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Low-Cost Implementation of P&O MPPT based on Microntroller PIC16F877A

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Abstract

The photovoltaic module has a nonlinear current-voltage characteristic curve presenting an operating point called a maximum power point (MPP) depending on the variation of weather conditions. Boost converter with MPPT controller based on Perturbation & Observation algorithm is proposed. This work studies an experimental prototype and its performances on decreasing the oscillation around the MPP and a low-cost implementation based on the microcontroller PIC16F877A.

Keywords: Photovoltaic, MPPT, Boost, Observation & Perturbation.

INTRODUCTION

Since the world economic crisis in seventies of the 20th century, the renewable energies have been taking an important situation in scientific research to substitute the fossil energy. Photovoltaic energy is one of these alternative sources, that has gained a lot of attention in recent years because it is environmentally friendly and sustainable compared to traditional energy sources. Good examples include large-scale grid-connected wind turbines, solar water heating, and off-grid stand-alone PV systems [1].The photovoltaic panels may seem like a good source of electricity that converting the sunlight via a number of solar cells connected in series and parallels to obtain the desired current and voltage levels, however their efficiency is still low (12 -40%) and their current-voltage curve characteristic is nonlinear presenting an operating point called maximum power point (MPP) depending on the variation of weather conditions such as irradiation and temperature [2]. To make PV panel providing a maximum power to load profile at all times, a power electronic DC-DC converter has to be located between them switched periodically with a maximum power point tracking (MPPT) controller.

Many different techniques or algorithms implemented in MPPT controller to maximize PV power to various loads have been developed [3] the Perturb & observe algorithm is widely used because of its simple structure and ease of implementation, nevertheless it provides some drawbacks such as oscillation around MPP, slow response speed and even tracking wrong direction under rapidly atmospheric conditions [4]

The incremental conductance MPPT is another approach to overcome the previous shortcomings whereas it is more complex in implementation than the P&O MPPT and it requires a fast computation for the incremental conductance dI/dV, if the speed of computation is slow under the rapidly changing weather condition the approximation of dI/dV is not valid [5]

The fuzzy logic MPPT is an intelligent method robust and simple widely used in literature, this technique does not require the knowledge of the exact model of system, on the other hand, the designer needs complete knowledge of the PV system operation .It based on the error (dP/dV) and the change in error (Δ(dP/dV))at sampled times k [6]

Recently, the Artificial Neural Network (ANN) has attracted widespread interest in tracking of the MPP, it is a good solution giving the best efficiency and response time in steady state, and under irradiation variations [7]

Other approaches are less effectiveness for tracking the maximum power point such as constant controlled voltage, short-current method, open voltage technique, temperature method [8].

This paper aims at investigating and analyzing experimentally the performances such as to decrease the oscillation around the MPP and a low-cost implementation based on the microcontroller PIC16F877A under the climate conditions in the south- west of Algeria.

Description of PV system

The PV system consists of PV module, DC-DC Boost converter, MPPT controller and load profile as shown in the figure 1:

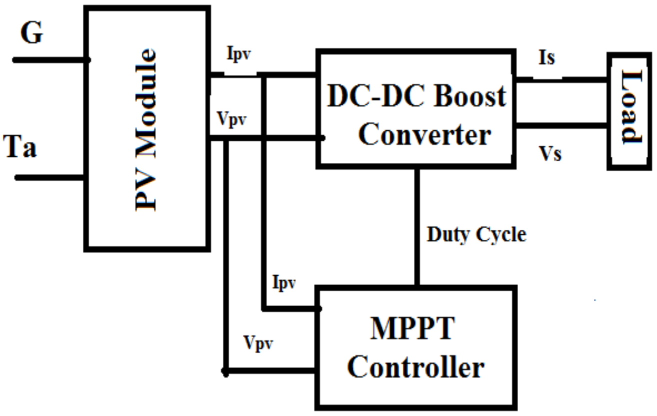


Figure 1: Typical PV system configuration with MPPT

Photovoltaic Panel

The PV panel is a number of cells connected in series and parallel, allows converting the sunlight into electrical current; it can be represented by the single diode circuit model as:

