Comparative Study of MPPT Nonlinear Controller, Using Boost Converter for PV Modules

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Abstract: - Due to nonlinear I-V characteristics of photovoltaic cells, a maximum power point tracking algorithm is adopted to maximize the output power. In this paper, an approach for peak power tracking using the nonlinear controllers (Sliding mode and fuzzy logic) is proposed. These controllers are Compared with the conventional duty cycle of perturb and observe (P&O) control method, they can track the maximum power point quickly and accurately. Matlab-simulink is used for simulation, analysis and interpretation the results of these controllers. A boost converter has been used to control the solar cell output voltage.

Key-Words: Photovoltaic, MPPT, Boost converter, Nonlinear Control, Sliding mode control, Fuzzy logic, Perturb and Observe.

1 Introduction

Solar energy is a valuable alternative to the energy from fossil fuels. The PV energy is developing very rapidly, it is durable and without polluting the environment. For controlling, the delivered electric power it is anticipated an action on electronic power interface connecting the PV generator with its load. The PV system generates a power that is dependent on the changing climate conditions: the solar irradiation, the temperatures of the panels and the load change [1]. Thus, a method of searching the maximum point power (MPP) for controlling the duty cycle of DC/DC converter is necessary to ensure optimal operation for PV system under different operating conditions [2].

Several techniques are developed for tracking the maximum point power (MPPT) satisfying the non-linearity of the characteristic of PV modules and the conditions described above [3-5].

In this paper, the nonlinear MPPT approaches: sliding mode and fuzzy logic are presented and compared with perturb and observe (P&0) method as one of the most widely conventional method used in this area. Simulation and analysis of sliding mode, fuzzy logic and P&O control are presented.

2 Problem Formulation

The photovoltaic panel is constituted by several cells either in series to increase the voltage for the same current, or parallel to increase the current for the same voltage. The simplest structure of a photovoltaic cell comprises a junction between two differently doped regions of the same material (homojunction) or of two different materials (heterojunction) to create an internal electric field.

The electrical circuit in Fig.1 can represent a cell, this circuit is made of a constant current source modelling the magnetic flux where I_{pv} is photocurrent create by radiation from sun and of diode which represents a P-N junction of the cell, The losses are modelled by two resistors : a shunt resistance and a series resistance [6-7] .

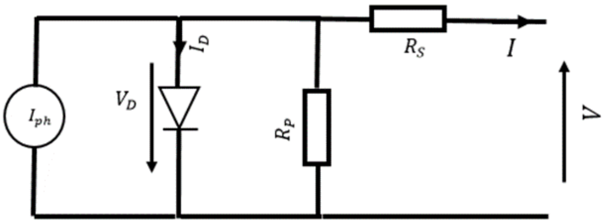


Fig.1 Equivalent circuit of the PV cell

The equations that describe the characteristic of the cell $I(V)$ are:

$$I = I_{pv} - I_0\left[\exp(\frac{V+R_s I}{\alpha V_T}) - 1\right] - \frac{V+R_s I}{R_P} \qquad (1)$$

$$I_0 = I_{on}\left(\frac{T}{T_n}\right)^3 \exp\left[\frac{qE_g}{\alpha k}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \qquad (2)$$

$$I_{pv} = \frac{G}{G_n}\left[I_{pvn} + K_1(T - T_n)\right] \qquad (3)$$

$$V_T = \frac{N_s kT}{q} \qquad (4)$$

$$I_{on} = \frac{I_{scn}}{\exp\left(\dfrac{V_{ocn}}{\alpha V_{Tn}}\right) - 1} \qquad (5)$$

$I-V$ and $P-V$ are nonlinear characteristics having a single optimal point where the power is maximal. The optimal voltage and current are I_{MPP} and V_{MPP} . $I-V$ and $P-V$ curves are shown in Fig.2 and Fig.3.

