Maximum power point tracking for photovoltaic power systems

Study of the Algorithm Adapted Incremental Conductance (AIC)

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Summary- **The work here aims to describe the principle of operation, characteristics and implementation of a Maximum Power Point Tracker (MPPT) for solar panels. The purpose of this device is to ensure that the working point of a photovoltaic cell is located as close as possible to the point where it provides the maximum available power.**

Of the various existing algorithms to implement an MPPT, the "Adaptive Incremental Conductance (AIC)" technique has been chosen due to its very good search speed and simple implementation. Variations are made to the operating parameters of the algorithm to analyze its behavior regarding the time of convergence towards the maximum power point and its oscillation in a stable state.

A SEPIC converter is used operating in continuous driving mode as a power stage and a digital signal controller for the implementation of the tracking algorithm.

Keywords - **Solar energy, MPPT, maximum power point tracking, solar panel, AIC, SEPIC, Irradiance.**

I. INTRODUCTION

The sun is considered one of the most promising sources of energy, due to this the solar energy exploitation technology have had a great boom in the market, where the technology that has most impacted is the photovoltaic, which directly converts solar energy in electricity. [1]

The photovoltaic cells have characteristic V-I curves that define their behavior under different operating conditions. The power of a solar cell is given by the product of the electrical intensity and the voltage of it. The point of maximum power (MPP, Maximum Power Point) is the product of the voltage at the maximum point (VMPP) and electrical current intensity at the maximum point (IMPP) for which the power extracted from the photovoltaic array is maximum (PMPP). The point of maximum power varies continuously, since it depends on factors such as the temperature of the solar cell and the irradiation conditions, that is, the energy density of solar radiation incident on a surface.

The maximum power point tracking algorithms (MPPT) are used in photovoltaic systems to maximize the energy delivered by them, this monitoring is basically done by varying the duty cycle value of a power converter, in our case a SEPIC. There are a variety of tracking algorithms for the maximum power point, such as: Perturb and Observe classic (P&O); P&O Interpolation; High Performance Adapted to Disturb and Observe (PI P&O); Classic Incremental Conductance (CI) and Adapted Incremental Conductance (AIC). These algorithms vary in their tracking capacity, disturbances in steady state, the need for predefined constants and difficulty of implementation, their cost, their efficiency and other aspects.

The objective of this work is to carry out a study of the tracking algorithm of the maximum power point with Adapted Incremental Conductance (AIC), using a digital signal controller, since the digital implementation offers flexibility when making variations in the operating parameters without hardware modification.

II. OPERATION OF A SOLAR CELL

The figure 1 shows the equivalent electrical circuit of a photovoltaic cell, it is observed that it is constituted by a current source, ICC, which represents the electric current intensity generated by solar radiation, a diode and two resistors, RS in series and Rsh in parallel. Rs represents the losses due to contacts and connections and Rsh represents the electrical leakage current of the diode.

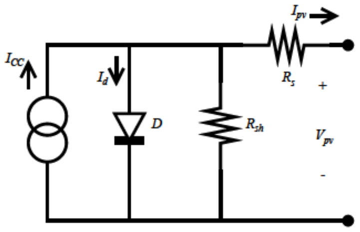


Fig. 1 Model of a photovoltaic cell.

To obtain an appropriate voltage and current for different applications, several solar cells are interconnected in series-parallel to form a photovoltaic module. These in turn can interconnect with each other to form what is known as a photovoltaic array [1].

The figure 2 shows the characteristic curves of a photovoltaic cell. It is observed, in the power curve, the existence of a maximum power point (MPP) to which correspond values of electrical current intensity at the point of maximum power IMPP and voltage at the point of maximum power VMPP. This point is unique for each solar cell and varies as the solar irradiance changes, that is, the power density of incident solar radiation on a surface, as shown in Figure 3.

