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The strategy of Tunisian Solar Plan: MPPT for Photovoltaic Panel using Incremental Conductance Algorithm

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***Abstract*—This research was aimed to present the version of the Tunisian Solar Plan, that focuses on the transition to a sober economy in energy and carbon, based on the improvement of energy efficiency aimed at better control of energy demand and recourse renewable energies aiming at the diversification of the energy mix for the production of electricity.**

For this purpose, we will explore the performance of a maximum power point tracking system which implements Incremental Conductance (INC) algorithm. The INC method was designed to control the duty cycle of DC-DC Boost converter connected of the photovoltaic panel and to ensure the MPPT work at its maximum efficiency. The system performance of INC algorithm connected to the PV process are presented. From the simulation results, the INC technique shows a better performance and also has a lower oscillation.

Keywords— Energy, TSP, Transition, Economy, Strategy, PV, MPP, INC, DC-DC Boost converter.

I. INTRODUCTION

For more than two decades, Tunisia has focused on the rational use of energy and the development of renewable energies. Ambitious energy demand management programs have reduced the rate of growth of energy consumption and substantially lowered energy intensity. Thanks to these programs, to produce the same level of wealth, Tunisia today consumes 20% less energy than in 2000 [3].

The analysis of the evolution of the Tunisian energy system and the challenges it will face during the next two decades highlights the need to transform this system on the basis of two priority actions: the reinforcement of energy efficiency and the recourse renewable energies [1,2,4,18].

Tunisia has prepared the first version of its solar plan in 2009. The evaluation of achievements highlights the need to update the Tunisian Solar Plan (TSP) so that it is consistent with the Mediterranean Solar Plan and more ambitious in terms of boosting energy efficiency and breakthrough renewable energy [5,6].

This version of the Tunisian Solar Plan is part of a transition to a low energy and carbon economy based on two major choices:

- Significant improvement in energy efficiency to better control energy demand.
- Substantial use of renewable energies to diversify the energy mix for electricity production.

In order to make the Tunisian Solar Plan succeed, the point of operation of the photovoltaic panel must coincide with the optimum power point. Hence, the use of a MPPT command is a necessity in order to extract the maximum power of the photovoltaic panel [12].

The PV system consists of many components such as PV modules, mounting structure and electrical connections and means of regulating and modifying the electrical output.

A DC-DC converter is needed for implementing MPPT. The DC-DC converter delivers the maximum power from PV module to load by adjusting the duty cycle and able to distribute a maximum power, when load is changes. Some common DC-DC converter topologies for implementing MPPT are Buck converter, Boost converter and Buck-Boost converter. The performance of Incremental Conductance (INC) algorithm outperformed the P&O algorithm when it implemented at Buck converter or Boost converter [15]. Another research had shown that implementing INC method on DC-DC Boost converter also able to find the maximum power point and had an efficient performance on some different weather condition [9,10].

This paper is organized as follows. The Tunisian strategy of the electric mix is presented in section 2. The long-term electricity mix and the objectives of the TSP are discussed at the end of the second section. Photovoltaic system characteristics are defined in section 3. Incremental conductance MPPT algorithm is presented at the end of the third section .To show the performance of the INC technique, some simulation results of PV energy process are discussed in section 4. Finally, conclusions are drawn in the final section.

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II. The Tunisian strategy of the electric mix

1. Prospective electrical demand

The forecast of the electrical demand is defined on the basis of two scenarios of evolution of the electrical intensity:

- An electricity efficiency scenario, according to which it is considered that the electricity savings of electricity efficiency actions launched between 2008 and 2012 continue to produce electricity savings until 2020. Beyond 2020, it is considered that intensity will continue to fall with the same average annual rate forecast for 2013-2020, is -0.6% per annum. Under this trend scenario of electricity efficiency, final electricity demand would reach 20.8 TWh in 2020 and 34.9 TWh in 2030.
- A proactive scenario of electrical efficiency (retained by the strategy of the electric mix), which also integrates efficiency actions between the years 2008 and 2012 those launched between 2013 and 2020. Beyond 2020 we consider that the intensity will decline less strongly or -1.5% between 2020 and 2025 and -1% between 2025 and 2030 reflecting the constraints of access to deposits of energy savings increasingly difficult to mobilize. The average annual rate of the decline in intensity between 2013 and 2030 will be -2% in this case [1,2,5].

