DESIGN AND ANALYSIS OF PV MODULE WITH TRACKING IN SIMULINK

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Abstract: Photovoltaic exhibit which is made out of modules are considered as the power transformation unit of PV age framework. The interest in photovoltaic power is expanding every day. The photovoltaic cluster has the most astounding vitality transformation yield by using the greatest accessible sunlight based power. This PV module requires extraordinary plan thought because of eccentric and sudden changes in climate conditions which can change sun oriented irradiance and working temperature. PV cluster has nonlinear qualities. This paper displays well ordered methodology for reproduction of photovoltaic modules with Simulink. Solkar 36w PV module is taken as a kind of perspective. The fundamental target is to get P-V and I-V attributes by differing light at a consistent temperature and by shifting temperature at steady illumination.

I. INTRODUCTION

As conventional sources of energy are rapidly depleting, the demand for renewable energy is increasing. Among the renewable energy resources, the energy due to the photovoltaic effect can be considered the most essential and sustainable resource because of the abundance and sustainability of solar radiant energy.

A photovoltaic system converts sunlight into electricity. This photovoltaic system is made of a photovoltaic cell. The cell may group to form panels or modules. Panels are grouped to form large photovoltaic cells. Different technologies are used to produce solar electric power, which converts solar irradiance directly to electrical energy using solar cells.

Being a semiconductor device, the PV system is static, free of moving parts, and has little operation and maintenance cost. The electric power obtained from the PV array does not have any environmental impact and contamination when exposed to solar radiation.

As the PV system produces less voltage and current, so this can be only used for low applications like lighting systems and DC Motors. For high power applications, power electronic converters are required to process the electricity from the PV device.

The performance of PV array depends on the operating conditions as well as solar cell and array design quality. The output characteristics of a PV module depend on solar isolation, the cell temperature, and the output voltage of the PV module. Since PV module has nonlinear characteristics, therefore it is necessary to model it for the design and simulation of the maximum power tracking point

Although solar cell prices were very expensive at the beginning, they became cheaper during the last decades due to development in the manufacturing process. So that it is expected that the electricity from the PV arrays will compete with the conventional ones in the coming years.

In this paper, a step by step procedure to develop a PV module with subsystem blocks, using Matlab/Simulink has been explained. Section II presents the PV module equivalent circuit and equation for the output current from the PV module. Section III provides a data sheet for Solkar made 36W PV module which is considered as a reference. Section IV presents the step by step procedure of PV module with simulation results.

II. Modeling OF PHOTOVOLTAIC MODULE

A solar cell is a p-n junction made with a thin layer of semiconductor. Photons in sunlight hit the solar panel and are absorbed by the semiconducting materials. Due to their special structure and the materials in a solar cell, the electrons are allowed to move in a single direction. Due to these radiations of solar energy can be directly converted to electricity through the photovoltaic effect. When PV cell is being exposed to sunlight, photons with energy greater than the band-gap energy of the semiconductor creates some electron-hole pairs proportional to the incident irradiation.

In the below figure the current source I_{ph} represents the cell photocurrent. R_{sh} and R_s are the shunt and series resistance of the cell respectively. Usually, the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis.

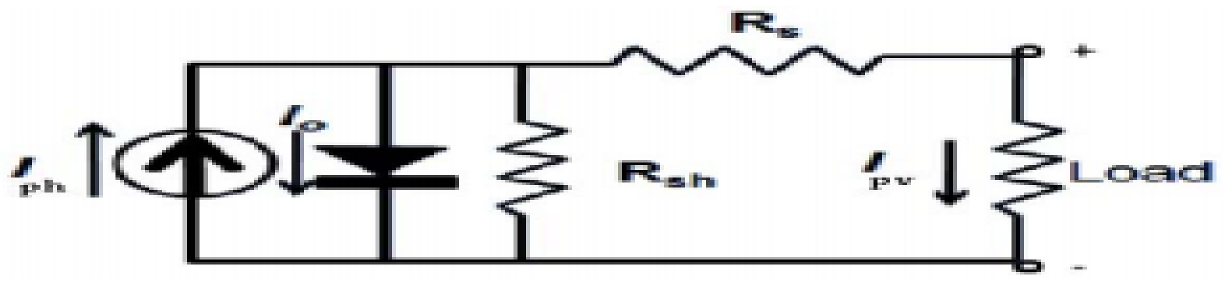


Figure1. Equivalent circuit of a PV cell

PV cells are grouped in larger units called PV modules which are further interconnected in a parallel- series configuration to form PV arrays.

The photovoltaic panel can be modeled mathematically as given in equations

Module photo-current:

$I_{ph} = [I_{scr} + K_i (T - 298)] * \lambda / 1000$ (1)

Modules reverse saturation current – I_{rs}:

$I_{rs} = I_{scr} / [\exp(q V_{oc} / N_s k A T) - 1]$ (2)

The module saturation current I_o varies with the cell temperature, which is given by

$I_o = I_{rs} [T / T_r]^3 \exp[(q * E_{go}/ B k)\{1 / T_r – 1 / T\}$ (3)

The current output of PV module is

$I_{pv}= N_p * I_{ph} - N_p*I_o[\exp\{q*(V_{pv}+ I_{pv} R_s)/N_s AkT_{opk}\}-1]$ (4)

