Simulation of a photovoltaic solar module for the study of the effects of random changes of solar radiation

LILIANA CORTEZ[1], J. ITALO CORTEZ[2], ALEJANDRO ADORNO[1], ERNEST CORTEZ[1], MARIANO LARIOS[2]
[1]Faculty of Electronics, [2] Faculty of Computer Science
Benemerita Universidad Autonoma de Puebla
MEXICO
email: jitalo@cs.buap.mx

Abstract: The present work is based on the simulation of the interconnection of 36 solar cells in a photovoltaic solar module (MS), of the Solar Shell brand, model Shell Power Max 85-P, by means of a mathematical simulator MATLAB, which offers swiftness and easiness of use. Relating the percentage of shade in given conditions of radiation to the point of maximum transference of power is intended, in order to be able to analyze the effects of random changes in solar radiation, on the production of energy, in outdoor conditions. The simulator provides the parameters of an open circuit tension (Voc)), the short circuit current (Isc), the maximum power (Pmax), and the characteristic curves of the solar module, depending on the shade effect that can hover on it, enabling the random study of changes of solar energy, in energy production. The experimental segment for attestation, as well as some of the trials carried out in different conditions of solar radiation are shown.

Key-Words: - Solar module (MS), MATLAB, point of maximum transference of power (Pmax), random changes of the radiation

1 Introduction

The problem of provision of electrical energy is one of the most important world-wide. The exhaustion of traditional resources, the climatic changes in addition to environmental restrictions everywhere in the world, will make it more and more difficult use of fossil fuel to satisfy the always growing need of energetics for the world population. [1,2,3]. Among the options to reduce the dependency on fossil fuel use as the main source of energy, the advantage of solar energy and its diverse secondary manifestations such as the Aeolian energy, hydraulic energy and the diverse forms of biomass; have been considered that is to say, the so called renewable energies. In Mexico, it exists a variety of installed photovoltaic Solar Systems, which are viable for sites located far away from the existing and applicable electrification networks. They are for rural telephony and water pumping, among others uses. Investigations and diverse projects for benefiting from of solar energy and its diverse manifestations have been developed within the country [2, 3, 4, 5].

The photovoltaic systems display problems in the operation by factors that affect the yield of the MS. This work details the theoretical-experimental analysis of one of the factors that diminish the yield of a photovoltaic system, which consists of determining the change on the production of energy of a MS, particularly with a MS Shell PowerMax 85-P, in conditions of random changes of solar radiation. For a certain voltage of operation, the CS current depends on the intensity of the light, thus, with a located shade in such a way, that it covers a part with MS (for example: shade of a tree, an object, a bird, etc.), a part of the CS will be working in conditions of illumination different from the rest of the module [4, 5, 6]. This condition causes imbalance in the flow of the current of the CS serially connected, which entails the appearance of hot spots and partial loss of power. The step diodes partly solve this problem, but their amount in a MS is limited and designed after a grouping of the CS.

The difficulty to characterize power loss of MS in conditions of random changes of radiation, resides first in the chaotic and unpredictable character of the changes of illumination. Secondly, it is the irregular form of the objects which provoke it. In the same way, the solar radiation displays the constant variation in time, which prevents relating all possible percentage of shade to the power, for a radiation given in outdoor conditions. Finally, the controller offers the optimal power in condition of maximum transference, for the posterior consumption that is not exactly the one provided by the MS.

The present work has limited to the consideration of the rectangular regular shades and one has been set out to relate the percentage of shade in given conditions of radiation to the point of maximum transference of power in order to analyze the effects on the energy production. Because the unique parameters that can be measured directly are the voltage of open circuit (Voc) and the current of short circuit (Isc), which provides null power. On the other hand these parameters allow us to know by means of the simulation characteristic curve V - I of the module, that can as well give the point of optimal work, which finally provides the power produced in such given conditions.

2 Simulation of a solar module in MatLab®

By means of a file type M, in MATLAB®, the model of a solar module was designed which consists of a series of 36 connected solar cells, as it is shown in fig 1.

