2ème conférence Internationale des énergies renouvelables CIER-2014
Proceedings of Engineering and Technology - PET

Experimental validation of a conventional MPPT controller for PV power systems

Radhia Garraoui #1, Oscar Barambones*2, Mouna Ben Hamed #3, Sbita Lassaad #3
#Photovoltaic, Wind and Geothermal Systems Research Unit, (SPEG)
National Engineering school of Gabes, Tunisia
[1]radhiagarraoui@gmail.com
[3]mouna.benhamed@enig.rnu.tn
[4]lassaad.sbita@enig.rnu.tn
**University of the Basque Country*
Department of Systems Engineering and Automation, E.U. de Ingeniería de Vitoria-Gasteiz,Spain
[2]oscar.barambones@ehu.es

***Abstract*— This paper presents a maximum power point tracking (MPPT) algorithm of a PV system under real climatic conditions. The proposed MPPT is based on the perturbation and observation (P&O) strategy that control the load voltage to ensure optimal operating point of a PV system. The proposed MPPT algorithm has been implemented by a dSPACE DSP controller. The experimental results show that the PV power system, using the proposed MPPT algorithm, is able to accurately track maximum power points under variable irradiance and load variations.**

***Keywords*—photovoltaic system; P&O approach; MPPT controller; DC-DC converter, a dSPACE DSP controller.**

I. Introduction

The low productivity of solar panels makes the optimal operation of a photovoltaic system so important. This low efficiency is due to the nonlinearity output characteristic of a PV system and the variable levels of ambient temperatures and solar irradiance [1]. Therefore, an MPPT technique is required to obtain maximum power from a PV system. A number of MPPT techniques have been elaborated for, PV systems. For all common MPPT techniques, the main problem is how to obtain optimal operating points automatically at maximum PV output power under variable climatic conditions and load variations.

MPPT techniques are diversified and different. However, the majority of control strategies depend on PV characteristics in real time. As an example there is the hill-climbing algorithm [2], the incremental conductance (INC) algorithm [3]. Not to forget the constant voltage algorithm [4] which is based on keeping the ratio between the PV voltage at the maximum power and the open circuit voltage as a constant value and also in this method the effect of solar irradiance variations is eliminated.

The perturbation and observation (P&O) algorithm [5] which is based forcing the direction of tracking toward an MPP is the topic of our experimental validation. The performance of the P&O method is evaluated by MATLAB/SIMULINK. The proposed system is then experimentally implemented. The DSPACE real-time control is used in the implementation of the MPPT hardware setup. Data acquisition and the control system are implemented by using dSPACE 1104 software and digital signal processor card on PC.

This paper focuses on maximizing PV system power outputs at all solar irradiance levels. In the second step, the electrical models of a PV panel and a boost converter are presented and analyzed then we describe the proposed MPPT algorithm and explain the P&O approach also we discuss the experimental setup followed by experimental results. Finally, some conclusions are presented. The experimental system as shown in Fig.1 illustrates a real-time implementation of a PV system using a fast dSPACE DSP controller. This system consists of four PV panels connected in series (the rated power of all panel is 220 W at a solar irradiance of 1000 W/m2 and a temperature of 25°C), a boost converter to control the load voltage, a dSPACE controller to implement the proposed MPPT algorithm, sensors to measure the PV voltage, PV current , load voltage and load current which are input signals to the MPPT controller, and a stand-alone resistive load.

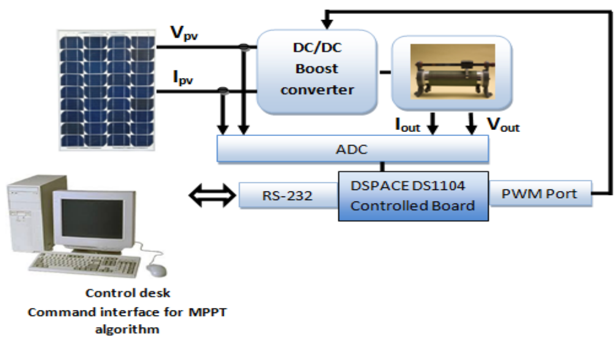

Fig.1. Block diagram of the hardware setup.

