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Comparative Study of the Main Maximum Power Point Tracking Techniques applied to Photovoltaic modules using PSIM Software

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Abstract - The amount of power generated by a photovoltaic system mainly depends on atmospheric conditions such as irradiation and temperature. The performance of photovoltaic (PV) systems can be improved by employing high-efficiency power control in order to extract the maximum power generated by PV modules. In this context, this paper proposes a comparison between the main techniques for the search of the maximum power point of photovoltaic modules connected to the grid. Thus, the following techniques are implemented and analyzed: Fixed Duty-Cycle, Constant Voltage, Perturb and Observe, Incremental Conductance and Beta Method. The simulation graphs and computational analysis carried out in PSIM software are presented in order to prove the performance of the methods under temperature and irradiance variation.

Keywords – Renewable energy, photovoltaic energy, MPPT techniques, maximum power point.

1. Introduction

Electrical energy has become increasingly more essential to society. The growing concern with environmental preservation is currently reflected in all sectors of the industry that seek alternatives to reduce environmental aggression in their production processes [1].

Many renewable energy sources like the wind, solar, geothermal, ocean thermal, and biomass can be used for electricity generation and for meeting society daily energy needs. Among a large number of energy sources, there is the solar energy, which can be directly converted to electrical energy by photovoltaic (PV) cells [2].

Electricity from PV modules is currently considered a primary, non-polluting, quiet, abundant source that requires little maintenance. Another factor that justifies the use of this technology is the primary source abundance. The irradiance incident on the earth's surface is about ten thousand times greater than the world's energy consumption.

These facts have motivated several companies and government to invest in photovoltaic energy by means of obtaining electricity, in which a conventional and alternative source is applied [3]. However, the low conversion efficiency of PV modules and the high cost of installation are the biggest obstacles of this type of generation. Along these lines, it becomes important using control techniques to extract the maximum power provided by these modules. It is known from the literature that the power generated is dependent on the load, temperature and incident radiation. As these variables change constantly, variations in the maximum power point (MPP) occur at all times. Thus, it is employed Maximum Power Point Tracking (MPPT) techniques that continuously track the maximum power point, draining as much energy as possible into the network. The voltage and current values for the MPPT under certain specific conditions are used to change the input impedance curve of the static converter so that it intercepts the maximum power point instantaneously [4-9].

In this context, the main objective of this paper is to simulate and evaluate the main techniques traditionally used for MPPT. These techniques are analyzed, implemented and simulated in PSIM software to provide means for a qualitative and comparative analysis of their efficiency. In order to perform the simulations, a set of eight Kyocera photovoltaic modules (model KD135-UPU) arranged in series was deployed in this study [10] and it was considered a boost converter with 400V output voltage.

This paper is organized as follows: Section 2 describes the general MMPT control strategy; Section 3 presents main MPPT technique implementation; Section 4 introduces the case studies and analyzes the computational simulation results and conclusions are drawn in Section 5.

2. General MPPT Control Strategy

Figure 1 shows a simplified block diagram of a typical grid-connected Photovoltaic System (GCPS). Boost and inverter control involves several functions. However, this work is limited to the implementation and analysis of MPPT techniques. Other specific functions of this system, such as topologies, network synchronization, protections, etc., are beyond the scope of this paper and can be found in reference [1].

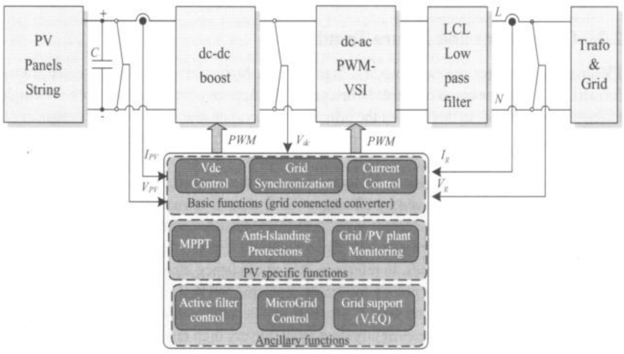

Fig. 1. Typical GCPS.

