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Optimization by Continuous Genetic Algorithm of the Maximum Photovoltaic Power Tracking under Different Climatic Conditions

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Abstract: Because of the changing of the maximum power operating point with respect of insulation and temperature (atmospheric conditions) a big importance is given to the maximum power point tracker. So, the heuristic techniques based on the concept of optimisation are nowadays of great importance because of their adaptability with photovoltaic arrays. The aim of this study, is the implementation of a continuous genetic algorithm (heuristic method) in order to meet the maximum power operating point whatever the climatic conditions are.

Key words: Continuous genetic algorithm, photovoltaic system, MPOP, optimization technique

INTRODUCTION

Nowadays, optimization techniques are being progressively applied to many engineering fields because of their usefulness, so their application to a wide variety of problems become more and more attractive. This tendency has been motivated by the increased availability of powerful computational platforms. Among these numerical techniques, we find the one of genetic algorithms which gives more rigorous results compared to the analytical ones (Davis, 1991; Goldberg, 1989).

Photovoltaic energy is a technique, which converts directly the sunlight into electricity. It is modular, quiet, non-polluting and requires very little maintenance, for this reason a powerful attraction to photovoltaic systems is noticed. By having a quick glance on both the current-voltage and the power-voltage characteristics of PV arrays, we see clearly the dependence of the generating power of a PV system on both insulation and temperature. (Labouret and Villoz, 2003).

In this study, we present an application of a continuous Genetic Algorithm (GA) on a photovoltaic system, which helps to catch the Maximum Power Operating Point (MPOP). This latter change instantaneously with changing radiation and temperature, what implies a continuous adjustment of the output voltage to achieve the transfer of the maximum power to the load. The justification of this application lies in the fact that both I-V and P-V characteristics are non linear because of the nonlinearity of the photovoltaic systems from one hand and because of the instantaneous change of both insulation and temperature from the other hand, what makes the two previous plots in fact fluctuating instead of the simulated smooth ones (Fig. 1 and 2).

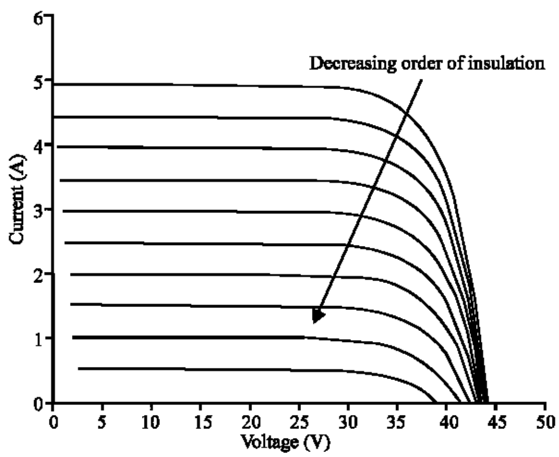

Fig. 1: I-V characteristics when insulation is changing

Therefore, the adoption of this novel adaptive continuous GA technique offers the possibility of dealing accurately with these optimization problems and to overcome the incapacities of the traditional numerical techniques. The proposed approach is employed in fitting both the I-V and P-V characteristics of a solar module referenced as BP SOLAR, BP 4160S with the characteristics shown in the index.

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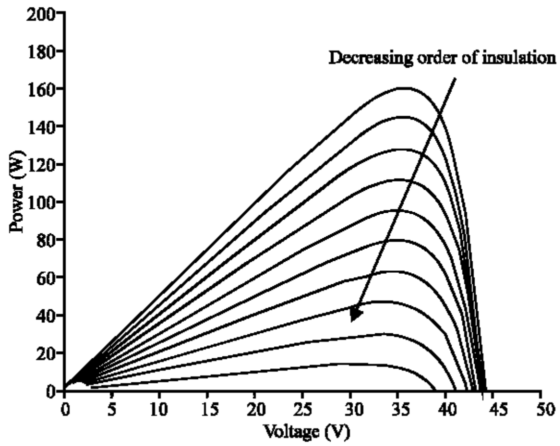

Fig. 2: P-V characteristics when insulation is changing

MODELLING OF THE PHOTOVOLTAIC GENERATOR

The I-V characteristic of the module can be expressed roughly by the Eq. 1-9. The model (one diode model) requires three points to be measured to define this curve: (Weiner and Levinson, 1996).