II. PHOTOVOLTAIC POWER SYSTEM CONFIGURATION

A PV cell model must be initially established, in order to model the PV system. An equivalent electrical circuit makes it possible to model the characteristic of a solar cell [6]. In a practical PV cell, there are two resistances: series resistance and parallel resistance. Series resistance accounts for the losses in the current path due to the metal grid, contacts and current-collecting bus. Parallel resistance due to the loss is associated in parallel with the load with a small leakage of current through a resistive path in parallel with the intrinsic device. Parallel resistance is large and its effect is negligible. An equivalent circuit model of a PV cell, which is composed also of a light generator source and a diode, is shown in Fig.2.

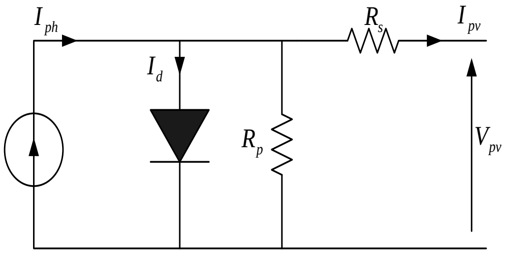

Fig. 2. Model of a PV cell.

The equivalent model of a PV cell is using the mathematical expression (1-3). Equation (1) describes the output current of the cell:

$$I_{pv} = I_{ph} - I_d \left[\exp\left(\frac{q(V_{pv} + I_{pv}.R_S)}{k_b T A}\right) - 1 \right] - \frac{V_{pv} + I_{pv}.R_S}{R_p} \quad (1)$$

The equation of photo-current as a function of temperature and irradiation can be written as:

$$I_{ph} = \frac{G}{G_n}\left[I_{scr} + k_i (T - T_r) \right] \quad (2)$$

The well known saturation current equation is given by:

$$I_d = \frac{I_{ph} - \dfrac{V_{ocs} - \Delta V_{oc}(T_r - T)}{R_p}}{\exp\left(\dfrac{q(V_{ocs} - \Delta V_{oc}(T_r - T))}{A k_b T}\right) - 1} \quad (3)$$

In this paper we are using a real solar model that its specifications are described in Table.1 and the P-V and I-v curves under standard tests are shown respectively in Fig.3 and Fig.4.

Table.1. Specifications of Atersa panel in standard test conditions. 1000W/m^2, cell temperature 25 C, and air mass 1.5

electrical characteristic	
Power (W in test ± 10%)	55W
number of cells in series	36
Current point of maximum power Imp	3.4 A
voltage point of maximum power Vmp	16.2V
short circuit current I_{sc}	3.7A
open circuit voltage V_{oc}	20.5V
Temperature Coefficient of I_{sc}	1.66mA/C
Temperature Coefficient of V_{oc}	-84.08mV/C
physical characteristics	
dimensions (length x width x thickness)	778x659x35mm
weight approx	6.2 Kg

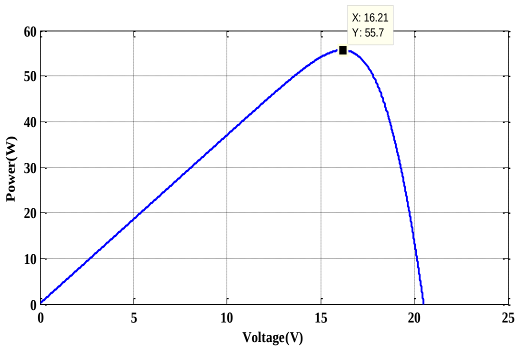

Fig.3. the P-V curve under G=1000W/m², T=25°C.

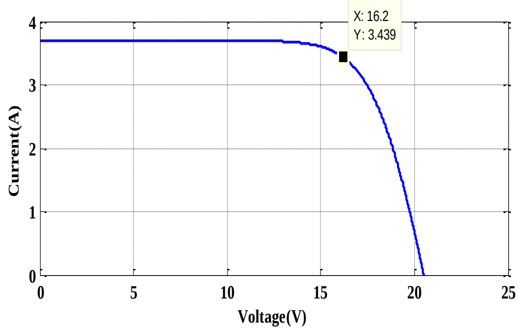

Fig.4. the I-V curve under G=1000W/m², T=25°C.