In a typical GCPS, the Boost converter is responsible for MPPT implementation and its control strategy is based on Figure 2.

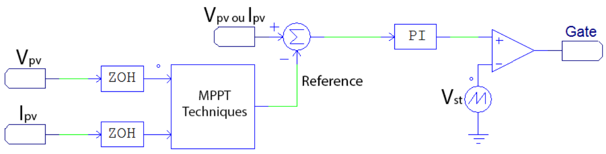

Fig. 2. Control Strategy of the Boost converter.

Depending on the MPPT method, it is necessary to measure voltage and/or current of the PV module. These signals are used by the MPPT algorithm to generate a reference signal which is used in the control loop shown in Figure 2.

The proportional-integral compensator (PI) is tuned in order to cancel its input signal, corresponding to the error between the reference generated by the MPPT algorithm and its corresponding signal.

The PI output is compared to a sawtooth wave (Vst) to generate gate attack pulses for the Boost converter. Thus, with this strategy, it is ensured that the voltage or current of the photovoltaic module is forced to match the reference signal generated by the MPPT method.

3. Main MPPT Techniques

In this section, the main MPPT techniques traditionally used for photovoltaic panel's maximum power extraction are presented.

A. Fixed Duty-Cycle Method

This method consists of a single adjustment of the apparent load resistance at the point of maximum power for a certain temperature and irradiance condition. For this purpose, the converter duty-cycle (D) is pre-set to obtain the MPP. It is considered an off-line method since the duty-cycle is fixed at a specific value.

The chosen duty cycle constant is dependent on the input and output voltage of the Boost converter, according to Equation (1).

$$\frac{Vo}{Vi} = \frac{1}{1-D} \qquad (1)$$

Where:

• D is the duty-cycle;

• Vo is the output voltage of the Boost converter, corresponding to the voltage to be maintained by the inverter;

• Vi is the input voltage of the Boost converter, corresponding to the panel output voltage for a given irradiance and temperature condition.

The voltage of each module, used in this study, is 17.7V for a temperature and irradiance of 25°C and 1000W/m², respectively. [10]. As the eight PV modules are arranged in series, the resulting voltage is 141.6 V. Since the inverter maintains the output of the Boost converter at 400 V, the duty cycle can be calculated using (1), resulting in D=0.6462 for this specific operation.

To generate the boost converter signal, a sawtooth wave with a peak value of 1 V is compared with a constant voltage signal, pre-set to the calculated duty-cycle (17.7).

B. Constant Voltage Method

This method consists in regulating the module voltage (Vin) to a reference value, which corresponds to the voltage of the PV module power point for a given irradiance and temperature condition. Figure 3 shows the control strategy of this method.

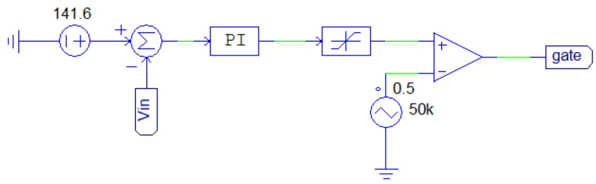

Fig. 3. Constant Voltage Method – PSIM Scheme

Unlike the fixed duty cycle method, this technique regulates the panel output voltage independent of the output voltage of the Boost converter, which ensures a more efficient MPPT.

C. Perturb and Observe Method

The Perturb and Observe (P&O) method varies the output voltage of the PV module set and verifies its extracted power. The implementation diagram of the P&O Method is illustrated in Figure 4.

In this method the instantaneous power (Pn) is calculated and compared with the power obtained in the previous cycle (P (n-1)), generating the difference between these two instants (ΔP). Positive power variations mean that the voltage disturbance contributed to the power increase and so the next voltage incrementation will continue to be positive. Negative power variations, on the other hand, mean that the disturbance in voltage did not contribute to the increase of power, resulting in a voltage decrease then [4].

Thus, the method operates periodically "disturbing" the output voltage of the module and when maximum power point is reached the voltage oscillates at this point.