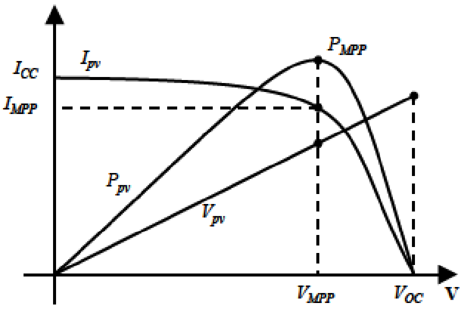


Fig. 2 Graphs of current, power and voltage of a photovoltaic cell.

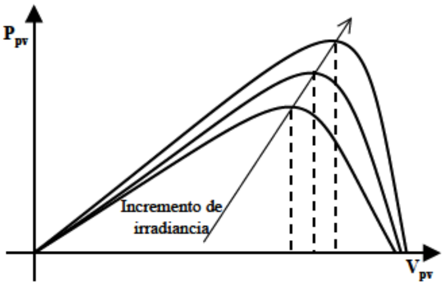


Fig. 3 Graph P-V normalized.

This variation raises the need to perform an algorithm capable of tracking constantly the MPP to get advantage of the maximum energy.

III. ADAPTED INCREMENTAL CONDUCTANCE ALGORITHM (AIC)

This algorithm is based on the calculation of the conductance and the study of its derivative to perform the search of the MPP, with this method we avoid introducing disturbances as in the P & O method.

We calculate the derivative of the power as a function of the voltage and we remember the characteristic curve:

$$dP_{\text{MPP}}/\,dV_{\text{MPP}} = I + (V * d\,I/dV) = 0 \quad (1)$$

Finally, if we evaluate the power derivative around all the voltage values, we obtain:

- $\Delta I/\Delta V = -I*V$, in the MPP
- $\Delta I/\Delta V > -I*V$, to the left of the MPP
- $\Delta I/\Delta V < -I*V$, to the right of the MPP

Once the MPP is reached, the operating point is maintained without any oscillation until no change in the current is detected.

In the figure 4, the normalized powers next to the derivative of the power with respect to the voltage are expressed as a function of said voltage in a PV system. Observing the curve $dP\ /\ dV$ we see how on both sides of MPP its value increases as a function of the distance with respect to the MPP, while in the values close to the MPP it rapidly decreases until arriving at the MPP point, where the value of $dP\ /\ dV = 0$.

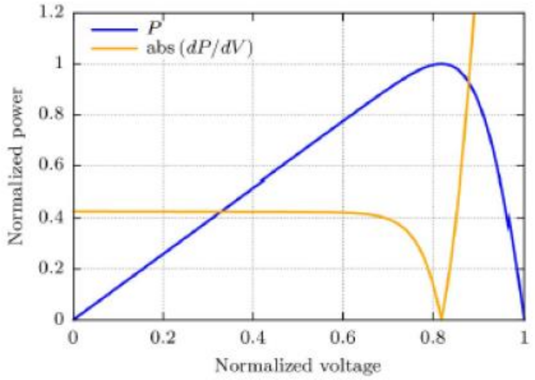


Fig. 4 Graph P-V normalized and absolute value (dP / dV).

The AIC method uses the absolute value of the curve $(dP\ /\ dV)$ as a rule for the correction of the value Dk. Taking into account that N is a constant to optimize depending on the variation of disturbance that we want.

The Figure 5 shows the flow diagram of the Adaptive Incremental Conductance algorithm used in this work, where Pk is the measured power, Pk-1 is the previous power, Dstep is the size of the disturbance and Dk is the useful cycle value used to vary the voltage of the photovoltaic array. The algorithm compares the current power with the previous one and based on it determines if the same disturbance is still applied or it should be changed in the next cycle.

