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Comparative Study of MPPT Controllers for PV System Implemented in the South-west of Algeria

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Abstract

The photovoltaic array characteristic is a non-linear curve that the maximum power point varies depending on the fluctuation of the solar radiation and temperature; however the energy transfer from the generator to the load requires an adapter circuit allowing the stabilization of system controlled by a command based on specific algorithm, in this paper we want to analyze the electrical performances of DC-DC converter assisted by MPPT control in comparison between Perturb & Observe,PID and fuzzy logic control (FLC) to loading a storage battery .Our contribution is to explain the precision, the rapidity and the stability of the Stand-alone Photovoltaic System (SPV) under each MPPT control , implemented in the south west of Algeria.

"Keywords: Photovoltaic, MPPT, Perturb & Observe, PID, Fuzzy logic Control"

1. Energy conversion and MPPT Control

The photovoltaic solar energy make up among the renewable energy having a great development potential, the solar potential in Algeria covers a surface of 2381745 Km^2 with 3000 hours of daylight per year [1], however the exploitation of the solar energy is very significant because of sunny country, on the other hand many villages in the south-west of Algeria are very far away from the productive electrical central where this situation imposes some economical and technical problems such as a great investment financing , several failures in the electrical network and an overload in use. The solar energy may be exploited to avoid these constraints by installing a photovoltaic system in each rural community.
The photovoltaic panel is the base element to generate an electrical current after converting from the sunlight through the semiconductor cells under a photovoltaic effect, this panel provides a non-linear characteristic curve where its operating point called maximum power point varies depending on the fluctuation of the solar radiation and temperature, hence for assuring a permanent transfer of energy from the generator to the load, an adapter device is indispensable to adjust this maximum power point on

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optimal function , the designed apparatus is made up of a DC-DC converter controlled by a MPPT command (maximum power point tracking) based on technical algorithm [2]

Our work was destined to study a DC-DC Boost converter connected to a photovoltaic panel and controlled via three algorithms studied on acuity Perturb & Observe (P&O) algorithm, PID control and fuzzy logic control, the objective of the comparison is to explain the performances of each algorithm and to give the implementation selection in the experimental site designed by an hybrid photovoltaic diesel..

Nomenclature

PV	Photovoltaic	q	charge of electron
I	Current of the PV cell	SOC	state of charge of battery
V	Voltage of PV cell	V_b	battery voltage
R_{sc}	series resistance	I_b	battery current
R_{ph}	Parallel resistance	n_{bat}	Charge and discharge efficiency.
T	cell temperature	D	Battery self-discharge rate
K_B	Boltzmann's constant	n_{Sbt}	Number of 2V cells in series
I_{ph}	photo-current	P	PV output power
L	inductance	n_S	number of cells in series
Voc	open- circuit cell voltage	V_T	thermal voltage

2. Conception and Modelling of the MPPT system

The MPPT Photovoltaic System (MPPTPS) is considered as PV generator coupled with DC-DC boost converter controlled by a MPPT dispositive ,permits to feed a storage battery by a direct current in condition to reduce the variation influence of the radiation and the temperature on the Maximal Peak Power (PPM)

The system being modeled is shown in fig.1, implemented in Matlab-Simulink, it consists a PV generator feeding a storage battery through a boost converter controlled by MPPT algorithm, the control of charge allows to supervise the state of charge (SOC) to avoiding the overcharge and over-discharge condition when the battery voltage reaches some critical values . Each component of the system represents a mathematical model plotted by some blocks hidden under mask.