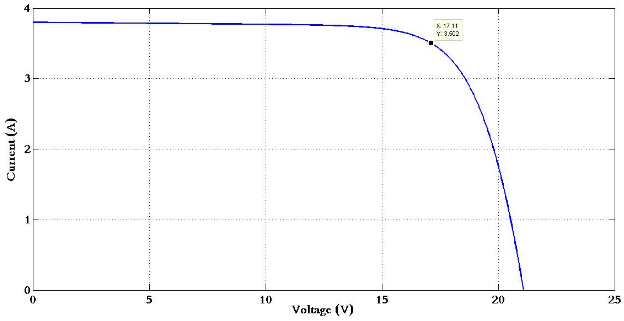


Fig.2 $I-V$ curves for PV

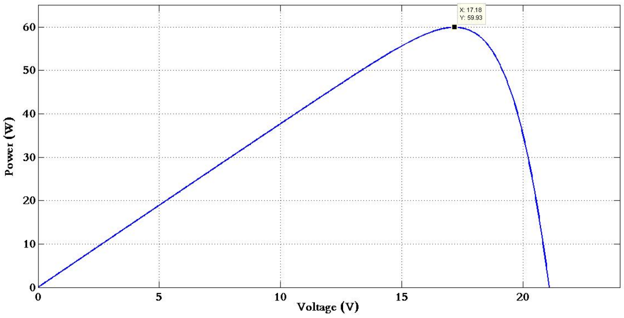


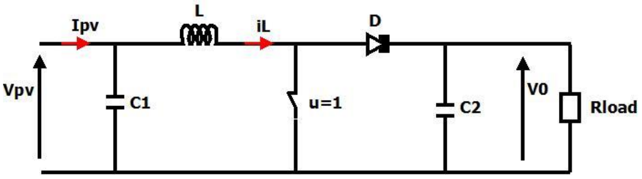
Fig.3 $P-V$ curves for PV

3. DC/DC static converter:

The used DC/DC converter also called boost converter is a static electronic power converter device thereby increasing the initial continuous voltage, it makes to impose the current I_{MPP} determined by MPPT algorithm.

The system including the boost converter consist of two operating sequence, the first sequence shown in Fig.4 is characterized by a closed switch (S=1) and the diode is open.

Fig.4 Boost converter equivalent circuit in the



first sequence

In this case, the equations describing the system are:

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{V_{pv}}{L} \\ \dfrac{dV_0}{dt} = -\dfrac{V_0}{RC_2} \end{cases} \qquad (6)$$

An open switch characterizes the second sequence and the diode is closed. This sequence is shown in Fig.5.

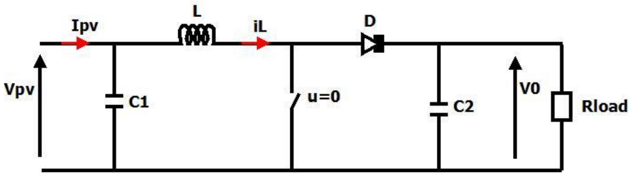


Fig.5 Boost converter equivalent circuit in the second sequence

In this case, the equations describing the system are:

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{V_{pv} - V_0}{L} \\ \dfrac{dV_0}{dt} = -\dfrac{V_0}{RC_2} + \dfrac{i_L}{C_2} \end{cases} \qquad (7)$$

From two systems of equations 6 and 7, the model mathematic of the boost converter is given by [8]:

$$\begin{cases} \dfrac{di_L}{dt} = \dfrac{V_{pv} - V_0}{L} + \dfrac{V_0}{L}u \\ \dfrac{dV_0}{dt} = -\dfrac{V_0}{RC_2} + \dfrac{i_L}{C_2} - \dfrac{i_L}{C_2}u \end{cases} \qquad (8)$$

Where u is the state of the switch S.

Equations (8) can be described by:

$$\dot{x} = f(x,t) + g(x,t)u + A \tag{9}$$

Where:

$$x = \left[x_1 \quad x_2 \right]^{Tr} = \left[i_L \quad V_0 \right]^{Tr} \tag{10}$$

$$f(x) = \begin{bmatrix} 0 & \dfrac{-x_2}{L} \\ \dfrac{x_1}{C_2} & \dfrac{-x_2}{RC_2} \end{bmatrix} ; g(x) = \begin{bmatrix} \dfrac{x_2}{L} \\ \dfrac{-x_1}{C_2} \end{bmatrix} ; A = \begin{bmatrix} \dfrac{V_{pv}}{L} \\ 0 \end{bmatrix} \tag{11}$$

4. MPPT control:

The characteristics of a cell are affected by temperature irradiation. According to the variation of the maximum power point (MPP) [2], our system must evolve rapidly and efficiently.

In order to overcome these constraints, we use the MPPT algorithm for control of the DC-DC converter, this command allows the converter of providing a maximum power by varying automatically the duty cycle to bring it to the optimal value to maximize the power delivered by PV [5].

Fig.6 shows the PV array characteristic curve with the maximum point power variation under different irradiation.

