Journal of Materials and Engineering Structures

Research Paper

Pattern Search algorithm for the Maximum Power Point Tracking in Photovoltaic System

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A R T I C L E I N F O

Article history:

Received 14 September 2021

Revised : 24 February 2022

Accepted : 6 March 2022

Keywords:

Photovoltaic system

Power, MPPT

Pattern Search algorithm (PS)

Optimization

A B S T R A C T

The aim of this paper is to present an intelligent control method for the maximum power point tracking (MPPT) of photovoltaic system under different climatic conditions with regard to temperature and irradiation. A Pattern Search algorithm (PS) is suggested to be combined with the maximum power point tracker as a strategic optimization for the photovoltaic panel. The voltaic system is composed of a solar panel and PS MPP tracker and it is simulated and evaluated. The system has shown a better performance as well as the effectiveness of PS MPP in terms of getting maximum energy production despite the changing climate conditions.

1 Introduction

The photovoltaic energy is the one that is characterized by the conversion of the solar energy into electricity. This is kind of energy has attracted a considerable attention recently thanks to its property, quietness, and appropriateness and it entails little maintenance. Taking a look at both the current-voltage and the power voltage characteristics of PV arrays, we can see their dependence on both the insulation and temperature [1, 2].

The challenge aspect in the field of solar energy is the non-linear nature of producing varying power and voltage related to the environmental conditions. As a result, full power generation is not guaranteed. To extract the maximum power generating from the PV configurations, MPPT technologies are fitted with appropriate controllers. a different algorithm of MPPT have been researched for years. These techniques are classified as classical, intelligent and optimization MPPT [3].

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e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

The most classical MPPT techniques used are the Perturb & observe (P&O) MPPT and the Incremental conductance (IC). Where the P&O algorithm enables to achieve the MPP by varying the PV panel output voltage with high tracking capability, simple and fast dynamic. However, there are oscillations remained around the MPP and high power loss in stable conditions. On the other side, IC algorithm outperforms P&O in that it can decide when the MPPT has arrived at the MPP, with low oscillations around the MPP. but there are different steps require complex and expensive controls [4-6].

The intelligent MPPT techniques are based on Fuzzy Logic Controller (FLC) and Artificial Neural Network (ANN). FLC achieves high efficiency without the need for a mathematical model and knowledge of the photovoltaic system. But unworthiness is the complexity of tuning the membership function and control rules given by FLC. While ANN does not require any detailed information about the system once trained with input sets, it can track any MPP, it is fast tracking and handle more complex problems. But its drawback is that it requires enormous data for the photovoltaic system information for training which makes the technique costly [4-7].

In optimization-based MPPT, many meta-heuristic algorithms such as cuckoo search (CS), particle swarm optimization (PSO), and artificial bee colony (ABC) ... etc., are used during the process of MPP tracking. All of these nature-inspired tracking algorithms are helpful for accurate tracking global maximum power point (GMPP) and provide high convergence along with higher efficiency. However, the objective function is a bit complicated and the risk of falling into a local maximum point tracking (LMPP) due to its dependence on randomness [4].

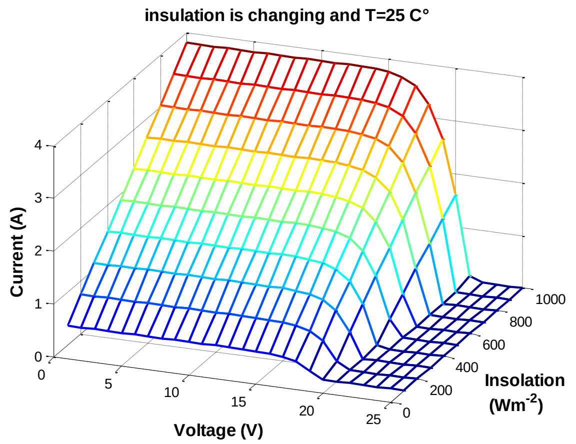

Fig. 1 – I-V characteristics when insulation is changing.