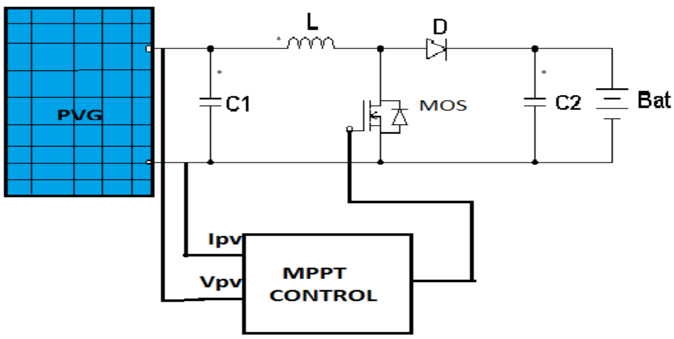

Fig.1 Photovoltaic System with MPPT Controller

2.1. Photovoltaic Generator

A solar cell is a semiconductor device that absorbs light to converting it into electrical energy. Today most common cell is a mass manufactured single p-n junction Silicon (Si) cell with efficiency up to about 17% [2],the cell characteristic is an implicit function given by (H.tarik) as [3]:

$$I = _{ph} - I_s\left(\exp\left(\frac{q(V + R_{sh} * I)}{\alpha * k_B * T}\right) - 1\right) - \frac{V + R_S.I}{R_{ph}} \qquad (1)$$

Where R_{sc} is the series resistance of the cell (Ω), R_{sh} is the shunt resistance (Ω), α is the ideal factor (usually α=1.2), T is the cell temperature (K) ,q is the electron charge (1.6021x10-19 C) ,K is the Boltzman's constant (1.3854x10-23 JK-1), Iph is the photo-current (A) and Is is the saturation current (A), V is cell terminal voltage , this equation can be represented as an equivalent circuit of solar cell :

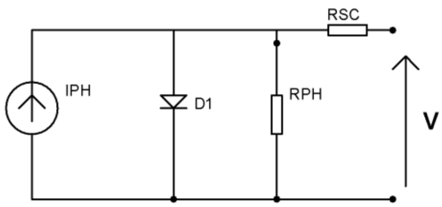

Fig.2 : Equivalent circuit of PV cell

The photovoltaic characteristic varies according to the radiation and the temperature that the increasing of radiation augments the produced power and the current but it decreases the terminal voltage, while the output power is reduced by increasing the temperature, the PV generator is modeled as below [4].

$$I = n_P.I_{ph}[1 - \exp(\frac{V - n_S.Voc + I.R_S.n_S / n_P}{n_S.V_T})] \qquad (2)$$

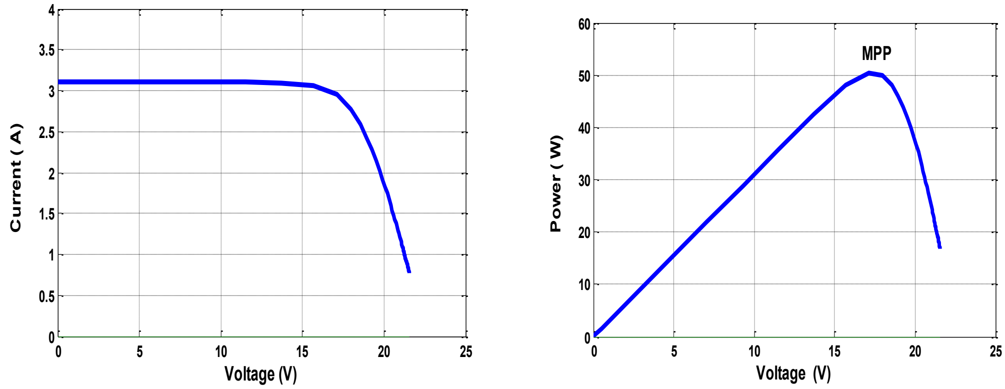

Fig3:I-V and V-P characteristics under Standard Conditions

2.2 DC-DC converter

The solar panel is rarely connected directly to a load, the DC-DC converter is necessary to be found between the generator and the load allowing to tracking the maximum power point based on MPPT control providing a duty cycle by exciting the converter's electronic switch, there are several converters used for this purpose, in our work the BOOST converter or step-up converter is proposed to enhance the output voltage supplying the storage battery, its equivalent circuit is given as [5]:

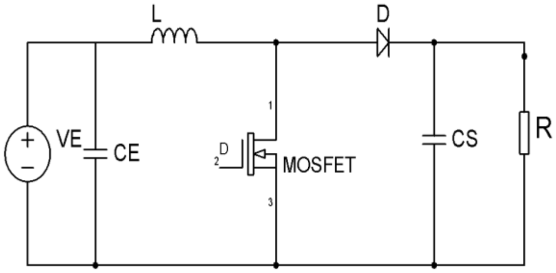

Fig.4. DC-DC Boost Converter

The functioning principle of the boost consist to excite the switch (MOSFET) transistor with a duty cycle D produced by the MPPT control, when the switch is closed the inductor L is loading during T.D time, afterward the switch is opened the inductor supplies the load R through the diode during (1-D).T, the state equations during the functioning is given by:

1) Switch closed:

$$\frac{dV_{Ce}}{dt} = \frac{1}{C_{1e}}[I_e - I_L]$$

$$\frac{dI_L}{dt} = \frac{V_e}{L}$$

$$\frac{dV_{CS}}{dt} = \frac{-I_0}{C_S}$$

2) Switch opened:

$$\frac{dV_{Ce}}{dt} = \frac{1}{Ce}.[I - I_L]$$

$$\frac{dI_L}{dt} = \frac{1}{L}.[V_e - V_S]$$

$$\frac{dV_{CS}}{dt} = \frac{1}{C_S}.[I_L - I_e]$$

We can put: $\dot{X}_1 = \frac{dV_{Ce}}{dt}$, $\dot{X}_2 = \frac{dI_L}{dt}$, $\dot{X}_3 = \frac{dV_{CS}}{dt}$, $V_{CS} = V_S$

The equation system combination is modeled as follow:

$$\begin{cases} \dot{X}_1 = \frac{-1}{C_{CE}} * X_2 + \frac{1}{C_{CE}} * I_S \\ \dot{X}_2 = \frac{D-1}{L} * X_3 + \frac{1}{L} * V_S \\ \dot{X}_3 = \frac{1-D}{C_{CS}} * X_2 - \frac{1}{R * C_{CS}} * X_3 \end{cases} \quad (3)$$

2.3. *Storage battery*

The battery model was based on lead-acid battery, its cells consist of two plates immersed in dilute sulfuric acid solution, and it has two mode of operation: charge and discharge, the battery in charge mode when the input current is positive, and in discharge mode when the current is negative, the battery is characterized by some parameters [6]:

- The initial state of charge: SOC.
- Number of 2V cells in series : nsb
- The maximum state of charge (SOCm)
- Charge and discharge efficiency.: n_{bat}
- Battery self-discharge rate : D

The equivalent circuit of battery is given as follow:

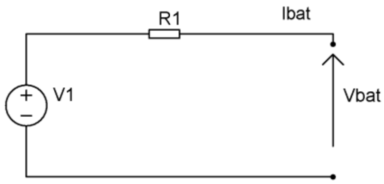

Fig.5: Equivalent circuit of battery

When the modeling of battery voltage is represented by: $V_{bat} = V1 + I_{bat} * R1$ (4)

In the charge mode: $V1 = [2 + 0.148 * SOC(t)] * nsb$. (5)

$$R1 = \frac{0.758 + \dfrac{0.1309}{[1.06 - SOC(t)] * n_{St}}}{SOCm} \tag{6}$$

In the discharge mode:

$$V1 = [1.926 + 0.124 * SOC(t)]\, n_{Sb} \tag{7}$$

$$R1 = \frac{0.19 + \dfrac{0.1037}{[SOC(t) - 0.14] * n_{Sb}}}{SOCm} \tag{8}$$

The current state of charge SOC (t) chosen for unit time (second) is given by:

$$SOC(t+dt) = SOC(t) * [1 - D * dt / 3600] + n_{bat} * [V_{bat} * I_{bat} - R1 * I_{bat}^2] * dt / 3600 . \tag{9}$$