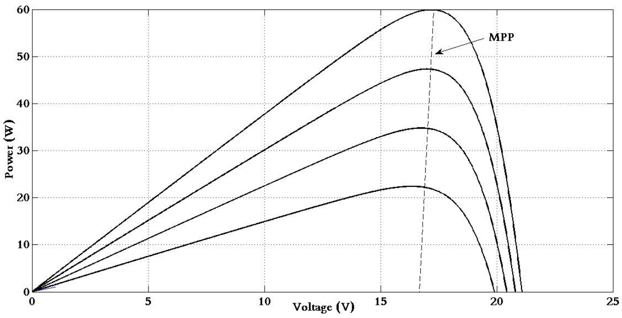


Fig.6 Maximum power point under different irradiation

4.1 Sliding mode control:

The sliding mode control is a nonlinear control, it is characterized by the discontinuity of the control in passage by switching surface called: sliding surface [9-10].

(1) Choice of sliding surface, the condition of maximum power point PPM is given by: $\frac{dP_{PV}}{dV_{PV}} = 0$

In this condition, it is guaranteed that the system state will hit the surface and produce maximum power output persistently.

$$S(x) = \frac{dP_{PV}}{dV_{PV}} = I_{PV} + \frac{dI_{PV}}{dV_{PV}} V_{PV} \tag{12}$$

(2) Calculation of the equivalent control, the equivalent control is determined from the flowing condition :

$$\dot{S}(x) = \frac{\partial S}{\partial x_1} \dot{x}_1 + \frac{\partial S}{\partial x_2} \dot{x}_2 \tag{13}$$

Knowing that the surface S depends on i_L then we can write:

$$\frac{\partial S}{\partial x_1} \neq 0 \; ; \quad \frac{\partial S}{\partial x_2} = 0 \tag{14}$$

$$\dot{S}(x) = \frac{\partial S}{\partial x_1} \dot{x}_1 = 0 \tag{15}$$

Then, the expression of equivalent control can be derived from the condition $\dot{x}_1 = 0$:

$$u_{eq} = 1 - \frac{V_{PV}}{V_0} \tag{16}$$

(3) Finally the real control signal is given by :

$$u = \begin{cases} 1 & u_{eq} + kS \geq 1 \\ u_{eq} + kS, \quad \text{for} & 0 < u_{eq} + kS < 1 \\ 0 & u_{eq} + kS \leq 0 \end{cases} \tag{17}$$

Where k is positive scaling constant, the equivalent control is comprised with u_{eq} and kS , where u_{eq} is the required effort for $S^{\bullet} = 0$ and kS can be considered as the effort to track the MPP. The surface sliding and duty cycle versus operation region are shown in Fig.7.

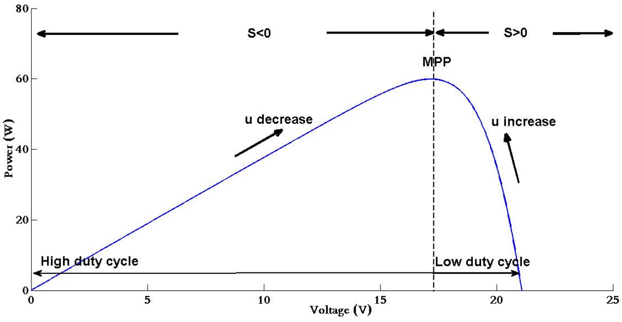


Fig.7 Duty cycle versus operation region

A Lyapunov function is defined as:

$$V = \frac{1}{2} S^2 \tag{18}$$

Knowing that:

$$I_{pv} = N_p I_{sc} - N_p I_{sc} \exp\left(\frac{V_{pv} - N_s V_{oc}}{n_s v_t} \right) \tag{19}$$

And

$$\frac{dI_{pv}}{dV_{pv}} = -\frac{N_p\ I_{sc}}{n_s v_t} \exp\left(\frac{V_{pv} - N_s V_{oc}}{n_s v_t} \right) \tag{20}$$

Substituting (19) and (20) into (12), the sliding surface can be written:

$$S(x) = N_P I_{SC} - \left\{ \begin{matrix} \left(N_P I_{SC} + \frac{N_P I_{SC}}{n_s v_t} V_{PV} \right) \times \\ \exp\left(\frac{V_{PV} - N_S V_{OC}}{n_s v_t} \right) \end{matrix} \right\} \tag{21}$$

The time derivative of S can be written as:

$$\dot{S}(x) = -\left\{ \begin{matrix} \left(2 + \frac{V_{PV}}{n_s v_t} \right) \frac{N_P I_{sc}}{n_s v_t} \times \\ \exp\left(\frac{V_{PV} - N_S V_{OC}}{n_s v_t} \right) \frac{dV_{PV}}{dt} \end{matrix} \right\} \tag{22}$$

- Case $S(x) > 0$:

In this case, the voltage must be increased to reach the PPM.It means that $\frac{dV_{pv}}{dt} > 0$. By replacing in equation (22), we get $\dot{S} < 0$, witch means $\dot{S}(x) S(x) < 0$.