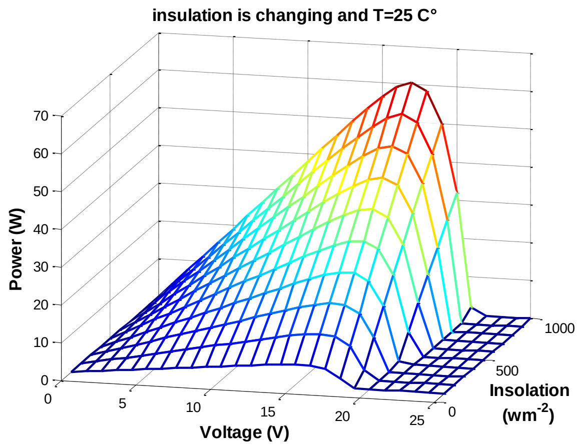

Fig. 2 – P-V characteristics when insulation is changing

In this paper a PS-MPPT algorithm method has been employed during the process traking of MPP for a faster convergence speed, high efficiency and neglects the process complexity. Therefore, adopting such new adaptive PS technique offers the possibility of dealing accurately with the potential optimization problems and to overcome the drawbacks of the traditional algorithms. The suggested approach is used in fitting both the I-V and P-V characteristics of a solar model referenced as Solarex MSX 60 with the characteristics shown in the index.

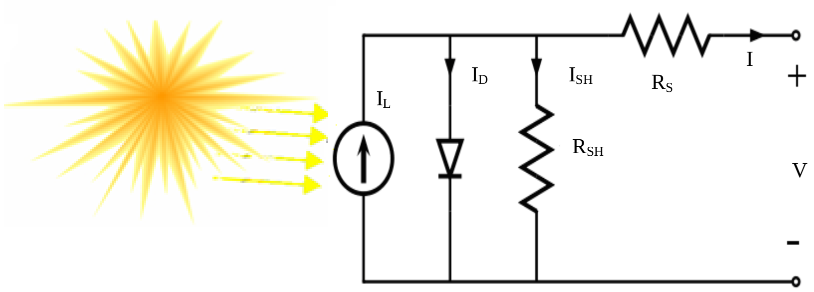

Fig. 3 – Circuit diagram of the PV model.

2 Modeling of the photovoltaic generator

Because the simplest equivalent circuit for the solar cell is the source of the current in parallel with a diode, the output of the current is proportional with the falling irradiation of the solar cell. It is agreed that with the lack of light, the cell is an inactive device functioning as a diode that does not produce either a current or a voltage. However, when it is connected to an external supply, it produces a diode current ID. The I-V characteristics of the cell are determined by the diode.

Enhancing the accuracy as well as the simplicity of the model through the introduction of the following amendments: [8-12]

- The diode saturation current I_0 and the photo current I_{ph} are dependent of the temperature.
- Series Resistance R_S is obtained accurately between the maximum power point MPP and the open circuit voltage V_{oc} and which represents the internal losses because of the current flow.
- Shunt resistance R_{sh} that is in parallel with the diode that represents the leakage current to the ground and it is commonly overlooked.
- Either allowing the diode quality factor n to become a variable parameter or fixed between 1 or 2.

An ideal cell $R_S = R_{sh} = 0$, which is relatively common assumption [10]. In this research, a model of moderate complexity has been presented. The net current of the cell is the difference between the photocurrent I_{ph} and the normal diode current I0:

$$I = I_L - I_0\left(e^{\frac{q(V+IR_S)}{nkT}} - 1\right) \tag{1}$$

The photo current and the saturation current of the diode are dependent on the temperature which are included in the solar model.

$$I_L = I_L(T_1) + K_0(T - T_1) \tag{2}$$

$$I_L(T_1) = I_{SC}(T_{1,nom})\frac{G}{G_{(nom)}} \tag{3}$$

$$K_0 = \frac{I_{SC}(T_2) - I_{SC}(T_1)}{T_2 - T_1} \tag{4}$$

$$I_0 = I_0(T_1)\times\left(\frac{T}{T_1}\right)^{\frac{3}{n}} e^{\frac{qV_q(T_1)}{nk\left(\frac{1}{T}-\frac{1}{T_1}\right)}} \tag{5}$$

$$I_0(T_1) = \frac{I_{SC}(T_1)}{\left(e^{\frac{qV_{OC}(T_1)}{nkT_1}} - 1\right)} \tag{6}$$

A series resistance R_S has been included to represent a resistance inside each cell in terms of the connection between cells.

The shunt resistance is overlooked. A single diode model was used with the diode quality factor set so as to reach the best curve match. The model is a simplified version of the two diode model presented by Gow, and Manning [10]. The equivalent circuit for the solar cell is shown in the Fig. 3.

$$R_S = -\frac{dV}{dI_V} - \frac{1}{X_V} \tag{7}$$

$$X_V = I_0\left(T_1\right) \times \frac{q}{nkT_1} e^{\frac{qV_{OC}(T_1)}{nkT_1}} - \frac{1}{X_V} \tag{8}$$

The I-V characteristic of the solar model can be expressed nearly by the Eq. 1-8. The model necessitates three points to be measured to define this curve: (3)

- The voltage of the open circuit V_{oc}.
- The current of the short circuit I_{sc}.
- The point of maximum power (I_{mp}, V_{mp}).

