An Experimental Study of P&O MPPT Control for Photovoltaic Systems

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ABSTRACT

Tracking the maximum power point plays an important role for the optimization of the solar energy. The objective here is to study experimentally optimizing photovoltaic (PV) systems connected to a DC-DC converter (Boost) and a resistive load. For this, tests were conducted to determine the law of open loop control (power versus the duty cycle) for different solar irradiance values and load with an approximately constant cell temperature. The obtained results showed that the power passes through a maximum point. In order to extract the maximum power, for different values of solar irradiance and load, an MPPT control "Perturb and Observe" P & O has been implemented on a DSPACE 1104. The experimental results showed the performance of the method suggested.

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1. INTRODUCTION

Using renewable energy systems in their maximum power point is very important in order to increase their effectiveness for using them in isolated sites or connecting them to the grid.Solar energy systems are considered as renewable energy sources clean and efficient. They are taken as a strategic solution for the production of electricity. They are used in many domains applications such as solar power plants, aerospace industries, and electric vehicles.

In order to maximize the power derived from the photovoltaic (PV) panel, it is crucial to operate the photovoltaic energy conversion systems near the maximum power point. The main problem is obtaining the optimal operating point (voltage and current) i.e get the maximum power under variable weather conditions.

A great number of Maximum Power Point Tracking (MPPT) techniques and various topologies of converters have been proposed to extract the maximum power. These techniques are different in terms of cost, speed of convergence, complexity, popularity, sensors required, implementation and other criteria [1].

Current research classified these methods in two categories: conventional techniques and artificial intelligence techniques. The most important techniques are Fractional Voc and Isc, Hill Climbing (HC), Perturb and Observe (P&O), Incremental Conductance (lnc Cond), and artificial intelligence techniques such as Fuzzy Logic and Neural Network [2, 3] and other analog methods such as the control loop of the voltage [4].

This paper focuses on the real-time tracking of the maximum power point for PV systems. The objective is to consolidate and complete our most recent publication entitled « Experimental Study of P&O MPPT Control for Wind PMSG Turbine » [5] by hybridization with a small horizontal axis wind turbine.This paper is organized as follows: Section II presents the specifications of photovoltaic systems. An open loop study of a PV associated with the Boost converter is discussed in Section III. Section IV describes the closed-loop system (PV, DC-DC converter, MPPT P & O). The experimental results are presented and discussed in section V.

2. THE SPECIFICATIONS OF PV SYSTEMS

The Laboratory of Electrical Engineering and Maintenance (LGEM) is equipped with various solar modules. Among them, we are interested in particular to the PV module ET-M53930.

a. 39 cells of 125 mm x 40 mm single crystal silicon, geometrically configured and connected in series to constitute a matrix.
b. An anodized aluminum alloy frame of ensuring the maintenance and mechanical protection of the panel.

The specifications listed in the table below are obtained under the Standard Test Conditions (STCs): 1000 W/m² solar irradiance, 1.5 Air Mass, and cell temperature of 25 °C.

Table 1. The characteristics of pv systems

Weight	3.5 kg
Dimensions	633x427x35mm
Maximum power voltage (Vmp)	19.4V
Maximum power current (Imp)	1.55A
Open circuit voltage (Voc)	23.8V
Short circuit current (Isc)	1.74A
Temp.coeff. of Isc (Tk Isc)	0.06 %/° C
Temp.coeff. of Voc (Tk Voc)	-0.397 %/° C
Temp.coeff. of Pmax (Tk Pmax)	-0.549 %/° C
Normal operating cell temperature	44.4+-2° C

