

# Study of Two MPPTs for Photovoltaic Systems Using Controllers Based in Fuzzy Logic and Sliding Mode

N. Ould cherchali, M. S. Boucherit, L. Barazane, A. Morsli

**Abstract**—In this study, we proposed two techniques to track the maximum power point (MPPT) of a photovoltaic system. The first is an intelligent control technique, and the second is robust used for variable structure system. In fact the characteristics I-V and P-V of the photovoltaic generator depends on the solar irradiance and temperature. These climate changes cause the fluctuation of maximum power point; a maximum power point tracking technique (MPPT) is required to maximize the output power. For this we have adopted a control by fuzzy logic (FLC) famous for its stability and robustness. And a Sliding Mode Control (SMC) widely used for variable structure system. The system comprises a photovoltaic panel (PV), a DC-DC converter, which is considered as an adaptation stage between the PV and the load. The modelling and simulation of the system is developed using MATLAB/Simulink. SMC technique provides a good tracking speed in fast changing irradiation and when the irradiation changes slowly or it is constant the panel power of FLC technique presents a much smoother signal with less fluctuations.

**Keywords**—Fuzzy logic controller, maximum power point, photovoltaic system, tracker, sliding mode controller.

## I. INTRODUCTION

THE needs in electrical energy are boosting in recent years and the constraints associated with its production, such as the effects of environmental pollution and global climate warming, drive research toward the development of renewable energy sources. In this context, photovoltaic systems present a very good solution and free solar power.

Photovoltaic power is viewed in many places and countries with a high solar power density like Mediterranean countries as an excellent candidate of energy. Stand-alone and grid-connected applications of solar energy have developed greatly and improved significantly during the last decades. These applications incorporate PV power plants [1], refrigeration, traffic light application [2], water pumping, spaceship, satellite and military applications [3]. However, there is some inconvenience for the PV systems. They have a very high manufacture cost and photovoltaic (PV) modules still have relatively low energy conversion efficiency. And more, they have nonlinear characteristics (V-I) depending on the temperature and insolation. Their maximum power point varies nonlinearly with solar irradiation, temperature and load

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current. These points plus the aging of solar cells are the main causes for the low electrical efficiency of photovoltaic systems. To overcome these problems, the maximum power point of the PV system is tracked using online or off-line algorithm or technique and the operating point of the system is pushed toward this optimal condition. This technique is known as the maximum power point tracking (MPPT) technique. The MPPT is employed to extract the maximum power generated by an array of Photovoltaic cells.

A significant number of MPPT control techniques have been developed, studied and implemented since the 70s, starting with simple techniques such as MPPT controllers based on the status of the return voltage and current [2], [3]. In recent years more robust MPPT control techniques were associated with MPPT control as fuzzy logic controller (FLC) and sliding mode controller (SMC) to increase the efficiency of solar panels [2]-[7].

In this context, we will present the different parts of a PV system, the FLC and SMC MPPT techniques will be studied and compared.

## II. THE PHOTOVOLTAIC SYSTEM

The model of solar cell can be categorized as p-n semiconductor junction like a Diode; when exposed to light, the DC current is generated. Fig. 1 shows the equivalent circuit diagram [7], [8].

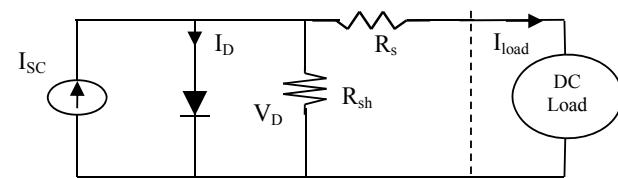


Fig. 1 Typical circuit of PV solar cell

Equations (1)-(3) describe the I-V characteristic of the PV model.

$$0 = I_{SC} - I_D - \frac{V_D}{R_{sh}} - I_{PV} \quad (1)$$

$$I_D = I_0(e^{V_D/V_T} - 1) \quad (2)$$

$$V_{PV} = V_D - R_s I_{PV} \quad (3)$$

where:  $I_{PV}$  is the cell current (A);  $I_{SC}$  is the light generated current (A);  $I_D$  is the diode saturation current (A);  $R_s$  is the cell series resistance (ohms);  $R_{sh}$  is the cell shunt resistance

(ohms);  $V_D$  is the diode voltage (V);  $V_T$  is the temperature voltage (V);  $V_{PV}$  is the cell voltage (V).