3 Pattern Search Optimization Technique

The Pattern Search (PS) algorithm is an evolutionary technique that is appropriate to overcome different kinds of optimization problems that lie outside the scope of the standard optimization methods. In general, PS is characterized by its simplicity in concept, and easy to be implemented and computationally efficient algorithm. Unlike other heuristic algorithms such as genetic algorithm GA, Particle Swarm Optimization PSO, aunt bee colony ABC, PS has a flexible and well-balanced operator to ameliorate and adapt the global and fine tune local search. Historically speaking, PS came from the direct search method for the unconstrained optimization [12, 13].

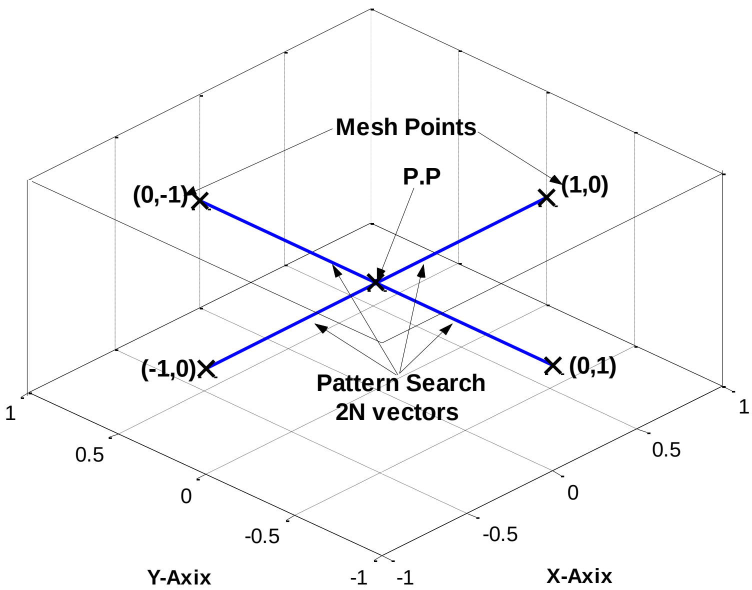

Fig. 4 – 2N Pattern Vectors which forms the mesh points

The Patten Search algorithm proceeds by a computing a sequence of points that may not approach to the global optimal point. The algorithm begins by making a set of points named mesh around the given points. This current point is the initial starting point supplied by the user or it could be computed from the previous step of the algorithm. The mesh is constructed by adding the current point to a scalar multiplied to a set of vector named a pattern. When a point in the mesh is found to ameliorate the aim function at the current point, the new point becomes the current point at the next iteration.

This could be better clarified through the following:

First: the pattern search starts at the initial point X_0 that is obtained as a starting point by the user. At the first iteration, with a scalar = 1 named mesh size, the pattern vectors are formed as X_1, they may be called direction vectors. Then the pattern search algorithm adds the direction factors to the initial point to compute the following mesh points [12].

$$X_0 + [0\ 1], X_0 + [1\ 0], X_0 + [-1\ 0] \text{ and } X_0 + [0\ -1]$$

Fig. 4 shows the construction of the mesh and pattern vector. The algorithm computes the aim function at the mesh points in the shown order. The algorithm or the mesh points by computing their objective function values until it finds one whose value is better than that of the objective function. If there is such point, then the poll is successful and the algorithm regulates this point as X_1.

After a successful poll, the algorithm steps to the next iteration and multiplies the current mesh size by two, (this is referred to the expansion factor with a default value of 2). The mesh at this iteration has the following point X_1: $2*[1\ 0]+X_1$, $2*[0\ 1]+X_1$, $2*[-1\ 0]+X_1$ and $2*[0\ -1]+X_1$. Through this procedure, the next current points and mesh size could be found for the next coming iterations.

Second: if the current iteration ends up by being unsuccessful poll, i.e. none of the mesh points has a better objective function value than the previous current value. In that case the poll is considered as unsuccessful poll. As a result, the algorithm does not change the current point at the next iteration, but it multiplies the current mesh size by 0.5 as a construction factor. The algorithm, then, polls with a smaller mesh size.

The PS algorithm will repeat the illustrated steps until it gets the optimal solution for the objective function. When the following conditions occur, the algorithm stops:

- The mesh size is less than the given mesh tolerance.
- The performed number of iterations exceeds the value of maximum iteration.
- The difference in distance between the points found by two successive successful polls is less than a given tolerance.

All the parameters involved in the process of the pattern search algorithm can be predefined according to the nature of the problem being solved.