To achieve this goal of reducing electricity intensity, Tunisia will put in place an ambitious strategy in terms of energy efficiency based on a coherent mix of instruments regulatory, institutional and incentive [7,8].
Thus, in the case of this scenario, demand would evolve more moderately to reach 16.9 TWh in 2020 and 26.7 TWh in 2030, or 24% below demand in the trend scenario.
Figure 1 present the scenarios of the demand for electricity in Tunisia.

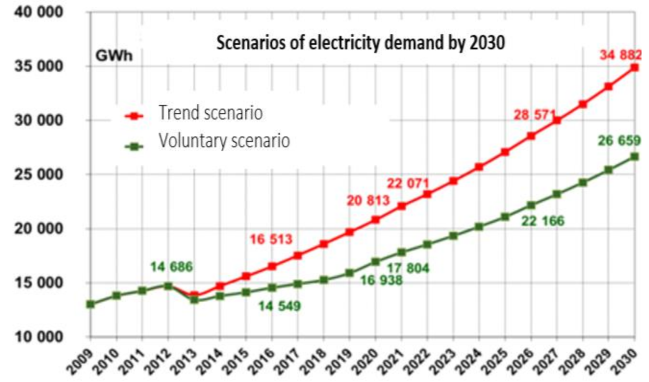

Figure 1. Scenarios of the demand for electricity in Tunisia (study electric mix, WI-ALCOR, ANME-GIZ).

2. The long-term electricity mix

2.1. Electricity generation targets by 2030

The Tunisian strategy plans to reduce the share of renewable energy in electricity production from around 2% in 2010 to 30% in 2030, compared to trend scenario at 5% renewable energy.
This share will be split between wind, solar photovoltaic and solar thermodynamic (CSP) as follows: 15% wind, 10% PV and 5% CSP.
Figure 2 present the scenario of the electric mix retention in Tunisia.

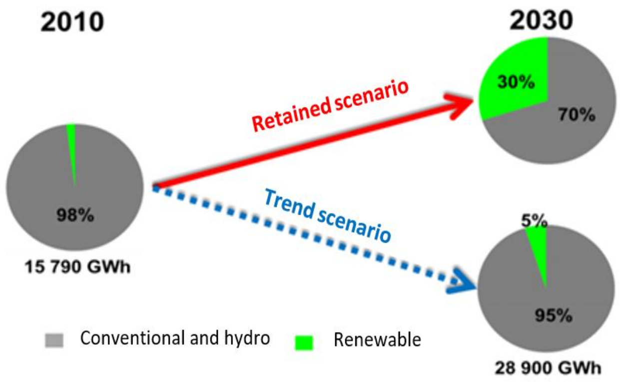

Figure 2. Scenario of the electric mix retention in Tunisia (study mix electric, WI-ALCOR, ANME-GIZ).

2.2. Objectives of the Tunisian Solar Plan

The TSP is the operational tool for implementing the Tunisian strategy for electricity mix with regard to the renewable electricity generation part. As such, he focuses solely on electricity generation connected to the grid and focuses more specifically on three sectors, namely: wind, grid-connected PV and thermodynamic solar energy (CSP) [3,4,7,18].
Thus, the quantitative objective of the TSP is to achieve a penetration rate of renewable energies in terms of electricity production of about 30% in 2030.
The prediction of installed electric capacity of renewable origin by die in Tunisia is presented in Figure 3.

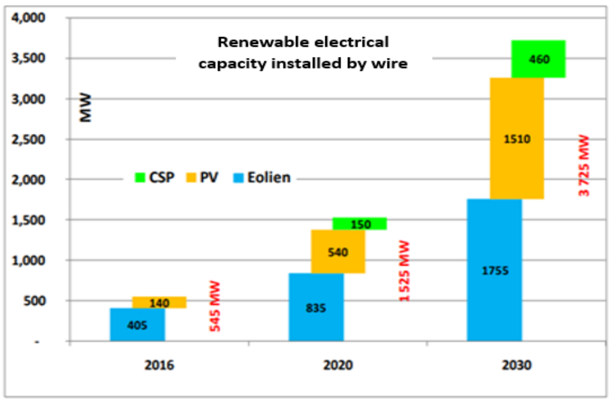

Figure 3. Prediction of installed electric capacity of renewable origin by die in Tunisia (study, WI-ALCOR, ANME-GIZ).

