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The transition to renewable energy in Tunisia: The case of the PV generation system connected to the Grid

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Abstract—This paper presents the situation and the guidelines Tunisia energy and the network-connected photovoltaic systems. Moreover a photovoltaic energy system connected to the grid under solar irradiation and temperature levels has been presented. For this purpose photovoltaic with maximum power point tracking model based on Perturb & Observe method (P&O) is developed and applied. Some reliable simulation results are provided to check the efficiency of the proposed algorithm for connection between the photovoltaic model and the grid.

Keywords—Energy; Prosol; Grid; Economic development; Sustainable development; Environment; Photovoltaic panel; P&O; DC/DC boost converter; DC/AC converter.

I. INTRODUCTION

Maghreb cities are characterized by a strong demographic and migratory boom. In Tunisia, the urban population increased from 37.5% to 66.9% between 1960 and 2009. This movement of urbanization, correlated to the national economic growth, induces increased energy needs and increased environmental impacts (Ministry Environment and Spatial Planning, 1995) [8;9,16].

Tunisia is one of the first developing countries to pursue a proactive energy saving, production and use of renewable energy technologies. There are no energy policies in Tunisia explicitly dedicated to the urban environment. We support the idea that the urban solar energy market has, in fact, developed as a result of the establishment of government support mechanisms. The implementation of these policies is a major focus of our thinking because the introduction of new sustainable energy consumption modes also contributes to a new management of the city. It is a question of how to build and of which the sustainable city is built through the question of the dissemination of solar equipment to Tunisian households. The impact of government programs on domestic consumption has been greater in the residential sector, primarily targeted [5;7].

The production of the Photovoltaic energy provide DC voltage who is converted to AC voltage with the DC/AC converter in order to be connected to the grid [3;11;14].

Usually the photovoltaic panel use a maximum power point tracking control unit to run the system at the optimized point.

Different control strategies MPPT using DC/DC converter have been proposed in literature. Among these, the most widely used ones are Perturb and Observe (P&O), Incremental Conductance (INC) and Fuzzy Logic algorithms [1,2;4;15].

Grid-connected PV systems are traditionally classified by power capacity, which are listed as small-scale, intermediate-scale, and large-scale. PV generators that are less than 50 kW are usually considered as small scale PV systems. A system that can produce more than 1 MW is commonly considered as large-scale or utility-scale, although this category now covers systems up to tens or even hundreds of MW. Systems between these two ranges are designated as intermediate-scale [3].

In this paper, the photovoltaic powered system mainly consists of a photovoltaic panel, DC/DC converter and DC/AC inverter.

This paper is organized as follows. In section 2, we introduce the situation and guidelines Tunisia energy. In section3, we presented the network-connected photovoltaic systems and the net-metering system. The promotion of renewable energies in Tunisia is described in section 4.

The fifth section deals the PV energy system. In section 6, we presented the Perturb & Observe MPPT algorithm. Then we discuss the numerical simulation results of PV model connected to the grid in section 7.

Finally, conclusions are drawn in the final section.

II. SITUATION AND GUIDELINES TUNISIA ENERGY: MECHANISMS FOR THE VALORISATION OF RENEWABLE ENERGY

Since the 1980s, the issue of energy sufficiency in Tunisia has gradually emerged as a major economic constraint. During the 1970s and 1980s, however, the energy sector played a key

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role in Tunisia's economic development. With an annual output of over 5 million toe since the early 1970s, hydrocarbons have in fact largely contributed to economic growth and the strengthening of public finances. They have long been among the basic elements of the trade balance and the main provider of foreign exchange for the country [6;10].

However, from the 1980s, the decline in revenues from hydrocarbon exports and the significant growth in national energy needs, a direct consequence of changes in consumption practices and the improvement of the standard of living of the population, contributed to more than halving the energy sector's share of GDP; it has risen from 12.9% to 5.9% between 1980 and 1997. To cope with this situation, the public authorities have put in place a strategy based on two major axes. The first axis sought to intensify oil and gas exploration and exploration efforts; the second aimed at implementing a voluntarist policy of energy management, encouraging the rational use of energy and the development of renewable energies [9].

