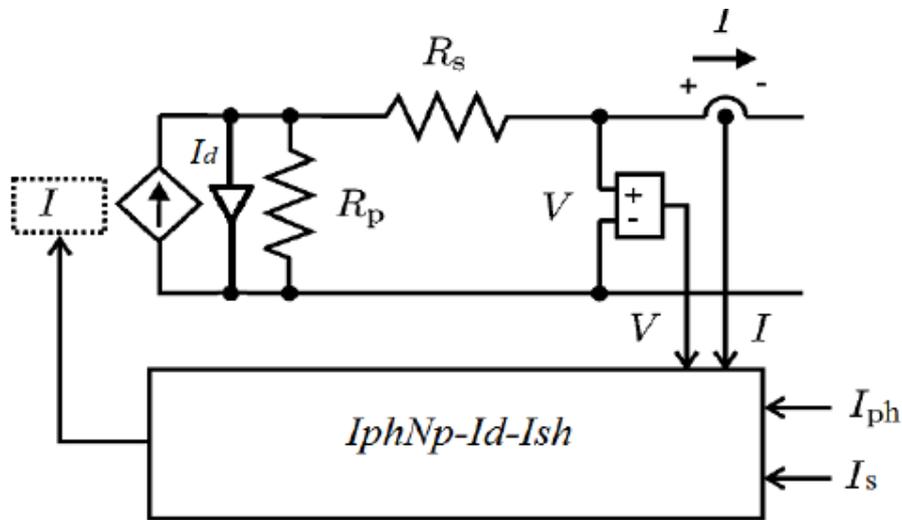


Fig. 3. A PV cell simulation set up [10]

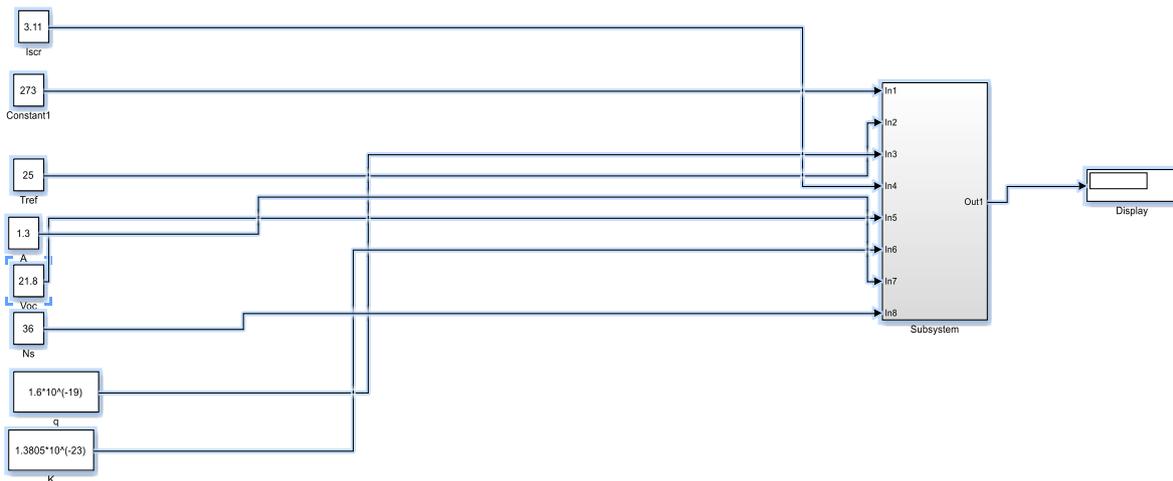


Fig. 4. A PV cell SIMULINK set up

Table 1. PV panel parameters

Attribute	Value
$V_{oc}$ (open circuit voltage )	21.8V
$I_{sc}$ (Short Circuit Voltage)	3.11A
$V_{mp}$ (Voltage at MPP)	17.44V
$I_{mp}$ (Current at MPP)	2.86A
$P_{mp}$ (Power at MPP)	50W