To simulate for time unit (minute) the equation can be written as:

$$SOC(t+dt) = SOC(t) * [1 - D * dt / 60] + n_{bat} * [V_{bat} * I_{bat} - R1 * I_{bat}^2] * dt / 60 \tag{10}$$

$$SOC(t) = SOC(t-1) + \int_{t-1}^{t} \left[\frac{(n_{bat} * V1 * I_{bat})}{60 * SOCm} - \frac{SOC(t-1) * D}{60} \right] * dt. \tag{11}$$

It can put: SOC (0) =SOC1= initial state of charge.

2.4. The Maximum Power Point Tracking (MPPT)

The P-V panel characteristic is a non-linear that output power varies in function of the irradiance and the temperature, there are two ways to increase the power coming from the photovoltaic panel, one can make a sun tracking system to raise the irradiance on the surface of the panel perpendicularly at each time , or another way to extract the optimal output power by using a maximum power point tracking control, the last method is our objective that we propose three MPPT controllers : Perturb & Observe algorithm ,PID control and fuzzy control .The V-I and V-P characteristic curves (fig.3) specify a unique operating point at which the maximum possible power is delivered, at the MPP, the PV operates at its highest efficiency [7].

2.4.1. Perturb and Observe Algorithm

The Perturb & Observe algorithm has been broadly used because of its practical implementation , the MPP tracker operates by periodically incrementing or decrementing the solar panel voltage, current or the duty cycle comparing to the PV output power with that of the previous perturbation cycle ,if a given perturbation leads to increase (or decrease) the output power of the PV ,the successive perturbation is generated in the same (or opposite) direction.[ ], on figure 7 , we consider that the maximum power point (MPP) is Xm, if the operating point Xi is on the left of MPP , we must decrease the duty cycle until MPP, if the operating point is on the right of the MPP , we augment the duty cycle to MPP [8].