The commitment of the Tunisian state did indeed manifest itself very early in the field of energy efficiency and renewable energies. This initiative marks the institutionalization of the desire for greater energy control. A national coordinating agency for energy strategies and the National Agency for Energy Management have been created to respond to the various energy challenges facing the Tunisian state, including the depletion of fossil resources, the deficit the country's energy supply (and its impact on the state budget), and the continued growth in the global cost of energy.

In addition, from the 1990s onwards, environmental concerns emanating from a greater awareness of the international community (global warming, the greenhouse effect, etc.) become more global. In 1993, Tunisia signed the Framework Convention and then the Kyoto Protocol in 2002, thus showing its concern to participate in the global dynamic. Yet, like other developing countries, Tunisia has no binding commitments to reduce greenhouse gas emissions [7;13].

The solar photovoltaic sector remains, during this decade, very embryonic and it is a system of financing intended for the actions allowing the preservation of the environment [10;12].

Efforts to control energy are not without interest because they allow Tunisia to exploit the financing opportunities provided by international agreements on climate change. In the 1990s, for example, the marketing of individual solar water heaters in Tunisia aroused the interest of donors and the international community, especially since its impact is beneficial to the environment, on the sole condition to address the problem of investment cost. The United Kingdom and Belgium have granted Tunisia a grant of $7.3 million to revive this project market. To ensure the sustainability of the development of this sector, the various stakeholders of the project. have taken measures to overcome the obstacles that have led to the failure of the diffusion of solar water heaters. One of the flagship initiatives was to put in place a non-refundable 35% cost of investment for water heating system users [5;8].

In the field of renewable energy and energy efficiency, a series of regulatory, fiscal and financial measures, synthesized, have indeed marked the evolution of the sector (that of the solar water heater in particular) from 1985 to the 2000s.

III. NETWORK-CONNECTED PHOTOVOLTAIC SYSTEMS AND THE NET-METERING SYSTEM: AN UNPRECEDENTED TUNISIAN EXPERIENCE IN THE MAGHREB

The Energy Control Law n° 8-2009 of 9 February 2009 stipulates that "Any establishment or group of establishments operating in the industrial, agricultural or tertiary sectors and which produces electricity from renewable energies. for its own consumption, enjoys the right to transport the electricity thus produced, through the national electricity grid to its points of consumption and the right to sell surplus exclusively to the Tunisian Electricity and Gas Company ". This law specifies that the incumbent monopoly operator, STEG, must buy back the renewable electricity surplus produced by the private beneficiary of the Prosol. This system is called "net-metering". It differs from the feed in tariff mechanism in force in most European countries or in southern Mediterranean countries such as Israel and Algeria. The latter has a feed in tariff system, but it has created neither the supply nor the demand for solar energy. According to the law 13/09 on renewable energies, in Morocco, "installations for the production of electric energy from renewable energy sources can only be connected to the national electricity grid of medium voltage, high voltage or very high voltage"[9;13;16].

Households are connected to the low-voltage grid. Morocco therefore does not have a regulatory framework that allows the "marketing" and "domestication" of photovoltaic by individuals.

IV. THE PROMOTION OF RENEWABLE ENERGY IN TUNISIA

Tunisia can, despite many failures, have more than twenty years of experience in the promotion of renewable energies. However, the Tunisian government made a real change of scale only from 2005, the year of creation of the National Fund for the Control of Energy, itself at the origin of the so-called programs "Prosol".

Public action has been decisive in the creation of a domestic market for solar energy in Tunisia. By structuring the demand, in a few months, it has stimulated a remarkable business creation dynamic. However, if the short-term success of this Tunisian solar energy policy is partially demonstrated, it is not assured without government support that would support a national sector. Greater local industrial integration, which would engage the country in the longer term, would allow the sector to be autonomous with regard to ad hoc support mechanisms and would anchor these sustainable

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consumption patterns more securely in everyday household practices Tunisian [7,8,9].

