International Conference on Green Energy and Environmental Engineering (GEEE-2014)
ISSN: 2356-5608
Sousse, Tunisia - 2014

Matlab/Simulink Based Modeling and Simulation of Photovoltaic Array Under Partial Shading

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***Abstract*— The performance of a photovoltaic (PV) system is affected by ambient temperature, solar irradiation, shading, and connection of PV module (Series, Parallel). This paper presents a Matlab-Simulink-based modeling and simulation scheme suitable for studying the P-V and I-V characteristics of a PV arrays under a uniform condition and non-uniform condition due to partial shading of PV arrays. The proposed model facilities the simulation of dynamic performance of photovoltaic system under different configuration.**

***Key words*— Photovoltaic, Modeling, Simulation,Partial Shading, Matlab-Simulink.**

I. Introduction

Renewable energy sources play an important role in electric power generation [1]. There are various renewable sources which used for electric power generation, such as solar energy, wind energy, geothermal etc. Solar Energy is a good choice for electric power generation [2], since the solar energy is directly converted into electrical energy by solar photovoltaic modules. These modules are made up of silicon cells. When many such cells are connected in series we get a solar PV module. The current rating of the modules increases when the area of the individual cells is increased, and vice versa. When many such PV modules are connected in series and parallel combinations we get a solar PV array, that suitable for obtaining higher power output.

The output power of a solar array is proportional to the irradiance of sunlight. However, in many applications, such as solar power plants, building integrated photovoltaic or solar tents, the solar photovoltaic arrays might be illuminated non-uniformly. The cause of non-uniform irradiation may be the shadow of clouds, the trees, booms, neighbor's houses, or the shadow of one solar array on the other.

Because of the nature of the electrical characteristics of solar cells, the maximum power losses are not proportional to the shadow, but magnify nonlinearly. Further, shadows of solar PV array can cause other undesired effects, The local hot spot in the shaded part of the solar PV array can damage the solar cells. The shaded solar cells may be work on the negative voltage region and become a resistive load and absorb power. Bypass diodes are sometimes connected parallel to solar cells to protect them from damage. However, in most cases, just one diode is connected in parallel to group of solar cells , and this hidden the potential power output of the array[3].

II. Modeling of Photovoltaic Panel

A. The simple electrical model of solar cell

The simplest model of a PV cell is shown as an equivalent circuit below that consists of an ideal current source in parallel with an ideal diode. The current source represents the current generated by photons; its output is constant under constant temperature and constant incident radiation of light. The current source produces the current image, which is directly proportional to solar irradiance [4].

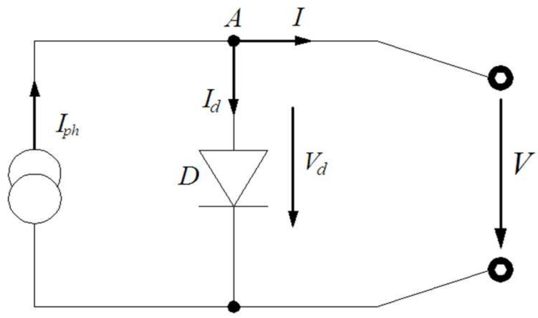

Fig.1 The simple electrical model of solar cell

The output current I of solar cell is given by:

$$I = I_{ph} - I_d \tag{1}$$

$$I_d = I_0 (e^{\frac{qV_d}{akT}} - 1) \tag{2}$$

$$I = I_{ph} - I_0 (e^{\frac{qV_d}{akT}} - 1) \tag{3}$$

Where
I : the diode current [A]
I_{ph} : the photocurrent [A]
I_0: the reverse saturation current of diode [A]
V_d: the diode voltage [V]
a : the diode ideality constant
k :the Boltzmann constant
T :the p-n junction temperature
q :the electron charge

ISSN: 2356-5608

V: the cell output voltage [V]

For a string of cells connected in series forming a photovoltaic panel the equation becomes:

$$I_d = I_0 (e^{\frac{qV_d}{NakT}} - 1) \quad (4)$$

Where N is the number of cells connected in series.

B. The practical model of solar cell

There are a few things that have not been taken into account in the simple model and that will affect the performance of a PV cell in practice.

Series Resistance R_s: In a practical PV cell, there is a series of resistance in a current path through the semiconductor material, the metal grid, contacts, and current collecting bus.