Where $V_{pv}= V_{oc}$, $N_p= 1$ and $N_s= 36$

Where

V_{pv} is an output voltage of a PV module (V)
I_{ph} is an output current of a PV module (A)
T_{ref} is the reference temperature = 298 K
T is the module operating temperature in Kelvin
I_{ph} is the light generated current in a PV module (A)
I_o is the PV module saturation current (A)
A = B is an ideality factor = 1.6
K_i is Boltzman constant = $1.3805 * 10^{-23}$
q is electron charge = $1.6 * 10^{-19}$ C
R_s is the series resistance of a PV module
I_{scr} is the PV module short circuit current at 25 °C and 1000W/m^2 = 2.55A
K_i is the short circuit current temperature co-efficient at I_{scr} = 0.0017A/°C
λ is the PV module illumination (W/m^2) = 1000W/m^2
E_{go} is the band gap for silicon = 1.1 eV
N_s is the number of cells connected in series
N_p is the number of cells connected in parallel

III. REFERENCE MODEL

Solkar make 36W PV module is taken as a reference module for simulation and the nameplate details are given in table 1

TABLE 1: DATA SHEET OF SOLKAR 36W PV MODULE

Rated Power	37.08W
Voltage at Maximum power (V_{mp})	16.56V
Current at Maximum power (I_{mp})	2.25A
Open circuit voltage(V_{OC})	21.24A
Short circuit current(I_{SCr})	2.55A
Total number of cells in series(N_s)	36
Total number of cells in parallel(N_p)	1

IV. STEP BY STEP PROCEDURE FOR MODELLING OF PV MODULE

PV module includes the temperature independence of the photocurrent sources, the saturation current of the diode and a series resistance makes the module moderate complexity. PV cell converts part of photovoltaic potential directly into electricity with I-V and P-V output characteristics when the cell is being illuminated with radiation of sunlight.

By using the equation given in section II Simulink modeling can be done in the following steps:

Step 1:
The subsystem is shown in figure 2. This system converts the photovoltaic module operating temperature which is given in degree Celsius to Kelvin.

1. Celsius to Kelvin
Figure2. Subsystem1.

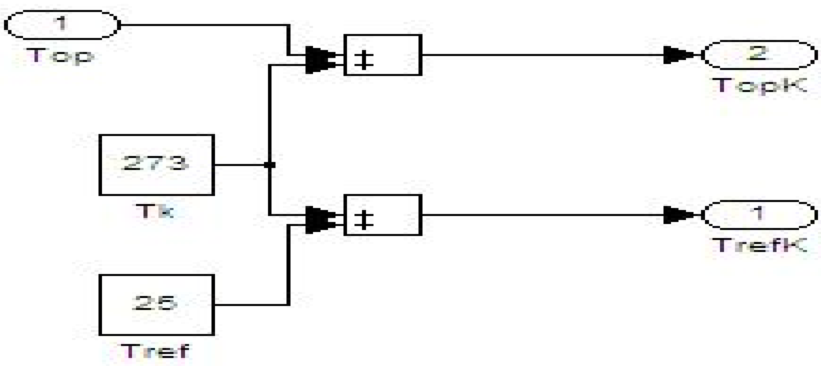


Figure3. Circuit diagram for Subsystem1.

The above figure is the circuit diagram for subsystem1. Here in this circuit reference temperature in Kelvin is obtained by summing the reference temperature in Kelvin and reference temperature using add block. The operating temperature in Kelvin is obtained by adding operating temperature in Celsius and temperature in Kelvin.

Step2: Subsystem2 is shown in Figure3.
Irradiation – (G / 1000) 1 kW/m^2 = 1
Operating temperature T_{opk} taken from 30 to 70^o C
Reference temperature T_{ref} is taken as 25^o C
Short circuit current at the reference temperature is 2.55 A

Figure4: Subsystem2

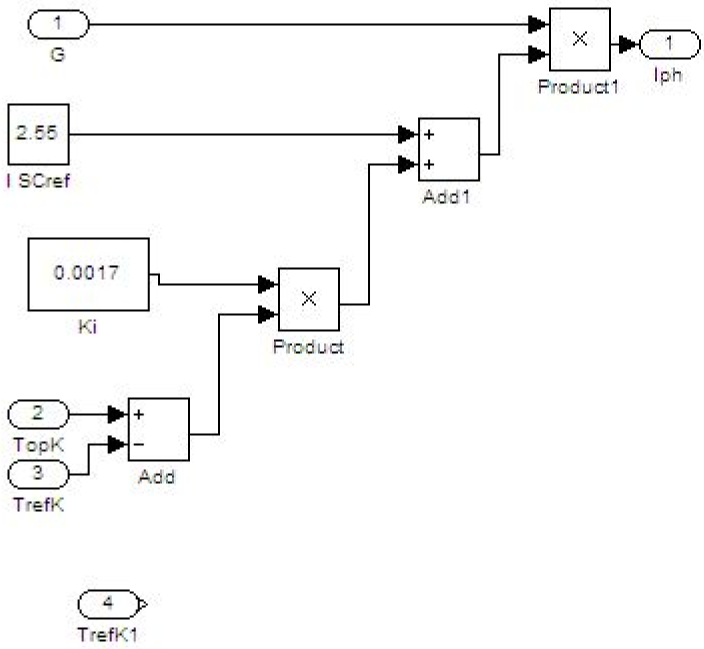


Figure5: circuit diagram of Subsystem2.

The above Figure5 is the circuit diagram for Subsystem2. Here the output of the circuit represents the photo-current I_{ph}. This I_{ph} mathematical equation can be obtained as when the operating temperature in Kelvin and reference temperature in Kelvin is multiplied with temperature coefficient k_i and the output from the product is added with I_{scr} and the output from the add block is multiplied with irradiation. Therefore the output from the product gives the photo-current.