- The voltage of the open circuit Voc.
- The current of short-circuit Isc.
- The point of optimum power (I_{opt},V_{opt})

$$I = Icc[1\text{-}C1(\exp.(\frac{V}{C_2 \cdot V_{oc}})\text{-}1] \quad (1)$$

$$C_2 = \frac{\frac{V_{opt}}{V_{oc}} - 1}{\mathrm{Ln}\left(1 - \frac{I_{opt}}{I_{sc}}\right)} \quad (2)$$

$$C_1 = \left(1 - \frac{I_{opt}}{I_{sc}}\right) \cdot \exp\left(\frac{-V_{opt}}{C_2 . V_{oc}}\right) \quad (3)$$

The adaptation of the Eq. 1 to other levels of radiation and temperatures gives:

$$In = I\,ref + \Delta I \quad (4)$$

$$Vn = V\,ref + \Delta V \quad (5)$$

Where

$$\Delta I = \alpha(\frac{E}{E_{ref}})\,\Delta T + (\frac{E}{E_{ref}}\text{-}1)Isc \quad (6)$$

$$\Delta V = -\beta \Delta T - Rs \cdot \Delta I \quad (7)$$

With:

α is the coefficient of variation of the current with the temperature

β is the coefficient of variation of the voltage with the temperature

$$\Delta T = T - T_{ref} \quad (8)$$

Where

T is the temperature of the module

T_{ref} is the reference temperature

The temperature of the module is related to the ambient temperature by the following relation:

$$Tm = Ta + K.E \quad (9)$$

Where K is the temperature factor of the module measured in m^2/w^2.

GENETIC ALGORITHM APPROACH (David, 2006)

Genetic algorithms offer an alternative approach and are gaining popularity in optimization problem solving. Being inspired by the biological evolutionary process, the basic idea of genetic algorithms for optimization problems is that solutions to a problem can be reproduced from a population of candidate solutions. Repeated reproduction and survival of the fittest creates successive generations of offspring which converge toward an optimum set of characteristics.

The problem with genetic algorithms lies firstly with the way to encode the variables of a problem in a meaningful way that can be used to develop a new set of values for the variables. This set of encoded variables is called a chromosome, this latter is comprised of genes and genes represent the encoded variables for the problem.

The second problem to overcome is to devise a way to measure the fitness of each chromosome, so a suitable structure for chromosomes is necessary.

The next big problem is how to reproduce, or combine, chromosomes to generate successive populations in order to develop a solution.

PROCEDURE OF CONTINUOUS GA

The goal is to solve some optimization problem where we search for an optimal solution in terms of the variables of the problem (current and voltage) by imposing the