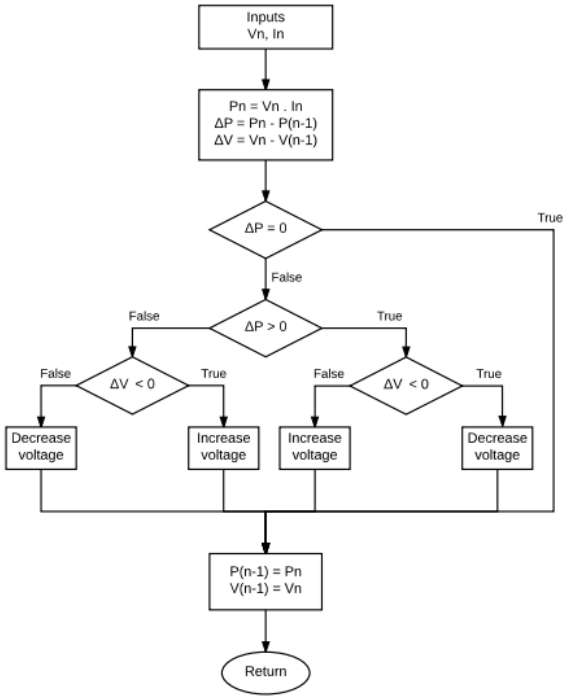

Fig. 4. P&O Method Flowchart

The size of the voltage step variation influences the speed of convergence of the method and steady state oscillation. Therefore, a suitable value for this variation is necessary to establish the balance between these two factors [4].

D. Incremental Conductance Method

The Incremental Conductance method operates in order to seek the maximum power of the module by analyzing the derivative point of the PV power in relation to the voltage. When the extracted power is maximum, the derivative of the power with respect to the voltage will be zero, according to (2) and (3):

$$\frac{dP}{dV} = 0 \qquad (2)$$

$$\frac{i(t)}{v(t)} + \frac{\Delta v}{\Delta i} = 0 \qquad (3)$$

The further from the MPP the PV module operates, the greater the value of the power derivative by the voltage. When analyzing this value, it is possible to modify the voltage of the PV module in order to reach the null derivative point of the power in relation to voltage [6]. The flowchart of the method is shown in Figure 5.

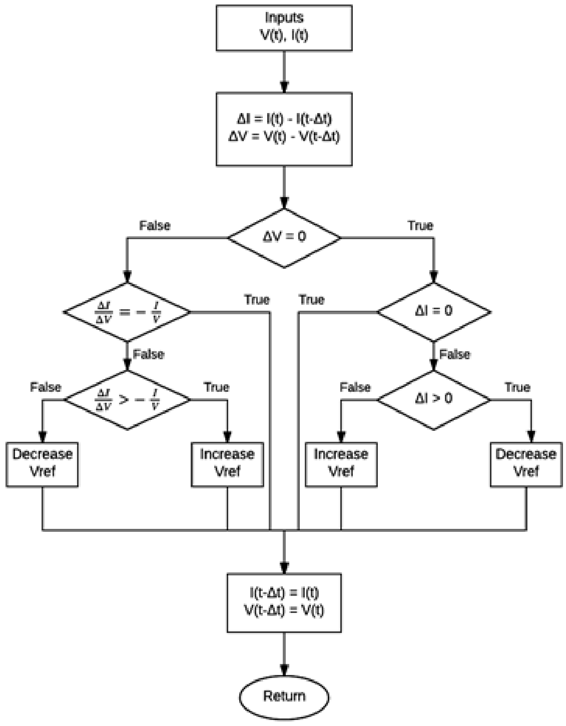

Fig. 5. Incremental Conductance Method flowchart

E. Beta Method

This method is based on the approximation of the maximum power point by means of the equation of a variable, commonly called Beta (β), expressed by (4) [7].

$$\beta = \ln(Io + c) = \ln\frac{Ipv}{Vpv} - c.Vpc \qquad (4)$$

To carry out the study of the Beta variable, it was used a parametrized model of the eight solar panels connected in series. For different temperatures and radiation incidence on the panel, the PSIM software presents the current and voltage values corresponding to the MPP (Figure 6). Therefore, it is possible to calculate β for different conditions. Table I shows the behavior of the Beta variable at different conditions for the set of eight solar panels connected in series.