### III. MAXIMUM POWER POINT TRACKING TECHNIQUES

Generally, MPPT is adopted to track the maximum power point in the PV system to generate the maximum possible power. The performance of MPPT depends on both the MPPT control algorithm and the MPPT circuit. The MPPT control algorithm is usually applied in the DC-DC converter (Buck, Boost or others). The DC/DC converter is normally used as the MPPT circuit. Classic diagram of the connection of MPPT in a PV system is shown in Fig. 2.

Figs. 3 and 4 show the performance of a photovoltaic panel simulation in accordance with irradiation variations under constant temperature and with temperature variations under constant irradiation. In fact, a photovoltaic generator connected to a load can operate in a large range of voltage and current depending on environmental operating conditions.

So, the MPPT controller must also track the new modified maximum power point (MPP) in its corresponding curve whenever irradiation and/or temperature variation occurs.

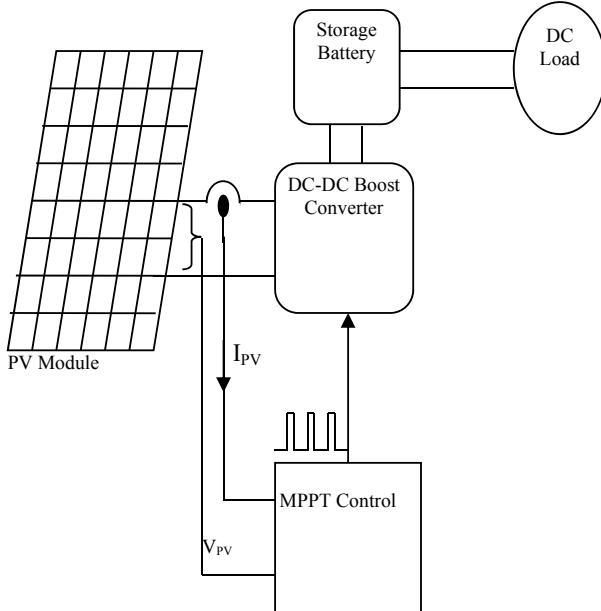


Fig. 2 Typical diagram of MPPT in PV System

#### A. MPPT Using Fuzzy Logic Control (Fuzzy MPPT)

The fuzzy logic controllers have been introduced in the tracking of the maximum power point (MPP) in PV systems [8]-[10] where Fuzzy Logic Control (FLC) gains several advantages of better performance, robust and simple design. The FLC MPPT technique does not need the knowledge of the exact model, but this technique do prerequisite in the other hand the complete knowledge of the operation of the Photovoltaic system by the designer.

The proposed Fuzzy Logic MPPT Controller, shown in Fig. 5, has two inputs and one output [7].

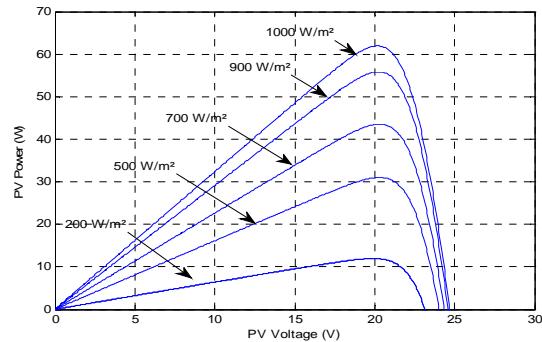


Fig. 3 Influence of the solar radiation for constant temperature (25°C)

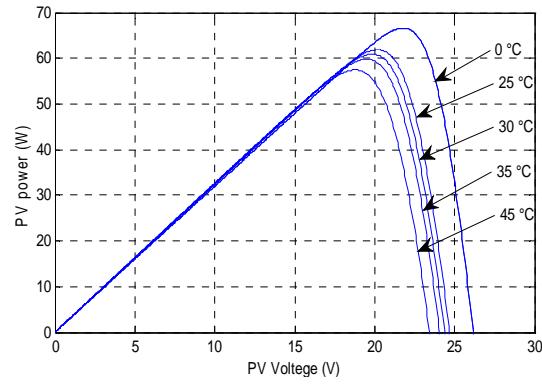


Fig. 4 Influence of the temperature of junction for constant irradiation (1000 W/m²)