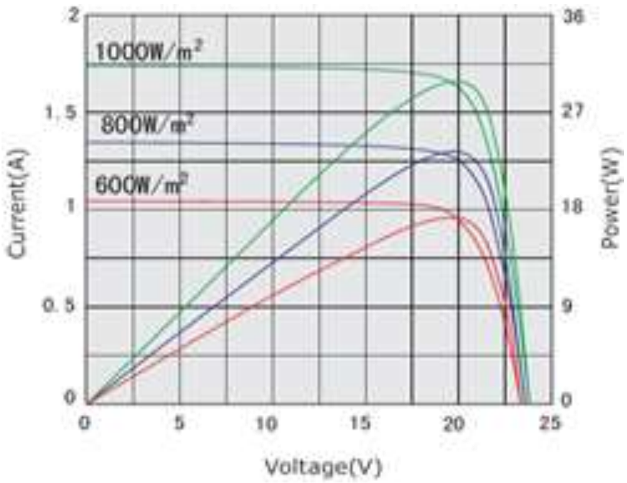


Figure 1. Electrical Performance cell temperature: 25°C

3. CONTROL OF THE PV SYSTEM WITHOUT MPPT

3.1. Open Loop Study

In order to determine the law of open loop control, we associated our PV with a Boost converter. Following several tests, for various values of solar irradiance and load, we measured the power at each duty cycle.We confirm, through these tests, that our PV has a maximum power point, which is the optimal point for an effective use of our system. Figure2 illustrates the power generated by the PV system according to the duty cycle for a fixed load of 100 Ω and different values of solar irradiance.

a. At 900 w/m² the maximum power is approximately 20W for a duty cycle 0.61.
b. At 500 w/m² the maximum power is approximately 12 W for a duty cycle 0.5.

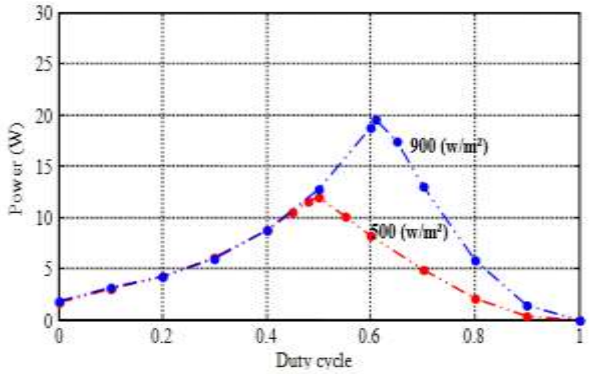


Figure 2. Power as a function of duty cycle for a fixed load of 100 Ω and a variable solar irradiance.

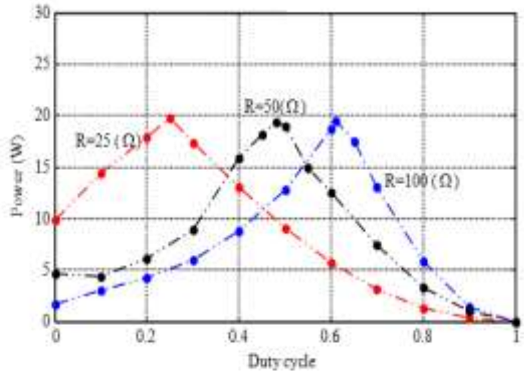


Figure 3. Power as a function of duty cycle for a variable load and a fixed solar irradiance.

In order to test the effect of the load on the power delivered by the PV system, we performed power measurements for a fixed solar irradiance (900 w/m²) and variable load (25 Ω, 50 Ω and 100 Ω). Figure 3 shows these measurements, we note that the maximum power remains constant regardless of the load value, and that for each load value, there is a duty cycle that corresponds to this optimal power

a. The optimal duty cycle is around 0.25 for a load of 25 Ω.
b. The optimal duty cycle is around 0.48 for a load of 50 Ω.
c. The optimal duty cycle is around 0.61 for a load of 100 Ω.

4. CONTROL OF THE PV SYSTEM WITH MPPT

4.1. Block Diagram in Closed Loop

We aim to exploit the maximum power supplied by the PV system for any given solar irradiance. To do so, we have implemented, in the DSPACE 1104 card the MPPT control of our PV system associated with a Boost converter. Figure 4 represents the block diagram of the hardware setup.