Moreover, the transposition of these solar equipment in a given urban environment comes up against technical requirements, while at the same time revealing socio-economic discrimination contrary to the challenges of sustainable development. The application of the Prosol programs, which underlies an attempt to democratize the use of solar energy, is a Tunisian singularity which, by showing its limits, makes it possible to take a step back on the means that the public authorities must deploy to concretely support the sustainability effort at the scale of the Mediterranean city [9,10;16].

V. PHOTOVOLTAIC SYSTEM ENERGY

The schematic global of the PV energy system connected to the grid is described in Figure 1.

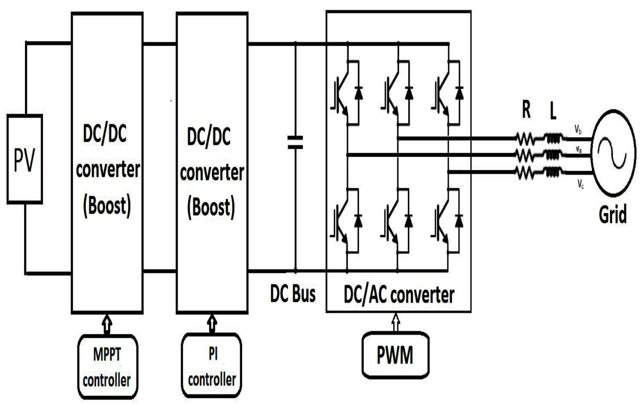

Figure 1. PV energy system connected to the grid.

1. Electrical PV Array Model

The photovoltaic cell can be modeled by the following equations [1]:

$$I_{pv} = n_p I_{ph} - n_p I_{rs}\left(e^{\frac{qV}{pKTn_s}} - 1\right) \quad (1)$$

The generated current I_{ph} is given by the following equation :

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

where $I_{ph,n}$ is the rated current generated by the PV model under standard condition of irradiation and temperature (G=1000W/m^2 and T=25°C).

I_{rs} is the reverse saturation current, is modeled by :

$$I_{rs} = I_{rr}\left(\tfrac{T}{T_r}\right)^3 \exp(qE_{gp}(1 - T_r - 1/T))/pK \quad (3)$$

where I_{rr} is the reverse saturation current at the reference temperature T_r.

2. DC/DC Converter

When a direct connection is carried out between the source and the grid, the output of the PV panel is seldom maximum and the operating point is not optimal. To overcome this problem, it is important to add an MPPT controller with a DC/DC converter, between the source and the grid.

There exist many type of DC/DC converter such as Buck, Boost and Buck-Boost. In summary [2]:

• The output voltage of the DC/DC buck converter is: $v_{out} = \mu v_{in}$

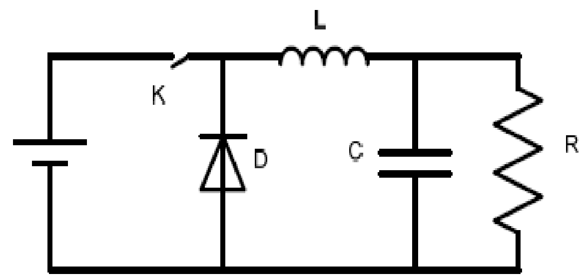

Figure 2. Buck converter.

• The output voltage of the DC/DC boost converter is: $v_{out} = \frac{1}{1-\mu} v_{in}$

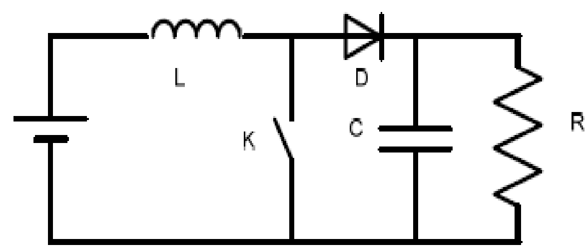

Figure 3. Boost converter.