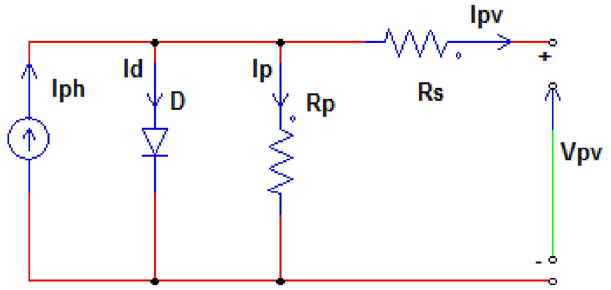


Figure 2: Equivalent PV module circuit

The mathematical model of the equivalent circuit is given through Kirchhoff's law [9]:

$$I_{pv} = n_P.I_{ph} - n_P.I_0\left(\exp\left(\frac{q}{n_S.A..k_B.T}\left(V_{pv}+R_S.I_{pv}\right)\right)-1\right)-\frac{V_{pv}+R_S.I_{pv}}{R_p} \quad (1)$$

where n_S and n_p are the number of cells connected in series and parallel respectively, Iph is the current generated by photons energy, I_0 is the reverse saturation current, q is the electron charge, A is the ideality factor, K_B (eV./ ° k)is the Boltzmann's constant, T (Kelvin) is the cell temperature, Rs and R_{sh} are the cell's series resistance and parallel resistance respectively, Ipv and Vpv are the panel's output current and voltage respectively.

The saturation current is defined as [10]

$$I_0 = I_{or}.\left[\frac{T}{T_r}\right]^3.\exp\left[\frac{q.E_{gap}}{K_B.A}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right] \quad (2)$$

where Ior is the reverse saturation current at reference temperature, Tr (Kelvin) is the

reference temperature, and E_{gap} (e.V) is the band gap energy.

The current generated due to photons energy is defined as [11]:

$$I_{ph} = \left[I_{SC} + \gamma(T - T_r)\right]\frac{G}{1000} \quad (3)$$

where Isc is the short circuit current at standard test conditions, γ (A/°C) is the short circuit current temperature coefficient, and G (W/m²) is the irradiation level.

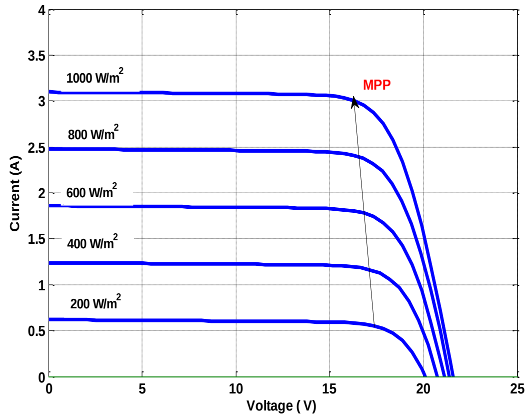


Figure 3: Current-voltage characteristic

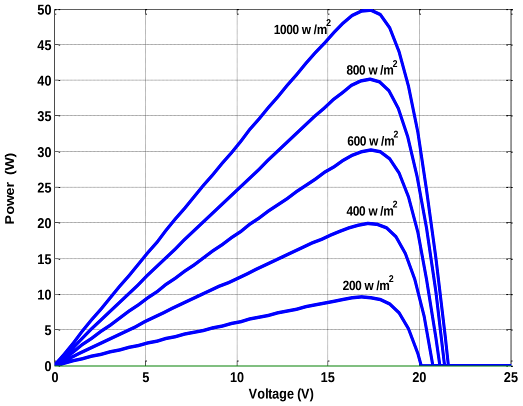


Figure 4: Power-voltage characteristic

DC-DC Boost converter

The boost converter is known as the step –up DC-DC converter that converting a low input –voltage to high output-voltage, during the first time DT when the switch Q is closed the input current flows through the inductor L, the diode is reversed biased. After the switch opened in the second time (1-D) T the high current through forward biased diode leads to a high voltage rise which is applied across the load [12]

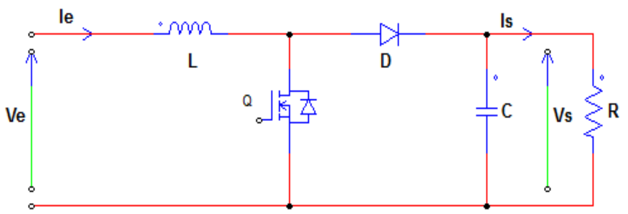


Figure 5: DC-DC Boost converter

The mathematical state equations are expressed as:

$$\frac{dV_{C1}}{dt} = \frac{1}{C1}(I_L - I_E)$$
$$\frac{dI_L}{dt} = \frac{1-D}{L} I_L + \frac{1}{L}.V_E \qquad (4)$$
$$\frac{dV_{C_2}}{dt} = \frac{D-1}{C_2}.I_L - \frac{1-D}{R.C_2}.V_{C_2}$$