Parallel Resistance R_p : This is also called shunt resistance. It is a loss associated with a small leakage of current through a resistive path in parallel with the intrinsic device [4][5].

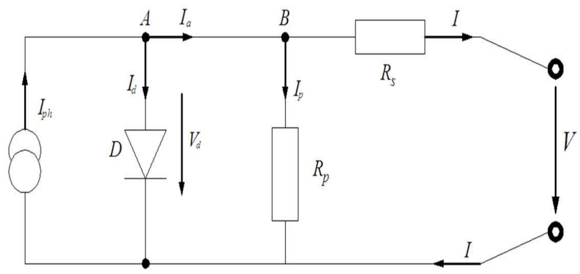

Fig.2 The practical electrical model of solar cell

$$I = I_{ph} - I_d - I_p \quad (5)$$

$$I_p = \frac{V_d}{R_p} = \frac{V + R_s.I}{R_p} \quad (6)$$

$$I_d = I_0 (e^{\frac{qV_d}{akT}} - 1) \quad (7)$$

$$I = I_{ph} + I_0 (e^{\frac{V+R_s.I}{V_t.a}} - 1) - \frac{v + R_s.I}{R_p} \quad (8)$$

The photocurrent:

$$I_{ph} = (I_{Ph,n} + k_i.\Delta T).\frac{G}{G_n} \quad (9)$$

The reverse saturation current :

$$I_0 = \frac{I_{sc,n} + k_i.\Delta T}{e^{\frac{V_{oc,n} + k_v \Delta T}{a.V_t}} - 1} \quad (10)$$

K_i: the short-circuit current/temperature coefficient
K_v: the open-circuit voltage/temperature coefficient
G: Actual sun irradiation
G_n: Nominal sun irradiation
ΔT: the difference between Actual temperature and nominal temperature
V_t: junction terminal voltage V_t =KT/q
$I_{ph,n}$: the nominal photocurrent
$I_{sc,n}$: the nominal short-circuit current

C. The I-V and P-V characteristic of a typical panel

The I-V and P-V curves of a typical photovoltaic module are shown in these figures:

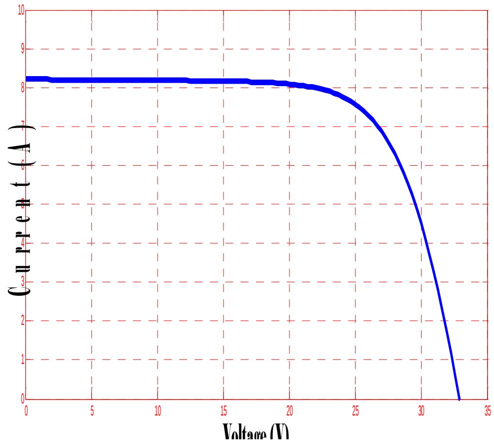

Fig.3 I-V Characteristic of typical panel under STC (25°C and 1000W/m^2)

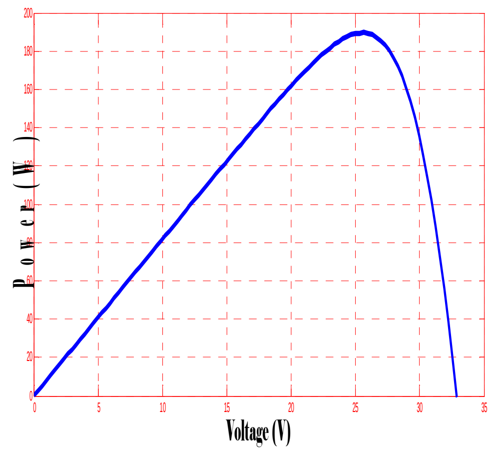

Fig.4 P-V Characteristic of typical panel under STC (25°C and 1000W/m^2)

E. Configuration of PV array with bypass diode and without bypass diode

A small configuration of a PV system with two PV modules is shown below:

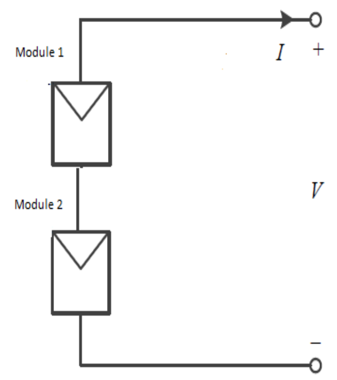

Fig.5 PV system without bypass diode

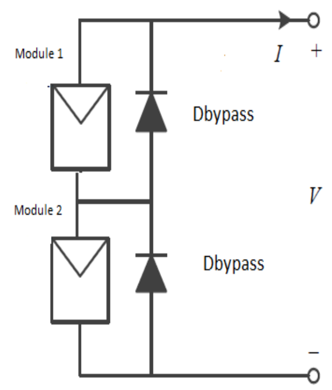

Fig.6. PV system with bypass diode

III. Simulations results

In this paper, the modules the KC200GT is chosen for simulation using Matlab Simulink under variation of ambient temperature and solar irradiation and partial shading [6][7][8]:

A. The Electricals Parameters of KC200GT

The electrical characteristic of KC200GT is given [9]

TABLE I: THE PARAMETERS OF KC200GT

Parameter	KC200GT
Maximum Power P_{max}	200 w
Short Circuit Current I_{sc}	8.21 A
Open Circuit Voltage V_{oc}	32.9 V
Maximum Power Current I_{mpp}	7.61 A
Maximum Power Voltage V_{mpp}	26.3 V
Temperature Coefficient K_v	-123 mV/°C
Temperature Coefficient K_i	3.18 mA/°C
Number of cells Ns	54

For simulation the characteristics I-V and P-V of panel KC200GT we use the matlab Simulink model presented by [10],[11]:

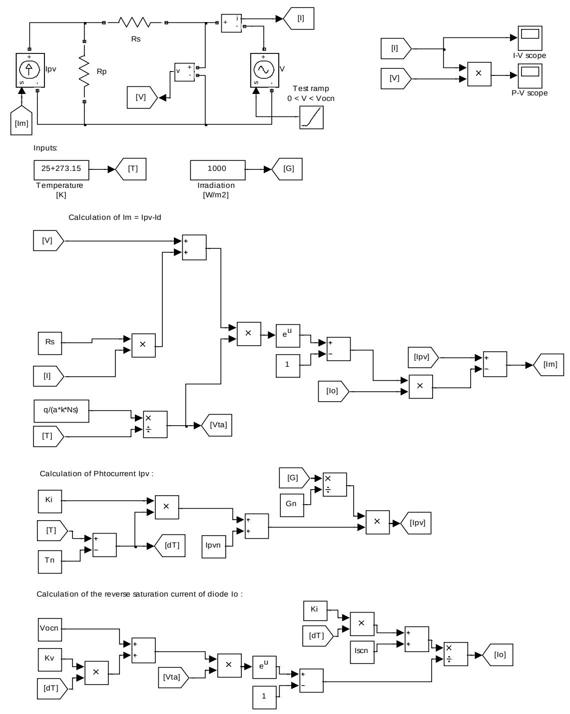

Fig.7. Matlab/simulink model for simulation of PV module (panel)

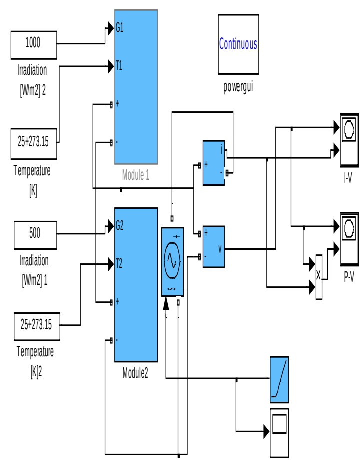

Fig.8. Matlab/simulink model for simulation of PV array under shading condition

C. Simulation

The following figures show the characteristic I-V and P-V of KC200GT module for different levels of irradiances (1000,800,600,400) and at constant temperature of 25 ◦C.

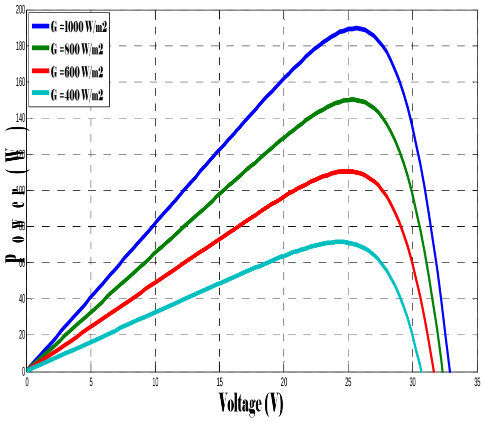

Fig.9 P-V Characteristic for different levels of irradiances and at temperature constant of 25 °C.