• The output voltage of the DC/DC buck-boost converter is: $v_{out} = -\frac{\mu}{1-\mu} v_{in}$

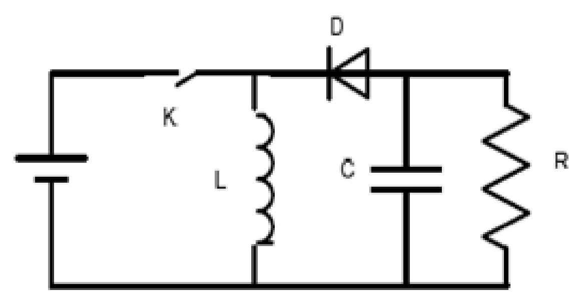

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Figure 4. Buck-Boost converter.

where μ is the duty cycle varies between 0 and 1.
In our case we use a DC/DC boost converter.

VI. PERTURB & OBSERVE MPPT TECHNIQUE

The maximum power point tracking used in this work is the Perturb & observe MPPT method (P&O).
The principle of this command is to generate the disturbances by reducing or increasing the duty cycle μ and to observe the effect on the power delivered by the photovoltaic generator [2,4,15].

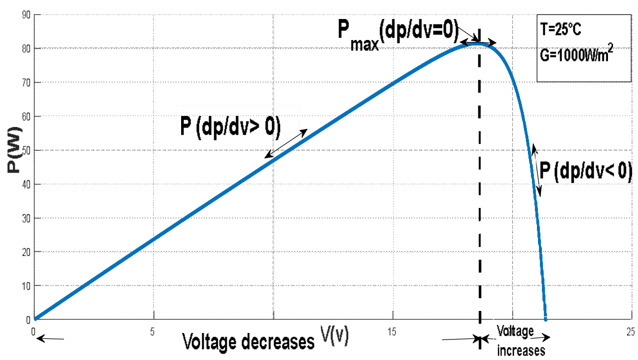

Figure 5. Characteristic of the power of the PV generator.

The algorithm of this command is shown in Figure 6.

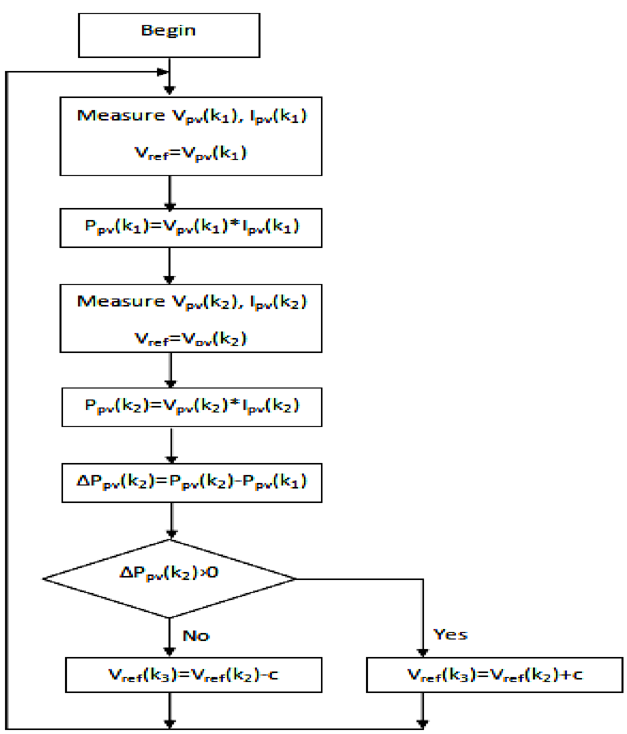

Figure 6. Flowchart of the Perturb and Observe method.

• If dpv/dVpv> 0, the voltage is increased, this induces an increase of the duty ratio μ(k)= μ(k-1)+C.
• If dpv/dVpv <0, the voltage is reduced, this results in a decrease in the duty cycle μ(k)= μ(k-1)-C.
where C is an accretion constant.

VII. NUMERICAL SIMULATION

In order to check the performance of the P&O algorithm, we have selected four pairs of temperature and irradiation.

The evolution of irradiation and temperature are given by Figures 7 and 8.