4 Applications of PS to MPOP

The objective is to find the optimal solution with regard to the variables of the optimization problem (current and voltage) with the constraints of the current and the voltage that should be higher than a zero.

To optimize the objective function (*F*) which is considered to have a maximum fitness value (*F*) in the searching process. The goal of PS has to be set to the maximization of fitness to be used as follows:

$$Fitness = \begin{cases} P(V,I)/P_{\max} & if\ P_{\max} < P \\ 0 & otherwise \end{cases} \quad (9)$$

The aforementioned steps and the integration of PS algorithm are described by the following chart of the fig. 5. It should be mentioned that all the parameters involved in the PS algorithm can be predefined as being subject to the nature of the problem being solved.

The PS operator is so important as it offers a great deal of control concerning the direction of the search. After a large number of experiments for many values of expansion and contraction factor is being carried out, the best combination has been found to be 2 and 0.5 respectively, giving an average best performance of optimal speed of C.P.U time as well as the right direction of the search.

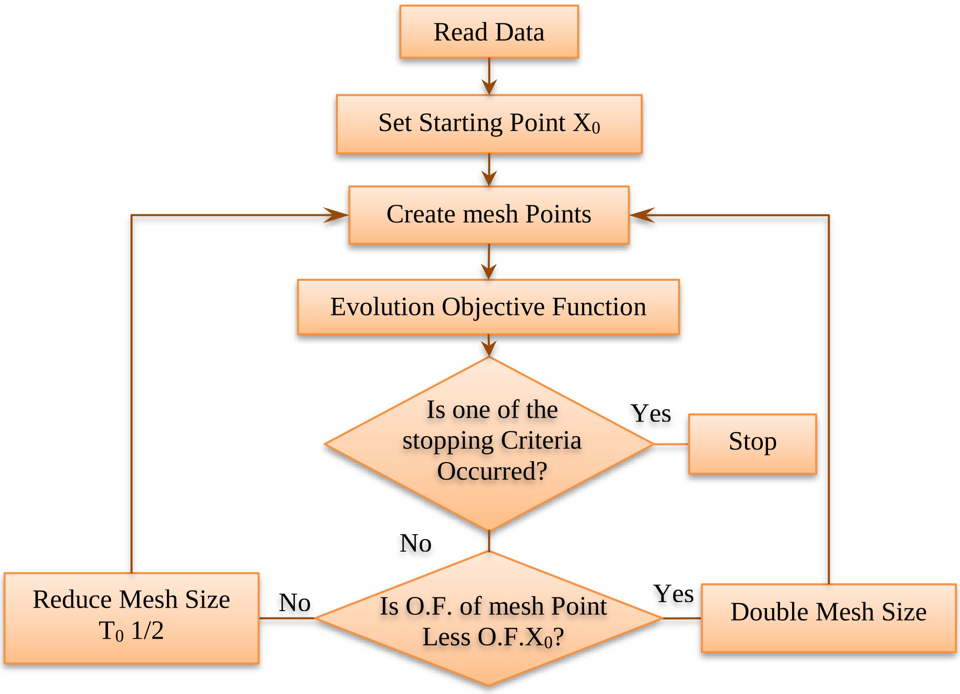

Fig. 5 – Flow chart of pattern search.

5 Results and Discussion

The MATLAB system has been used in order to develop and execute the program which was written on Pentium 4 having 2.4 GHZ 1GBDDR RAM.

The key parameters of PS algorithm such as the initial mesh size and the mesh expansion and contraction factors, in this research, are fixed as 1, 2 and 0.5 respectively. The starting points, i.e. X0 were randomly generated to provide as an initial guess for the PS algorithm to proceed. As far as the stopping criteria are concerned, all tolerances were set to 10-6 maximum numbers of iterations and function evaluations were set to 50.