III. BOOST CONVERTER MODEL

A DC/DC boost converter is used in this research to connect a PV panel with a load in order to adjust the operating voltage and current of the PV panel at optimal values. A simplified diagram of a boost converter is illustrated in Fig. 5. The boost converter contains an IGBT and a diode which are represented as a dual ideal switch SW in order to simplify the circuit analysis. If SW is a state of 0, the diode is on and the IGBT is off and vice versa if SW is a state of 1. The boost converter contains also passive components: an inductor L, and capacitor C1 and C2, also a resistance Rload. The operation principle of the boost converter can be demonstrated for each switching period under the continuous conduction mode (CCM) into two modes: If the switch is off, the diode is on and the system is presented in the configuration reported in the corresponding state space model:

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}.(V_{c_1} - V_{c_2}) \\ \frac{dV_{c_1}}{dt} = \frac{1}{C_1}(i_{pv} - i_L) \\ \frac{dV_{c_2}}{dt} = \frac{1}{C_2}(.i_L - \frac{V_{c_2}}{R}) \end{cases} \quad (4)$$

For an ON mode, the state equations can be represented as follows:

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}.V_{c_1} \\ \frac{dV_{c_1}}{dt} = \frac{1}{C_1}(i_{pv} - i_L) \\ \frac{dV_{c_2}}{dt} = -\frac{V_{c_2}}{C_2 R} \end{cases} \quad (5)$$

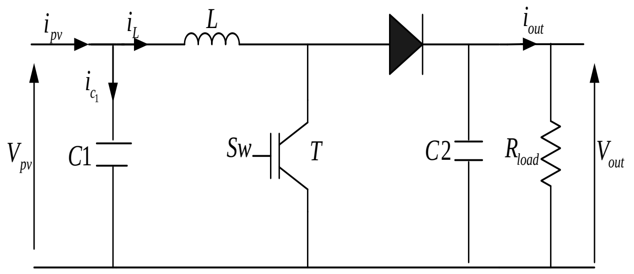

Fig. 5. Model of a boost converter.

The dynamic equation of the system can be described by:

$$\begin{cases} \frac{di_L}{dt} = \frac{1}{L}.(V_{c_1} - (1-u).V_{c_2}) \\ \frac{dV_{c_1}}{dt} = \frac{1}{C_1}(i_{pv} - i_L) \\ \frac{dV_{c_2}}{dt} = \frac{1}{C_2}((1-u).i_L - \frac{V_{c_2}}{R}) \end{cases} \quad (6)$$

The design of a boost converter for a PV system is a complex task which involves many factors. In general, the input and output voltages of the boost converter are varied with the solar irradiances and load variations. The output voltage is also varied which follows the reference voltage generated from an MPPT controller. Thus, the selection of boost converter components (the input inductor and the output capacitor) is a compromise between dynamic responses and the MPPT algorithm trigger time. The maximum value of the state variables should be calculated to estimate the value of the boost converter. The specifications and parameters of the boost converter are listed in Table II.

Table. II. The specifications and parameters of the boost converter

Parameters	*Values*
Switching frequency	***20KHz***
Maximum input voltage	***60V***
Maximum input current	***20A***
Maximum output voltage	***250V***
Maximum output current	***20A***
Minimum Duty cycle	***0.1***
Maximum Duty cycle	***0.9***
Capacitance C1 and C2	***10000µF and 3000µF***
Inductance	***(560/6) µH***

IV. MPPT ALGORITHM BASED ON P&O APPROACH

Maximum power point trackers are so important in photovoltaic systems to improve their overall efficiency. This paper presents a photovoltaic system with maximum power point tracking controller. P&O controller method is proposed in this paper. Fig.6 presents the flow chart of P&O method.