where $V_{c2}=V_S$, D : duty cycle

MPPT controller

The solar panel is used mainly to supply electrically the load profile via the DC-DC converter. So a Maximum Power Point Tracking (MPPT) controller is required to switch periodically this converter in order to close the peak power from the panel, getting high conversion efficiency and maintain tracking for wide range of variation in weather conditions. In our project, the MPPT controller based on Perturbation &Observation algorithm is proposed. It operates by periodically perturbing (i.e. incrementing or decreasing) the terminal voltage or the duty cycle and comparing the PV output power with that of the previous perturbation cycle. If the perturbation leads to an increase (decrease) in panel power, the subsequent perturbation is made in the same (opposite) direction. In this manner, the peak power tracker continuously seeks the peak power condition. The flow chart in the figure ( ) as following [13]:

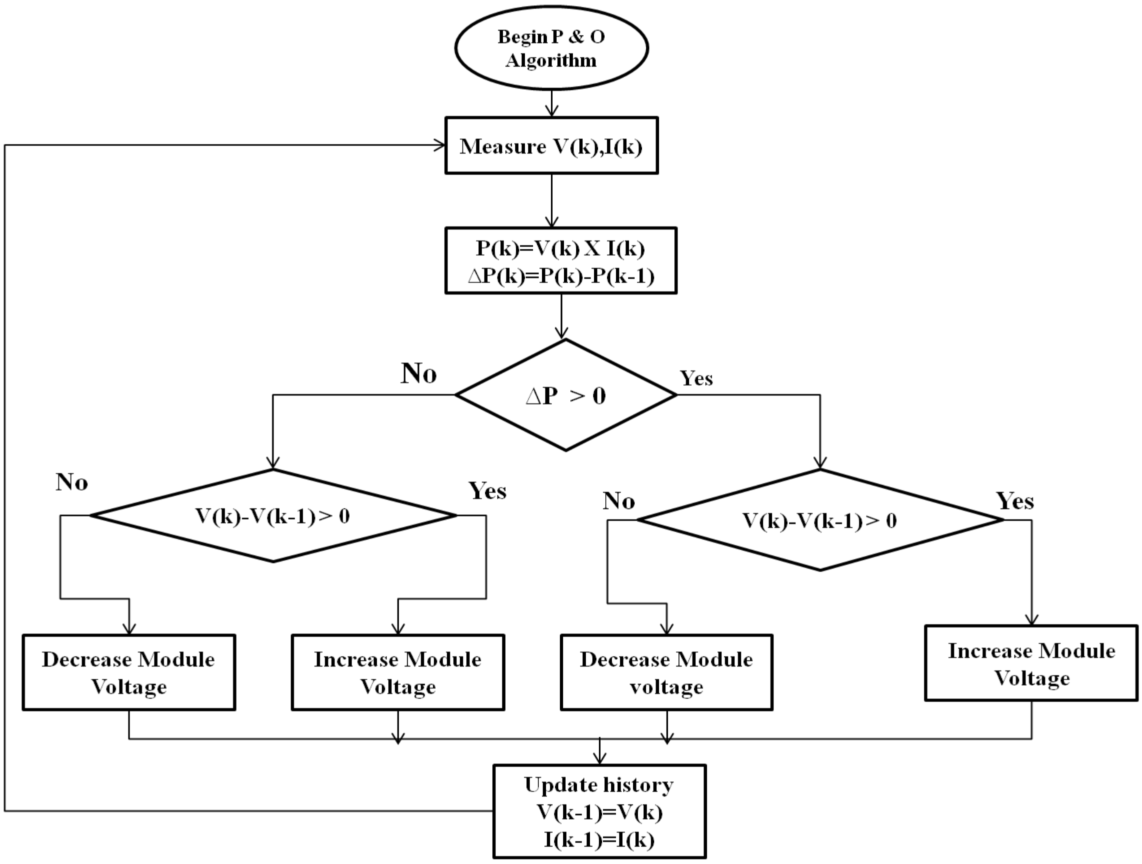


Figure 6: Flow chart of Perturb &Observe Algorithm

Sizing and Implementing PV System

The proposed photovoltaic system was implemented using a digital controller based on PIC16F877A. sizing the system devices was the second step should be carried out in order to the PV system operating optimally under the site environmental conditions, the PWX500 module was selected according to manufacturing data, the resistance 1kΩ/250kw was used as a load profile,the boost-MPPT components were sized to meet the load requirements and validate the conversion efficiency. However, there are several factors to be considered when selecting the key devices or components to be used in PV system; one of the most important was the power loss associated with each device, i.e the loss power in boost converter and MPPT controller should be minimal. It has been limited at 10 %.