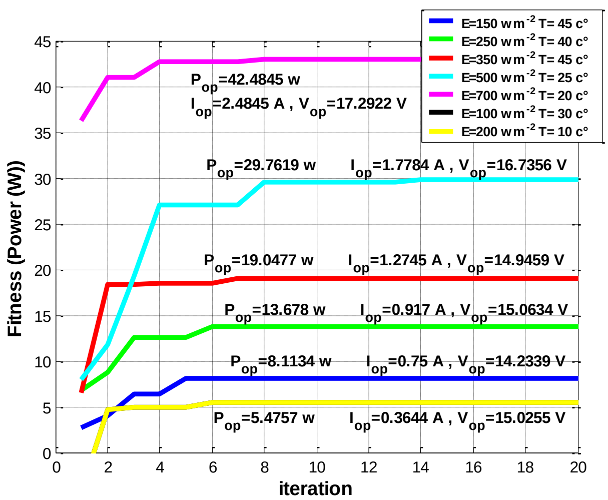

Fig. 6 – Convergence of PS under different conditions

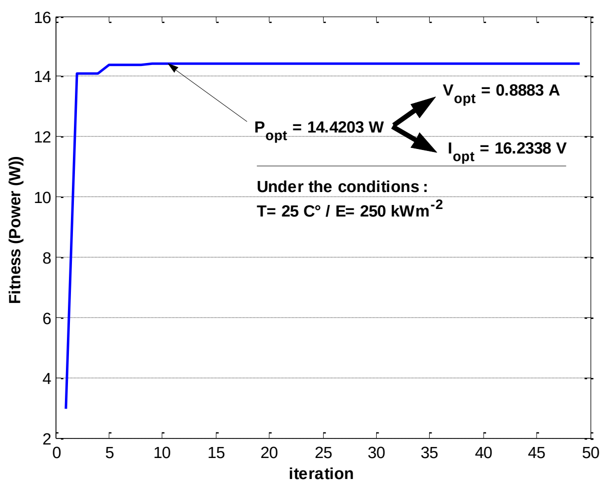

Fig. 7 – Convergence of PS for T = 25 C° and E = 250 Wm^{-2}

The obtained values of this optimization problem are shown in simulations 1-2. These simulations are the result of several runs of the PS technique. It is evident that the variation of the MPOP with regard to either insulation and/or temperature with great accuracy. (Figs. 11-14).

The convergence of optimal solution using PS is shown in Fig. 6-7, where it was found after about 10 iterations. Nonetheless, the PS continues the searching in the neighbourhood for optimal point to increase the confidence in the result. PS stops after 50 iterations and returns the optimal value.

Fig. 8 describes the mesh size during the convergence process. From the Fig. 8, it is clear that the mesh size decreases until the algorithm ends. In this case, the mesh size equals to 1.1921e-7 which is smaller than the stopping criteria which indicates that this particular run did not terminate using the mesh size tolerance [13, 14].

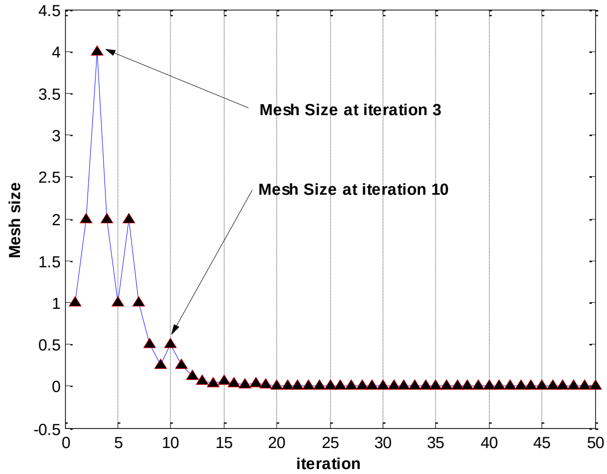

Fig. 8 – Convergence of PS mesh size

So as to simulate the system, it is imperative to use the irradiance data for a specific location in a 24 hours' period. Any location would be sufficient to test the model. The data have been chosen from Golden, Colorado on March 08th, 2010 and May 11th, 2009 because of data availability and an accuracy confidence [15].

Apparently, the data for May 11th, 2009 is an appropriate example of a typical sunny day, while that of March 08, 2010 is good case scenario for a cloudy day. Both of these days could be useful for simulation purposes [14].

It goes without saying that the system works more effectively under sunny conditions. However, the data used for the cloudy day dropped the power maximal of PV array by about 75%, which means that the maximum of two consecutive cloudy days can be handled by the system.

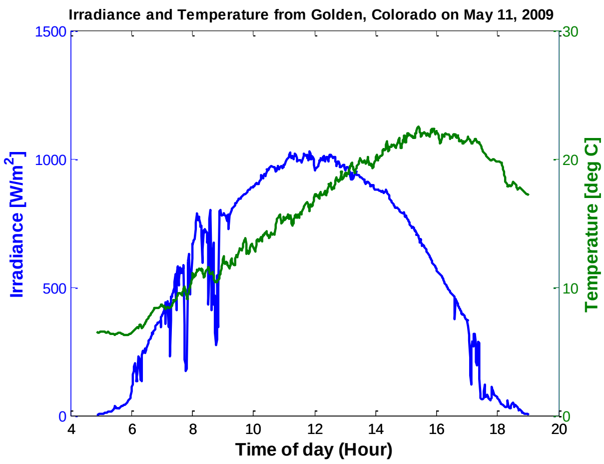

Fig.9- Irradiance and Temperature data for sunny day simulation purposes.