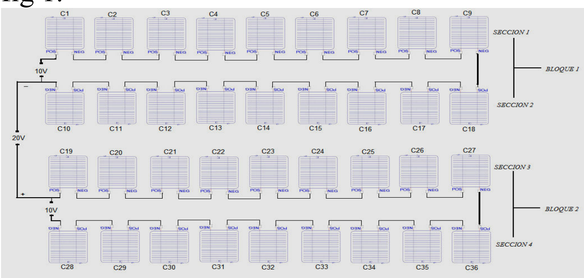

Fig. 1. Connection series of the solar module

For the simulation of the solar module it was used the equation (1), which describes the mathematical model of a solar module.

$$I = I_{sc}\left[1 - exp\left(\frac{V - V_{oc} + I\cdot\frac{R_s}{N_{cs}}}{V_t}\right)\right] - \frac{V + I\cdot\frac{R_s}{N_{cs}}}{\frac{R_p}{N_{cp}}} \qquad (1)$$

The algorithm that corresponds to the mathematical model and the parameters of the solar module is as follows: [7, 8, 9, 10].

```
% The filling factor calculates
(FF) = (Vmax*Imax)/(Voc*Isc);
% calculate the thermal voltage (Vt) of the cell, for that is predetermined;
% The thermal voltage is calculated (Vt) of the cell, for that is predetermined;
k = 1.38e-23;    % Constant of Boltzman' s
q = 1.60e-19;   % Load of an electron
t = k*Tc/q; % Voc of each cell
        voc = Voc/Vt;
% FFo calculates.
        FFo = (voc-log(voc+0.72))/(voc+1); %%
% The resistance of each cell calculates in series
Rs = (1-(FF/FFo))*((Voc/Isc)); %%
%%Se applies the representative formula of a solar module
V = (0:0.0001:Voc); %% A vector is designed as large as Voice.
I = zeros(size(V)); % It forms a vector of zero Is  the same size as  that vector
VI = Isc.*(1-exp(((V-Voc)/Ncs+(I*Rs)/Ncp)/(Vt)));
%% %% calculates the power of the module. P = I.*V;
```

The execution of the file in the simulator of the photovoltaic module, unfolds the option where the user must introduce the irradiation to study.

Once the solar value of irradiation to be studied is provided the possible options of shade effect that can be in the solar module are opened. Each option gives us the parameters and characteristic curves of simulation on the solar module to study.

3 Experimentation of the simulator

With the use of a solar module of the Solar Shell brand model Shell PowerMax 85-P, the operation of the simulator was verified. The data characteristic of the solar module (table 1), are used to obtain the parameters and the characteristic curves, using (1).

Engineering data module Shell Powermax 85-p $1000\ ^{W}/_{m^2}$, $25\ °C, AM\ 1.5$
Cells Series: (Ncs) 36 monocrystalline solar cells
Cells Parallel: (Ncp) 1
Temperatura Nominal (TNOCT): 45.5 °C
Tension of maximum power (Pn): 85w
Maximum power(Pmax): 85w
Current of short circuit (Isc): 5.45 A
Tension of open circuit (Voc): 22.2 V
Current of maximum power (Imax): 4.95 A
Tension of maximum power (Vmax): 17.2 V

Tabla 1. Technical Data

For standard conditions of measurement($1000\ ^{W}/_{m^2}$, $25\ °C, AM\ 1.5$), we have:

• The current of short circuit (Isc) that provides each cell is:

$$Isc_c = \frac{Isc}{Ncp} = \frac{5.45\ A}{1} = 5.45\ A$$

• The voltage of open circuit (Voc) of each cell is:

$$Voc_c = \frac{Isc}{Ncs} = \frac{22.2V}{36} = 0.617V$$

• Maximum current of power (Imax) of each cell is:

$$Imax_c = \frac{Imax}{Ncp} = \frac{4.95\ A}{1} = 4.95\ A$$

• Maximum voltage of each cell is:

$$Vmax_c = \frac{Vmax}{Ncs} = \frac{17.2\ V}{36} = 0.477\ V$$

- Maximum power of each cell is:

$$Pmax_c = (5.45\ A)(0.478\ V) = 2.6W$$

- Filling factor of each cell is:

$$FF_c = \frac{(17.2V)(4.95A)}{(22.2V)(5.45A)} = \frac{05.14}{120.99} = 0.7036$$

- The thermal voltage of each cell is:

$$Vt = \frac{kT}{e} = \frac{(1.38 \times 10^{-23})(293.15)}{1.6 \times 10^{-19}} = 0.0252$$

- Voltage of open circuit of the ideal device of each cell is:

$$voc_c = \frac{Voc}{Vt} = \frac{0.67\ V}{0.0252\ V} = 880.95$$

- Filling factor for the ideal device of each cell is:

$$FFo_c = \frac{880.95 - ln(880.95 + 0.72)}{880.95 + 1} = 0.9911$$

- Resistance series of each cell is:

$$Rs = \left[1 - \frac{0.8462}{0.8316}\right] \cdot \left[\frac{0.617}{0.226}\right] = 0.0656\Omega$$

Simulating in the ideal conditions of irradiation and without effect of shade on the solar module the characteristics that the manufacturer grants in the specification sheets (table 1) are verified. The comparison of the values granted by the manufacturer and the simulator is observed next (table 2).