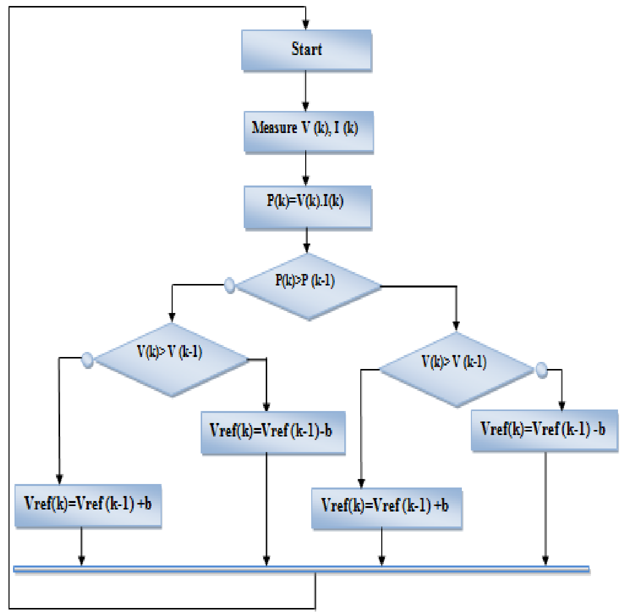

Fig. 6. The P&O diagram.

Perturbation and observation (P&O) method is an alternative method to obtain the maximum power point of the PV module. It measures the voltage, current, and power of the PV module and then perturbs the voltage to encounter the change direction. In order to implement the P&O MPPT method, the PV voltage and current must be initially measured. The change in the voltage and the change in the power must then be calculated. The PV voltage must then be perturbed by a constant value. If the perturbation in the voltage causes the power to increase, the next perturbation must be kept in the same direction. Otherwise, the next perturbation must be reversed.

V. EXPERIMENTAL SETUP AND RESULTS

P&O MPPT algorithm is implemented using a digital controller based on a dSPACE DSP unit. The dSPACE is a powerful tool to modify the MPPT controller parameters real time and to monitor real processes while an experiment is operated. The system components are: Four PV panels as power source (its specifications are listed in Table I), a dSPACE DSP controller board which is interfaced with a PC as and mentioned by number 1 in Fig.7, a resistive load (with number 2) and number 3 is a boost converter as a power process unit.

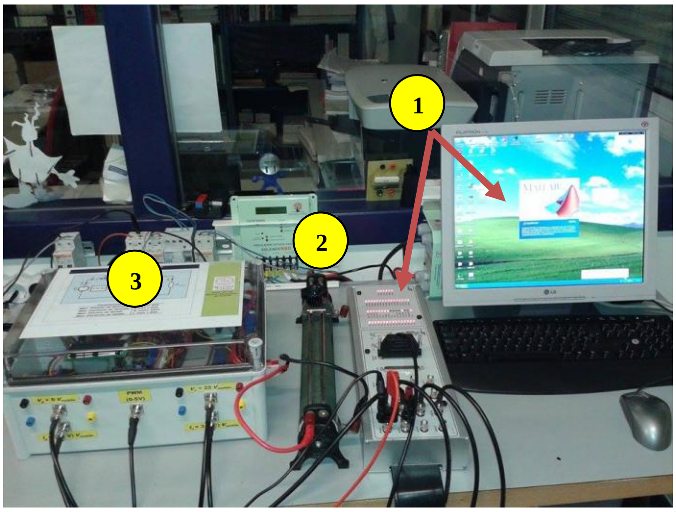

Fig. 7. The real processes.

The MPPT algorithm is modeled in Simulink for dSPACE implementation as shown in Fig. 8. The output signals of the voltage and current transducers are sampled in dSPACE DSP via DS1104-ADC blocks. Low pass filters are used in measuring units to eliminate the unwanted high-frequency noise. The PWM pulses from the dSPACE DSP is sampled via a DS1104-DSP-PWM block to generate standard 20 kHz fixed-frequency PWM pulses.