In accordance with the strategy of the mix, the TSP foresees a distribution of the renewable energy mix in 2030 between the main sectors as follows:

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- 15% wind energy
- 10% solar PV
- 5% thermodynamic solar

In terms of installed capacity, the TSP plans to reach an installed capacity of renewable energies in 2030 of around 3725 MW compared to a total electricity capacity of approximately 10900 MW. It should be recalled that the renewable electric power at the end of 2012 is about 250 MW, mainly wind power (245 MW) and PV (5 MW) [6].
Lastly, the TSP also plans to promote the control of electricity demand by combining development of renewable energies and energy efficiency actions in its activities [8].

Now, we are interested in studying the different characteristics of the PV process in order to make the strategy of the Tunisian Solar Plan succeed.

III. PHOTOVOLTAIC SYSTEM CHARACTERISTICS

The photovoltaic power generation system considered in this paper, consists of a PV array and a DC-DC Boost converter.
The electrical equivalent circuit of the PV cell is given by Figure 4.

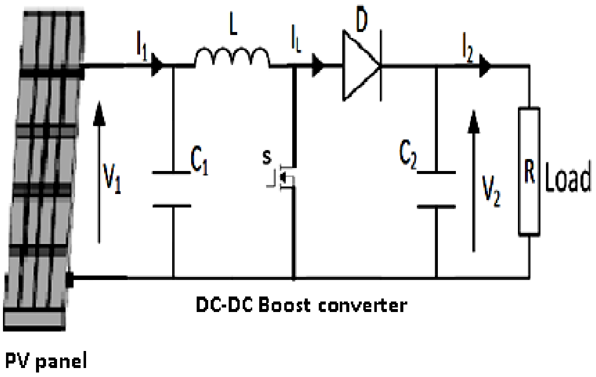

Figure 4. Configuration of the photovoltaic energy system.

1. Photovoltaic panel

A solar cell is a p-n semiconductor junction. When exposed to light, a DC current is generated. The generated current varies linearly with the solar irradiance [9,10,17].
The output current generated by the PV panel can be expressed by:

$$I_{pv} = I_{ph} - I_s\left[\exp\left(\frac{q(V+R_sI_{pv})}{n_s kT}\right) - 1\right] - \frac{(V+R_sI_{pv})}{R_{sh}} \quad (1)$$

The photocurrent of the PV panel, varies with temperature and irradiation. It is described by the following equation:

$$I_{ph} = (I_{ph,n} + K_I \Delta T)\frac{G}{G_n} \quad (2)$$

$I_{ph,n}$ is the rated current generated by the photovoltaic panel under standard conditions of temperature and irradiation (T=25°C and G=1000 W/m^2):

$$I_{ph,n} = \frac{(I_{ph} + K_I \Delta T)}{exp\left(\frac{(V_{oc} + K_v \Delta T)}{V_t}\right) - 1} \quad (3)$$

with:

$$V_{oc} = n_s \frac{KT}{q} Log\left(\frac{I_{cc} + I_s}{I_s}\right) \quad (4)$$

where, I_s is a reverse saturation current, V_{oc} is the open circuit voltage, I_{cc} is the short circuit current.
The PV generator is strongly influenced by the variation in irradiation and temperature. In fact, in Figure 5, the PV generator is subjected to variations in irradiation, where it clearly appears the decrease in the power and the change of the maximum power point (MPP) during the decrease in irradiation.

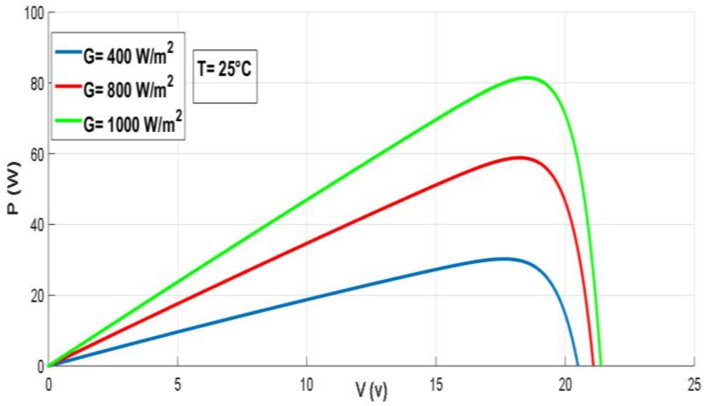

Figure 5. P-V curves with different values of irradiation.