For an ideal Boost converter the duty cycle is the ratio between the output voltage and the input voltage [14]:

$$V_S = \frac{V_{PV}}{1-D} \quad \text{where } (D<1) \qquad (5)$$

In this case the inductor is given from the equations as following:

$$L = D.T.\frac{V_{PV}}{\Delta I_L}$$

Where T: cycle period (sec) , V_{PV} : Maximum PV output voltage , ΔI_L: Inductor current ripple (A),

the capacitor is calculated from : $C = \frac{I_S.D}{\Delta V_S.f}$ Where I_S: boost output voltage (A) , ΔV_S : Maximum output voltage ripple (V), f : duty-cycle frequency

All other devices as diode, IGBTN, comparator, driver circuit, current sensor, voltage sensors.. etc, were chosen due to their electrical characteristics and must be suitable for specific function, for example driver circuit supplying IGBTN with important current during opening and closing period .current and voltage sensors were used to pick up the PV output current and the PV output voltage respectively forward the MPPT controller, in other word, LA25-NP current sensor connected to TL071 amplifier circuit in order to obtain the actual PV output current from equation: $I_{MES} = \frac{I_{PV}}{1000}$ and the actual PV output voltage picked up via the voltage divider with law: $V_{MES} = \frac{R_2}{R_1+R_2}.V_{PV} = \frac{1}{5}.V_{PV}$, .

Table 1: Electrical data of PWX500 [15]

Electrical characteristics of PWX500	
Parameter	Value
Peak Power	50 w
Rated Power	45w
Maximum Power Voltage (Vm)	17,2
Maximum Power Current (Im)	2.9
Open circuit Voltage (Voc)	21.6
Short Circuit Current (Isc)	3.1
Temperature coefficient (Voc)	-79mV/°C
Temperature coefficient (Isc)	0.95 mA/°C
Temperature coefficient (P/P)	0.43 % /°C
Standard Conditions (STC)	G=1kw/m²,Ta=25°C, AM1.5