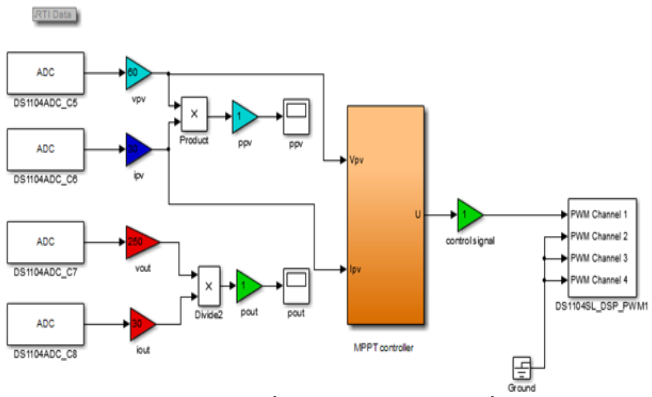

Fig. 8. Simulink model of the MPPT algorithm for dSPACE implementation.

In the first test, a P-V and I-V curves respectively in Fig.9 and Fig.10 are determined in order to see the maximum power that corresponds to the climatic conditions with T=25,94°C and G=138W/m² by varying the Rload from 0 ohm to 47.5 ohm. The optimal values are: P_{opt}=35.08W, V_{opt}=14.97V and I_{opt}=2.34A. The MPPT controller is tested under a sunny case for a time of 60 s. the curves of solar irradiations is shown in Fig.11. The purposes of tests are to investigate the dynamic characteristics of a PV system and to calculate the amount of power increase using the proposed MPPT controller based on P&O approach. As shown in Fig.12 and Fig.13, the Power is reaching the optimal value successfully as the same case for the PV voltage. The PV system will generate a maximum voltage for the resistive load that is mentioned in Fig.14. In Fig.15, there is a Comparison of the experimental results obtained with and without using MPPT controller, it is clear that the P&O controller provide an accurate operating. The proposed algorithm is tested under another climatic condition is when the irradiation is changing as shown in Fig.16. Under sudden irradiance changes the P&O controller succeeds to track the maximum power every time this is clear when examining the response of power, voltage, current and load voltage mentioned respectively in figures Fig.17to Fig.20. There is another test of robustness which consists on an abrupt change of load as shown in Fig.21.We move suddenly from position A where the Rload=45 ohm to another position B where Rload=29 ohms. This test aims to investigate the dynamic response of the PV system in PV operating points. It can be observed from Fig. 22 and Fig. 23 that presents the load voltage and current, the effect of load change. The P&O controller seems to be robust; indeed, it resists with the load change and keeps constant power, voltage and current as shown in figures Fig.24 to Fig.26.

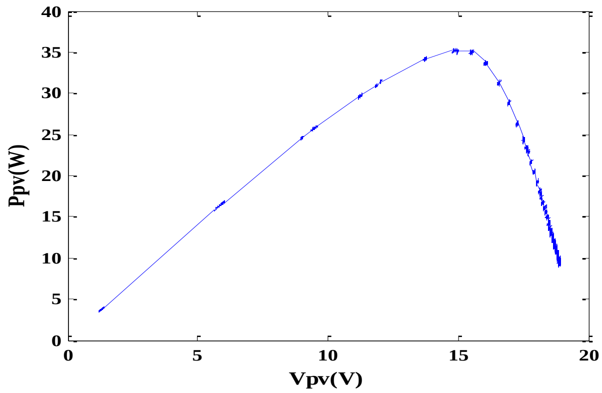

Fig. 9. The P-V curve.

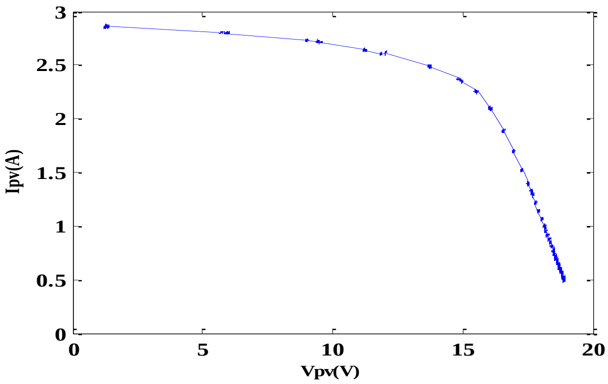

Fig. 10. The I-V.