In Figure 6, the PV generator is subjected to temperature variations under constant irradiation, here again the MPP changes.

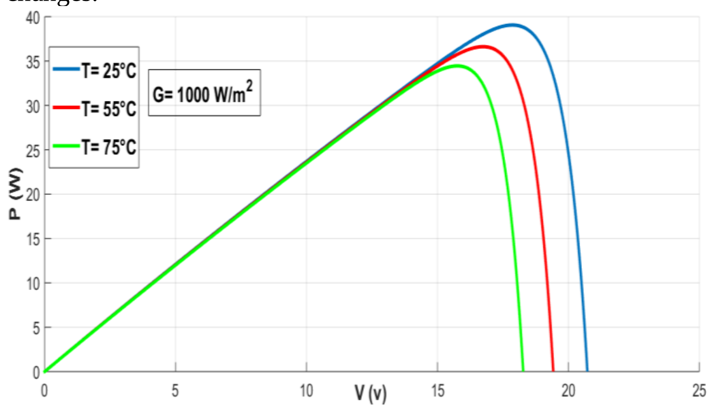

Figure 6. P-V curves with different values of temperature.

We must reconcile these behaviors with the load. During the source-load connection, it is therefore essential to take into account the variable nature of the power delivered by the PV generator, but also the characteristic of the load so that an operating point is possible. The operating point corresponds to the intersection of these two characteristics (Figure 7).

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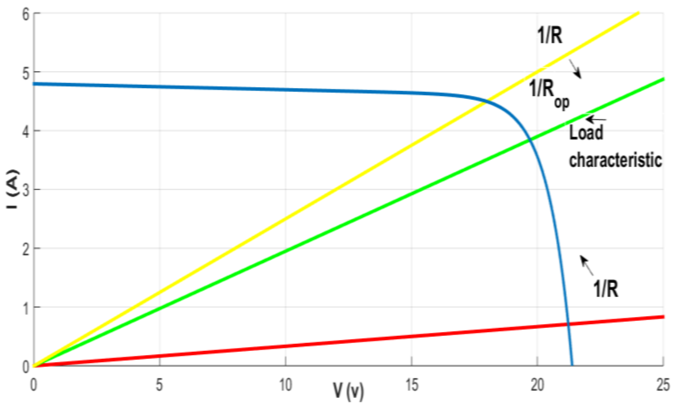

Figure 7. Influence of the load on the operating point.

The operation of the generator depends strongly on the characteristics of the load with which it is connected. In addition, for different values of R, the optimal adaptation occurs for a single operating point (R_{op}) named Maximum Power Point (MPP). Consequently, in order for the generator to operate most often at its maximum point, the solution commonly used is to introduce a DC-DC converter that acts as a load source adapter (Figure 4), in this case the generator delivers maximum power [13,15].

2. DC-DC Boost converter

The solar array is connected to a DC-DC Boost converter used to perform the following functions:

- Ensure the operation of the photovoltaic generator at the MPP. This function is generally required in grid-tied PV systems.
- Adequate the DC voltage and current signals at the generator output to a certain level according to the application.
- Non-inverted output voltage [11,12].

The dynamic model of the DC-DC Boost converter can be described by the following state equations:

$$\frac{di_L}{dt} = \frac{1}{L}(V_1 - V_2(1-\alpha)) \quad (5)$$

$$\frac{dV_2}{dt} = \frac{1}{C}(i_L(1-\alpha) - \frac{V_2}{R}) \quad (6)$$

Where i_L is the current on the inductance L and α is the duty ratio of the Pulse-Width-Modulation (PWM) signal.

3. Incremental Conductance MPPT Algorithm

The INC technique is considered as the most algorithms used in practice by the majority of authors to track the maximum power point.