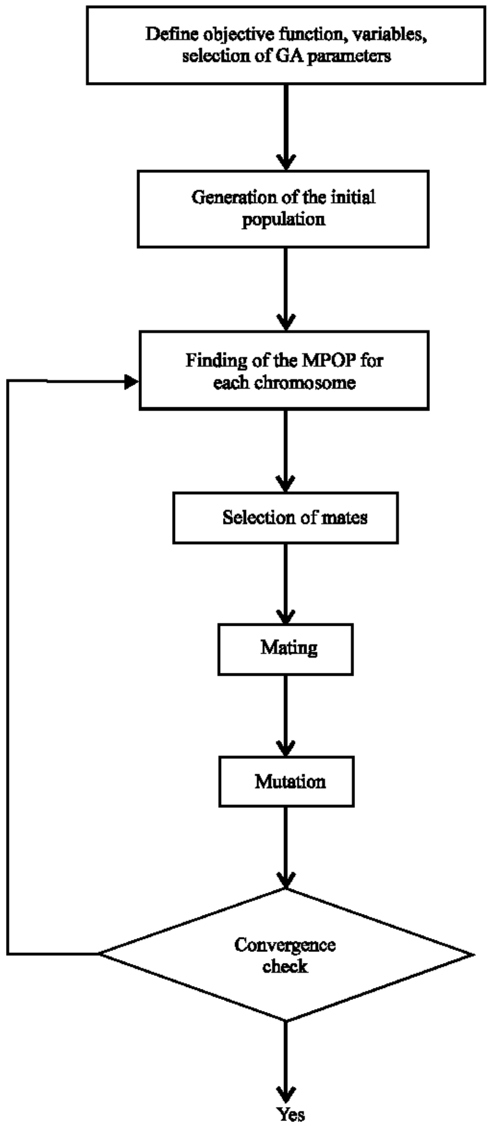

Fig. 3: Flowchart of a continuous GA

constraints on the current and the voltage which should be both bigger than zero. Consequently, we have to find a chromosome in the form of an array of variable values to be optimized.

Since our equation to be optimized is a function only of current and voltage, so the chromosome variables are very clear.

$$\text{chromosome} = [I, V] \tag{10}$$

Our goal is to find the global maximum value of f (I, V) (Fig. 3).

To start the continuous GA, we have to define an initial population of N_{pop} which is a matrix that represents the population with each row in the matrix being a $1\times N_{var}$ array (chromosome) of continuous values. Given an initial population of N_{pop} chromosomes, the full matrix of $N_{pop}\times N_{var}$ random values is generated by the following statement:

$$\text{pop} = \text{rand}(N_{pop}, N_{var}) \tag{11}$$

We start solving Eq. (1) by filling the $N_{pop}\times N_{var}$ matrix with uniform random values ranging from zero to the value of the open circuit voltage on one axis and from zero to the short circuit current on the other axis. In our case N_{pop}= 8.

The process of natural selection occurs at each iteration of the algorithm. Of the N_{pop} chromosome of any generation, only the top N_{keep} are kept for mating and the rest are discarded to make room for new offspring. In our case N_{keep} = 4 most fit chromosomes from mating pool. Two mothers and fathers pair in some random fashion. Each pair produces two offspring that contain traits from each parent. The parents survive to be part of the next generation. The process described previously is iterated until an acceptable solution is found.

After the run, the algorithm gives the real maximum value of the fitness function (1) according to the tables and the plots shown next.

RESULTS AND DISCUSSION

The program has been developed and executed under MATLAB system. The resulted values of this optimization problem are reported in Table 1-3.

These tables consider simulation results of many sample runs of the continuous GA technique. We see clearly the variation of the MPOP with respect to either insulation or temperature and both of them with great accuracy (Fig. 4-9).

Table 1: Optimization results when insulation is varying at temperature of 25°C

Insulation [Wm^{-2}]	V_{max} [V]	I_{max} [A]	M_{pop} [W]
1000	35.8020	4.4729	160.1399
900	35.7571	4.0246	143.9091
800	35.6680	3.5767	127.5736
700	35.5347	3.1281	111.1551
600	35.3572	2.6778	94.6813
500	35.0471	2.2310	78.1897
400	34.6486	1.7817	61.7324
300	33.9849	1.3356	45.3891
200	33.0118	0.8874	29.2937
100	31.1105	0.4413	13.7280

Table 2: Optimization results when temperature is varying at insulation of 1000 W m^{-2}

Temperature [°C]	V_{max} [V]	I_{max} [A]	M_{pop} [W]
0	39.6006	4.1263	163.4032
15	37.3214	4.3343	161.7613
20	36.5617	4.4036	161.0033
25	35.8020	4.4729	160.1399
30	35.0857	4.5367	159.1716
35	34.3251	4.6059	158.0981

Table 3: Optimization results when temperature and insulation are varying simultaneously

Temperature [°C]	Insulation W m^{-2}]	V_{max} [V]	I_{max} [A]	M_{pop} [W]
8	350	39.0063	1.3773	53.7235
16	500	38.3143	2.0603	78.9384
24	650	37.1338	2.7943	103.7637
32	800	35.5575	3.5852	127.4798
40	950	33.7946	4.4217	149.4303