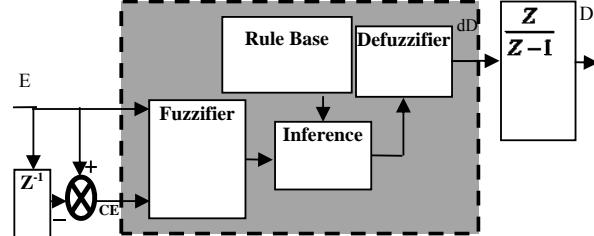


Fig. 5 Structure of a FLC

The two FLC input variables are the error  $E$  and change of error  $CE$  at sampled times  $k$  defined by:

$$E(k) = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \quad (4)$$

$$CE(k) = E(k) - E(k-1) \quad (5)$$

The input  $E(k)$  shows if the load operation point at the instant  $k$  is located on the right or on the left of the MPP on the P-V characteristic, while the input  $CE(k)$  expresses the moving direction of load operation point.

The fuzzy inference is carried out by using Mamdani's method, and the output (the duty cycle  $dD$ ) is calculated by using the Defuzzifier block (7). The centre of gravity is used to compute the output of this FLC which is the duty cycle, which uses the rule base of Table I. The output ( $dD$ ) is given

to the DC-DC converter.

Fig. 6 shows the antecedent and consequent membership functions.

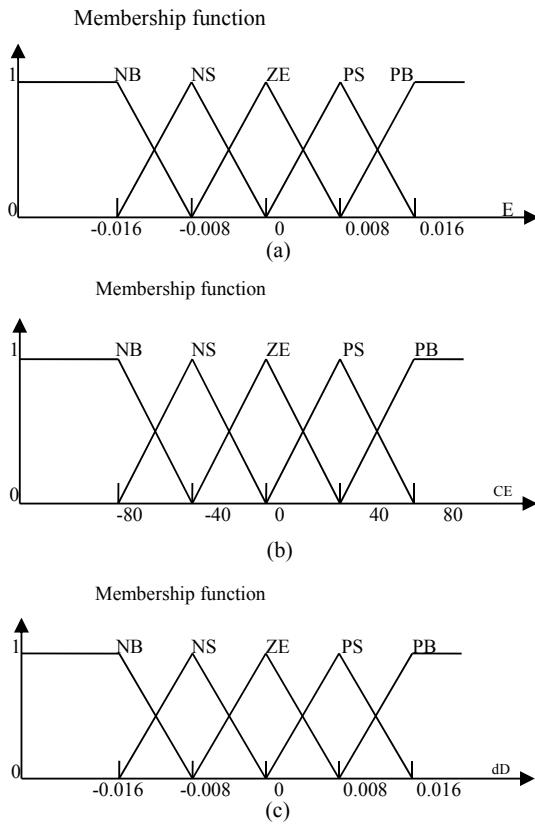


Fig. 6 Membership function of (a) error E (b) change error CE (c) duty ratio D

TABLE I  
FUZZY RULE TABLE

| CE | NB        | NS        | ZE        | PS        | PB        |
|----|-----------|-----------|-----------|-----------|-----------|
| E  | <b>NB</b> | <b>ZE</b> | <b>ZE</b> | <b>PB</b> | <b>PB</b> |
| NB | <b>ZE</b> | <b>ZE</b> | <b>PB</b> | <b>PB</b> | <b>PB</b> |
| NS | <b>ZE</b> | <b>ZE</b> | <b>PS</b> | <b>PS</b> | <b>PS</b> |
| ZE | <b>PS</b> | <b>ZE</b> | <b>ZE</b> | <b>ZE</b> | <b>NS</b> |
| PS | <b>NS</b> | <b>NS</b> | <b>NS</b> | <b>ZE</b> | <b>ZE</b> |
| PB | <b>NB</b> | <b>NB</b> | <b>NB</b> | <b>ZE</b> | <b>ZE</b> |

Assume that there are M rules in the Fuzzy system, where the  $i^{\text{th}}$  rule has the following form:

$$R: \text{if } E \text{ is } F_E^i \text{ and } CE \text{ is } F_{CE}^i \text{ THEN } dD \text{ is } U \quad (6)$$

$$dD_0 = \frac{\sum_{j=1}^n \mu(D_j) - D_i}{\sum_{j=1}^n \mu(D_j)} \quad (7)$$

#### B. MPPT using Sliding Mode Control (SMC)

In this section, a sliding-mode control (SMC) is summarized, where is described in [11]-[13].