Step3: Subsystem3 is shown in Figure6. The module takes the short circuit current 2.55 A at the reference temperature is 25^o C.

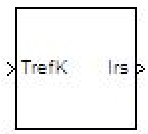


Figure6: Subsystem3

The below Figure7 is the circuit diagram for Subsystem3. The output of the circuit is I_{rs}. The mathematical equation for reverse saturation current is obtained by multiplying the number of series cells, reference temperature in Kelvin, ideality factor and Boltzman constant. The electron charge and open circuit voltage gets multiplied and gives to the divide block. The output from the product1 and product gets multiplied and the output is given to math function and the output from the math block is given to the add block. Short circuit current I_{scr} and the output from the add block is given to divide1 block. Therefore required mathematical equation for I_{rs} is obtained from the circuit.

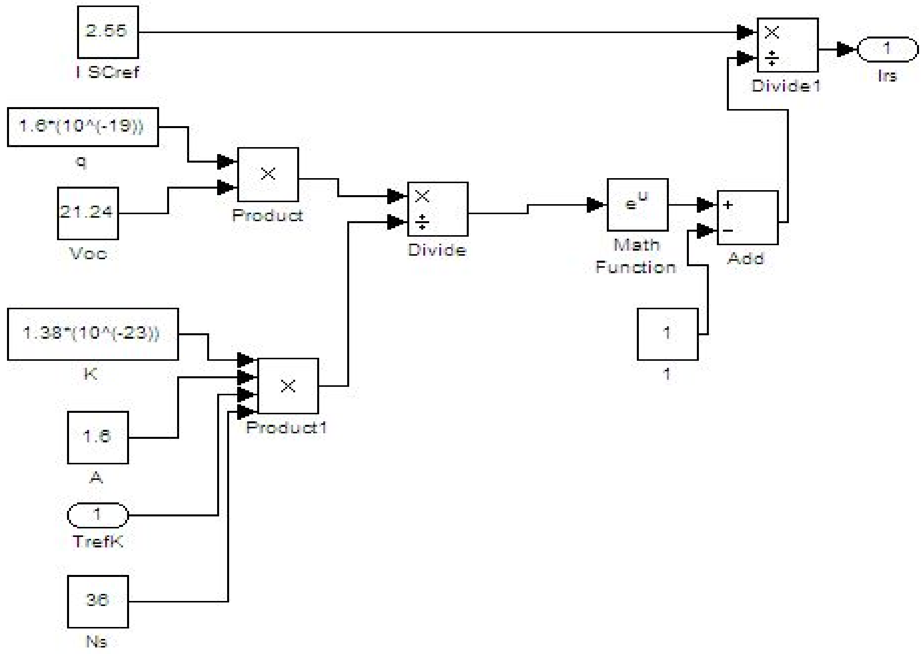
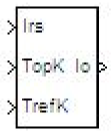


Figure7: circuit diagram for Subsystem3.

Step4: Subsystem4 is shown in Figure8. The system takes reverse saturation current I_{rs}, reference temperature T_{ref} at 25º C and operating temperature T_{op} and calculates saturation current.



Figutre8: Subsystem4

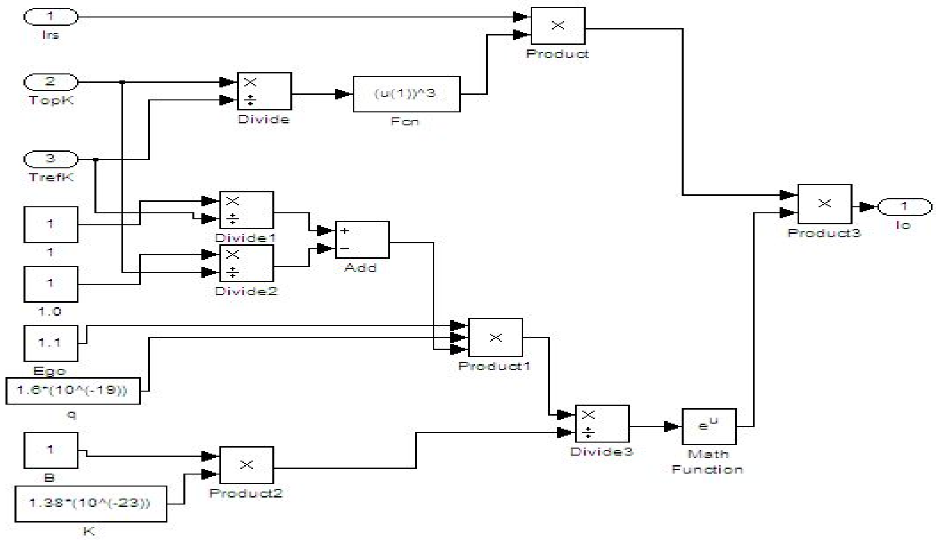


Figure9: circuit diagram for subsystem4

The Figure9 is used to calculate module saturation current I_o. The ideality factor gets multiplied by the Boltzman constant. The reverse saturation current I_{rs} is given to product block. The operating temperature T_{opk} is given to divide block. The output from the function block gets multiplied with reverse saturation current. The output from the math function and the output from the product block gets multiplies and gives the required module saturation current I_o.

Step5: Subsystem5 is shown in Figure10. This subsystem is used to calculate the product $NsAkT_{opk}$, the denominator of the exponential equation in equation(4).