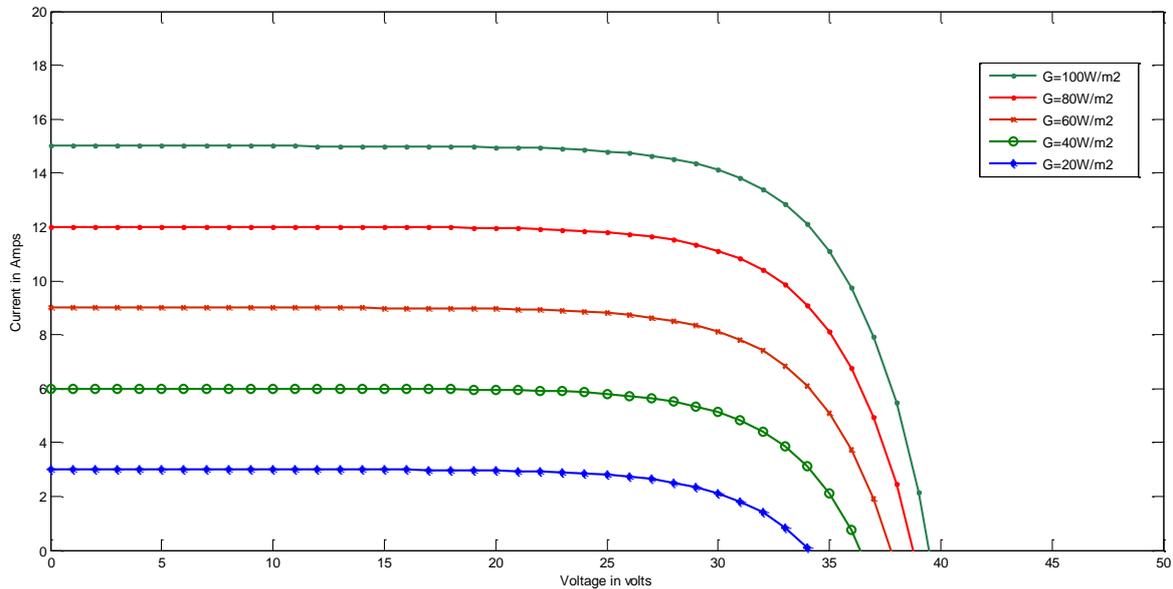
## 4. RESULTS AND DISCUSSION

### 4.1 Results

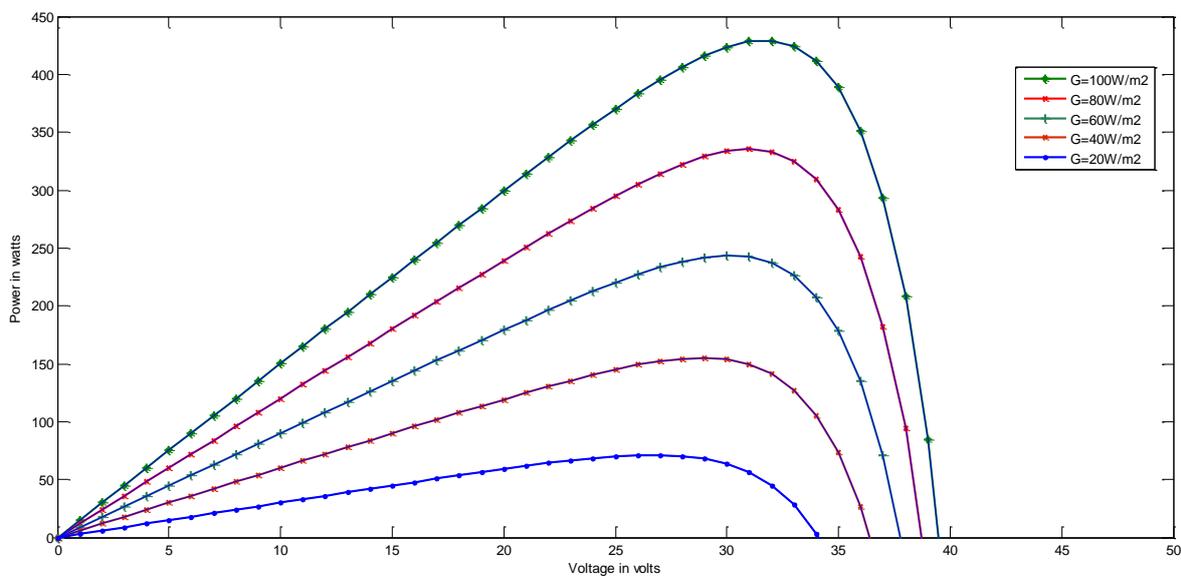
Table 1 showed the results from the simulated model [11] at standard temperature conditions.

Figs. 5 - 8 shows the Current-Voltage (*IV*), Power-Voltage (*PV*), Power-Current (*P*) and