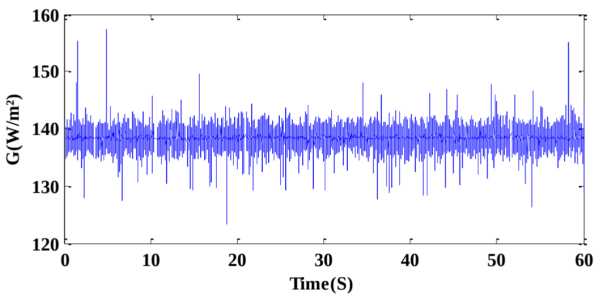

Fig. 11. The real irradiance.

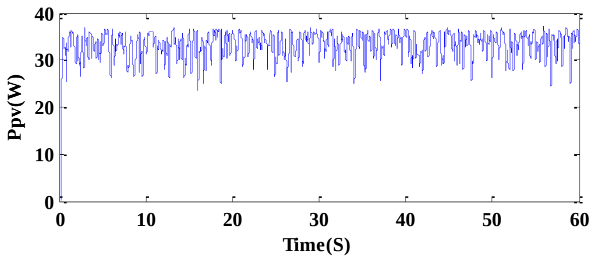

Fig. 12. The Experimental PV power.

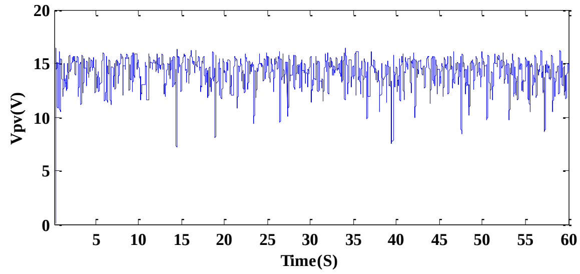

Fig. 13. The Experimental PV voltage.

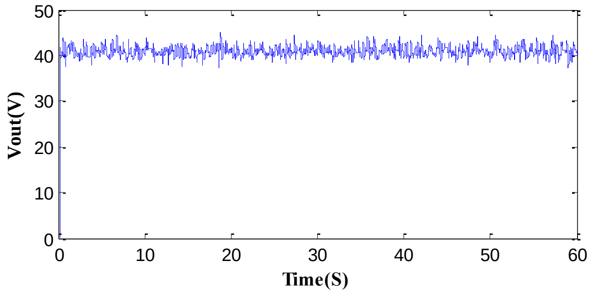

Fig. 14. The Experimental load voltage.

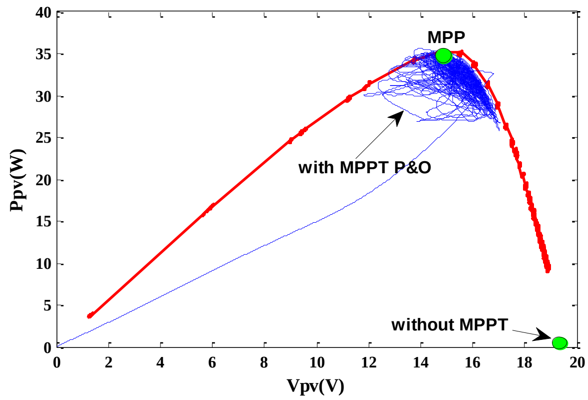

Fig. 15. Comparison of the experimental results obtained with and without using MPPT controller.

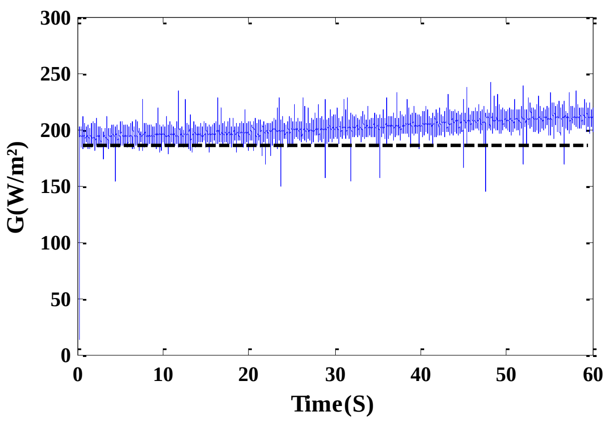

Fig. 16. The Experimental irradiance.