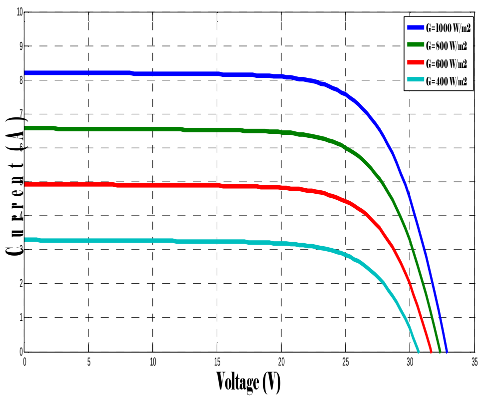

Fig.10 I-V Characteristic for different levels of irradiances and at temperature constant of 25 °C.

The following figures show the characteristic P-V and I-V of KC200GT module for different levels of temperature (15,25,35,60) and at irradiance constant of 1000W/m^2.

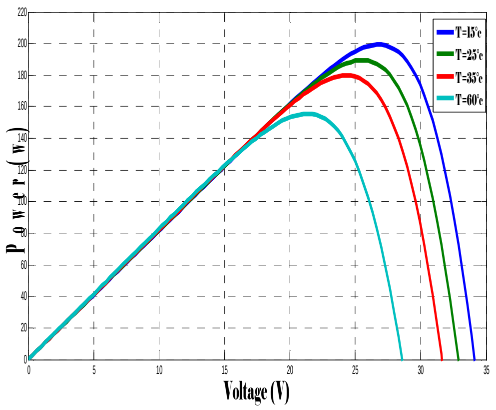

Fig.11 P-V Characteristic for different levels of temperature and at irradiance constant of 1000W/m^2.

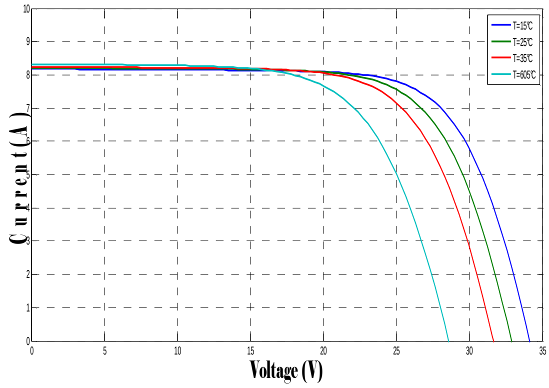

Fig.12. I-V Characteristic for different levels of temperature and at irradiance constant of 1000W/m^2.

The figures 9 and 10 show that the short-circuit and maximum power delivered by the module increases with the increase of irradiation.
The figures 11 and 12 the open circuit voltage and maximum power decrease when the temperature increases.

A small PV system with two PV modules: module 2 is shaded (500 W/m^2) and module1 is receiving normal irradiance (1000 W/m^2).

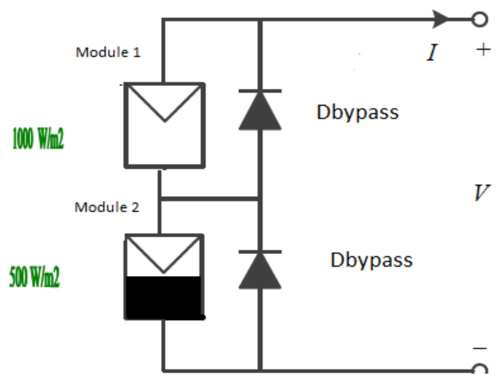

Fig.13 the PV array under partial shading module 1 1000 W/m^2 and module 2

The following figures show the simulation of photovoltaic The following figures show the characteristic P-V and I-V of PV array (figure 13) under uniform condition and non-uniform condition (partial shading effect) with the presence of bypass diode and without bypass diode.

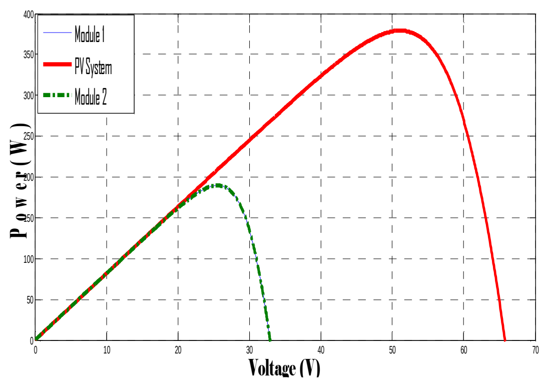

Fig.14 P-V curve uniform condition (Module1 and Module2 under irradiation 1000W/m^2).