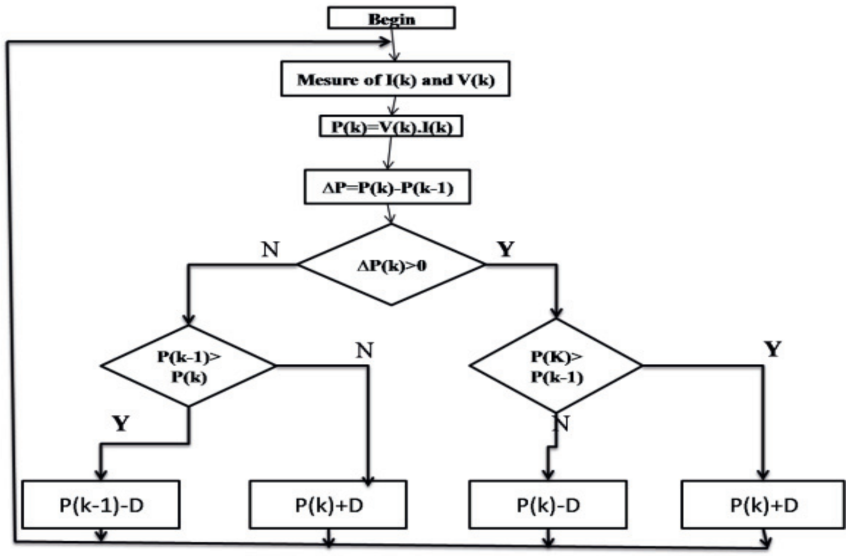

Fig. 6: Flowchart of the Perturb and Observe method

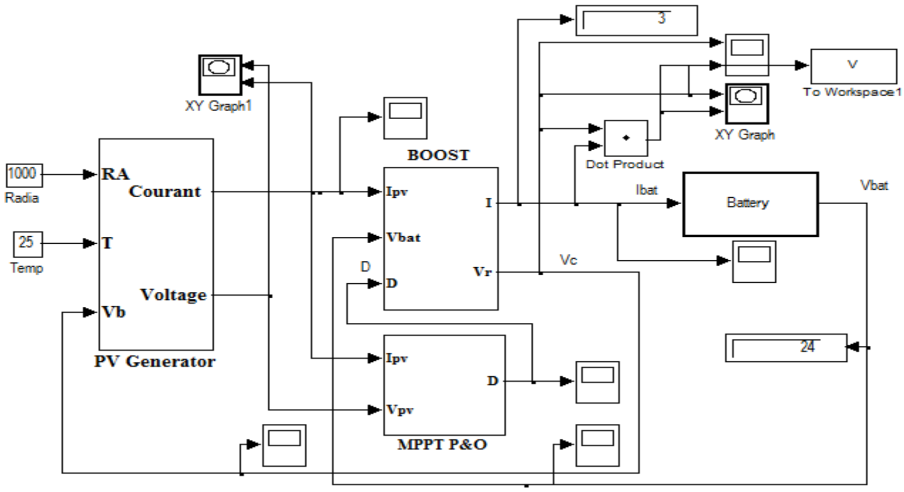

Fig .7: Implementation MPPT System P&O

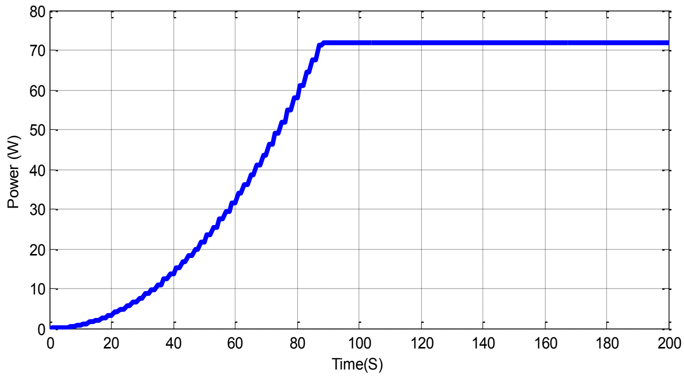

Fig.8 Power curve according to P&O Controller

2.4.2 Fuzzy logic control

Fuzzy logic control (FLC) is used mainly in control engineering; it is based on approximate reasoning which employs linguistic rules in the form IF-THEN [ ], Fuzzy logic control is very important when there is no specific mathematical model or while the process to control has no linearity imprecision, the regulator based on fuzzy logic can be represented by the following scheme [9]:

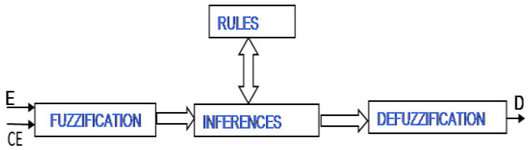

Fig.9 Fuzzy Logic steps

Table1: Inference Rules combination

CE E	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	ZE	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