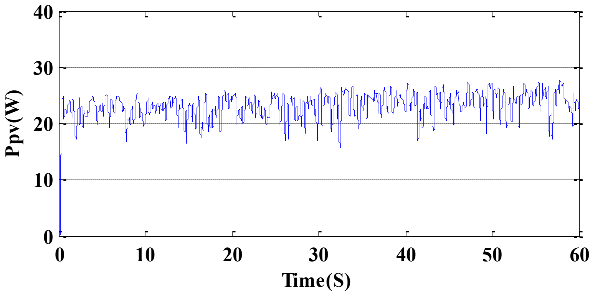

Fig. 17. PV power under variable irradiance.

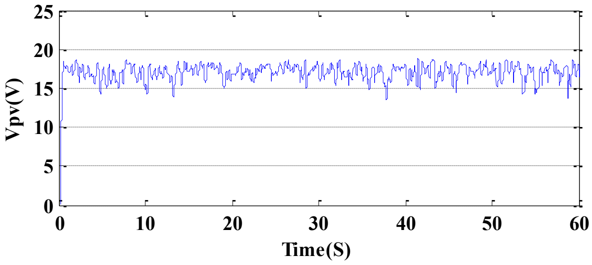

Fig. 18. PV voltage under variable irradiance.

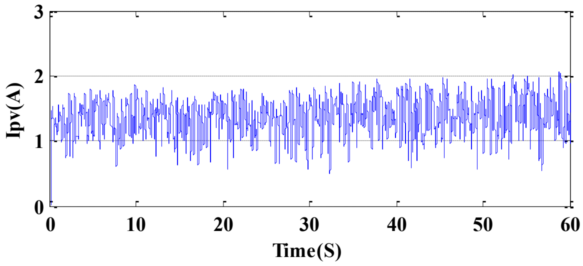

Fig. 19. PV current under variable irradiance.

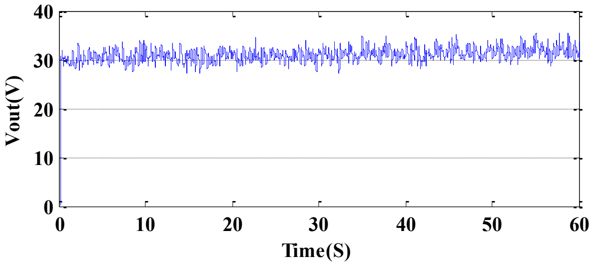

Fig. 20. Load voltage under variable irradiance.

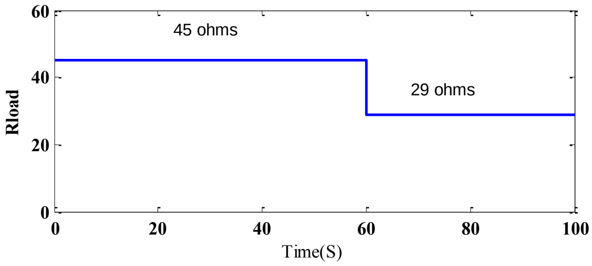

Fig.21. load change.

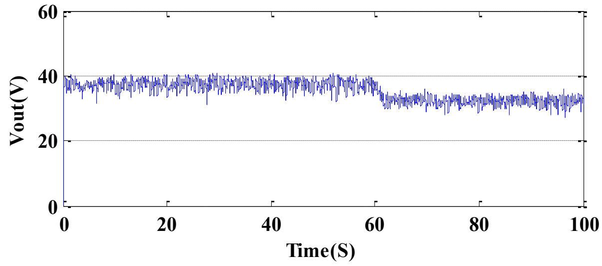

Fig.22. load voltage.