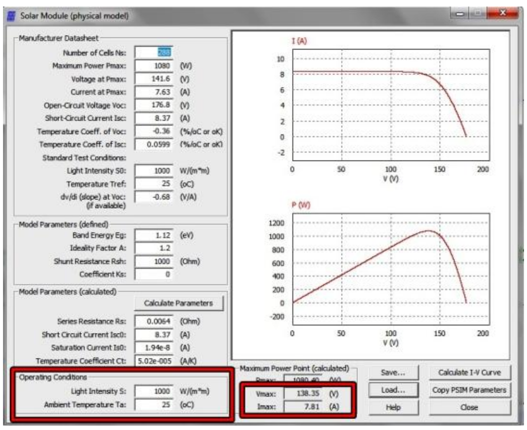

Fig. 6. PSIM MPP voltage and current for the Beta Method

Table I. - Beta values for different conditions of irradiance and temperature.

Incident Radiation (W/m²)	Panel Temperature Beta (β)	
	25°	45°
1000	-18,439	-17,076
900	-18,490	-17,195
800	-18,543	-17,348
700	-18,603	-17,370
600	-18,657	-17,403
500	-18,804	-17,544

It is observed that the β variable remains practically constant when the temperature is fixed, and radiation varies. On the other hand, the β value is drastically changed when the module temperature changes. Therefore, the Beta method can be used in environments where the temperature does not fluctuate too much [7]. The Beta method implementation in PSIM is presented in Figure 7.

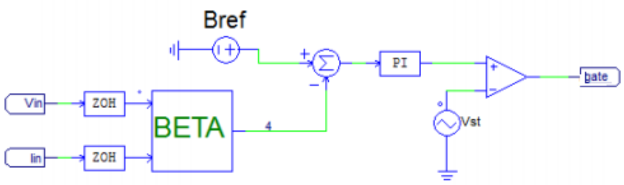

Fig. 7. Beta Method - PSIM Scheme

For a given irradiance and temperature condition, the value of β is calculated (Equation 4) and used as a reference (βref).
From the module voltage and current measurements, the β value is calculated (Equation 4) using a designed block called "Beta", illustrated in Figure 7. This signal is then forced to match the reference (βref) by means of a PI controller.
The chosen Beta value as a reference in this study (-18.4494), were optimized to increase the efficiency of the method. For this, it was possible to vary its value in a range around the reference value and to check the extracted generated power of the module. The optimum value of the βref value occurred when the extracted power from the panel approached the maximum value. For this purpose, the PSIM block "Parameter Sweep" was used to change the value of βref. This block varies the value of this variable from an initial value to a final value, incrementing it by a set increment step. In this study, the Beta variation range and the increment step value was 20% and 0.5 V, respectively, as shown in Figure 8. Therefore, using this block, a graph of the extracted power of the panel in function of Beta values was generated (Figure 9). It is noted that for the value of β = -18.6392 the power extracted from the panel reaches its maximum value, practically equalling the power available for the simulated temperature and irradiance conditions (1000 W / m² and 25 ° C).

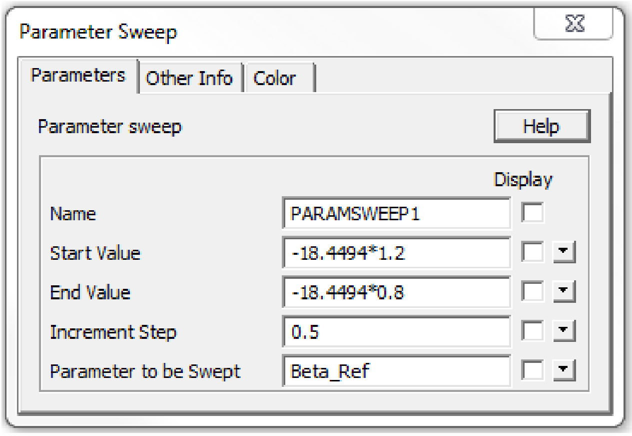

Fig. 8. Value of the parameters for beta variation.