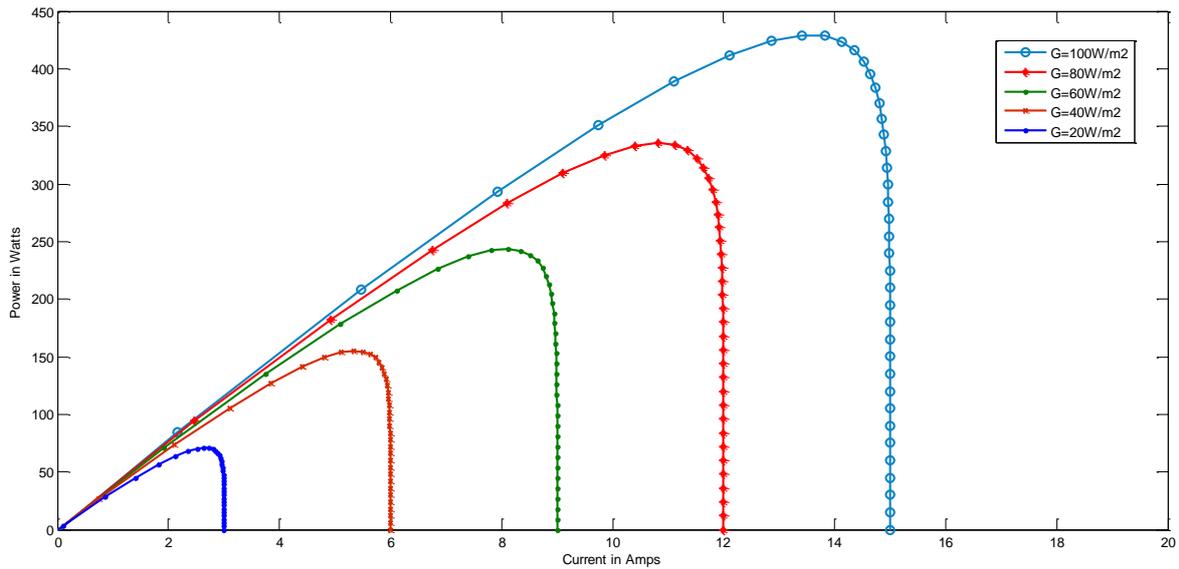
Power-Temperature (*PT*) curves at different irradiance  $G$  ( $W/m^2$ ) respectively with constant  $T_{op}=25$ . Fig. 5 – 8 shows that the maximum power is obtained when the impedance between the panel output and load is equal. The short circuit current is proportional to the solar radiation (Figs. 5 and 6); on the other hand, temperature is inversely proportional to open-circuit voltage.



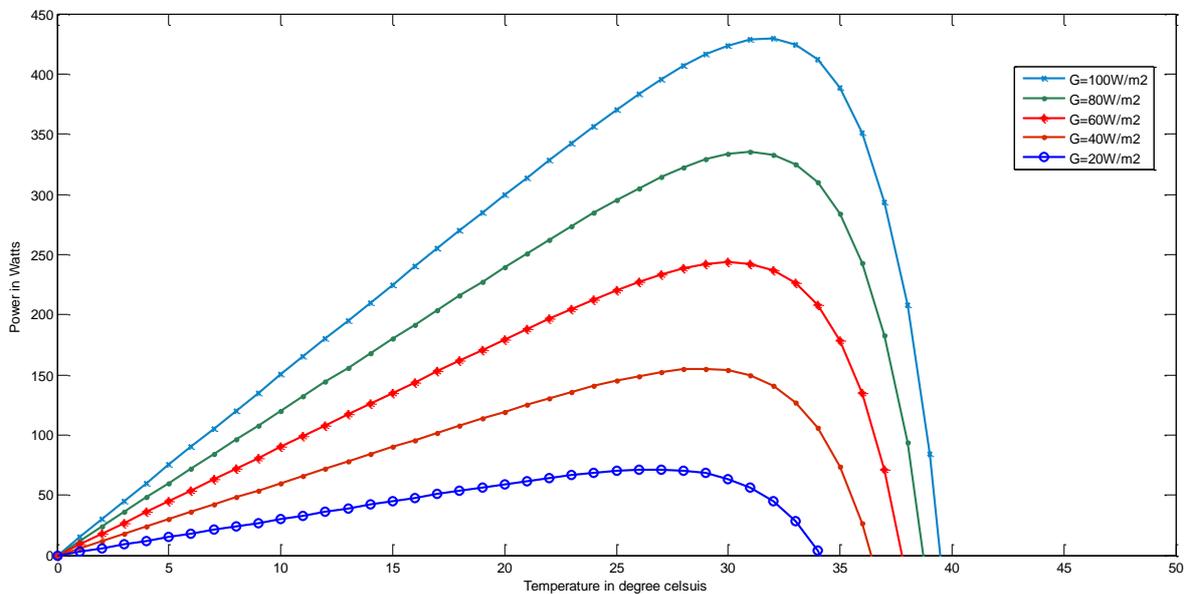
**Fig. 5. Current-Voltage curves at different Irradiance (G)**



**Fig. 6. Power-Voltage curves at different Irradiance (G)**



**Fig. 7. Power-Current curves at different Irradiance (G)**



**Fig. 8. Power-Temperature curves at different Irradiance (G)**

### 4.2 Discussion

Figs. 5 - 8 shows that the irradiance increases with power. The Voltage - Power characteristics and Voltage - Current characteristics of a solar cell mainly depends upon the solar irradiation. The solar irradiation level changes with variation in environmental condition that yields different maximum power. Therefore, the maximum power point tracking algorithm can be useful for maintenance of 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 on the solar cell, there will be higher excitation energy causing mobile electrons to be active, they therefore increase the mobility level of electron resulting in more power is generation.

