Maximum Power Point Tracking using Fuzzy Logic Controller for Stand-Alonephotovoltaic System

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Abstract- **This article presents two techniques of maximum power point tracking (MPPT) using a sliding mode and fuzzy logic controllers for photovoltaic systems under varying environmental conditions. The output power of photovoltaic (PV) panel depends on solar irradiation, temperature and load. Therefore it is crucial to operate the PV module at his MPP all the time. In this paper a comparative study between a PI fuzzy and a sliding mode controller is elaborated. The different steps of the design of these controllers are exposed together with its simulation under matlab/Simulink environment. The simulation results show that the fuzzy logic controller can track the maximum power point (MPP) faster and minimize the power oscillation around the MPP.**

Keywords—Photovoltaic, sliding mode, fuzzy controller, maximum power point tracking.

I. INTRODUCTION

In the last few decades, the demand of using alternative energy sources is dramatically increasing. The photovoltaic (PV)has attracted much attention with many feasible applications and because it has many advantages such as abundance, clean and renewability.To maximize theoutput power of PV systems, it is crucial to operate the PV generator at its MPP all the time. Several MPPT techniques have been elaborated in the literature to track the maximum power point of PV system, starting with perturbation and observation (P&O) method which is used widely due to its simplicity, however there is serious power oscillations around MPP which decreases the efficiency of PV system [1]. Other techniques based on artificial intelligence techniques such as neural networks and genetic algorithms have developed. These methods suffer from oscillation of the operating point around the MPP which leading to significant energy losses especially in large scale photovoltaic systems [2]. In this work an intelligent maximum power point tracking based on fuzzy logic control is elaborated and compared with a sliding mode MPPT technique.

This paper is organized as follow: In section II, the modeling of photovoltaic system; Section III exposes the fuzzy logic MPPT controller.In section IV, the slidingmode MPPT is described and sections V presents the obtained simulation results. Finally, conclusion is contained in section VII.

II. PHOTOVOLTAIC SYSTEM MODELING

The fig.1 presents the block diagram of the MPPT system configuration. The system consists of PV panel, Dc-Dc converter and a resistive load.

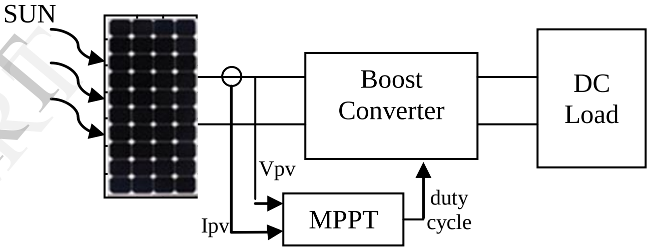

Fig. 1.General diagram of the photovoltaic system[4].

A. Photovoltaic panel model

A photovoltaic cell is a P-N semiconductor junction which converts solar irradiation into electric energy. Fig. 2 presents the equivalent circuit model of solar cell. This circuit includes a light generated source, diode, a series resistance R_s and a parallel resistance R_{sh}.The characteristic equation for a photovoltaic cell is given by (1).

$$I_{pv} = I_{ph} - I_0\left[\exp\left(\frac{q(V_{pv}+R_sI)}{nKT}\right)-1\right]-\frac{V_{pv}+R_sI}{R_{sh}} \qquad (1)$$

Where I_{pv} and V_{pv} are the output current and voltage of photovoltaic cell, n is the ideality factor, kis the Boltzmann's constant, T is the cell's operating temperature in Kelvin, qis the electron charge,I_0 is the reverse saturation current and I_{ph} is photo generated current. This last varies with temperature and solar insolation. I_{ph} is expressed by (2):

$$I_{ph} = [I_{SC}+K_I(T-T_r)]\frac{G}{1000} \qquad (2)$$

Where T_r is the reference temperature,$K_I$is the cell's short-circuit current temperature coefficient, I_{SC} is the short circuit current at T_r and G is the irradiation in W/m^2.

The reverse saturation current I_0 depends on temperature T as follows:

$$I_0 = I_{rs}\left(\frac{T}{T_r}\right)^3 \exp\left[\frac{qE_g}{nK}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right] \qquad (3)$$

Where I_{rs} is the saturation current at the reference temperature, E_g is the band gap energy of the semiconductor used in photovoltaic cell.

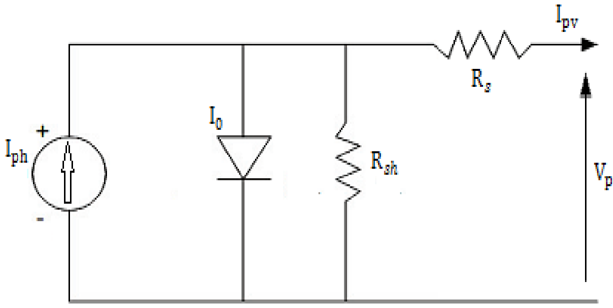

Fig. 2.Equivalent circuit of photovoltaic cell.