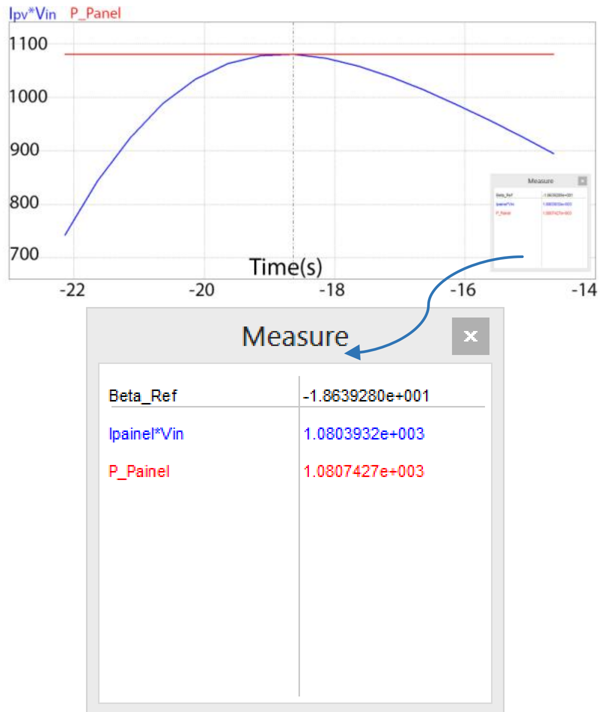

Fig. 9. Extracted power as a function of the Beta variable

4. Computational Simulation Results

In this section, it is presented the main computational simulation results of the methods described in Section 3.
As mentioned before, to evaluate the efficiency of the methods in extracting maximum power, a set of 8 modules connected in series were simulated and submitted to irradiation and temperature steps.

A. Degree of Irradiance

To evaluate the efficiency of the method under irradiance variations, the temperature was kept constant at 25°C and a step function with irradiance value ranging from 500 W/m² to 1000 W/m² was applied. Figures 10-14 present the results obtained through the simulations. The power extracted from the PV modules (using each MPPT technique) and PV module maximum available power are represented by the blue and red curves, respectively.

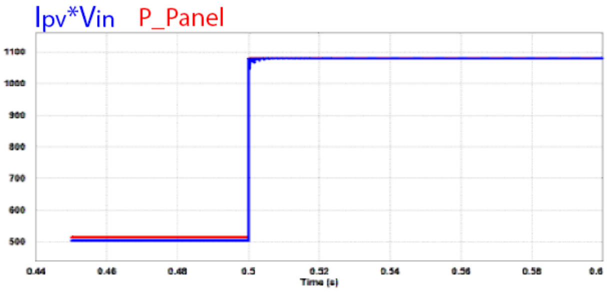

Fig. 10. Fixed Duty Cycle - Irradiation step from 500W/m² to 1000W/m².

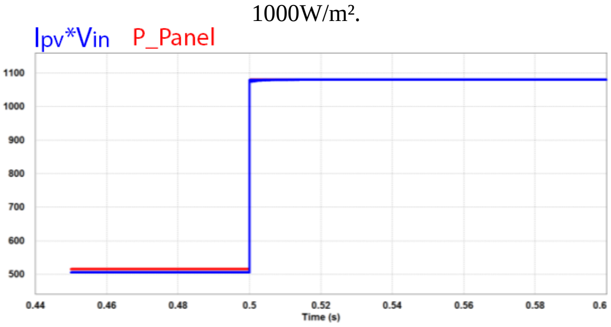

Fig. 11. Constant Voltage - Irradiation step from 500W/m² to 1000W/m².