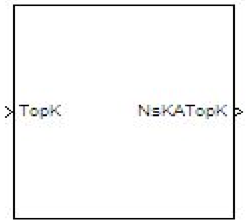


Figure10: Subsystem5

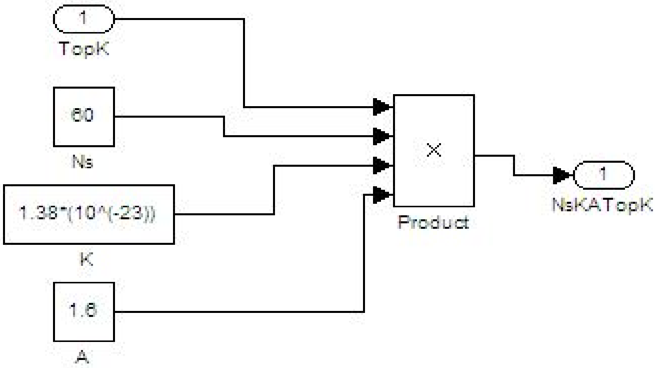


Figure11: circuit diagram for Subsystem10

Figure11 describes the circuit diagram of Subsystem10. Here the $NsAkT_{opk}$ is calculated by multiplying the operating temperature, a number of series-connected cells, Boltzman constant and ideality factor.

Step6: The Subsystem6 is shown in Figure12. Here it executes the function given by equation(4). The functional equation is given as

$$I_{pv} = u(3)-u(4) * (exp((u(2)*(u(1)+u(6)))/(u(5)))-1)$$

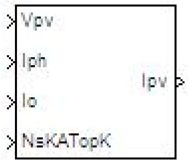


Figure12: Subsystem6

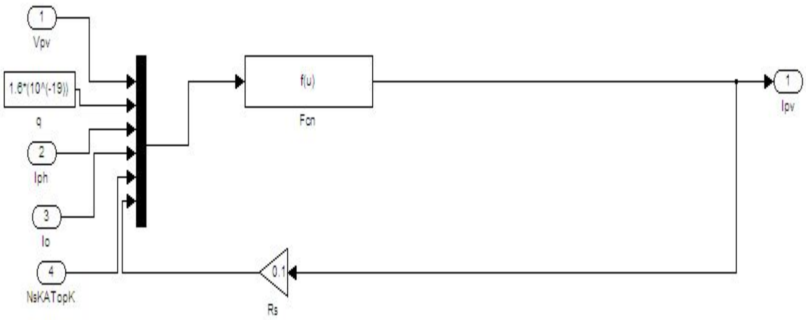


Figure13: circuit diagram of Subsystem6

From the Figure13 we can calculate the output current of the PV module. This can be done by giving inputs output voltage V_{pv} of the PV module, electron charge, photon current of the module, saturation current of the module, $NsAkT_{opk}$ and feedback from the series resistance R_s to the function block. By using these parameters output current I_{pv} of the PV module is calculated.

The entire simulation circuit is shown in Figure14

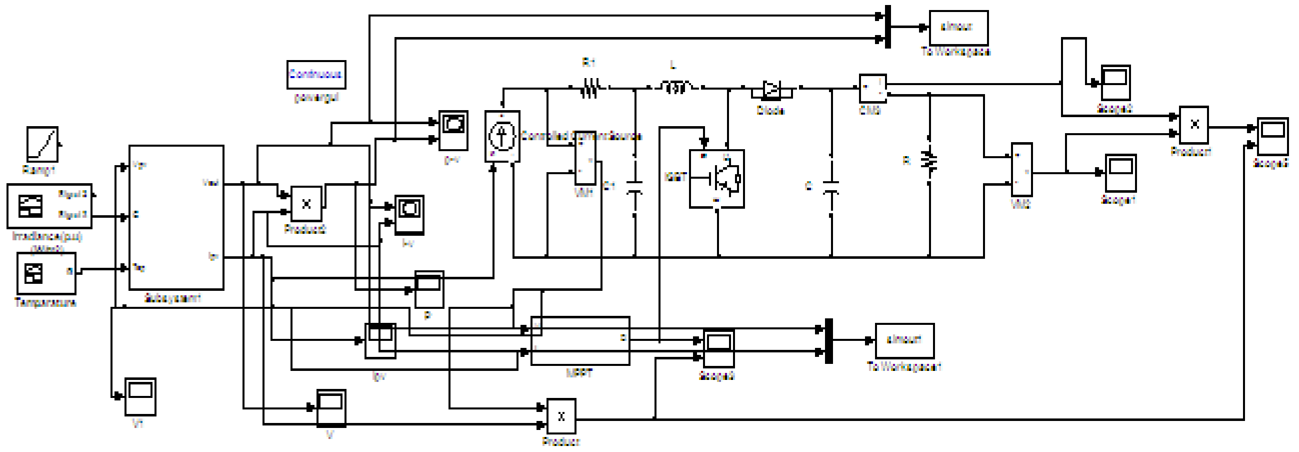


Figure14: Simulation model of PV module

The final model takes irradiation, operating temperature in Celsius and the input from the MPPT. MPPT technique is used in order to obtained maximum power from the module. The MPPT technique used here is perturbed and observe. The boost converter is a DC-DC converter is also connected to the PV module so that it can step up voltage and can meet the high power applications.

IV. SIMULATION RESULTS:

Here characteristics of P-V and I-V can be estimated in two ways.

1. I-V and P-V characteristics under varying irradiation and constant temperature.
2. I-V and P-V characteristics under varying temperature and constant irradiation.