- Case $S(x) < 0$:

In this case, the voltage must be decreased to reach the PPM. It means that $\frac{dV_{pv}}{dt} < 0$. By replacaing in equation (22), we get $\dot{S} > 0$, witch means $\dot{S}(\mathrm{x}) \mathrm{S}(\mathrm{x}) < 0$.

It is concluded that the sliding mode is provided.

4.2 Fuzzy logic:

The fuzzy logic controller is advantageously a robust control, which does not require the exact knowledge of the mathematical model of the system. This command is better adapted to the nonlinear systems [11-13].

The proposed fuzzy logic controller is shown in Fig.8; it consists of two inputs and one output. The two input variable are the error (E) and change of the error (CE) that expressed by equation (23, 24):

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \tag{23}$$

$$CE(n) = E(n) - E(n-1) \tag{24}$$

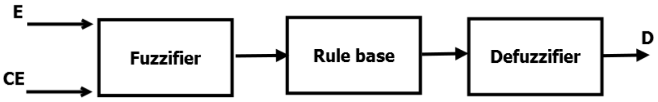


Fig.8 Fuzzy controller diagram

The fuzzy controller contains the three following steps:

•Fuzzification: is the process of converting the numerical input variables E and CE into linguistic fuzzy sets using fuzzy membership function. The membership functions of power error, change error and duty cycle are shown in Fig.9, Fig.10 and Fig.11. These variables in this case are expressed in terms of five linguistic variables: NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big).

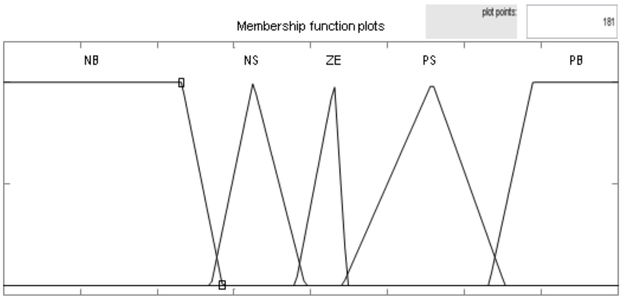


Fig.9 Membership Function of Power Error

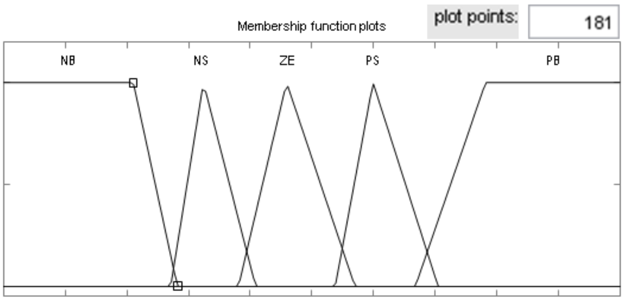


Fig.10 Membership Function of change in Error

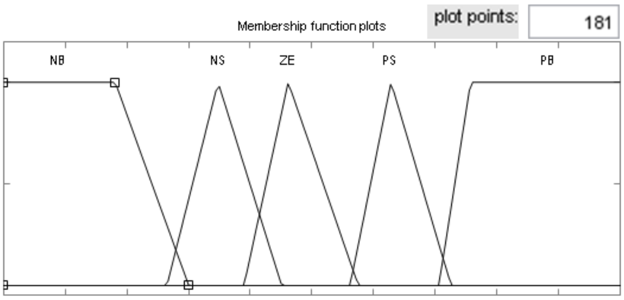


Fig.11 Membership Function of Duty Cycle

•Rule base: the logical relationships are established between input and output variables while defining the rules of membership.Tab.1 shows the fuzzy rules algorithm includes 25 fuzzy control rules.

Table.1 Fuzzy rule base tables

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

•Defuzzification: this operation converters the inferred fuzzy control action into a numerical value at the output by forming the union of the outputs resulting from each rule.