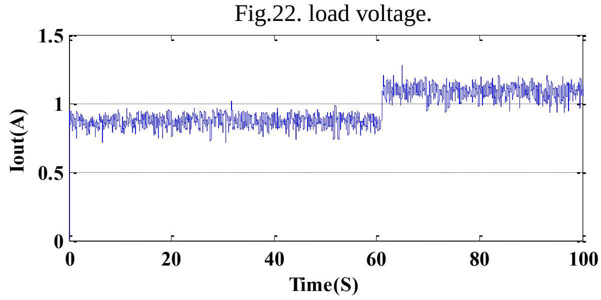

Fig.23. load current.

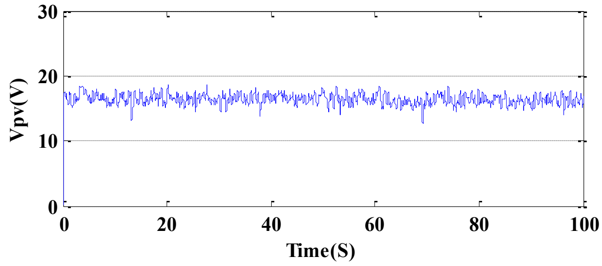

Fig.24. PV voltage.

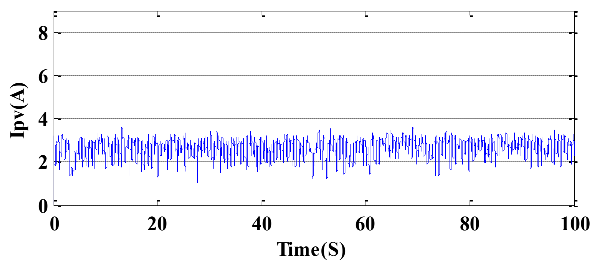

Fig.25. PV current.

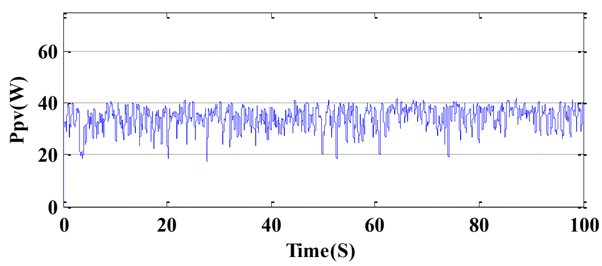

Fig.26. PV power.

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VI. CONCLUSION

This paper presents P&O algorithms of the photovoltaic array maximum power point tracking. The main aim of this research is to develop an MPPT controller for a PV system to obtain maximum power with weather fluctuations. Mathematical models of a PV panel and a DC-DC boost converter are introduced. A P&O strategy has been adopted for implementing the MPPT algorithm. The proposed MPPT algorithm has been implemented in a dSPACE controller to validate the performance of the PV power system. The experimental results show that the proposed MPPT algorithm is accurate which has a fast dynamic response under rapid solar irradiance variations and it is robust under load variation. Future work recommended using other MPPT algorithms in order to get high efficiency and more performances from PV system.

Nomenclature	
G: Global insulation (W /m²).	*Rs: series resistance(Ω)*
G_n: Reference insulation (W /m²).	*Rsh: Parallel resistance(Ω)*
T: Cell junction temperature (°C).	*A: ideality factor.*
T_r: Reference cell temperature (°C).	*α: the control signal*
I: output current (A).	*K_b: Boltzmann constant (1.38e-23).*
I_{ph}: Light-generated current (A).	*v_{oc} :The open circuit voltage(V)*
Δv_{oc} .Short circuit voltage temperature coefficient	*q: charge of an electron.*
I_{sat}: PV saturation current (A).	*L:inductance(H)*
I_{scr}: short circuit current (A).	*C_i: capacitance(F)*
V_{0ut}: output voltage(V)	*P:PV power(W)*
V: PV output voltage (V).	*K_i: Short circuit current temperature Coefficient (A/°K).*
R_l: load resistance(Ω)	

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ACKNOWLEDGMENT

The work was carried out in a research lab within the engineering school of University of the Basque Country Department of Systems Engineering and Automation, E.U.I, Vitoria, Spain