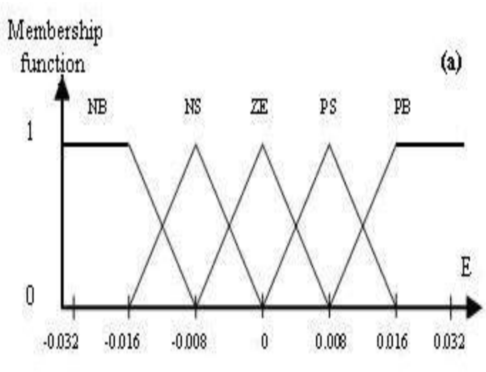

Fig.11: Error variation Membership

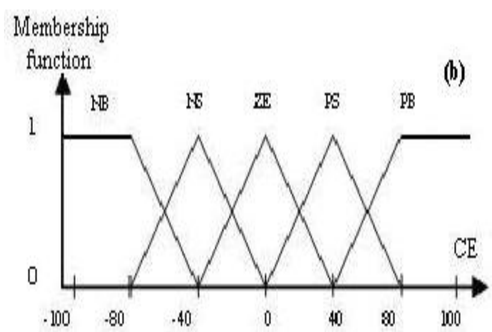

Fig.10:Error Membership

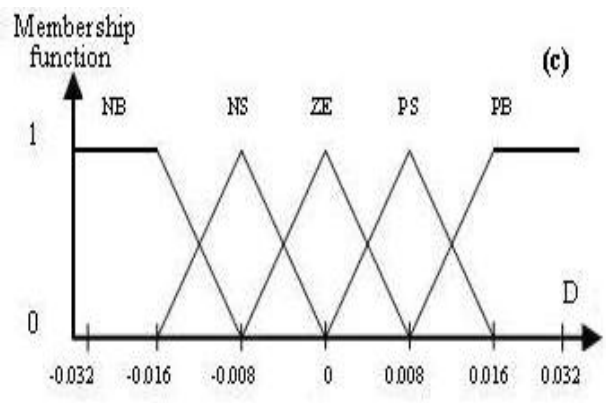

Fig.12: Output Membership

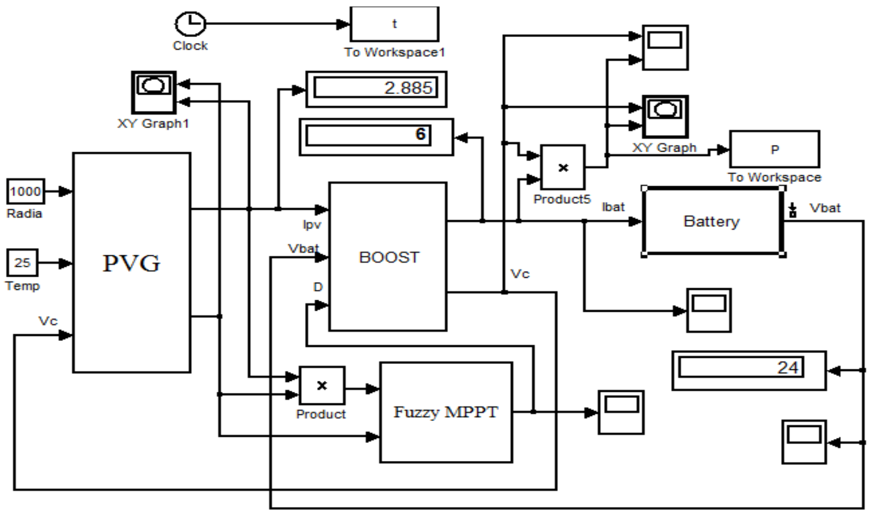

Fig.13: PV System controlled by Fuzzy MPPT

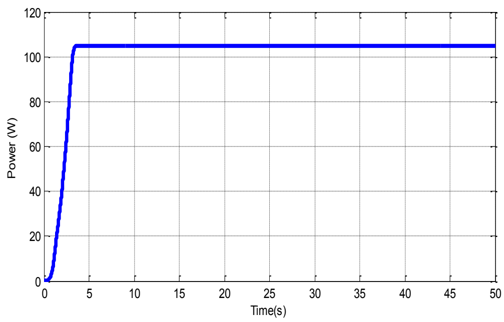

Fig.14: Power from the Boost with Fuzzy MPPT

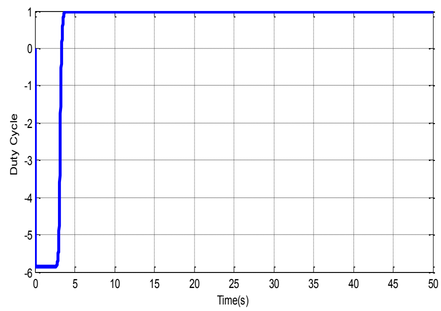

Fig.15: Duty Cycle out Fuzzy MPPT

2.4.3 PID control

Proportional-Integral-Derivative (PID) controller is a robust in wide range of performance that allows the system to compensate the difference between the set-point and the actual response ,in the process control industrial, it used to optimize the system performance like the stability , the rapidity and the precision .the PID tuning can be effected by many methods as Ziegler Nichols technique , the PID control is not suitable for non-linear system , to exceed this drawback ,it can be exploit the Fuzzy logic Control (FLC) for carrying out a MPPT control [10]