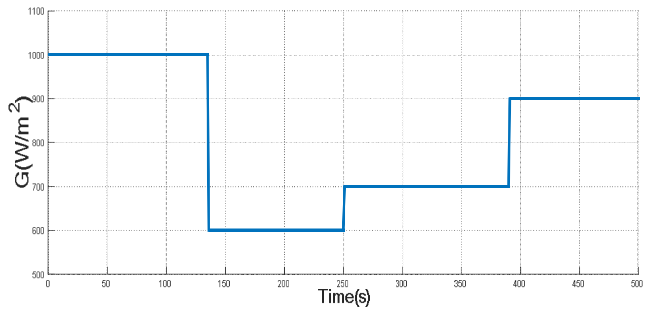

Figure 7. Evolution of irradiation.

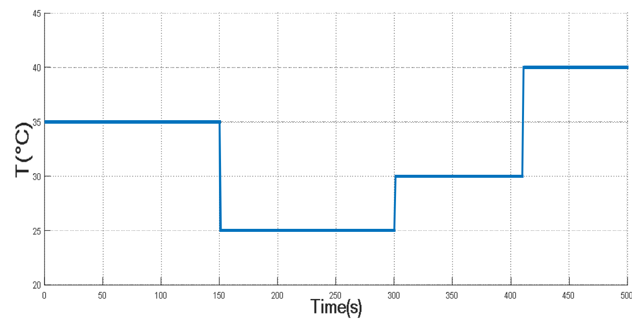

Figure 8. Evolution of temperature.

The evolution of the PV voltage, the error of PV voltage, the evolution of PV current and the error of PV current according to the P&O algorithm are presented respectively in Figures 9, 10, 11 and 12.

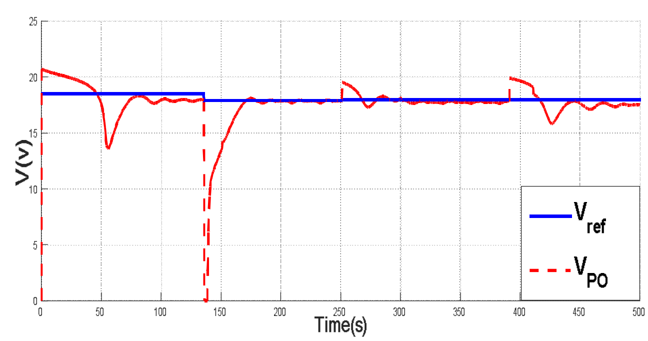

Figure 9. Evolution of the voltage for P&O algorithm.

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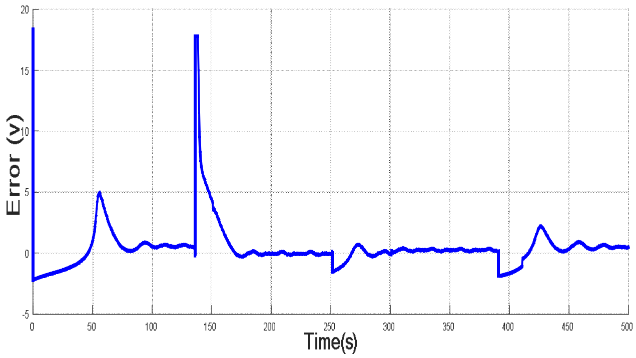

Figure 10. Evolution of the error PV voltage.

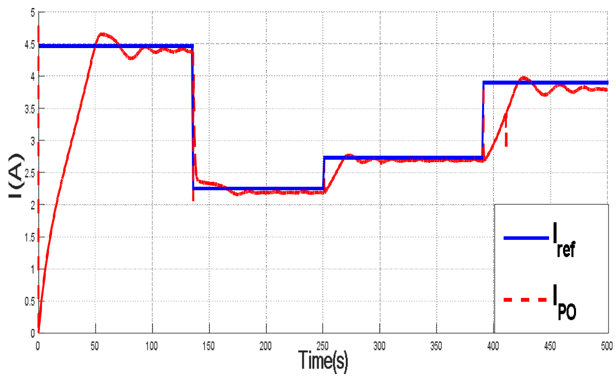

Figure 11. Evolution of the current for P&O algorithm.