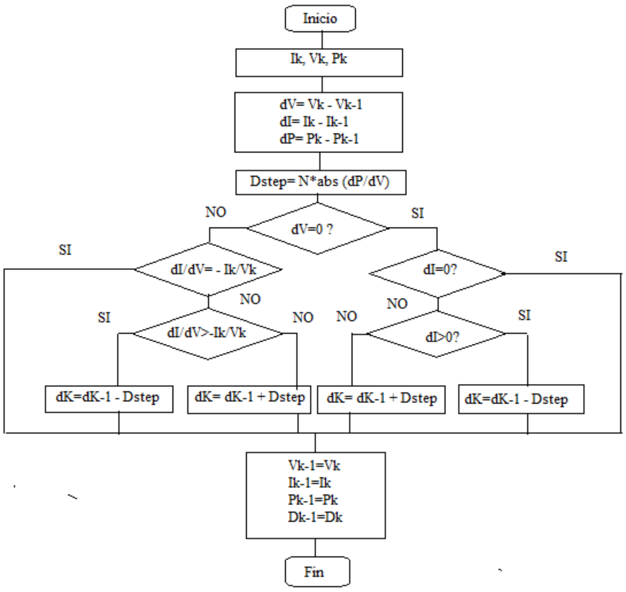


Fig. 5 Adapted Incremental Conductance Algorithm.

IV. DEVELOPMENT OF THE PROPOSED SYSTEM AND RESULTS

The SEPIC converter is used to modify its input resistance value and achieve maximum energy transfer between the photovoltaic panels and the connected charge. It is connected between the panels and the used charge. In figure 6, its circuit is observed. According to [2], [3] the SEPIC transfer function was analyzed to operate in continuous driving mode.

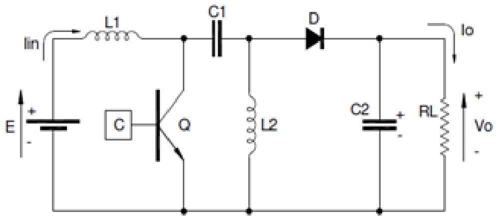


Fig. 6 SEPIC converter.

A change of the algorithm is proposed in order to obtain a substantial improvement in the time of convergence to the point of maximum power and at the same time decrease the oscillation in stable state, depending on which side the work point is located. The flow diagram with the proposed modification is presented in Figure 7.

The prototype was tested comparing the proposed algorithm with one of the most used, the P&O algorithm. To accomplish that, different simulations were run with MATLAB and Simulink programs.

The P&O algorithm consists of modifying the duty cycle of a power converter connected to the output of the photovoltaic array comparing the obtained power value in the current instant with the previous one. With the change of the duty cycle, the electric current intensity extracted from the photovoltaic panel is modified, consequently the power obtained is modified in relation to the change of the duty cycle of the tripping signal of the power converter [5]. In Figure 8 and 9 you can see the difference between the P&O algorithm and AIC algoritm.