	Features Shell PowerMax Solar Module 85-P	
	Open Circuit Voltage (Voc)	Short circuit current (Isc)
Manufacturer	22.20 V	5.450 A
Simulator	22.21 V	5.4468 A

Table 2. Comparison of characteristics Voc and Isc

The simulator provides the characteristic curves V-I, the curve Pmax-V and Pmax- I, of the proposed conditions. These are the ideal graphs of the solar module Shell PowerMax 85-P, and are observed in fig 3, 4 and 5.

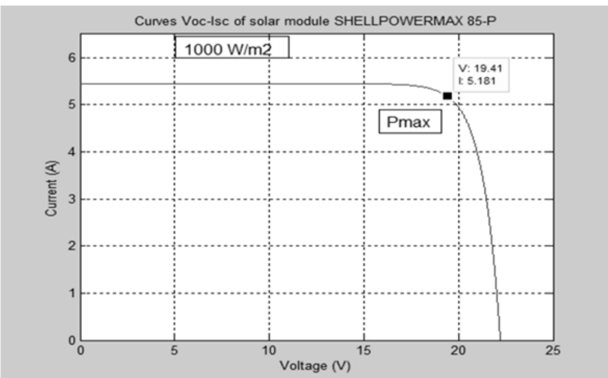

Fig.3. Characteristic graph Voc-Isc for $1000\ \frac{W}{m^2}$

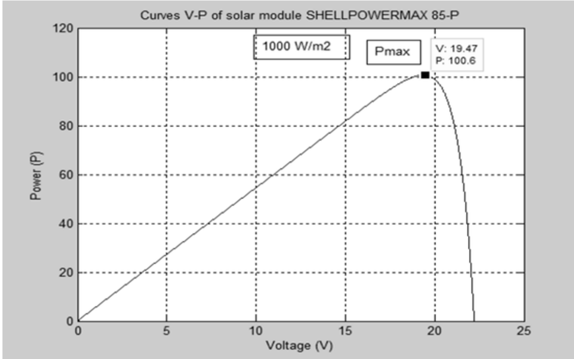

Fig.4. Characteristic graph V-P for $1000\ \frac{W}{m^2}$

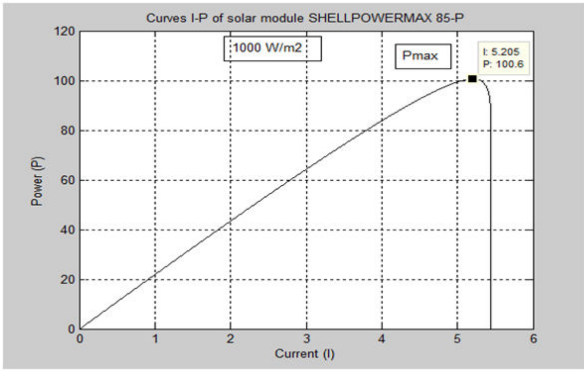

Fig.5. Characteristic graph I-P for $1000\ \frac{W}{m^2}$

In the experimental stage, several simulations of effect of shades were propossed on the solar module Shell PowerMax 85-P, which is in the prototype of the Benemerita Universidad Autónoma de Puebla, Mexico, in the Facultad en Ciencias de la Computacion.

In each case, shades were placed so, that they completely covered each solar cell depending on the test to accomplish, the cases go from covering the module completely and by covering portions of sections of the same, as it is seen (fig 6).