Variable structure system is referred to a system which its

structure changes. This kind of systems has an attractive feature for control applications, which consists in a sliding mode, this mode occurs on switching surface, and the system remains insensitive to parameter variations and disturbance.

Many sliding surfaces (switching surfaces) provide stability and adequate dynamics. In this case, the sliding surface can be designed with the error of the output power and the integral output error was added to achieve zero steady-state [13].

A possible choice of the structure of a sliding mode controller is:

$$U = U_{eq} + K \cdot \sin g(S) \quad (8)$$

with:  $U_{eq}$  is called equivalent control which dictates the motion of the state trajectory along the switching surface; K is a constant, representing the maximum controller output required to overcome parameter uncertainties and disturbances; S is called the switching function because the control action switches its sign on the two sides of the switching surface

The structure of a sliding mode controller is defined by:

$$U = D(k+1), \quad U_{eq} = D(k) \quad (9)$$

with  $D(k)$  and  $D(k+1)$  are the duty cycle a time k and k+1 respectively.

The switching function S is defined as:

$$\begin{aligned} S(k) &= \frac{P_{pv}(k) - P_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} = 0 \\ &\Rightarrow \frac{P_{pv}(k) - P_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} = \frac{I_{pv}(k)^2 R_{pv}(k) - I_{pv}(k)^2 R_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} \end{aligned} \quad (10)$$

where  $R_{pv}(k)$  is the equivalent load in the terminals of the photovoltaic panel and is given by:

$$R_{pv}(k) = \frac{V_{pv}(k)}{I_{pv}(k)} \quad (11)$$

$$\Leftrightarrow I_{pv}(k)(2R_{pv}(k) + I_{pv}(k) \frac{R_{pv}(k) - R_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)}) = 0 \quad (12)$$

$$\Rightarrow 2R_{pv}(k) + I_{pv}(k) \frac{R_{pv}(k) - R_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} = 0 \quad (13)$$

To ensure proper working of the system around the MPP, we must choose the sliding surface equal to zero (12), so the formula of sliding surface is given by (13):

$$\begin{cases} S(k) = 2R_{pv}(k) + I_{pv}(k) \frac{R_{pv}(k) - R_{pv}(k-1)}{I_{pv}(k) - I_{pv}(k-1)} = 0 \\ R_{pv} = \frac{V_{pv}(k)}{I_{pv}(k)} \end{cases} \quad (14)$$

In order to get the equivalent control ( $U_{eq}$ ) suggested by

[11], the equivalent control is determined from the following condition:

$$\dot{S} = 0 \quad (15)$$

The equivalent control is then derived [11], [12]:

$$U_{eq} = 1 - \frac{V_{pv}}{V_{R\_load}} = D(k) \quad (16)$$

Since the range of duty cycle must be limited to  $0 \leq D(k) \leq 1$ , the real control law has been proposed as:

$$D(k+1) = \begin{cases} 1, & D(k) + K \cdot \text{sing}(S) \geq 1 \\ D(k) + K \cdot \text{sing}(S), & 0 < D(k) + K \cdot \text{sing}(S) < 1 \\ 0, & D(k) + K \cdot \text{sing}(S) \leq 0 \end{cases} \quad (17)$$

#### IV. MODEL OF THE SYSTEM

The proposed MPPT techniques have been modeled and simulated using MATLAB/Simulink.

The DC-DC converter is the boost chopper. Fig. 7 shows the boost chopper structure.

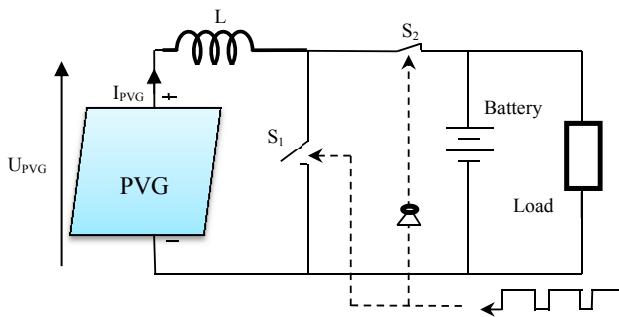


Fig. 7 Basic structure of Boost chopper

#### V. SIMULATION RESULTS AND DISCUSSION

Fig. 2 shows the functional diagram of the simulated photovoltaic system where 14 panels are used. The DC-DC converter is the boost chopper (Fig. 7). The previous MPPT controllers FLC and SMC were simulated under variable irradiation and constant temperature ( $25^\circ$ ).