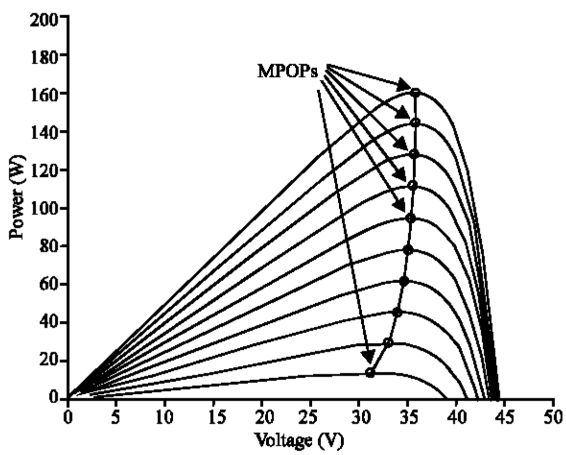

Fig. 4: MPOPs variation with insulation from P-V characteristics

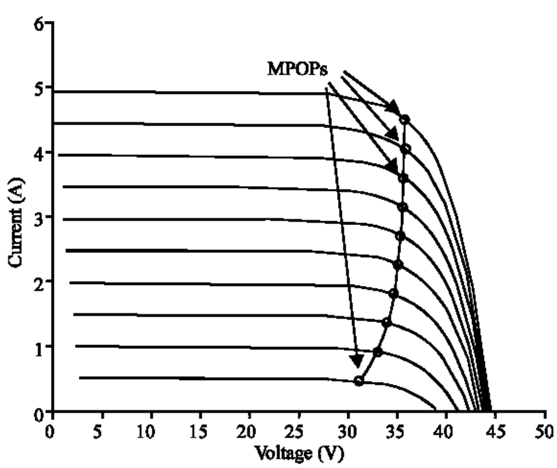

Fig. 5: MPOPs variation with insulation from I-V characteristics

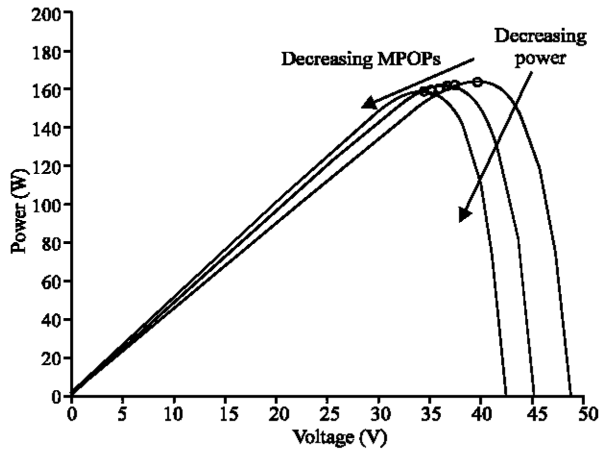

Fig. 6: MPOPs variation with temperature from P-V characteristics

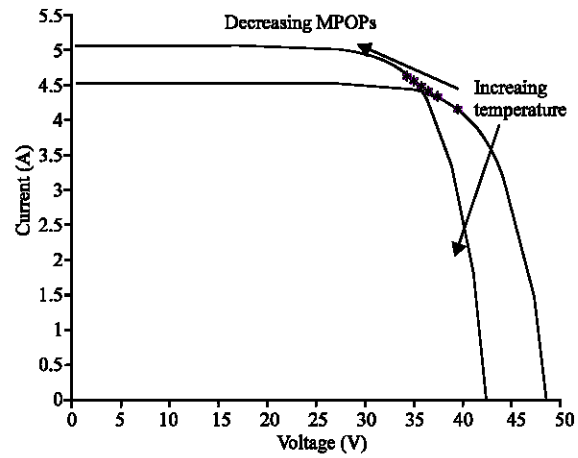

Fig. 7: MPOPs variation with temperature from I-V characteristics

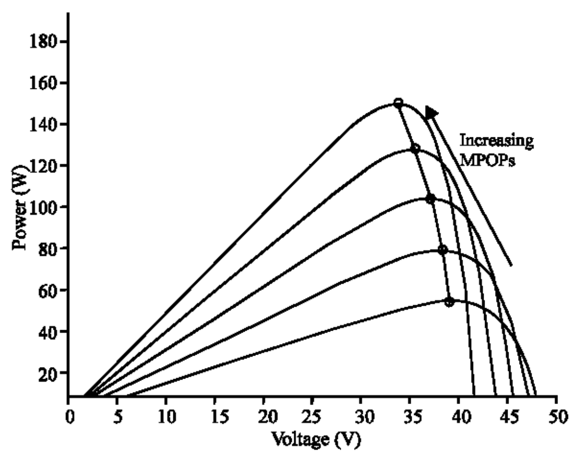

Fig. 8: MPOPs variation with insulation and temperature at th same time from I-V characteristics

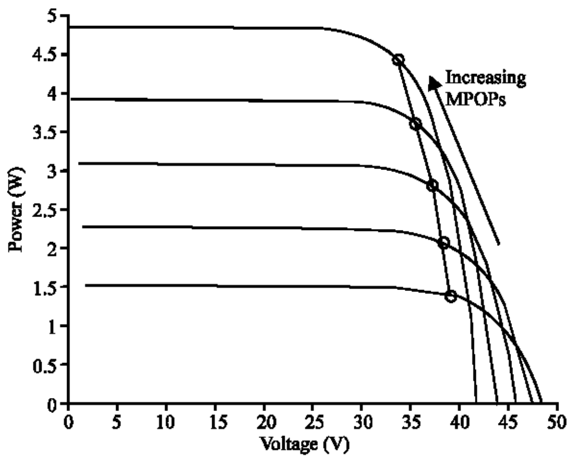

Fig. 9: MPOPs variation with insulation and temperature at th same time from P-V characteristics

In summary, the presented results demonstrate noticeably the interests and benefits of this suggested procedure and how accurate it is.

In order to see clearly the results of this optimization study, the Fig. 4-9 plot the multiple variation of both current with respect to voltage and power with respect to voltage.

The maximum power operating point MPOP of each curve is represented either by "o" or "*" and it shows the maximum value of power (current and voltage) that the module can supply instantaneously under different climatic conditions.

CONCLUSION