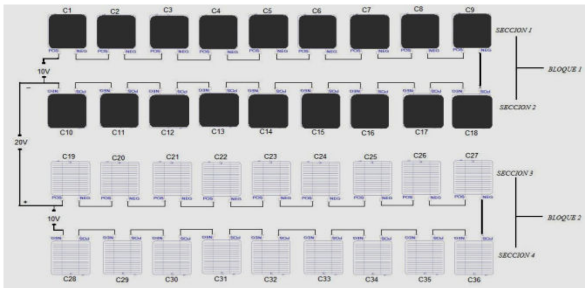

Fig. 6 Simulation of shades in the middle of a solar module

During the tests, measurements of solar irradiation of voltage of open circuit (Voice) and the current of short circuit (Isc) at the moment were taken. After simulating the conditions, the results of simulation were compared to the measurements previously taken (Table 3)

	Irradiation of the day: **353 W/m^2**			
	Without shade		With shade	
	Simulated	Measured	Simulated	Measured
(Voc)	20.49 V	19.6 V	15.24 V	15.05 V
(Isc)	1.92 A	1.82 A	1.84 A	1.86 A

Table 3 Simulation with shades in two different sections from the solar module, for the irradiation of 353 $\frac{W}{m^2}$

The simulator gives the characteristic curves as well, (fig 7, 8, 9) for the study of the random changes of solar radiation in the production of energy of the photovoltaic module.

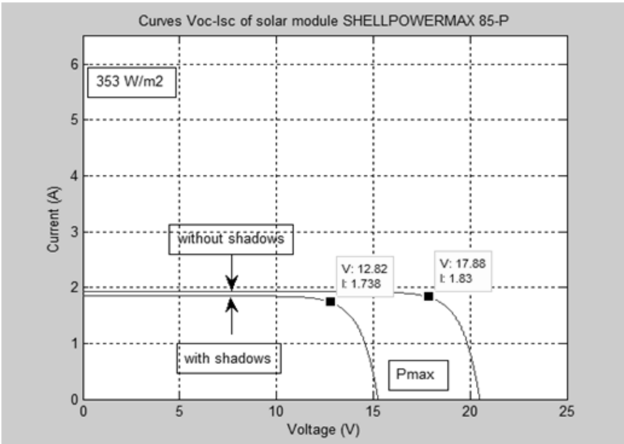

Fig.7 Curves V-I of the module pave, half of the module with shades

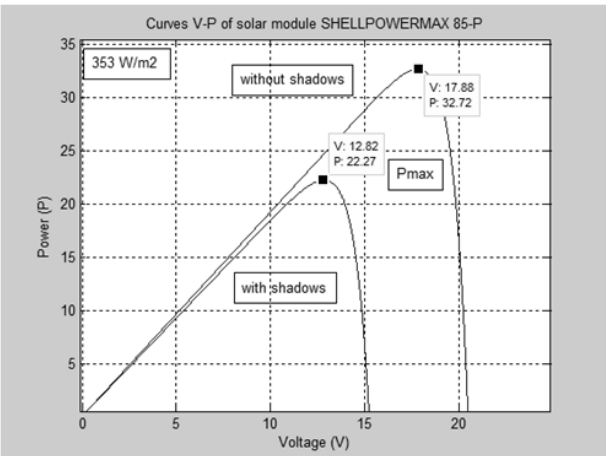

Fig. 8. Curves V-P of the solar module, half of the module with shades

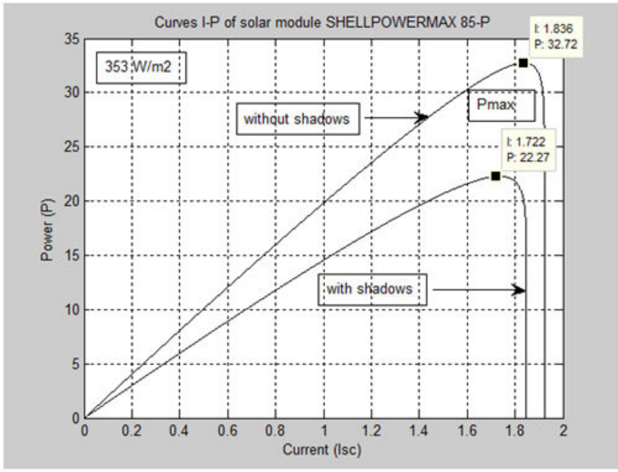

Fig. 9. Curves I-P of the solar module, half of the module with shades

3 Result

The factors that most affect the point of maximum power transfer in the solar module are the radiation of the day, as it constantly varies, and the amount of partial shade that may exist in MS [11, 12, 13,14].