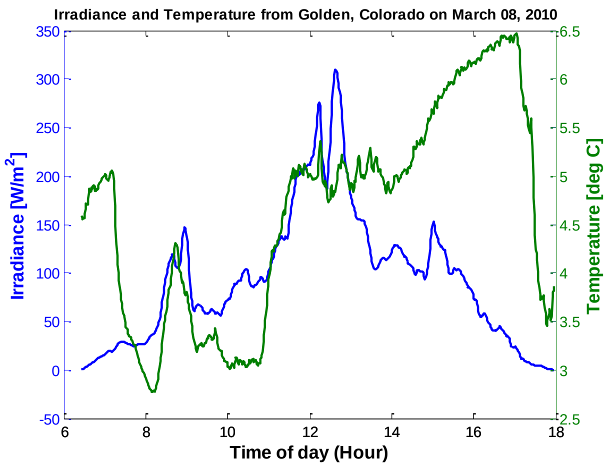

Fig.10-Irradiance and Temperature data for cloudy day simulation purposes.

Simulation 1: Sunny day conditions

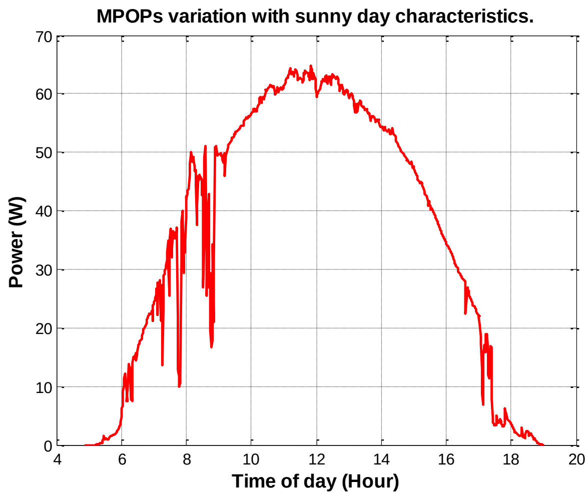

Fig.11-Power optimal for sunny day simulation purposes.

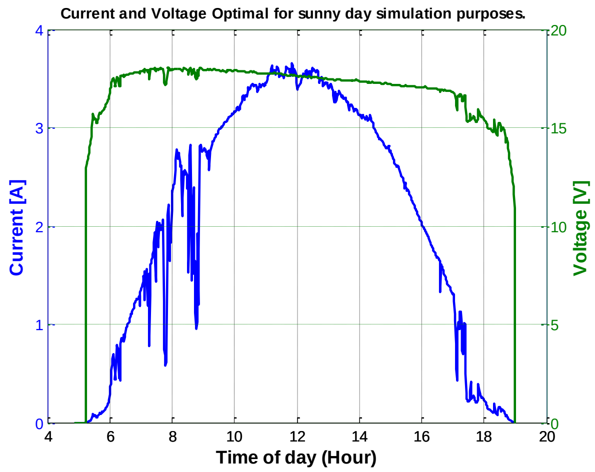

Fig.12 - Current and Voltage optimal for sunny day simulation purposes

Simulation 2: cloudy day conditions.

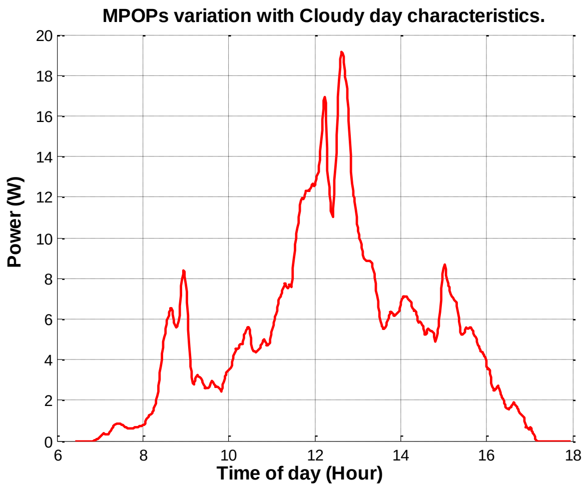

Fig.13- Power optimal for cloudy day simulation purposes.