The value of the duty ratio (D) at  $t=0$ s is 0.5 for both MPPT techniques.

For a sampling frequency equal to 100Hz, Figs. 8-10 show the result of the test. Where, Fig. 8 shows the performance of the PV system using the two MPPT techniques (FLC and SMC) under variable irradiation. Fig. 9 is the zoom of the panel power at different intervals of time; however, Fig. 10 shows the performance of the PV system using the two MPPT techniques (FLC and SMC) under variable temperature.

Table II summarizes the performances of the two MPPT techniques in four irradiation cases (four intervals of time).

Case 1. ( $0s < t < 10s$ ) start-up

Case 2. ( $20s < t < 30s$ ) constant irradiation ( $1000 W/m^2$ )

Case 3. ( $40s < t < 50s$ ) slow increase in the irradiation from  $700$

to  $1000 W/m^2$

Case 4. ( $44.6s < t < 45.6s$ ) the irradiation decreases rapidly from  $1000$  to  $700 W/m^2$  and it becomes constant.

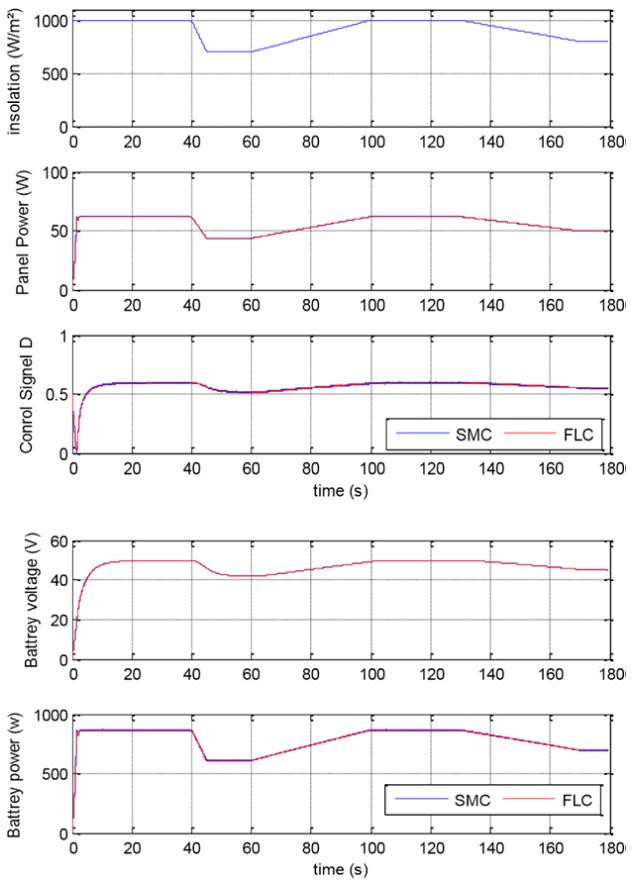


Fig. 8 The performance of the PV system using FLC and SMC algorithms under variable irradiation

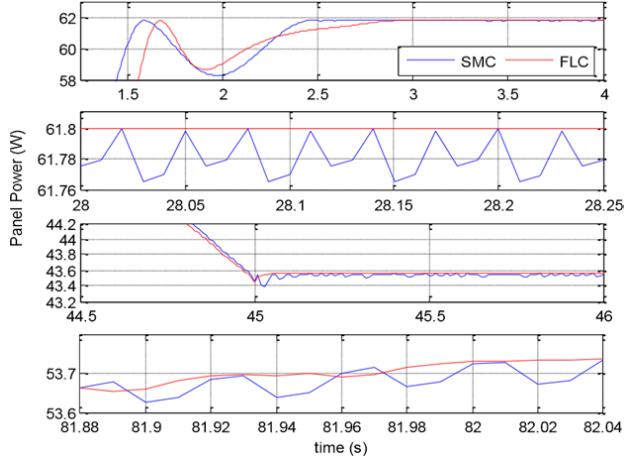


Fig. 9 Zoom of the panel power using FLC and SMC algorithms under variable irradiation