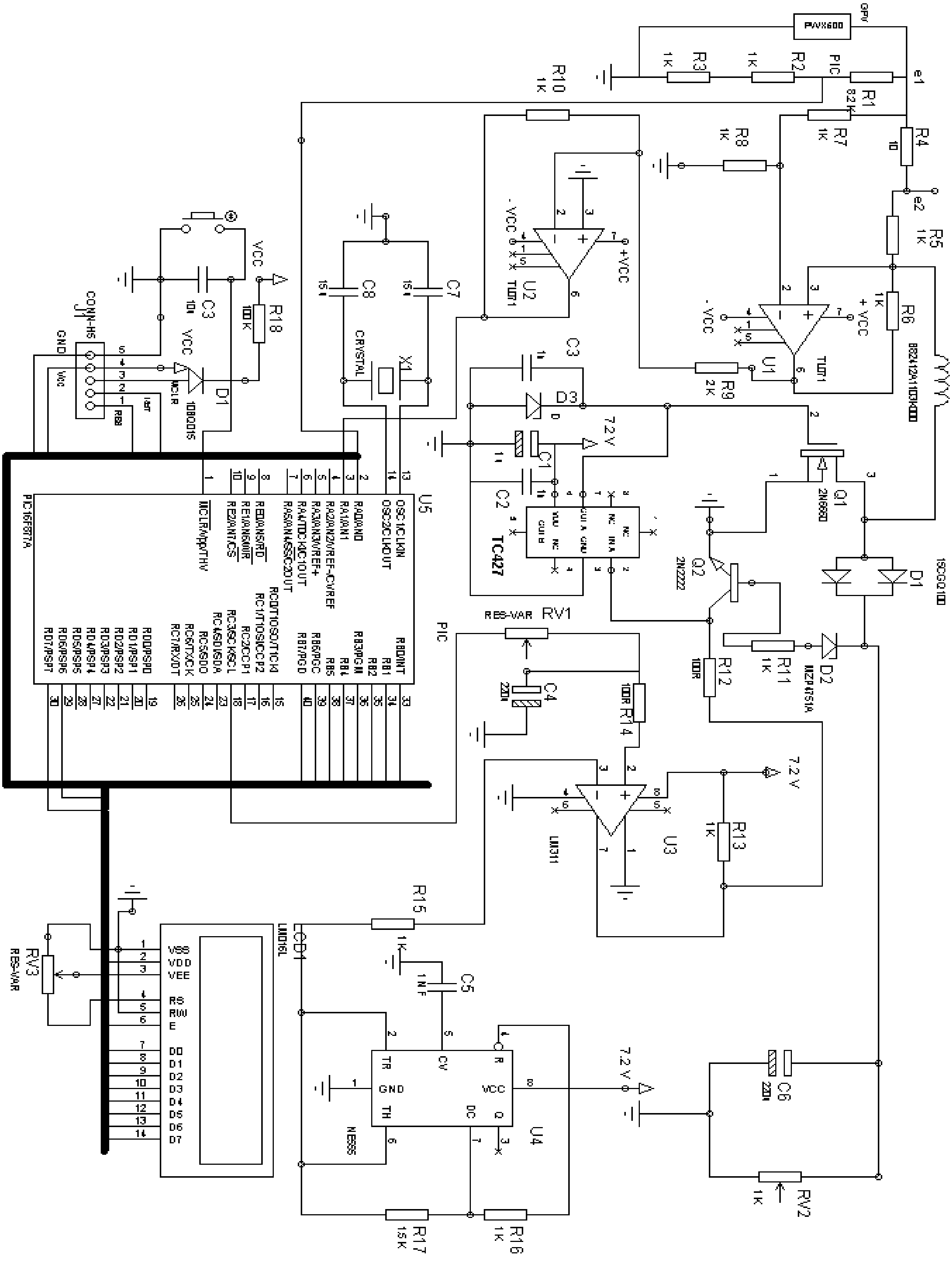


Figure 7: Electrical diagram of PV system

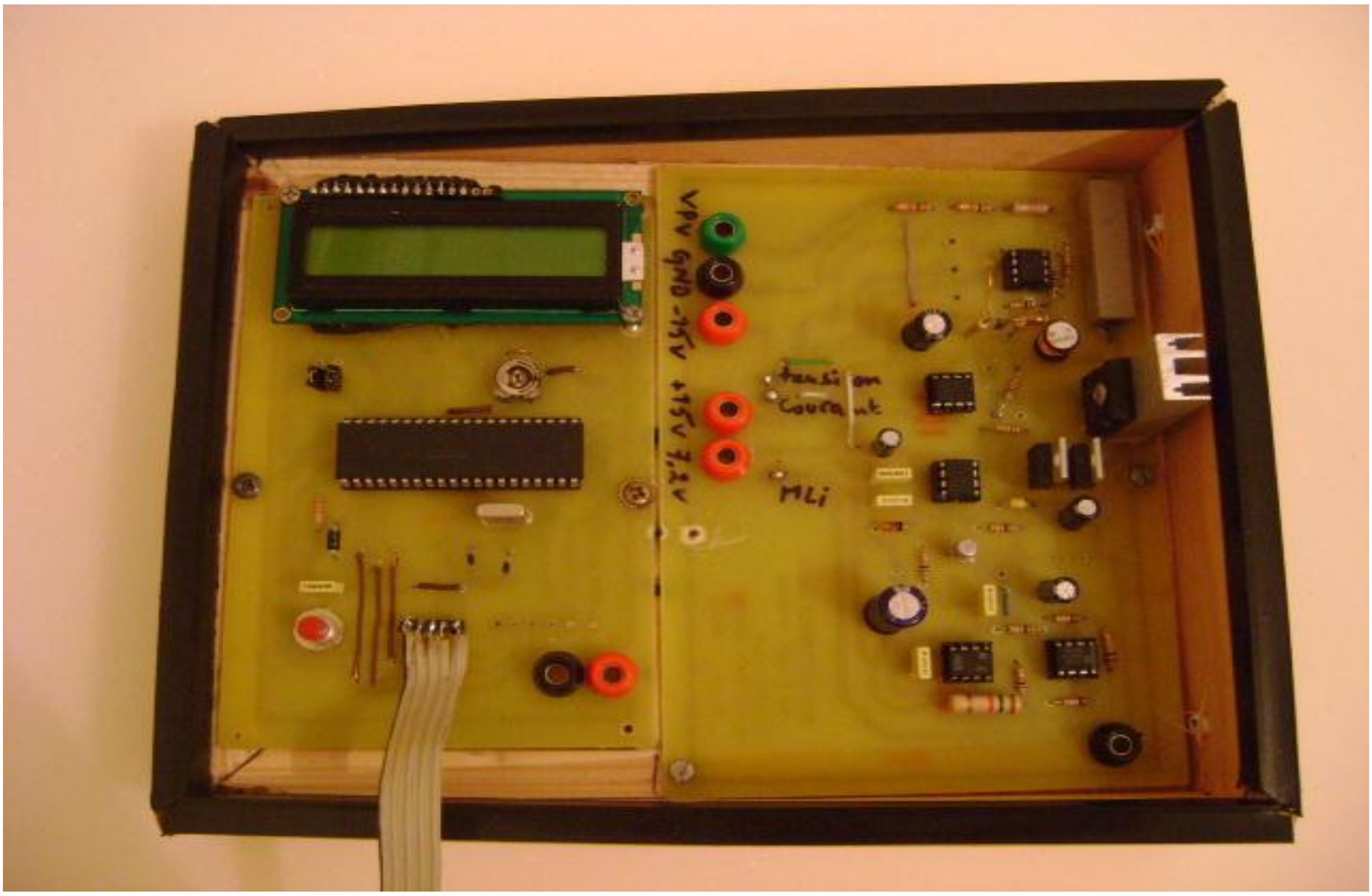


Figure 8: Boost-MPPT Electronic Board

RESULTS AND DISCUSSIONS

At the beginning, PWX500 module is tilted at 30° facing the sun in accordance with the latitude of Bechar site, south-west of Algeria L=30.38 ° toward the geographical south and 0° with azimuth angle . This position allows the PV module to harvest the optimal incident irradiance measured by a solar sensor having a conversion ratio 101.5 mV/kw.m^{-2}.

The Perturb & observe algorithm is programmed by assembly language and implemented in the PIC16F877A which all register ports (RP) supplied with 5V,hence it is necessary to configure the Analog-digital converter (ADC) of the microcontroller for acquiring the PV output voltage and PV output current owing to these signals range from 0 to 20 V and from 0 to 3.5A respectively , signals conversion has been taken sequentially with delay time 20us,in the mean time, evaluating the PV output power required eight operations to decrease the conversion error and giving the average power. All these steps are presented in the flow chart below in the figure:

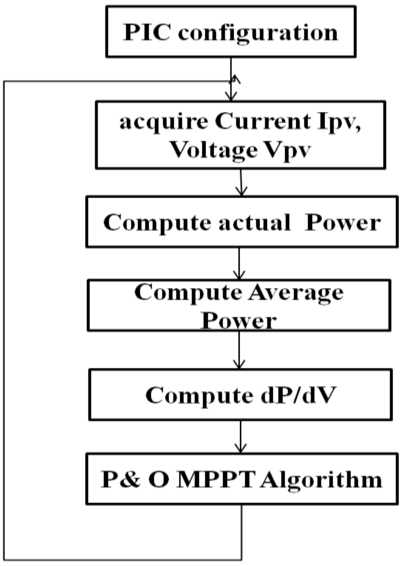


Figure 9: Flow chart of digital MPPT

For scoping signals and highlighting on their performances the realized electronic board was connected to personnel computer (PC) and a digital oscilloscope, From different current and voltage readings are taken during the experiment, the PV system performances represented in the figures explaining the duty-cycle, triangular waveform, the irradiation effect and a partial shadow on the PV module.

The PIC16F877A microcontroller carries out a duty-cycle signal with frequency 1Khz and an amplitude 0.35 as indicated in the figure (12) while the NE555 circuit produces a triangular waveform with frequency 250 KHz as shown in the figure (13). Both the previous signals are compared by LM311 circuit to generate a Pulse Width Modulation (PWM) defined in the figure (14-15) at this step the PWM signal should be enhanced by TC 427 Driver in order to switch the boost converter.