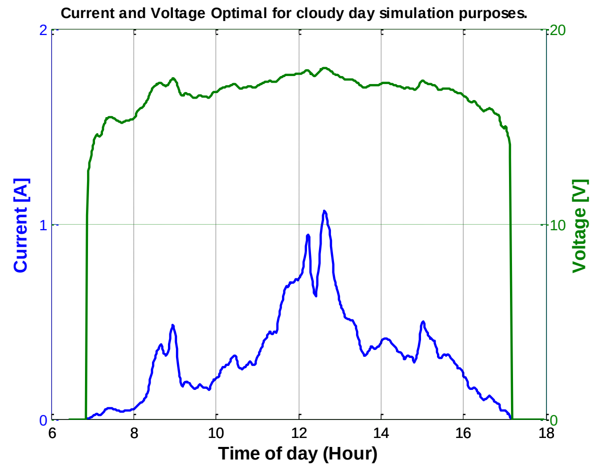

Fig.14- Current and Voltage optimal for cloudy day simulation purposes.

For better results, it is recommended that several simulations would be run for more cloudy day scenarios. Moreover, a simulation in which a cloudy day is followed by a sunny day may give us an idea of how quickly the system would be able to rebound back to normal conditions.

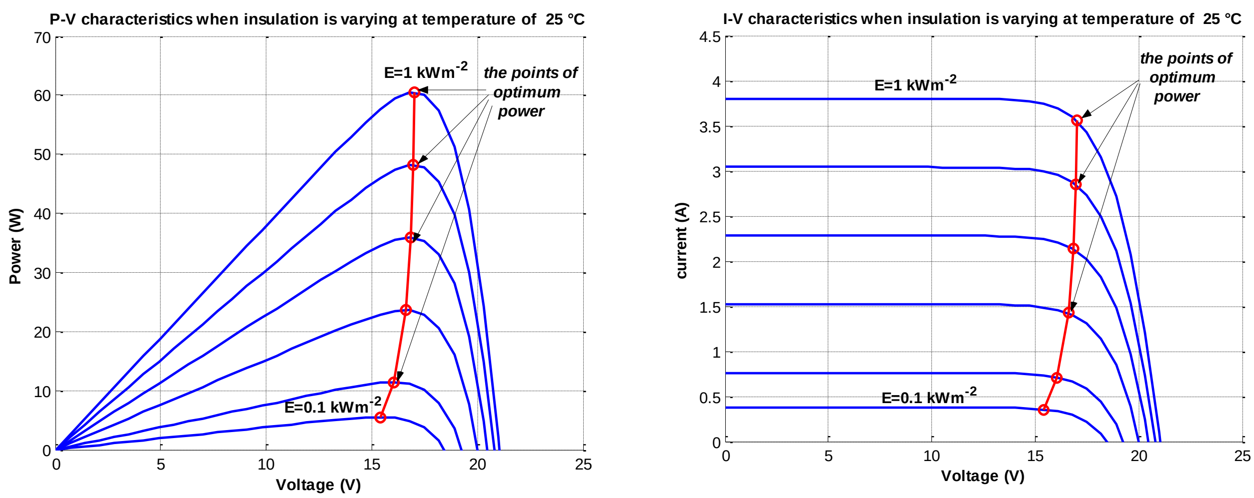

Fig. 15- MPOPs variation with insulation from I-V and P-V characteristics.

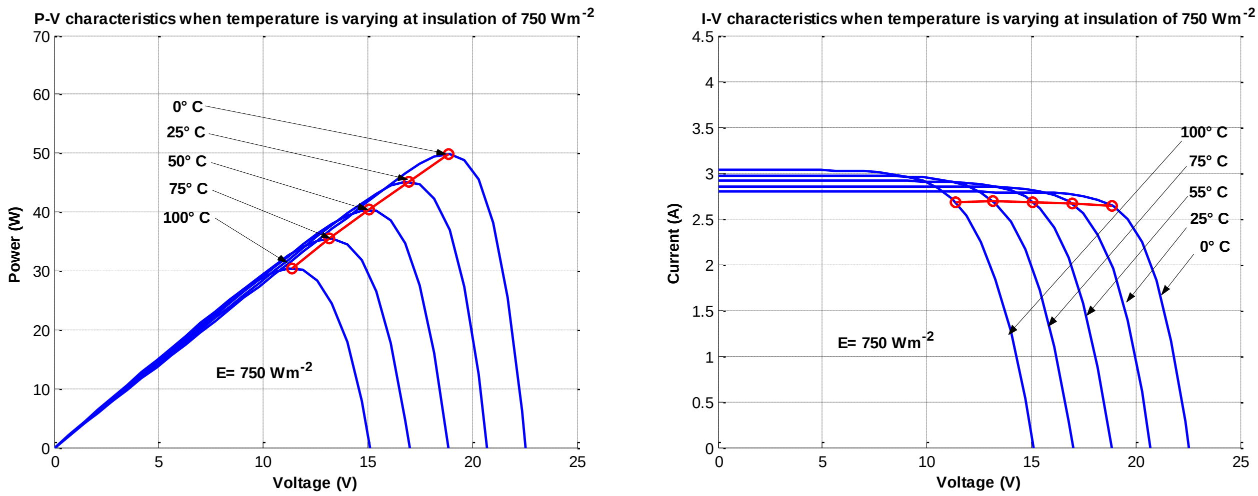

Fig. 16 – MPOPs variation with temperature from I-V and P-V characteristics.