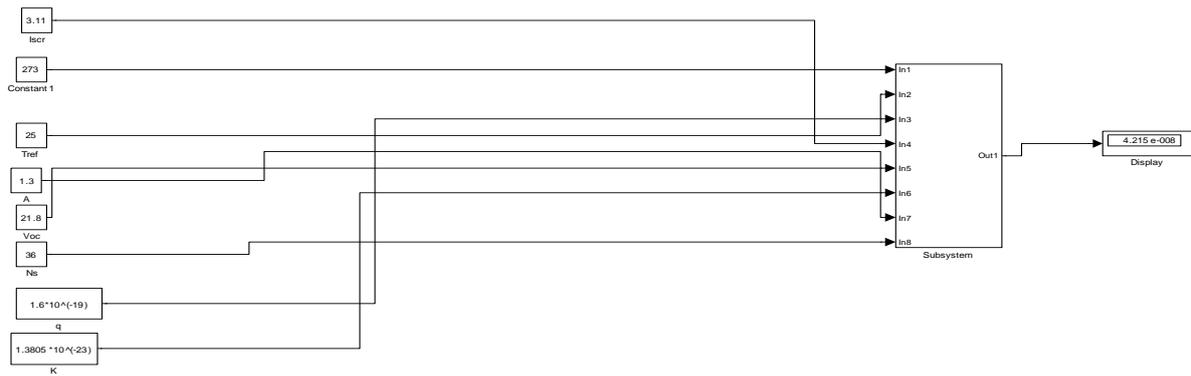


Fig. 9. A PV cell simulation with result displayed

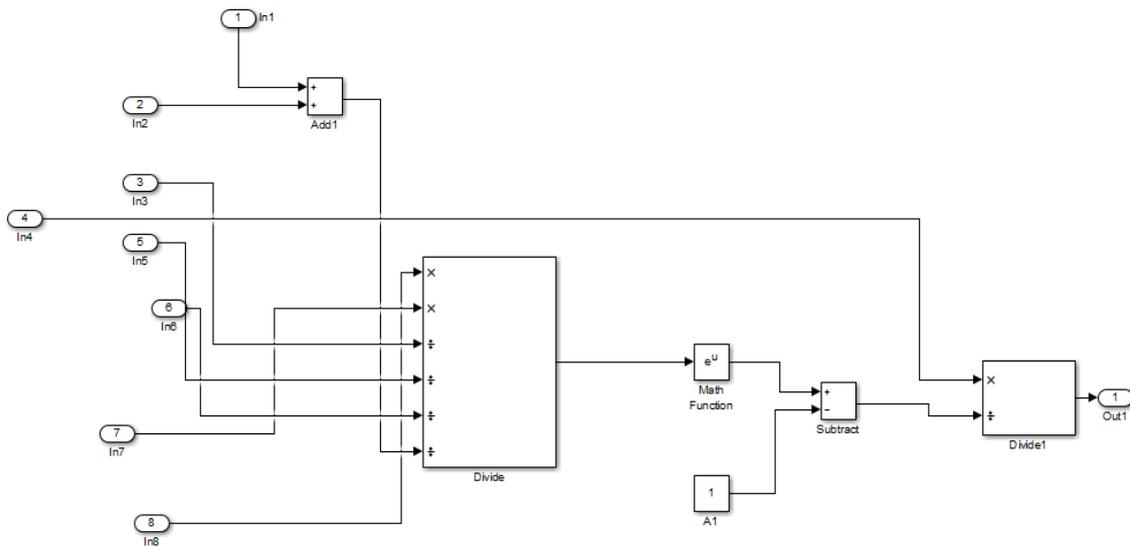


Fig. 10. Subsystem embedded in the PV model in simulink

From the simulation results which are depicted in Figs. 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 can help in the development of the MPPT algorithm by understanding how these variables work. The ideal condition to obtain the maximum power from the PV panel are  $T_{op} = 25^\circ\text{C}$ ,  $A.M = 1.5$ ,  $R_s = 0.18$  ohm,  $R_p = 360$  ohm and  $n = 1.36$  which is shown in Fig. 5 with legend  $G=1000$   $\text{W/m}^2$  (blue colour). This ideal condition was also specified in the Solarex MSX-60 datasheet [8].

## 5. CONCLUSION

The research evaluated the performance of MPPT for PV model, it is conclusive that the MPPT was able to maintain a steady and maximum output at environmental fluctuations such as changes in solar irradiance. MPPT can

be adopted in the design and manufactures of Solar Panels in order to make them stand the test of time.

## DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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