INC was designed based on an observation of P-V characteristic curve. This algorithm was developed in 1993 and was intended to overcome some drawback of P&O algorithm. INC tries to improve the tracking time and to produce more energy on a vast irradiation changes environment. The MPP can be calculated by using the relation between dI/dV and –I/V [14,16].

If dP/dV is negative then MPPT is lies on the right side of recent position and if the MPP is positive the MPPT is on left side. The equation of INC method is:

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I\frac{dV}{dV} + V\frac{dI}{dV} = I + V\frac{dI}{dV} \quad (7)$$

MPP is reached when dP/dV=0 and

$$\frac{dI}{dV} = -\frac{I}{V}$$

$\frac{dP}{dV}$>0 then V_p<V_{MPP}

$\frac{dP}{dV}$=0 then V_p=V_{MPP}

$\frac{dP}{dV}$<0 then V_p>V_{MPP}

In Figure 8, it is given a flowchart which describes the INC technique.

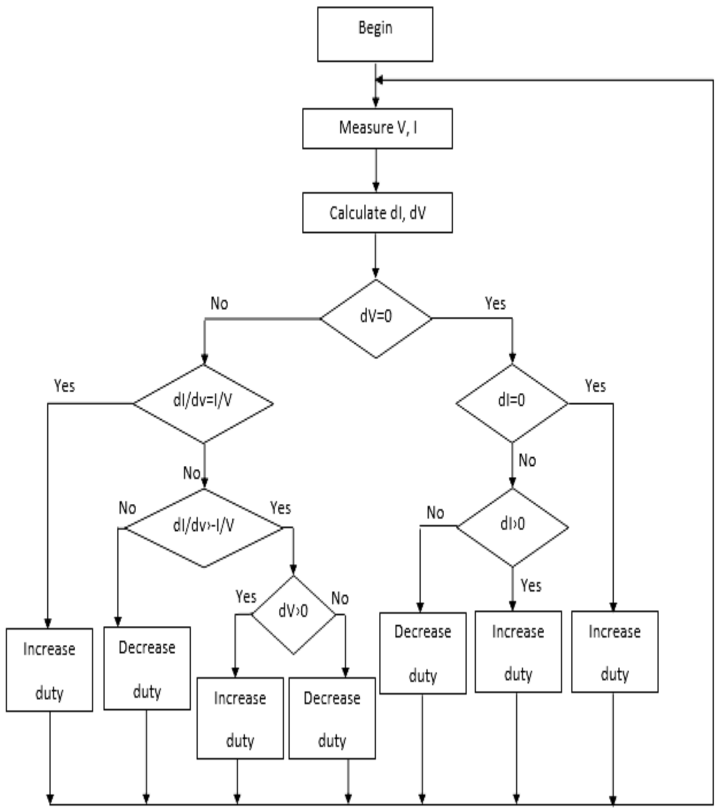

Figure 8. Flowchart of the INC algorithm.

If MPP lies on right side, dI/dV< -I/V and then the photovoltaic voltage must be decreased to reach the MPP. INC method can be used for finding the MPP, improve the PV

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efficiency, reduce power loss and system cost. Implementation INC on a microcontroller produced more stable performance when it compared to P&O. The oscillation around MPP area also can be suppressed in trade of with its implementation complexity [11,15].

IV. SIMULATION RESULTS

This section is reserved for presenting the main results. We use Matlab/Simulink program to simulate the behavior of the energy PV conversion system.

To explain the characteristic of the INC MPPT used, we apply a sudden change in temperature and irradiation.

The variation of the temperature and solar irradiation are given, respectively, by the following Figures 9 and 10.

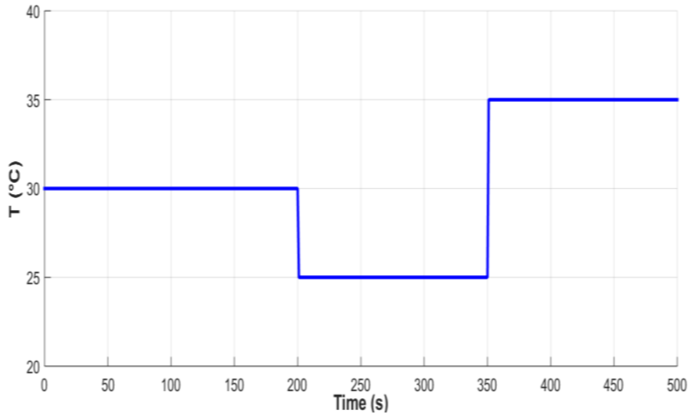

Figure 9. Variation of temperature.