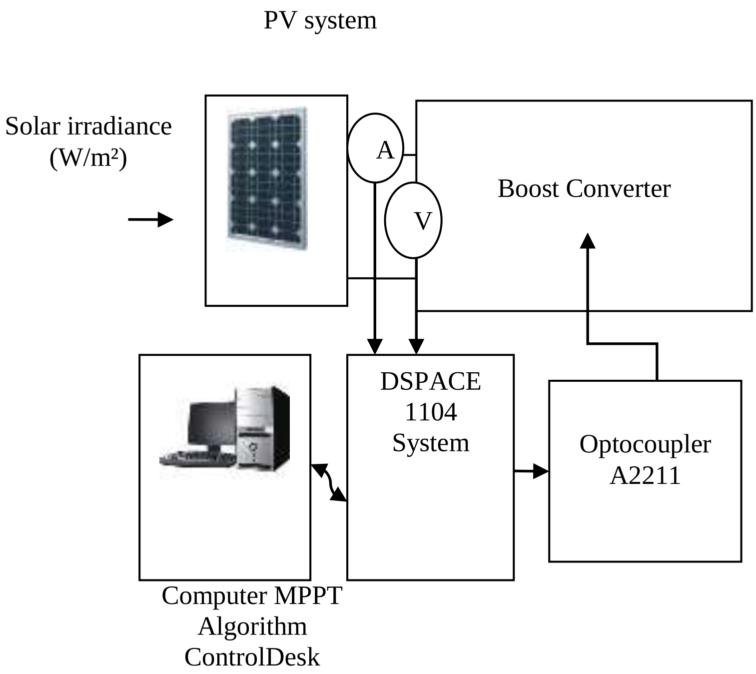


Figure 4. Block diagram of the hardware used for the experimentation.

4.2. DC-DC Converter (Boost)

The basic circuit of the Boost topology DC-DC [6] is represented in Figure 5. If the inductance and capacity (L, Ce, Cs), are carefully calculated, they could filter the current and minimize the ripple factor of the input voltage and the output voltage of the converters. r in series with the inductance represents the resistance of the conductor of coil. The equations below represent, in continuous mode, the expressions which make possible the deduction of the values from each element of the converters (inductance L, output capacitor Cs, input capacitor Ce).

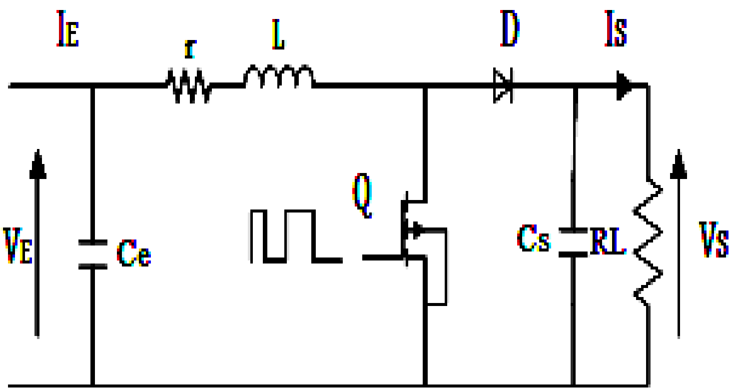


Figure 5. Boost converter

$$L > \frac{V_E . X_0}{f . I_{smin}}, X_0 = 0.125 \quad (1)$$

$$C_s > \frac{D . I_s}{f . \Delta V_s}, I_s = I_{smax}, \Delta V_s = 10mv \quad (2)$$

$$C_e > \frac{D}{8.L.f^2} \frac{1}{\Delta V_E / V_E} \frac{\Delta V_E}{V_E} = 1\% \quad (3)$$

4.3. The MPPT Control (P&O)

The MPPT algorithm P&O is mainly used, due to its ease of implementation and its low cost.It is based on the following criterion: (Figure 6) if the operating voltage of the generator is perturbed in a given direction and dp/dV>0, it is known that the perturbation moved the operating point toward the MPP. The P&O algorithm would then continue to perturb the generator voltage in the same direction. Otherwise, if dp/dV<0, then the change in operating point moves away from the MPP, and the P&O algorithm reverses the direction of the perturbation. In other words, the system works by increasing or decreasing the operating voltage and observing its impact on the output power.