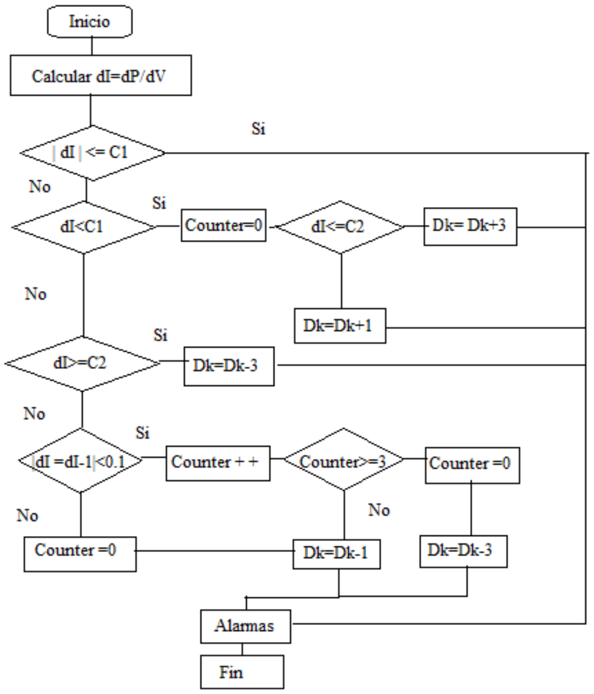


Fig. 7 Modification AIC Algorithm

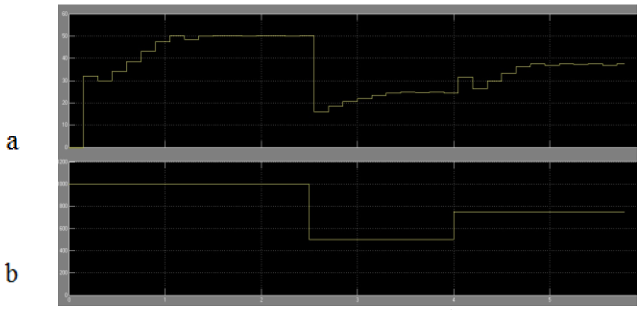


Fig. 8 Test with AIC Algorithm. a) Output power of the solar panel. b) Irradiance [w / m2]

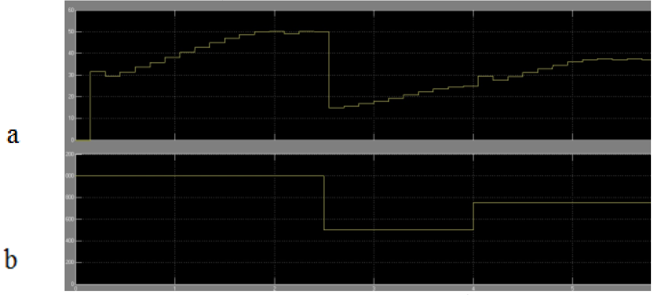
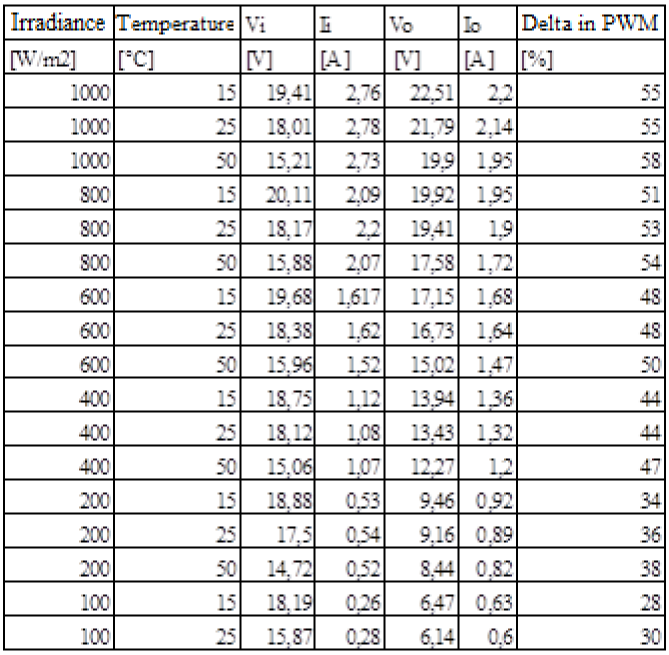


Fig. 9 Test with P & O Algorithm. a) Output power of the solar panel. b) Irradiance [w / m2]

Different irradiance and temperatures were used in the disturbance to check its behavior regarding the voltage and current towards the MPP and its oscillation in stable state, obtaining as a result what is indicated in table I.