- Results for I-V and P-V characteristics under varying irradiation and constant temperature is shown in Figure15(a) to 15(f)
   a) I-V output characteristics of a PV module with varying irradiation at 1000W/sq.m at constant temperature 25C.

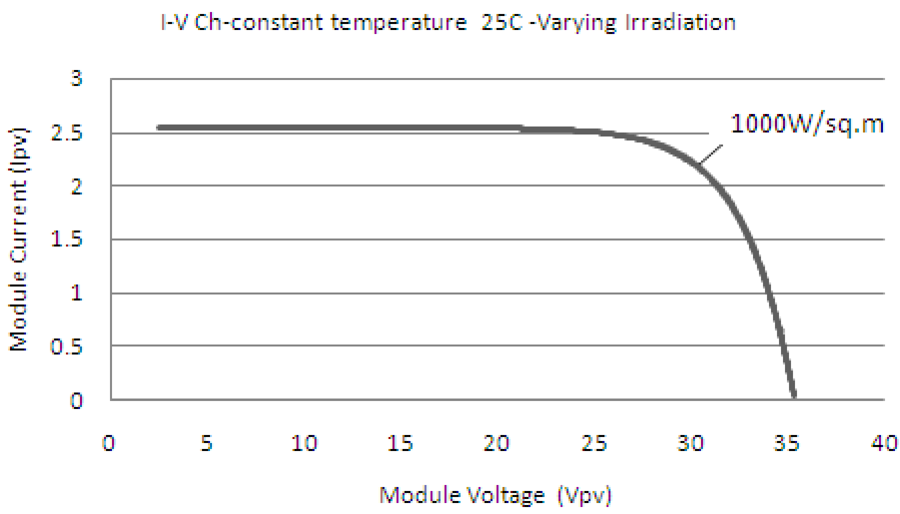


Figure15 (a) Output I-V characteristics with varying irradiation at 1000W/sq.m

   b) I-V output characteristics of a PV module with varying irradiation at 600W/sq.m at constant temperature 25C.

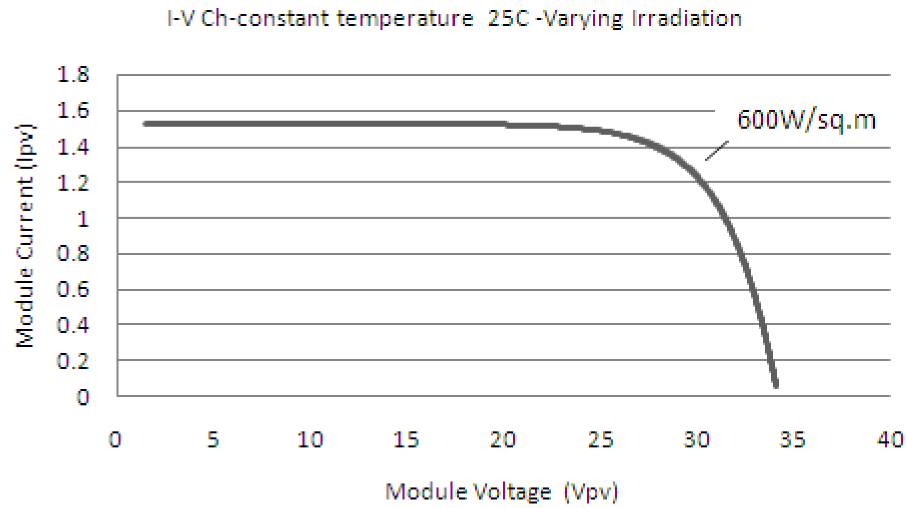


Figure15 (b) Output I-V characteristics with varying irradiation at 600W/sq.m

c) I-V output characteristics of a PV module with varying irradiation at 200W/sq.m at constant temperature 25C.

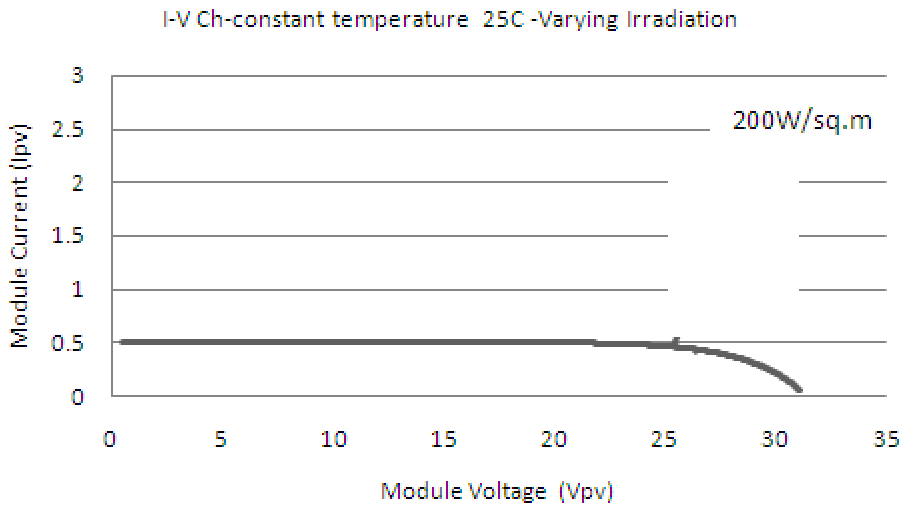


Figure15 (c) Output I-V characteristics with varying irradiation at 200W/sq.m

d) P-V output characteristics of a PV module with varying irradiation at 1000W/sq.m at constant temperature 25C.