The Perturb and Observe (P&O) has been implemented to extract maximum power at each instant. Figure 7 summarizes the control action of the P&O method. The flowchart of the implemented algorithm is shown in Figure 7. The operating voltage is perturbed with every MPPT cycle. As soon as the MPP is reached, it will oscillate around the ideal operating voltage. For example if the controller senses that the input power increases (dp>0) and the voltage (dV<0), it will decrease (-) Vref to bring it closer to the MPP [5].

5. EXPERIMENTAL RESULTS

5.1. The Hardware Setup of the MPPT System

In order to validate our proposed method, as well as the results obtained in simulation, the implementation of the MPPT hardware setup is done by using DSPACE real time control in our research lab. Figure 8 shows the hardware setup of the MPPT system. The experimental results were achieved with the parameters of the boost converter mentioned in Table 2.

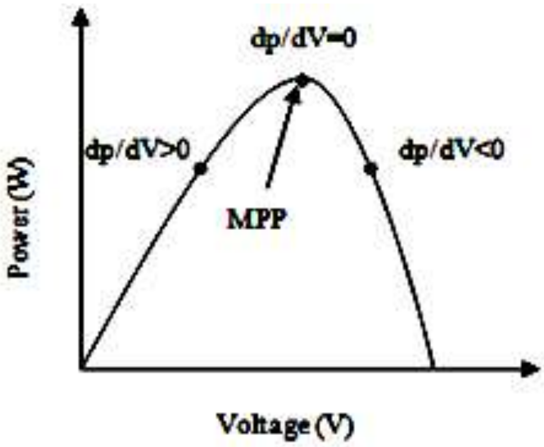


Figure 6. Sign of the dP/dV at different positions on the power characteristic

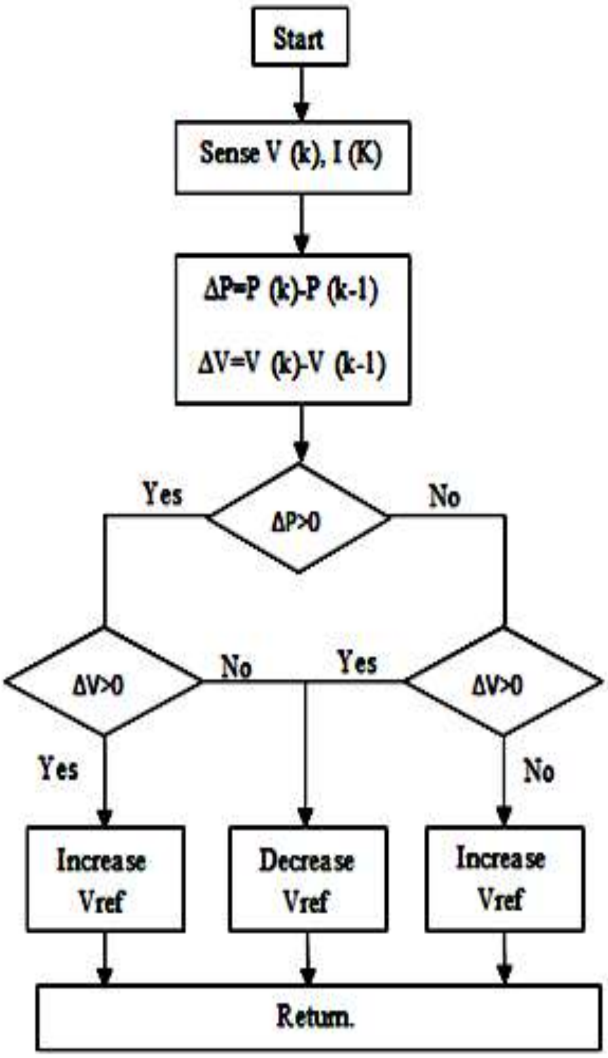


Figure 7. The flowchart of the P&O MPPT method

Table 2. Boost converter components and hardware used in the test

Boost Converter Parameters	
L	42uH
r	0.2 Ω
Ce	Ce=1000uF/250V
Cs	Cs= 1000uF/250V
Resistive Load R_L	100 Ω.
Controller type :dsPACE 1104 DSP	
Mosfet Type : IRFp450	
Diode Type :BYW98-200	
Components used in the measurement circuit	
Current Transducer	AC/DC Current Probe 10A/1V-100A/1V
Voltage Sonde	ST1000