TABLE I. DELTA IN PMM IN TERMS OF IRRADIANCE AND TEMPERATURE WITH MPPT



Irradiance	Temperature	Vi	Ii	Vo	Io	Delta in PWM
[W/m2]	[°C]	[V]	[A]	[V]	[A]	[%]
1000	15	19,41	2,76	22,51	2,2	55
1000	25	18,01	2,78	21,79	2,14	55
1000	50	15,21	2,73	19,9	1,95	58
800	15	20,11	2,09	19,92	1,95	51
800	25	18,17	2,2	19,41	1,9	53
800	50	15,88	2,07	17,58	1,72	54
600	15	19,68	1,617	17,15	1,68	48
600	25	18,38	1,62	16,73	1,64	48
600	50	15,96	1,52	15,02	1,47	50
400	15	18,75	1,12	13,94	1,36	44
400	25	18,12	1,08	13,43	1,32	44
400	50	15,06	1,07	12,27	1,2	47
200	15	18,88	0,53	9,46	0,92	34
200	25	17,5	0,54	9,16	0,89	36
200	50	14,72	0,52	8,44	0,82	38
100	15	18,19	0,26	6,47	0,63	28
100	25	15,87	0,28	6,14	0,6	30

The figure 10 shows the output power of the solar panel with MPPT, and in figure 11 the case where it is without MPPT, both for a temperature of 25 ° C in the solar panel.

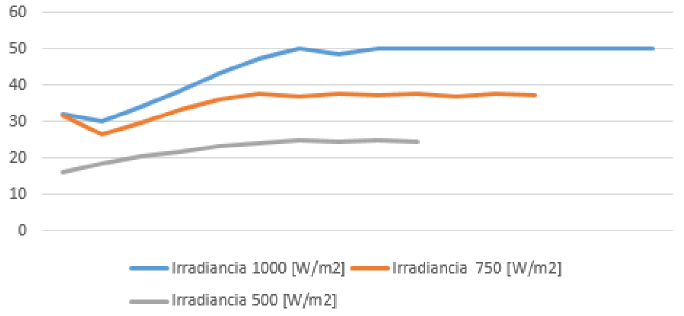


Fig. 10 Power output of the solar panel with MPPT (W)

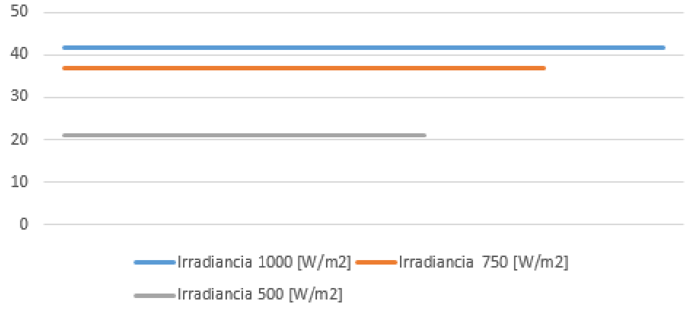


Fig. 11 Power output of the solar panel without MPPT (W)

V . CONCLUSIONS

This project arises from the need to optimize the performance of a photovoltaic system through a low-cost, robust device that requires the least possible maintenance.

Solar energy has the advantage of being available anywhere, which offers the possibility of installing a photovoltaic system in areas far from electricity distribution networks. Despite this advantage, the cells have a high cost in relation to the performance they possess. Therefore, if we think about the magnitude of the investment that represents the installation of photovoltaic systems it is necessary to use devices that maximize the energy obtaining from them.

The system is designed for use in small, low power installations, where the increase in performance can mean a large part of the supply.

The Adaptive Incremental Conductance (AIC) algorithm is widely used due to its simplicity of operation and its very good efficiency. Starting from the basis of a classic IC algorithm, this method proposes a correction of the variable of control of the time of operation (duty cycle, Dstep) of our DC-DC converter, connected to the solar panel, to make a more adequate balance between the speed of tracking and the oscillations in stable regime.

In other words, in situations far from the MPP, the correction term must be large and reduced once the maximum power point has been reached. The convenience of the AIC algorithm was demonstrated in the tests, compared to the P & O, where the power response is more stable. While the AIC algorithm keeps oscillating around the MPP once it finds it, the P & O algorithm takes a while to establish itself in it. That is why the MPPT with the best tracking capability is the AIC algorithm.

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