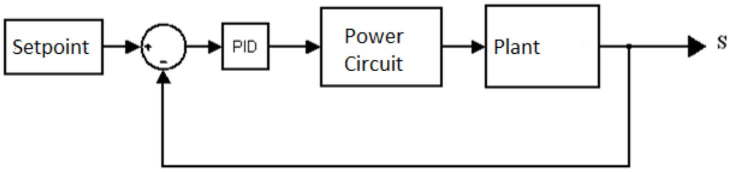

Fig 16: PID Control System Conception

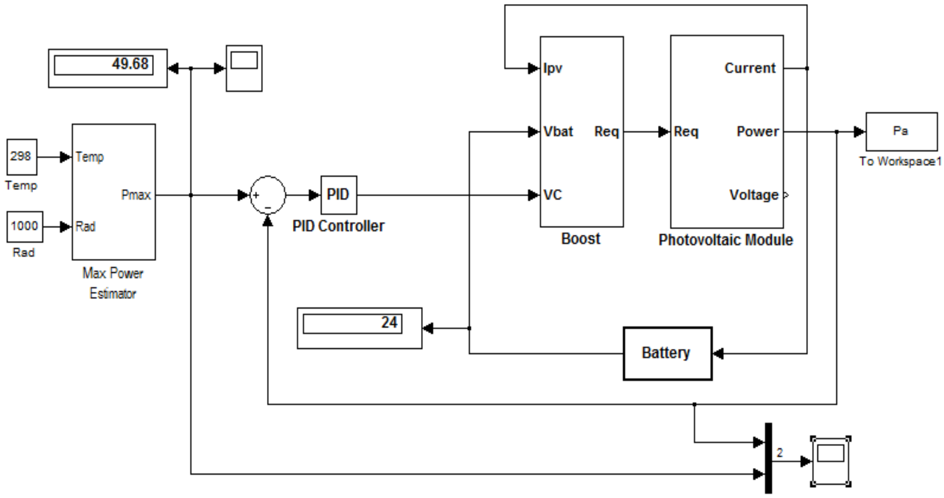

Fig17:MPPT Photovoltaic System with PID

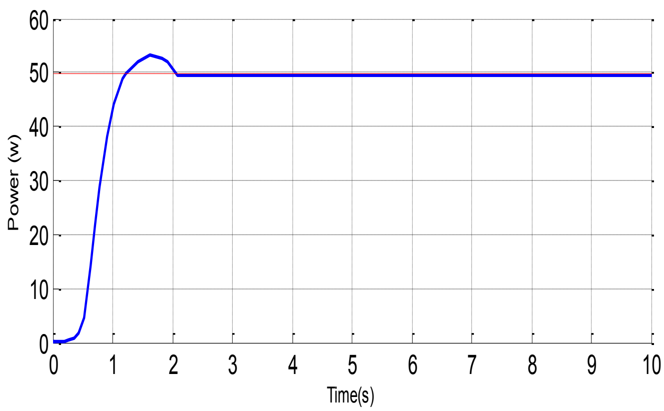

Fig.18: Power Plot from the PVG with PID

The Fuzzy-PID hybrid control can be implemented as the same way according to another tuning of PID with fuzzy sets.