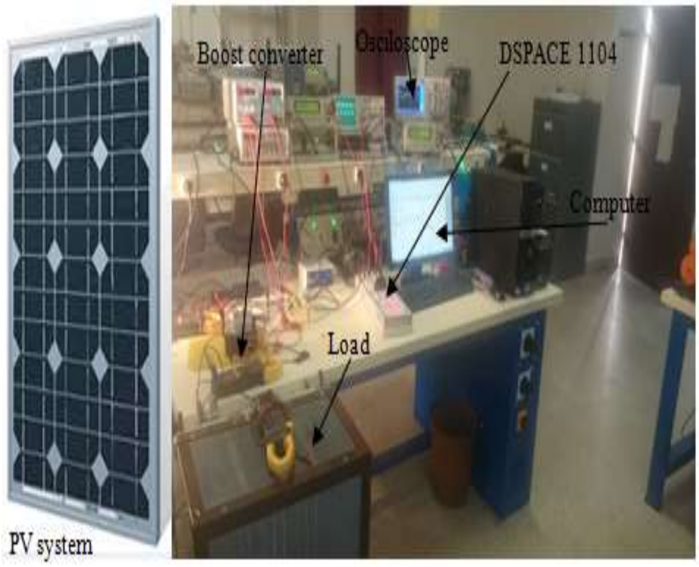


Figure 8. The experimental hardware used in our lab

5.2. Implementation of the MPPT Method

With so many MPPT techniques available to PV system users, it might not be obvious for the latter to choose which one better suits their application needs. The ease of implementation is an important factor in deciding which MPPT technique to use. However, this greatly depends on the end-users knowledge. Some might be more familiar with analog circuitry, in which case, fractional ISC or VOC, RCC, and load current or voltage maximization are good options. Others might be willing to work with digital circuitry, even if that may require the use of software and programming. Then, their selection should include hill climbing/P&O, IncCond, fuzzy logic control, neural network, and dP/dV or dP/dI feedback control.

The perturb and observe (P&O) algorithm is the most commonly used in practice because of its ease of implementation and its simplicity. Moreover, it is well known that the P&O methods can fail under rapidly changing atmospheric conditions. Several studies, compares the performance of different MPPT approach proposed in literature [7]. The experimental results obtained in this paper present the performance of my approach.

In order to track in real time the maximum power point MPP of our PV system, the SIMULINK MPPT control block, shown in Figure 9, must be downloaded to the DSPACE board. The filters are used for removing any high frequency noise or any switching noise that appears in the signals. As shown in Figure 9 the instantaneous measured voltage and current is then multiplied by each other to obtain the wind turbine instantaneous power [8].

The current and voltage are applied to the MPPT algorithm to generate the required duty cycle. The output signal of the MPPT algorithm is then applied to the DS1104SL_DSP_PWM block which is used to generate the required switching signal to drive the MOSFET.

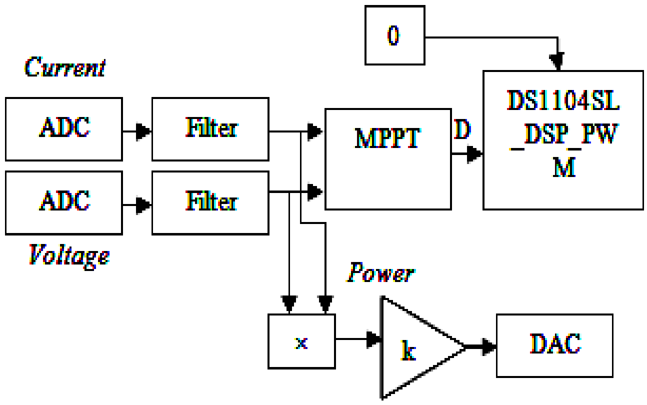


Figure 9. MPPT SIMULINK model implemented in dSPACE 1104

5.3. MPPT Control Tests in Real Time

The experiments are conducted at the University Mohammed 1 in Laboratory of Electrical Engineering and Maintenance (LGEM) from January 25th to 31st 2016 with an ambient temperature approximately equal to 16°C. Several tests were performed to validate and verify our MPPT control:

a. Testing the MPPT control with a fixed solar irradiance and a variable load.
b. Testing the MPPT control with a variable solar irradiance and a fixed load.

5.3.1. Testing the MPPT Control with a Fixed Solar Irradiance and a Variable Load

In order to measure the flexibility of our MPPT control with the load variation, we conducted a test on a fixed solar irradiance of 900w/m² and a variable load of 100 Ω to 50 Ω. The graphs below show the results. During this test, we started with a load of 100 Ω and after 280 seconds, a change of load towards 50 Ω is imposed on the system in order to see its reaction.We found that this change did not influence on the maximum power, i.e. the maximum power remains constant even if there is any change on the load (see Figure 10 and Figure 11). However the change of the resistive load has changed the optimal duty cycle of the control, on the interval of 100 Ω the duty cycle is 0.61, and on the interval of 50 Ω the duty cycle became 0.5.

5.3.2. Testing the MPPT Control with a Variable Solar Irradiance and a Fixed Load

In order to test the reaction of our system to the variation of the solar irradiance, we have performed a test with a variable solar irradiance and a fixed load of 100 Ω. In Figure 13, by using Controldesk, We note that the maximum power is changed accordingly to the evolution of the solar irradiance. The MPPT method follows the maximum power under these conditions successfully. We obtained also the same results as displayed on the oscilloscope, with a scale of (20 Watt=10v) and (1000w/m² = 10v), as shown in Figure 12.

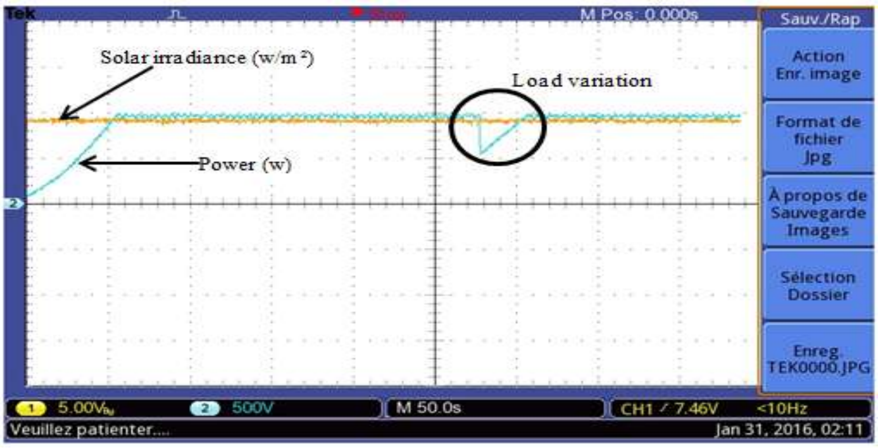
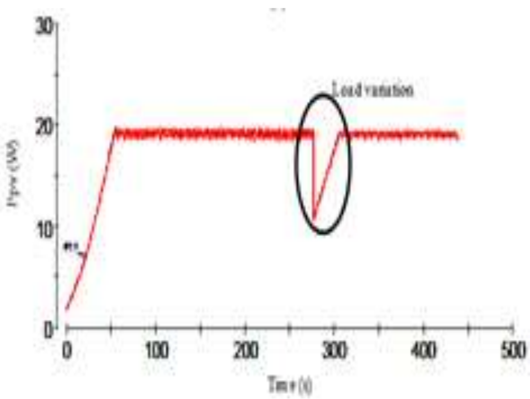
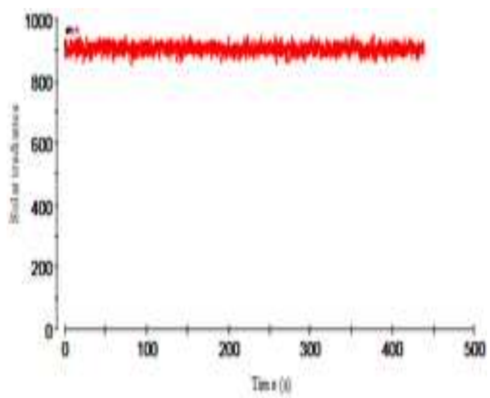