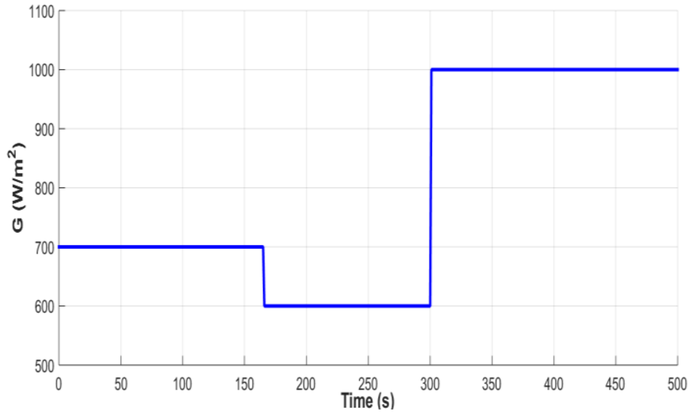

Figure 10. Variation of irradiation.

To check the performance of the photovoltaic panel, we can used the INC MPPT algorithm.

The Figures 11, 12, 13 and 14 illustrate, respectively, the evolution of the voltage, the error voltage, the evolution of the current and the error current according to the MPPT algorithm used.

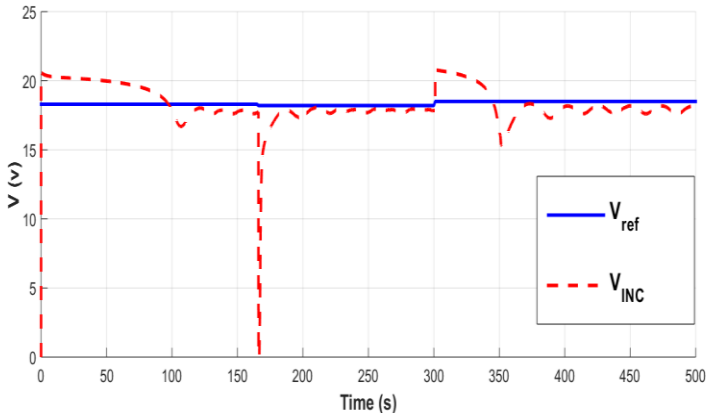

Figure 11. Evolution of the voltage based on INC technique.

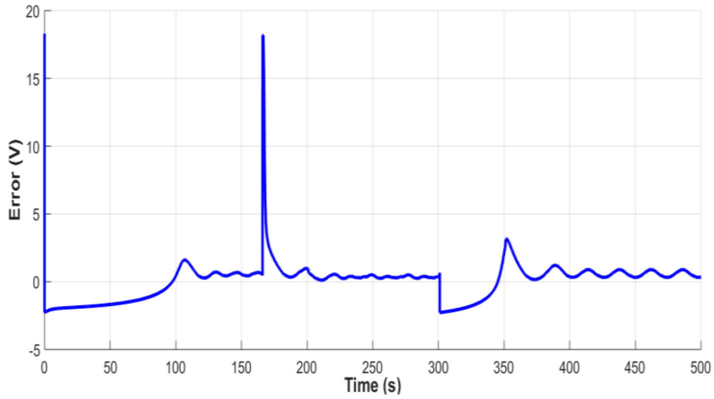

Figure 12. Evolution of the error voltage.