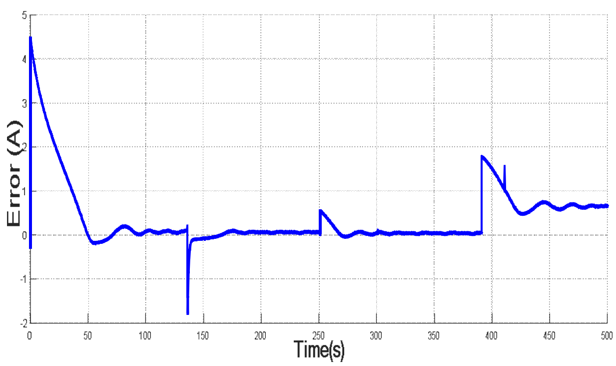

Figure 12. Evolution of the error PV current.

The Figure 13 shows the panel delivered power.

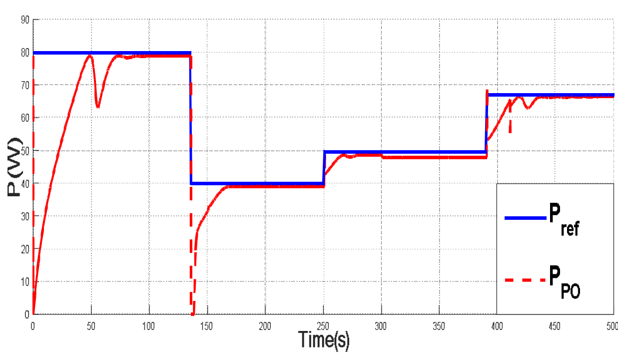

Figure 13. Evolution of the power for P&O algorithm.

In Figures 9, 11 and 13, we can notice momentary peaks, they are due by the abrupt and significant change in temperature and irradiation.

It can be seen in Figures 10 and 12 that the P&O algorithm present less oscillations and the errors tend towards zero.

We can observe that the P&O MPPT algorithm can be tracking the maximum power point of the PV panel.

In order to increase the output voltage of the DC/DC Boost converter, we used another DC/DC Boost converter with PI controller.

To achieve grid interconnection by converting the DC current from the PV panel to a sinusoidal signal synchronized with the grid you must using a DC/AC inverter with an RL filter to improve the waveform quality of the signal and to have the shapes of three-phases signal [3;11;14].

The Figure 14 shows the current signal waveform of the photovoltaic panel after connection with the DC/AC converter.

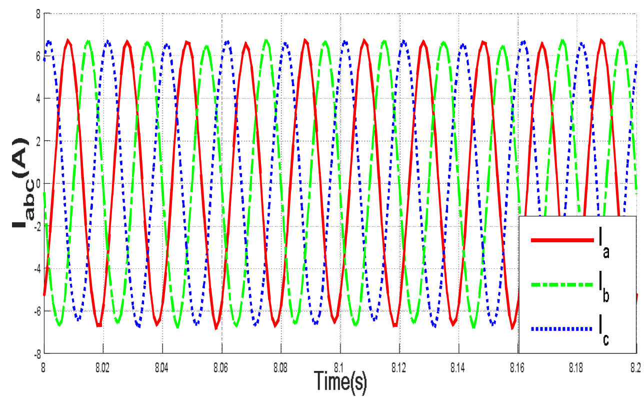

Figure 14. Currents at DC/AC converter connected to the grid.

It can be seen that the inverter currents have the shapes of three-phases signal.
In fact, the frequency, the current and the voltage signals from the photovoltaic process are been converted to the synchronous frequency of the utility grid by the DC-AC inverter.

VIII. Conclusion

In this work, the situation and the guidelines Tunisia energy and the network-connected photovoltaic systems and the net-metering system have been studied.

In addition, we have presented a photovoltaic energy system and the complete mathematical model for the PV panel and we have described the P&O MPPT algorithm for the

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maximum power point tracking of the solar power generation system connected to the grid.

We can conclude that the simulation results show the performance and the efficiency of the proposed MPPT algorithm.
In a future work, we can realize the pumping system by using a PV process.

Nomenclature

T	Temperature
G	Irradiation
E_{gp}	Band-gab energy
q	Charge of electron
K	Boltzmann's constant
n_s	Number of serial PV cells
n_p	Number of parralel PV cells

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