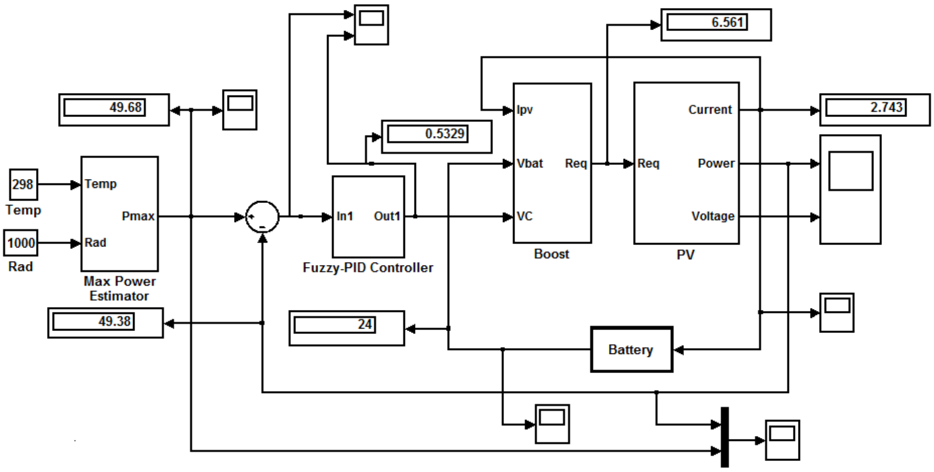

Fig.19: PV System controlled by Fuzzy-PID MPPT

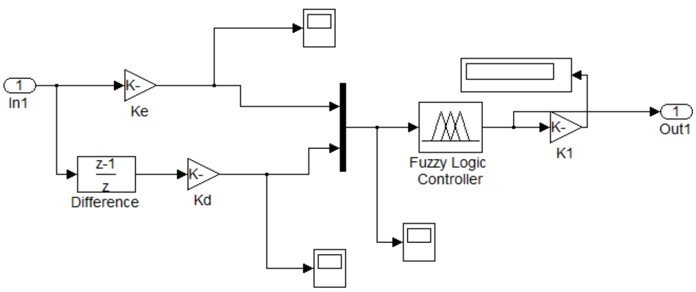

Fig.20: Fuzzy-PID MPPT under Mask

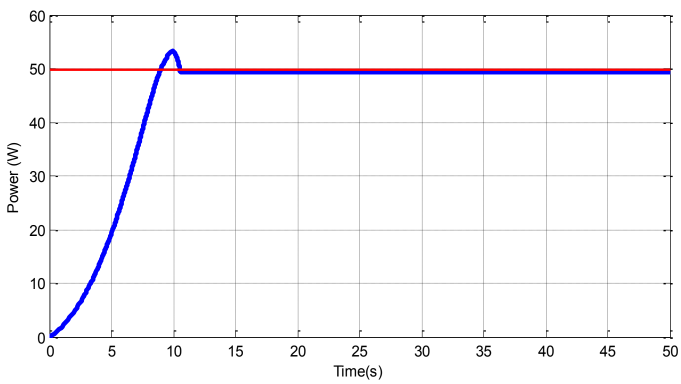

Fig.21: Actual Power and Power set-point with Fuzzy-PID controller

3. Analysis and Performances of MPPT Controllers

The MPPT control is a technique to track the Maximum Power Point under the influence of the variation of the radiation and the temperature to feed a storage battery , The proposed power conversion system was simulated using Matlab-Simulink simulation program to validate the control strategy and evaluate the performance of the system. According to the four previous configurations, the Perturbation & Observe control gives the permanent phase after too long time (90 s) as shown in fig.8, which makes some difficulties for the stability and the precision , otherwise ,the Fuzzy MPPT control provides a performance to arrive at the stable step during less than 5 s, another word in spite its robustness the PID control regulates the system but without tracking the Maximum Power Point under the variation the radiation and the temperature, while the combination between the PID and the Fuzzy logic is necessary to optimize the output power according to the demanded energy and to seek the MPP at the same time .
The simulations have highlighted on the different techniques and proved that the fuzzy-PID control is the best method which regulates the Power set-point and the actual Power to improve the efficiency and the performances as the rapidity, the precision and the stability .

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