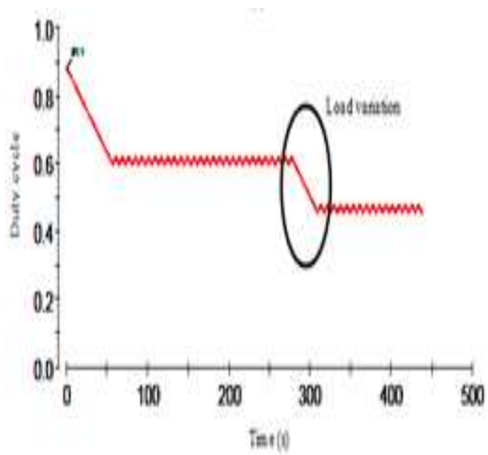
Figure 10. Experimental tracking of the MPP with change of load. (in osciloscope)



(a)



(b)



(c)

Figure 11. Experimental Tracking of the MPP with change of load (in ControlDesk) of a) power, b) solar irradiance, and c) duty cycle

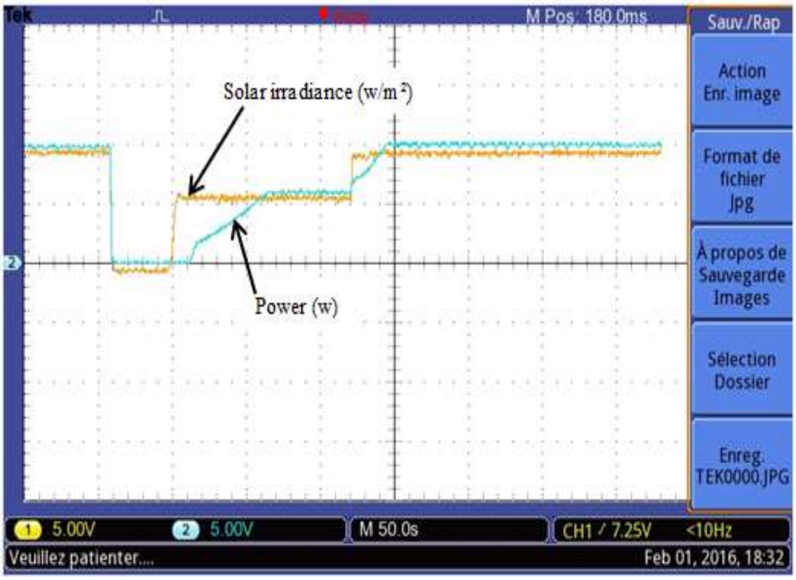
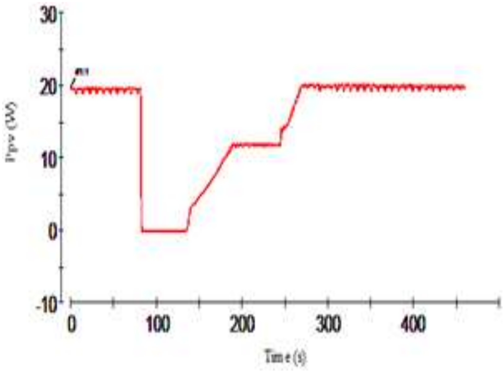
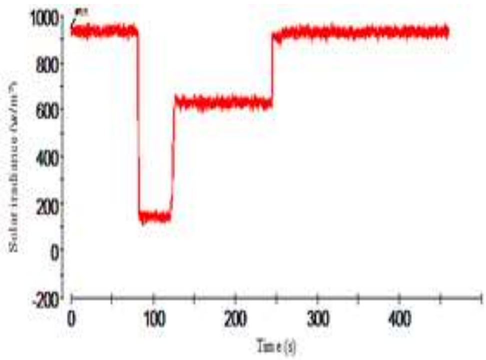