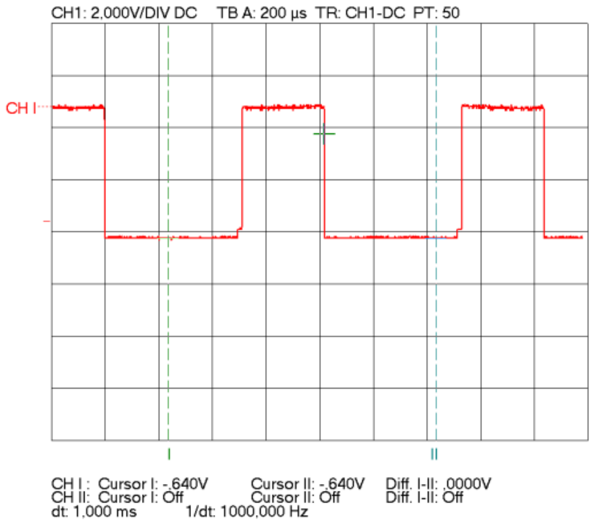


Figure 10: PIC 16F877A duty-cyle

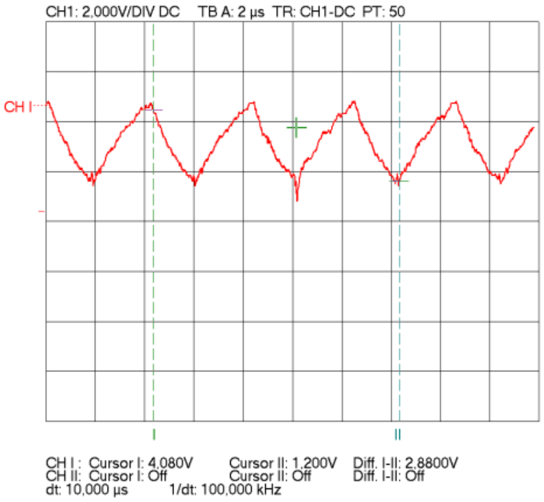


Figure 11 : Triangular waveform

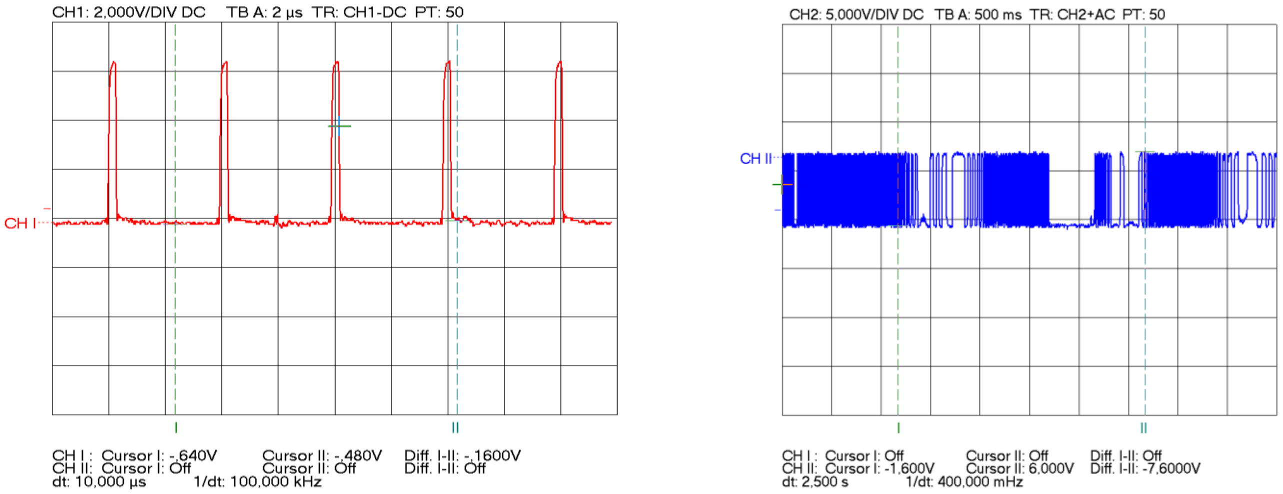
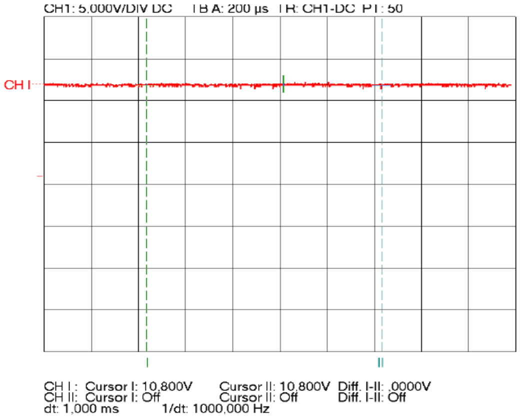


Figure 12-13: Pulse width Modulation

The load voltage is a direct current (DC) generated from boost converter but it is fluctuated as a ripple or oscillation around the maximum power point as showing in the figure (16-17) , this outcome created due to the fixed step size imposed in the P&O algorithm



Figue14: load voltage

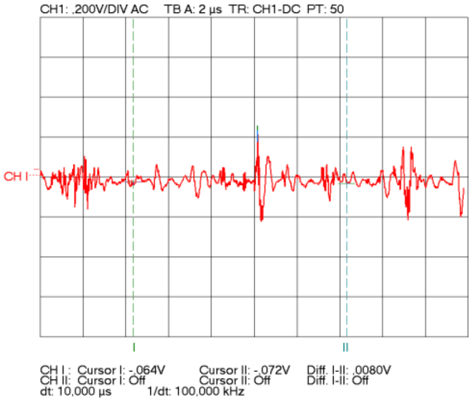


Figure 15: Oscillation around the load voltage

Under solar irradiation 650 w/m², the PV output voltage is 15 V (red line) and the PV output current is 2.18 A, while the boost output voltage (blue line) increased at 22 V and output current 1,61A , the conversion efficiency achieved at 90 %, figure (18)