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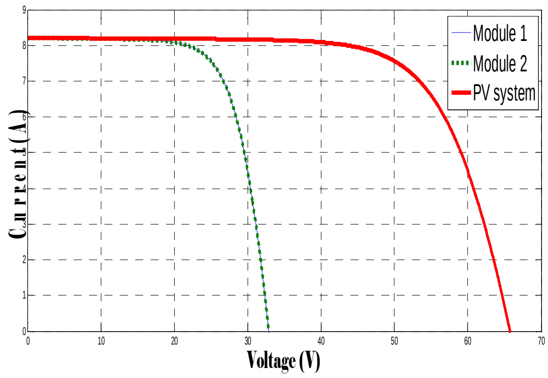

Fig.15 I-V curve uniform condition (Module1 and Module2 under irradiation 1000W/m^2).

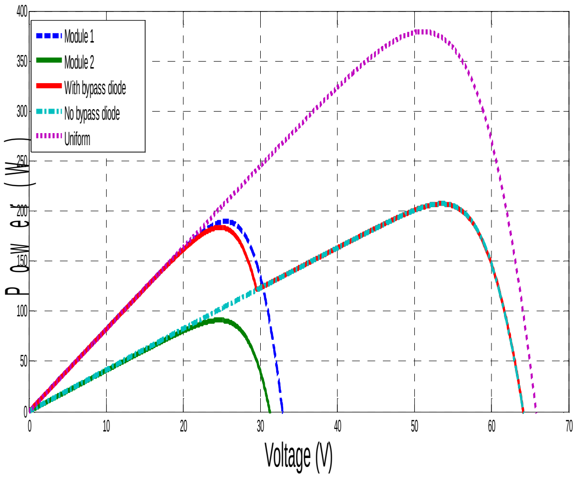

Fig.16 P-V curve of PV array under uniform and non-uniform condition due to partial shading with bypass diode and without bypass diode.

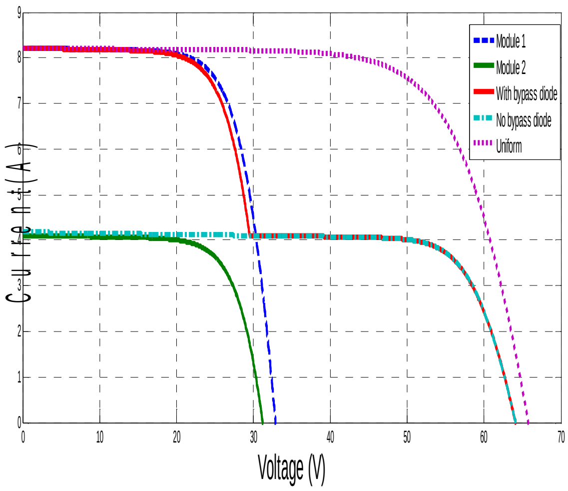

Fig.17 I-V curve of PV array under uniform and non-uniform condition due to partial shading with bypass diode and without bypass diode.

The figures 16 and 17 show that the effect of partial shading on PV system:

The maximum power of PV system decrease from 379.1288 W (under uniform condition module 1 1000 W/m^2, module 2 1000 W/m^2) to 207.1620 (under non-uniform condition module1 1000 W/m^2 module2 500 W/m^2).

The current court-circuit of PV system decrease from 8.2096 A (under uniform condition module 1 1000 W/m^2, module 2 1000 W/m^2) to 4.1776 A (under non-uniform condition module1 1000 W/m^2 module2 500 W/m^2).

Two peaks powers points (non-uniform condition with bypass diode).

IV. CONCLUSION

In this paper we have presented the basic equivalent electric circuit of PV cell, module and the matlab/simulik model of PV module, and small PV array with two panels. The characteristic I-V and P–V curves of KC200GT panel are obtained using the Matlab/Simulink for different values of irradiance and different values of temperatures, and also the characteristic I-V and P–V curves of PV array are obtained under uniform condition and non-uniform condition due to partial shading. The simulations where carried out in Matlab environment which gives a good understanding of the effect of partial shading on the photovoltaic system (array) and a good presentation of characteristics I-V and P-V under different variation of irradiation and temperature.

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