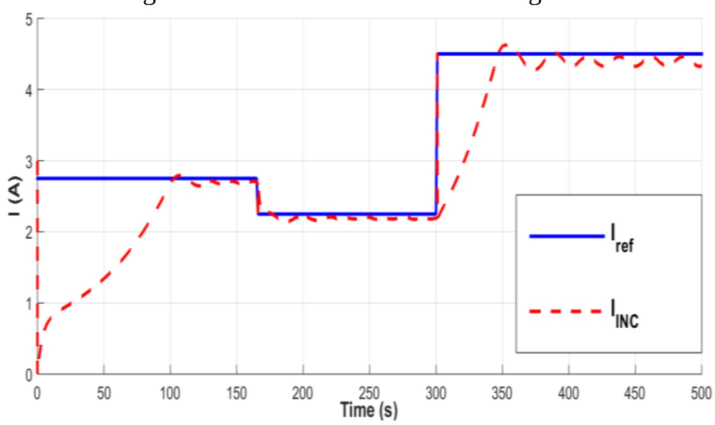

Figure 13. Evolution of the current based on INC technique.

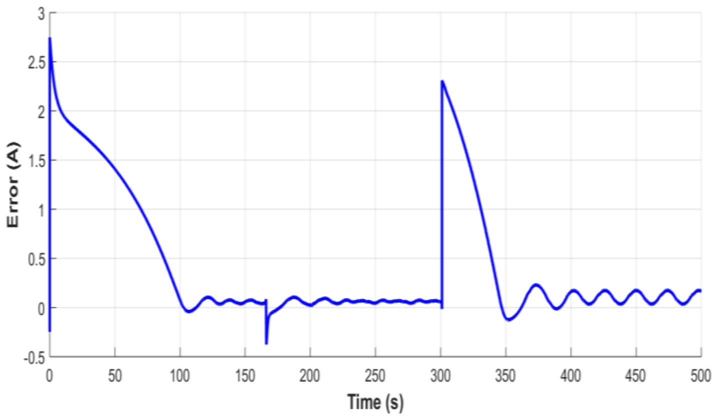

Figure 14. Evolution of the error current.

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We can observe momentary peaks, which are resulted from sudden change in temperature and solar irradiation in Figures 11 and 13.
The power regulation response generated by using the INC MPPT algorithm is illustrated in Figure 15.

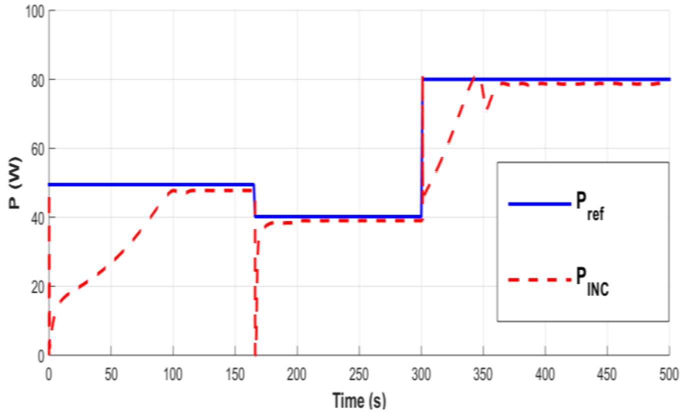

Figure 15. Evolution of PV power based on INC technique.

In Figure 15, we can seen that the INC MPPT technique track the maximum power point.
Based on simulation results, it was observed that the INC technique were able to follow irradiation and temperature changes and retain the optimal point.
Incremental Conductance algorithm had proved able to detect irradiation and temperature changes and had successfully shifted the MPP by adjusting the PWM duty cycle. Duty cycle will be changed to follow changes in solar irradiation and temperature so that output voltage of DC-DC Boost converter remains on MPP point.
It is also clear that the generated solar power achieves rapidly the maximum value under the radiation conditions considered and maintains the real MPP after each temperature and irradiation variation, hence a good stabilization is obtained thanks to INC technique.
INC method also reduced the oscillation around MPP point. Using MPPT with INC method increases output power of system.

V. Conclusion

This research aimed to study the Tunisian Solar Plan which is not only an action plan, but also a strategic commitment, carrying original and innovative characteristics and ensuring the development of renewable electricity generation in Tunisia.

The electricity generation targets for 2030 in Tunisia have been studied and detailed.
The method discussed in this paper to extract maximum power from photovoltaic system is the Incremental Conductance. The simulation results show the performance of the proposed algorithm.
We can deduce that INC method can track the maximum power point with less chattering phenomenon.

In a future work, we can make a comparative study between the different MPPT commands used to extract the MPP from the photovoltaic panel, in order to realise the TSP program under the right conditions.

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