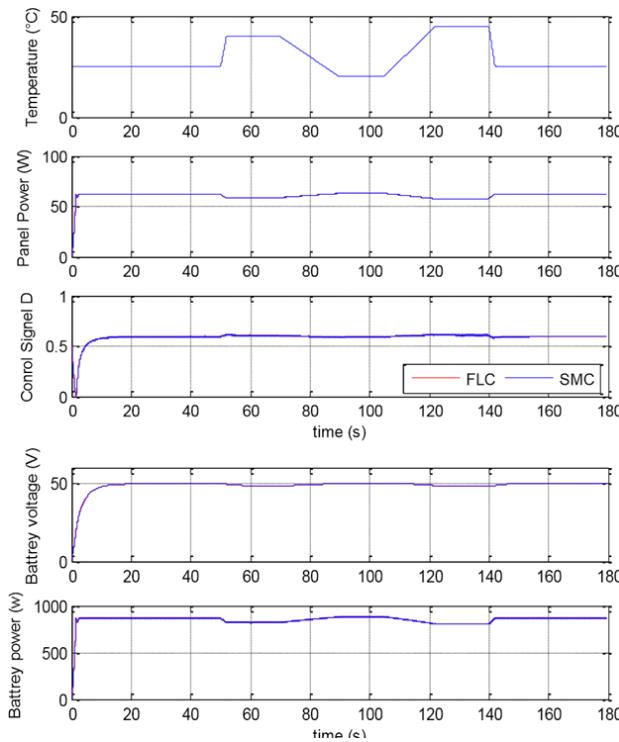


Fig. 10 The performance of the PV system using FLC and SMC algorithms under variable temperature

| TABLE II<br>ENERGY GENERATED BY THE SOLAR PANEL AS A FUNCTION OF THE 2 MPPT TECHNIQUES AND IRRADIATION INPUT |          |           |           |               |
|--|----------|-----------|-----------|---------------|
| Energy (J)   | 0s - 10s | 20s - 30s | 40s - 50s | 44.6s - 45.6s |
| FLC  | 556.3451 | 617.9948  | 483.1229  | 44.6951       |
| SMC  | 560.3241 | 617.8141  | 483.2300  | 44.7063       |

The FLC and SMC are proposed to improve the MPPT dynamic performance under changing environmental operating conditions, by considering the duty cycle in the controller output.

In the proposed FLC, the triangular membership functions, as shown in Fig. 6, are selected for the input  $E(k)$ ,  $CE(k)$  variables and output variable  $D(k)$ . The peak values of each fuzzy set in the membership functions will influence the overshoot, stability, and steady-state error of system step responses. If the peak values of NS and PS in the membership function of  $E(k)$  are moved toward the center point, the overshoot and oscillation of the step responses will increase, while the rise time will decrease. Therefore, adjusting the peak values in the membership functions  $E(k)$  of  $CE(k)$  and can achieve desired dynamic and static performance.

To validate the robustness of the proposed technique, the comparisons between the FLC and SMC but in different irradiation and temperature are presented in Figs. 8 and 9 for irradiation and Fig. 10 for temperature. The effect of irradiation change can be seen clearly on the power panel signal and the same think of the effect of temperature change.

When the irradiation is constant (Fig. 9:  $28s < t < 28.6s$ ) the panel power of FLC technique presents a much smoother

signal with less fluctuations and for SMC technique there is a ripple in the panel power.

From Table II, it observed that in case of SMC, the energy generated by the solar panel is more than the other technique in all cases except case 2. In case 2 ( $20s < t < 30s$ ) where the irradiation is constant, the energies generated by SMC technique are less than the energy generated by FLC.

SMC MPPT technique provides a good tracking speed and FLC technique provides less variation around the MPP.

## VI. CONCLUSIONS

This paper presents two MPPT techniques for PV system. The first is a robust and intelligent control (FLC) and the second is a robust technique (SMC) used for variable structure system. Both strategies are applied to the PV system. The simulation results in different variations of irradiation and temperature (weather conditions change) show that the proposed MPPT techniques using FLC and SMC can improve system performance. SMC technique provides a good tracking speed in fast changing irradiation and when the irradiation changes slowly or is constant the panel power of FLC technique presents a much smoother signal with less fluctuations.

Find and try other MPPT methods to optimize the performance seemed like a good idea.

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