The comparison of the results of voltage of open circuit (Voc), in conditions of abrupt changes of radiation with and without shade are shown in figure 10. It is observed that with any solar radiation present, it exists minimum variation of voltage because the cells are interconnected in series, seeking to reach the required characteristic tensions. When there is a percentage of shade on the module, it is observed that the greater percentage of shade and depending on its location a slight diminishing of voltage exists in comparison to that there is no shade in the module.

In fig 11 the results of current short circuit (Isc) based on the percentage of shade are shown. In this case it is possible to observe that when there is a great percentage of shade or this is located in 3 or 4 different sections of the solar module, there is a great diminishing of current reaching (10-15) % from the current without shade for a given radiation. That is due to the fact that the cells are interconnected in series and if the shade on one or more cells takes place, the current of all the chain series will be limited by the one that generates the minor current, that is to say, the one under the shade.

When analyzing the graph of the maximum power (Pmax) based on percentage of shade (fig 12), it is observed that the factor which considerably affects the point of maximum transference of power in the solar module is the percentage and location of the shade that can there be on the solar module.

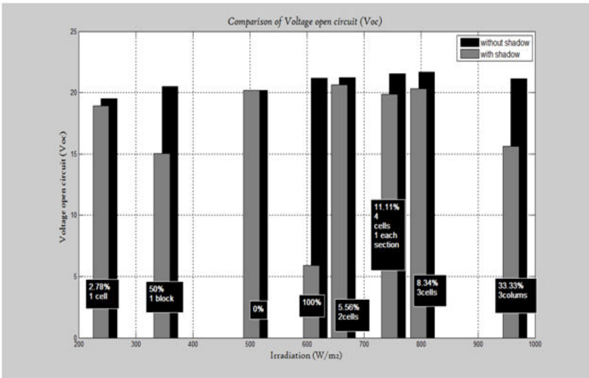

Fig. 10 Comparison of Voltage of open circuit (Voc)

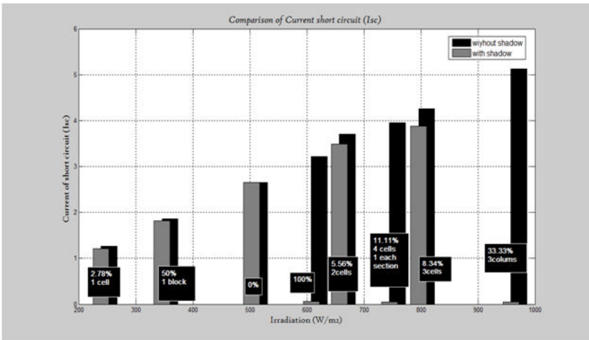

Fig. 11 Comparison of Current of short circuit (Isc)

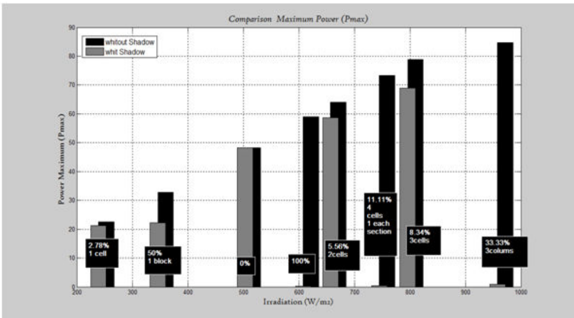

Fig. 12 Comparison of the Maximum power (Pmax)

4 Conclusion

The schematic model and the representative mathematical model of interconnection of solar cells of unit Shell PowerMax 85-P was developed with the possibility of introducing partial shading depending on its configuration and location.

A new methodology for the characterization of the effects of random changes in radiation, under outdoor conditions has been proposed relating the percentage of shade to the operation at the point of maximum transference of power.

The field tests and the later analysis of the results, demonstrated that to any irradiation a minimum variation of voltage exists, because the cells are interconnected in series, seeking to reach the required characteristic tensions and that to a greater percentage of shade and depending on its location, an insignificant diminishing of voltage exists when compared to when there is no shade in the module.

The diminishing of current is drastic when there is a great percentage of shade, or it is located in different sections series of the solar module. This happens when a shade is produced on one or more cells serially connected, the current of the whole chain, it will be limited by the one which generates the minor current, that is to say, the one in the shade. The factor that considerably affects the point of maximum transference of power, in the solar module, in case of random changes of radiation, is the percentage of shade on the solar module and the location of the same.

It is necessary to indicate that this is an initial study and that the actual system will be constructed later. The contribution of this study will help so that the actual system can be calculated and measured, considering the results of the simulations here shown.

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