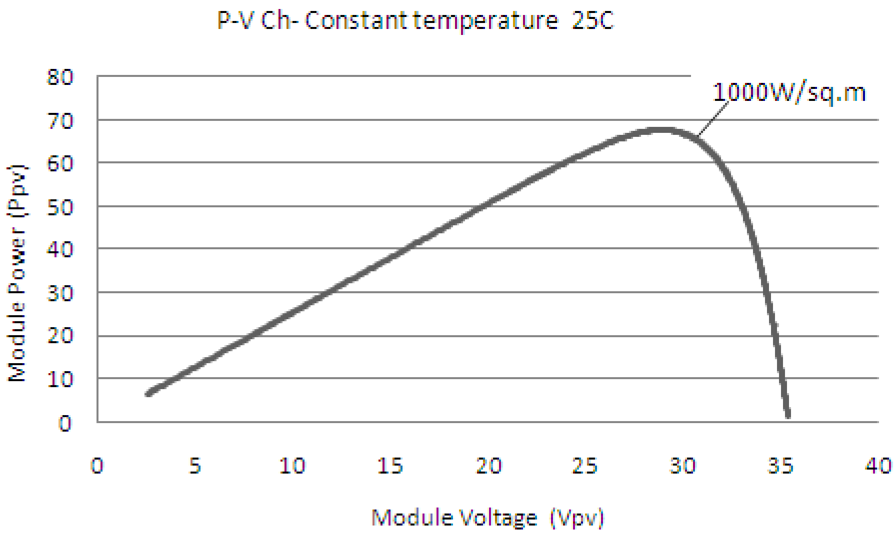


Figure15 (d) Output P-V characteristics with varying irradiation at 1000W/sq.m

e) P-V output characteristics of a PV module with varying irradiation at 600W/sq.m at constant temperature 25C.

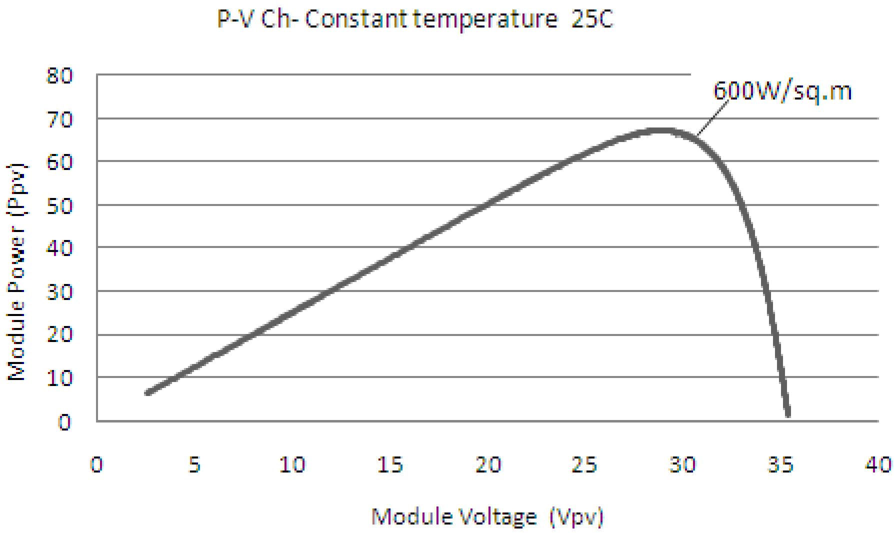


Figure15 (e) Output P-V characteristics with varying irradiation at 600W/sq.m

f) P-V output characteristics of a PV module with varying irradiation at 200W/sq.m at constant temperature 25C.

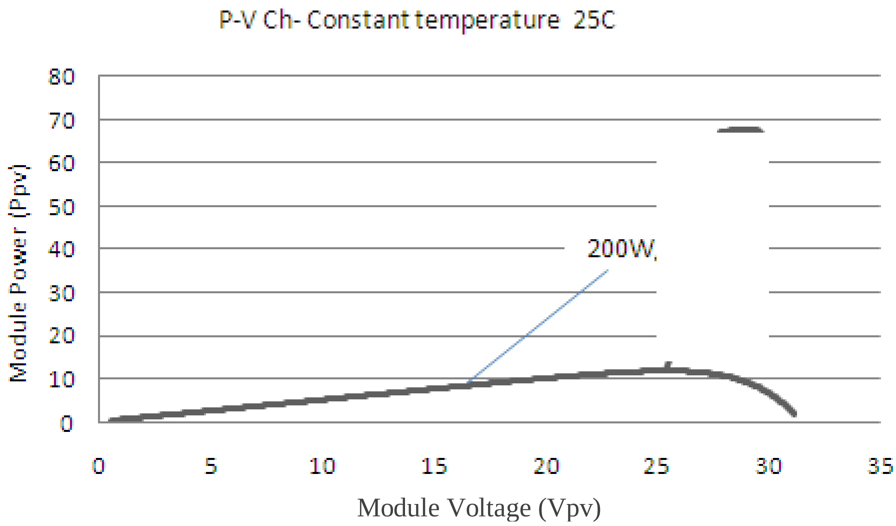


Figure15 (f) Output P-V characteristics with varying irradiation at 200W/sq.m

The above graphs are friendly. When the irradiation increases, current output also increases, voltage output also increases. Therefore net power output also increases with increase in irradiation at a constant temperature.

- Results for I-V and P-V characteristics under varying temperature and constant irradiation is shown in Figure16(a) to 16(f)

a) I-V output characteristics of the PV module with the varying temperature at 25^{o} C at constant irradiation of 1000W/sq.m.