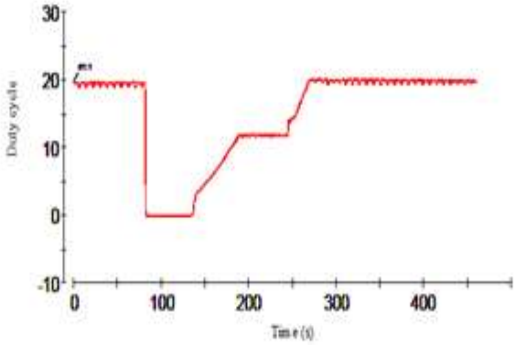
Figure 12. Experimental tracking of the MPP with changing of the solar irradiance (in osciloscope)



(a)



(b)



(c)

Figure 13. Experimental tracking of the MPP with changing of the solar irradiance. (in Control Desk) of a) power, b) solar iradiance, and c) duty cycle

6. CONCLUSION

In order to validate our MPPT algorithm in real time, we studied and successfully implemented an experimental setup using a boost converter connected to a resistive load, the implementation of the MPPT control is done by using DSPACE DS1104. The experimental results show the validity of the proposed MPPT algorithm. The MPPT control tracks in real time the maximum power point MPP of our PV systems whatever the variation of the solar irradiance or resistive load.

REFERENCES

[1] A. Jusoh, T. Sutikno, T. K. Guan, S. Mekhilef, "A Review on Favourable Maximum Power Point Tracking Systems in Solar Energy Application", *TELKOMNIKA*. March 2014; Vol. 12; No. 1; pp. 6-22.

[2] A.J. Lubis, E. Susanto, U. Sunarya, "Implementation of Maximum Power Point Tracking on Photovoltaic Using Fuzzy Logic Algorithm", *TELKOMNIKA*. March 2015; Vol. 13; No. 1; pp. 32 - 40.

[3] M. Yaichi, M.K. Fellah, A. Mammeri, "A Neural Network Based MPPT Technique Controller for Photovoltaic Pumping System", *International Journal of Power Electronics and Drive System (IJPEDS)*. June 2014; Vol. 4; No. 2; pp. 241- 255.
[4] M. seddik, S. Zouggar, F.Z. Kadda, A. Aziz, L. Ahafyani, R. Aboutni, "The automatic voltage control developed for the maximum power point tracking of a PV", International Journal of Electrrical Engineering & Technology (IJEET). September - October 2013; vol 4; issue 5; pp. 173-183.
[5] B. Lahfaoui, S. Zouggar, M.L. Elhafyani, M. Seddik, *"Experimental study of P&O MPPT control for wind PMSG turbine"*, Renewable and Sustainable Energy Conference (IRSEC'15), IEEE International Marrakech Morocco. 10-13 Dec. 2015; pp. 1 - 6.
[6] B. Lahfaoui, S. Zouggar, M.L. Elhafyani, F.Z. Kadda, " *Experimental Modeling and Control of a Small Wind PMSG Turbine"*, Renewable and Sustainable Energy Conference (IRSEC'14), IEEE International Ouarzazat Morocco. Oct. 2014; pp. 802 – 807.
[7] Trishan Esram Illinois Univ, Urbana, IL Patrick L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques", *IEEE Transactions on Energy Conversion*; June 2007; Vol. 22; No. 2; pp. 439 – 449.
[8] B. Lahfaoui, S. Zouggar, M.L. Elhafyani, A. Benslimane, *"Modeling validation and MPPT technique of small wind PMSG turbines using DSPACE hardware"*, Renewable and Sustainable Energy Conference (IRSEC'15), IEEE International Marrakech Morocco. 10-13 Dec. 2015; pp. 1 - 6.