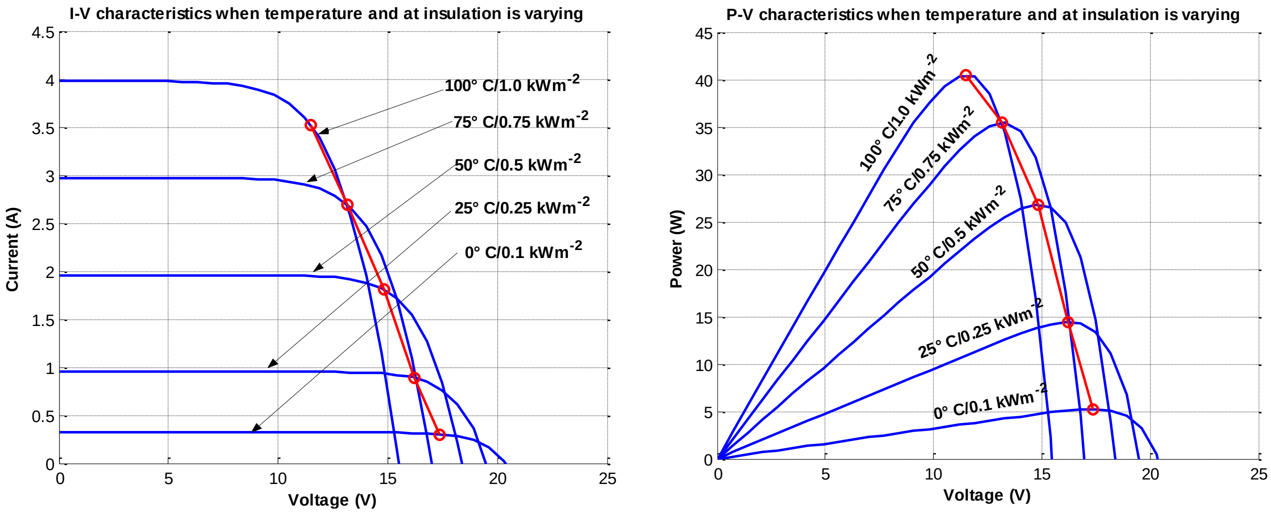

Fig. 17 – MPOPs variation with insulation and temperature at the same time from I-V and P-V characteristics.

So sum up, the presented results show clearly the interests as well as the benefits of the proposed procedure and how accurate it is. In order to see clearly the results of this optimization study, Figs. 15-17 plot the multiple variation of both current and power regarding the voltage. The maximum power operating point MPOP of each curve is represented by "o" and it shows the maximum value of power (current and voltage) that the module can supply instantaneously under different climatic conditions.

6 Conclusion

This research has introduced a new approach based on Pattern Search optimization algorithm that tracks instantaneously the MPOP of a PV model so as to maximize the produced power. Because of the P-V characteristics, this heuristic method is used to seek the global maximum power and to avoid the wrong value of local maximum one. The obtained results of this investigation have been presented in figs.10-14.

The usefulness of a model for a PS technique has proved to be significant. It is possible to simulate a variety of conditions or make a change to the parameters of the system. Although, there are some minor difficulties, however, the model performs effectively and it is not overly difficult to use. The optimal power solution determined by the PS is well capable of determining the global or near global MPOP.

One of the drawbacks of PS is its lack of somewhat solid mathematical foundation for analysis. Where the setting of step size parameter is made by a predetermined magnitude, to ensure that all iterates remained on a rational lattice and the algorithm convergence. This problem could be overcome by proposing an intelligent technique for predetermine the appropriate step size value and conducting further research in this particular area.

Appendix A. Solarex MSX 60 Specifications (1kW/m^2, 25°C)

Characteristics	SPEC.
Typical peak power (P_m)	60W
Voltage at peak power (V_m)	17.1V
Current at peak power (I_m)	3.5A
Short-circuit current (I_{SC})	3.8A
Open-circuit voltage (V_{OC})	21.1V
Temperature coefficient of open-circuit voltage (α)	-73 mV/°C
Temperature coefficient of short-circuit current (β)	3 mA/°C
Approximate effect of temperature on power	-0.38W/°C
Nominal operating cell temperature (NOCT^2)	49°C

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