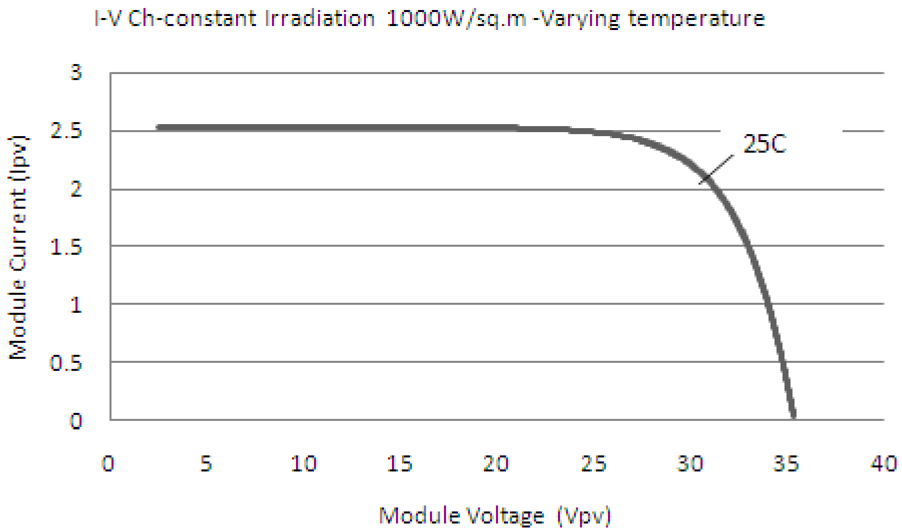


Figure16 (a) Output I-V characteristics with the varying temperature at 25° C.

b) I-V output characteristics of the PV module with the varying temperature at 50° C at constant irradiation of 1000W/sq.m.

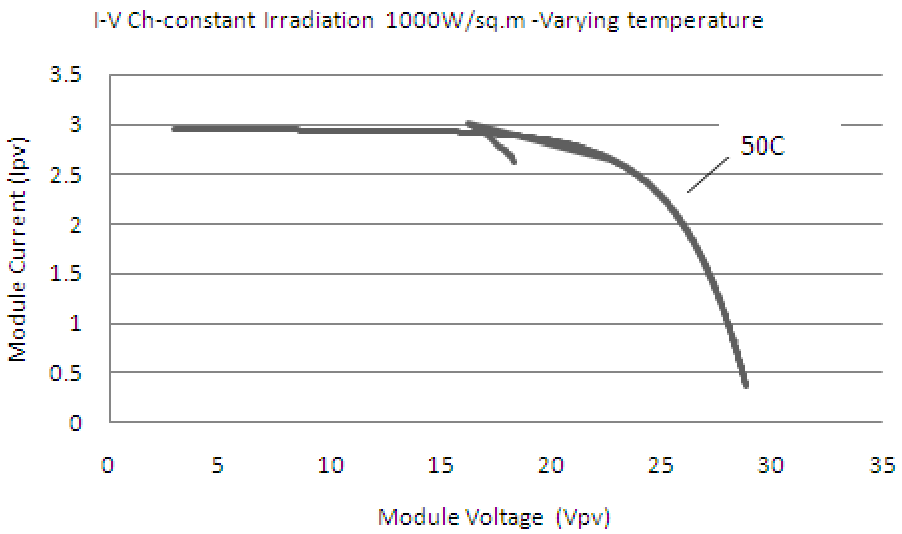


Figure16 (b) Output I-V characteristics with the varying temperature at 50° C.

c) I-V output characteristics of the PV module with the varying temperature at 75° C at constant irradiation of 1000W/sq.m.

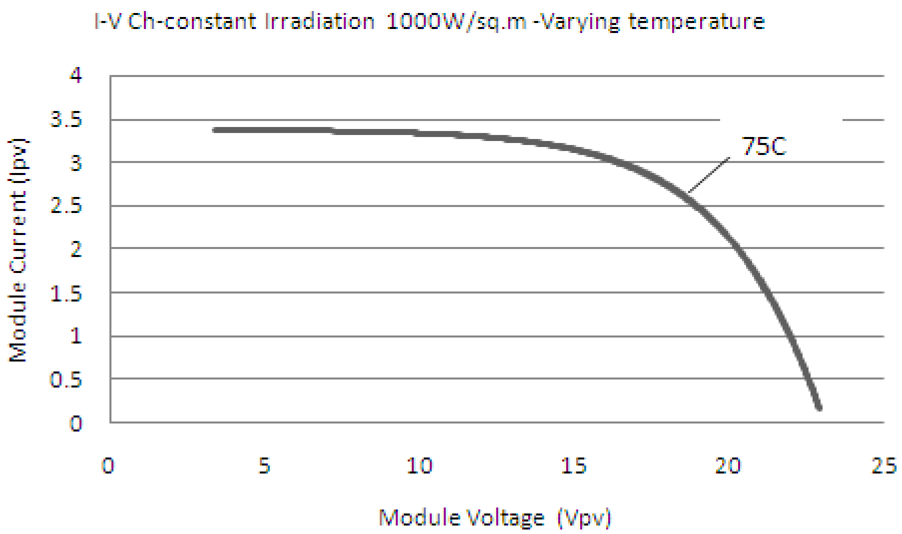


Figure16 (c) Output I-V characteristics with the varying temperature at 75° C.

d) P-V output characteristics of the PV module with the varying temperature at 25° C at constant irradiation of 1000W/sq.m.