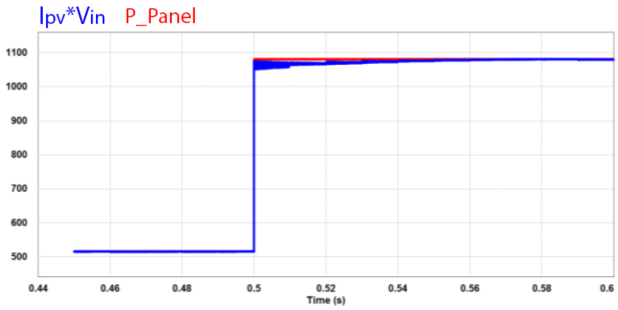

Fig. 12. Incremental Conductance - Irradiation step from 500W/m² to 1000W/m².

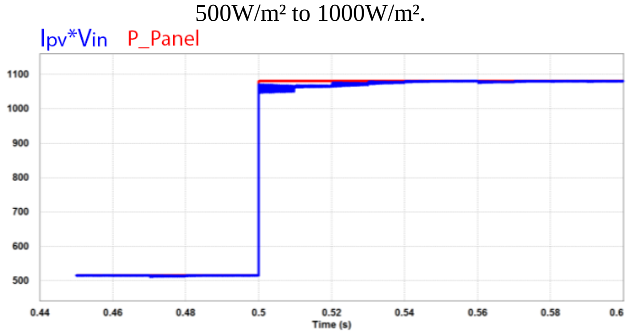

Fig. 13. P&O - Irradiation step from 500W/m² to 1000W/m².

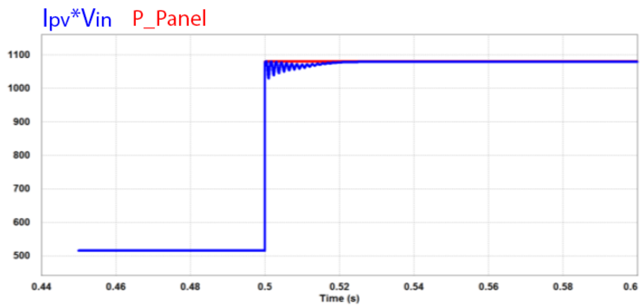

Fig. 14. Beta - Irradiation step from 500W/m² to 1000W/m².

Analysing the obtained results, it is noticed that the most efficient methods for extracting the maximum power are Beta, incremental conductance, and P&O. These methods present satisfactory results in both irradiation conditions. However, the implementation of these methods requires the use of current and voltage sensors, which is an economic disadvantage compared to the fixed duty-cycle and constant voltage method. These methods use fewer sensors than the others but they are efficient only in the irradiation condition considered in their projects (25° and 1000W/m²) [8-9].

B. Temperature Degree

To evaluate the efficiency of the methods in face of temperature variations, a step function was used with temperature value ranging from 25 ° C to 45°C. For this purpose, the irradiance was kept constant at 1000 W/m². Figures 15-19 present the results obtained through simulations.