4.3 Perturb and Observe (P&O):

Perturb and Observe method (P&O) is based on the perturbation of the system, by increasing or decreasing the reference voltage Vref, or by a direct action on converter duty cycle, then the observation of the effect of output power for PV .If the present value power P(k) for PV is larger than the previous value P(k-1), then we keep the same previous perturbation direction, if not we reverse the previous perturbation cycle [14-15]. A scheme of the algorithm is shown in Fig.12.

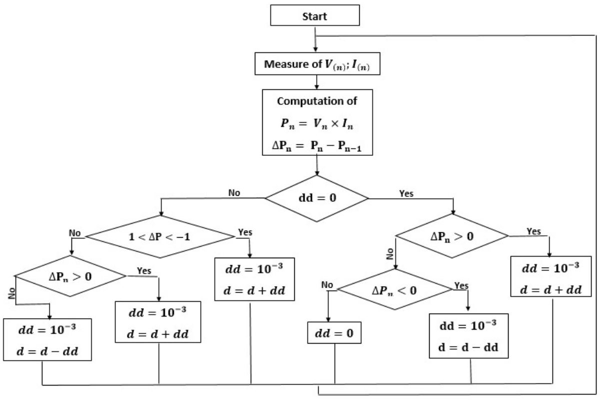


Fig.12 P&O algorithm

4 Simulation result

A simulation for three techniques has been done using Matlab: Sliding mode, fuzzy logic and P&O controllers.

Fig.13 shows the output power of the boost converter obtained using Perturb & Observe algorithm, Sliding mode and Fuzzy logic controllers.

From the above result, it can be deduced that with a nonlinear controllers, the transitional regime and power curve are improved significantly when compared to P&O algorithm.

Fig.14 shows the output voltage of boost converter using Fuzzy Logic, Sliding Mode and P&O Controllers.

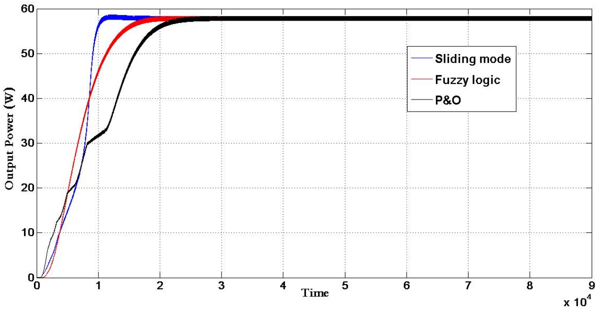


Fig.13 Power output under step changing irradiation for P&O,Sliding mode and fuzzy logic controllers

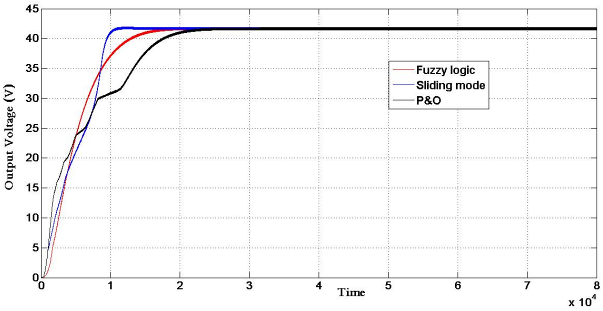


Fig.14 Voltage output under step changing irradiation for P&O,Sliding mode and fuzzy logic controllers

4 Conclusion

In this paper, P&O, Sliding mode and fuzzy logic controller have been designed and simulated for the proposed PV system, comparison for simulation results have been presented for same environmental conditions.

The maximum power point (MPP) to be achieved through the tree controller, sliding mode has a fast response time, stable response and the system is insensitive in the perturbation, response fuzzy logic controller is fast and stable than P&O controller but is slow as sliding mode controller.

We note that the fuzzy logic does not require a precise model mathematic and is easy to introduce, sliding mode require too many calculation and system equation but is robust and performance controller.

Appendix

Table.2 PV MODULE PARAMETERS

Temperature (T)	$25^{\circ}C$
Maximum power (P_{max})	$60\ W$
Voltage at P_{max} (V_{mp})	$17.1\ V$
Current at P_{max} (I_{mp})	$3.5\ A$
Short-circuit current (I_{sc})	$3.8\ A$
Open-circuit voltage (V_{oc})	$21.1\ V$

Table.3 Boost converter parameters

Inductance (L_1)	$300\ 10^{-3}H$
Capacitance (C)	$200\ 10^{-6}F$
Carrier switching frequency (f_c)	$10\ KHZ$
Rload (R)	$30\ \Omega$

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