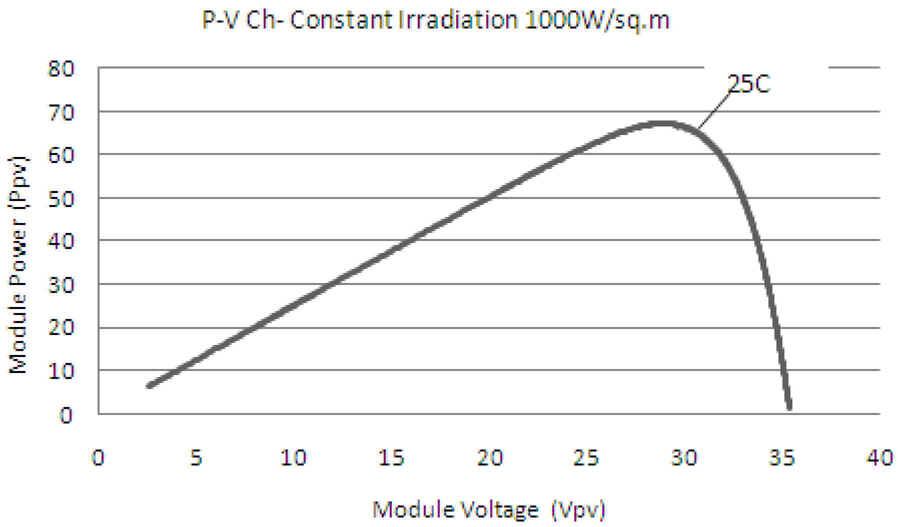


Figure16 (c) Output P-V characteristics with varying temperature at 25° C.

e) P-V output characteristics of the PV module with the varying temperature at 50° C at constant irradiation of 1000W/sq.m.

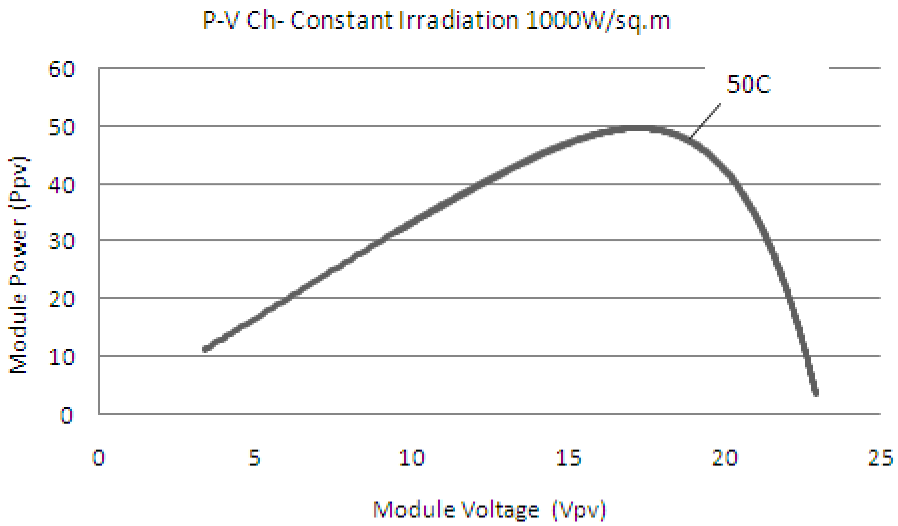


Figure16 (c) Output P-V characteristics with the varying temperature at 50° C.

f) P-V output characteristics of the PV module with the varying temperature at 75° C at constant irradiation of 1000W/sq.m.

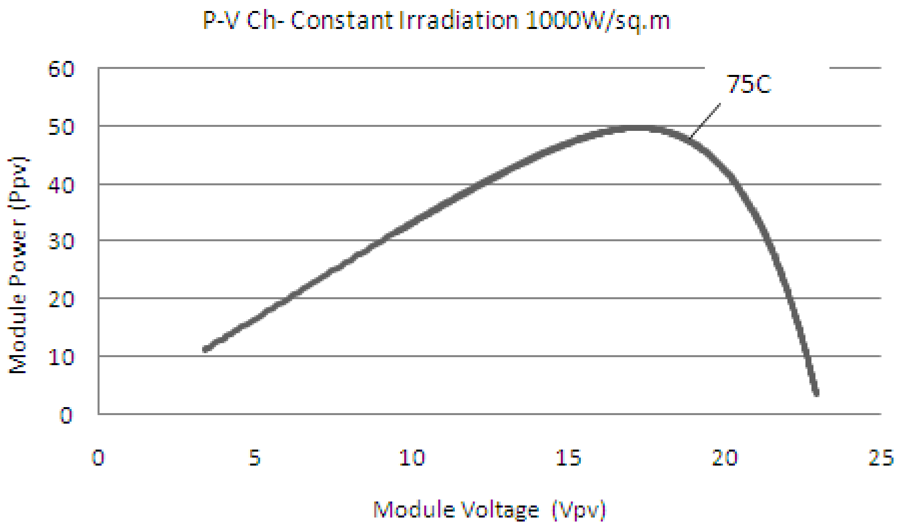


Figure16 (c) Output P-V characteristics with the varying temperature at 75° C.

The above graphs are user-friendly. The current output increases marginally, but the output voltage decrease drastically. As a result, there is a net reduction in power output.

VI. CONCLUSION:

The procedure provides an accurate, reliable module of the photovoltaic module. A step by step procedure for simulating a PV module, with user –friendly icons in Matlab/Simulink is shown in this paper. This helps in understanding the I-V and P-V curves easily.

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