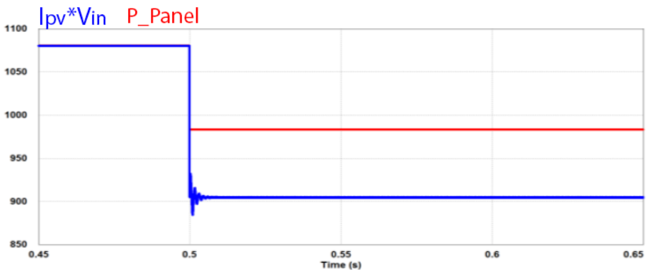

Fig. 15. Fixed Duty Cycle - Temperature step from 25°C to 45°C

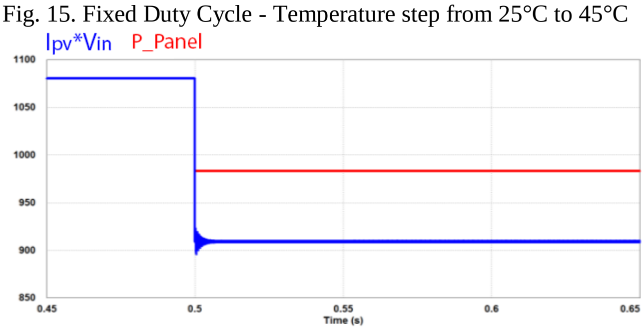

Fig. 16. Constant Voltage - Temperature step from 25°C to 45°C

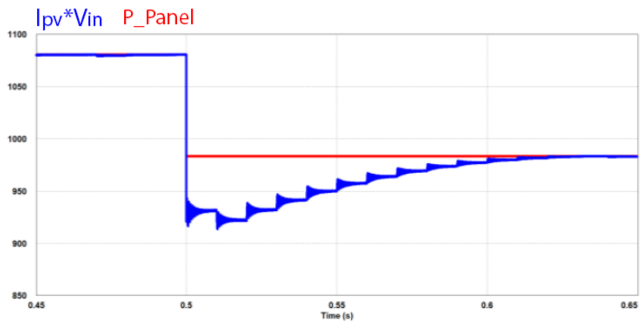

Fig. 17. Incremental Conductance - Temperature step from 25°C to 45°C

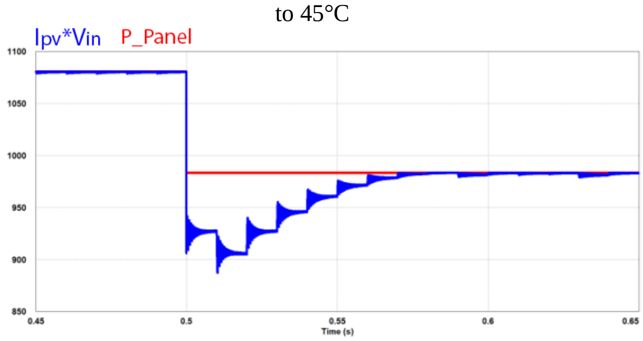

Fig. 18. P&O - Temperature step from 25°C to 45°C

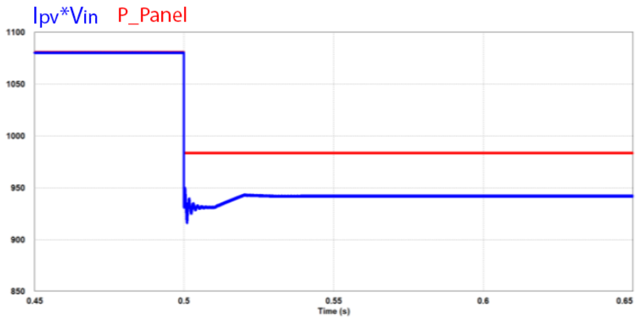

Fig. 19. Beta - Temperature step from 25°C to 45°C

Fig. 12 shows that fixed duty cycle, constant voltage, and beta methods are strongly influenced by temperature. Considering that the methods are designed to operate at 25°C, extraction of the maximum power is impaired after the temperature step to 45 ° C.
Otherwise, the P&O and Incremental Conductance methods are practically insensitive to the temperature change, which justifies their use in places that experience great variations in daily or annual temperatures.

5. Conclusion

This paper presents the analysis, implementation, and simulation of the main MPPT techniques available in the literature. These techniques seek to extract maximum power from photovoltaic panels so that losses in system power generation are minimal. It is concluded from the MPPT implementation that it is necessary to analyze, in advance, the meteorological conditions of the place, mainly the temperature and irradiance that are determinant factors for a photovoltaic panel performance. The study of the place where the generation system will be installed allows the best adaptation of the method to be used, as it is possible to decide which MPPT technique will perform better according to its application characteristics.
As a proposal for future work, the authors propose the computational analysis and simulation of other MPPT methods, such as Modified Incremental Conductance, Ripple Correlation, Pilot Cell etc., as well as the implementation of these methods in a physical plant for an experimental validation of the efficiency of these techniques of maximum power in SFCR.

Acknowledgement

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