Yet under low illumination 403 w / m² the PV output voltage is 3.8 V and the boost output voltage is 5V where the efficiency reached 64 % figure (19)

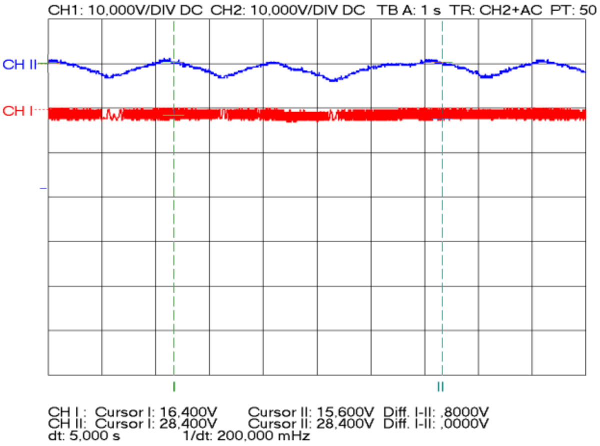


Figure 16: PV voltage Under irradiation

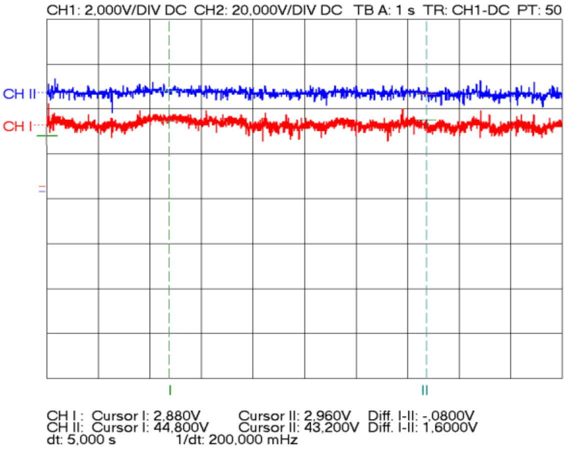
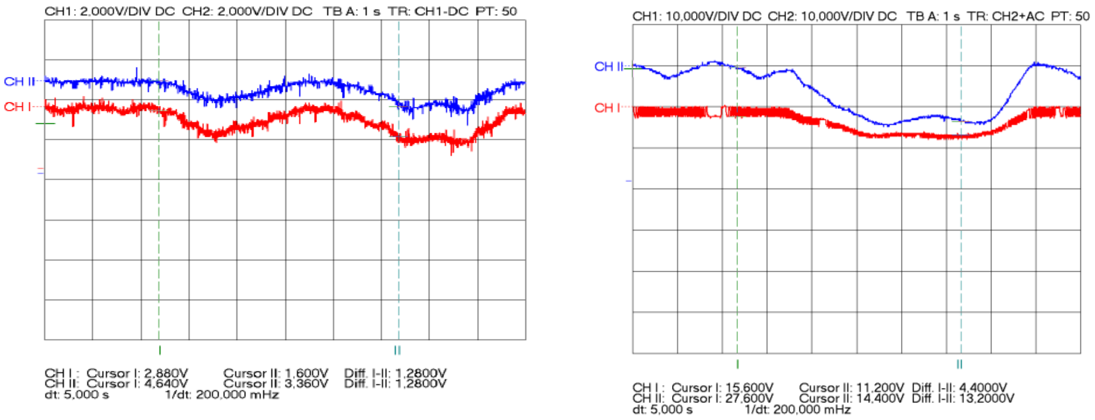


Figure 18 : PV output voltage under low irradiation

In other experiment a partial shading on the PV module to check the response and the sensitivity of the system under weather fluctuations, it is clear that the MPPT controller tracks the maximum power despite the irradiance drops rapidly as illustrated in the figure (20-21),



Figures 19-20: output voltages under shading event

CONCLUSION

This paper presents the design and the implementation of the PV system consisting of the PV module cascaded with Boost converter used to step up output voltage. Perturbation and observation (P&O) method is widely used in photovoltaic (PV) systems because of its simplicity and ease of implementation. This P &O technique allowed tracking the Peak Power Point according to atmospheric conditions. The performances demonstrated in the previous experimental results clarify that the power efficiency is important with low-cost implementation, Furthermore computing the average power allows reducing the fluctuation around the MPP. Our future project is to introduce a fuzzy logic control and feedback voltage control to implement a variable step size P &O MPPT in order to optimize further performances.

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