This study presents a continuous genetic algorithm, which calculates instantaneously the MPOP of a PV module in order to maximize the profits in terms of the power issued from the PV module. Because of the instantaneous changing character of either the I-V or the P-V characteristics, this heuristic method is used to seek the real maximum power and to avoid the wrong values of local maxima. In fact, the implementation of this technique reduces considerably the time of the computing process and yields to more results that are accurate.

The obtained results of this investigation are reported in Table 1-3 and depicted in Fig. 4-9.

It is worth to note that, this powerful stochastic identification approach can find its application within many other models like the simplified model and the two diodes model. From the presented study, we can say with confidence that the continuous GA approach is a promoting tool that is useful for optimization of multi-dimensional engineering systems even with multi-objective function.

Appendix1 : This appendix contains the electrical characteristics of the BP 4160S photovoltaic module

Electrical characteristics	BP 4160S
Maximum power (Pmax)	160W
Voltage at Pmax (Vmp)	35.4V
Current at Pmax (Imp)	4.52A
Warranted minimum Pmax	152W
Short-circuit current (Isc)	4.9A
Open-circuit voltage (Voc)	44.2V
Temperature coefficient of Isc °C	(0.065 ± 0.015)%/
Temperature coefficient of voltage	-(160 ± 20)mV/°C
Temperature coefficient of power	-(0.5 ± 0.05)%/ °C
NOCT	47± 2°C
Maximum series fuse rating 15A (S,L versions)	20A (H version)
Maximum system voltage rating)	600V (U.S. NEC 1000V (TÜV Rheinland rating)

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