The parameters of the PV panel used in this study are depicted in table 1 and its P-V and I-V characteristics are shown in fig.3, fig. 4, fig. 5 and fig. 6 respectively.

TABLE I. ELECTRICAL CHARACTERISTICS OF THE KYOCERA KD135GX-LP PANEL.

Parameter (at STC)	Value
Maximum power (P_{max})	135.04 w
Voltage at $P_{max}(V_{mpp})$	17.7v
Current at $P_{max}(I_{mpp})$	7.62A
Open circuit voltage (V_{oc})	22.09v
Short circuit current (I_{sc})	8.36A
Temperature coefficient of $I_{sc}(K_i)$	5.022mA/°c
Cell serial modules (n_s)	36

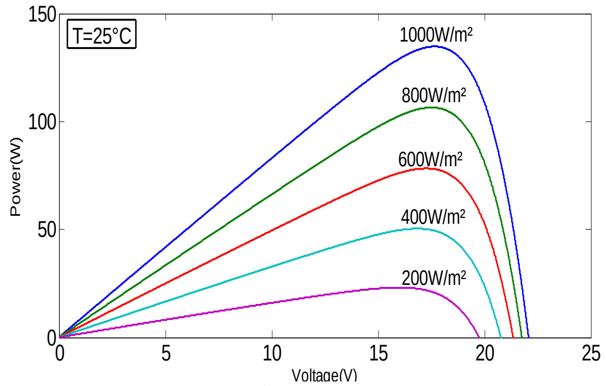

Fig. 3.P-V Characteristics of the photovoltaic panel at constant temperature T=25°C.

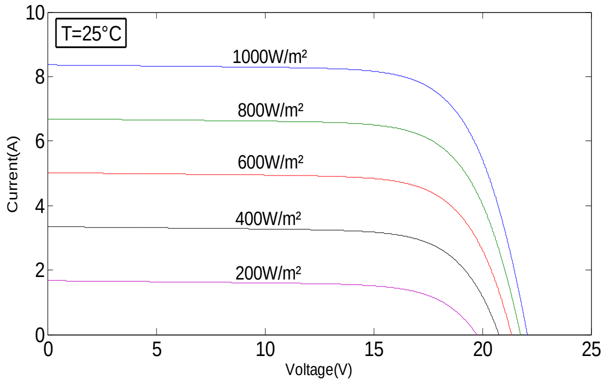

Fig.4. I-V Characteristics of the photovoltaic panel at constant temperature T=25°C.

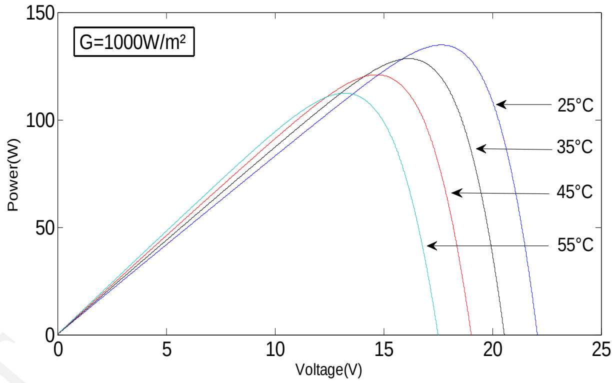

Fig. 5. P-V Characteristics of the photovoltaic panel at constant irradiation G=1000W/m².

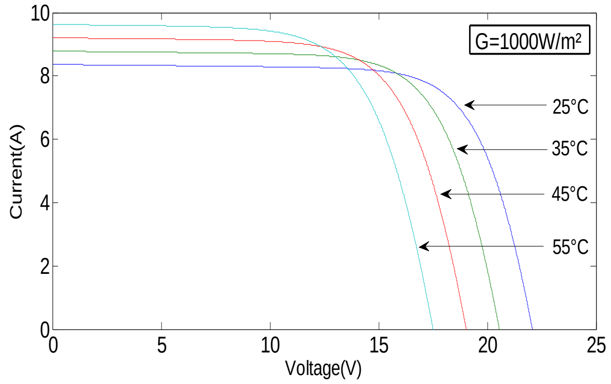

Fig. 6. I-V Characteristics of the photovoltaic panel at constant irradiation G=1000W/m².

B. DC-DC Boost converter

DC/DC Converters are most widely applied in photovoltaic systems as an intermediate between the PV panel and the load to track the maximum power point (MPPT)[3]. In this work a boost converter is used. This converter consists of capacitor, inductor and switch. All of these components in the ideal case do not consume power; this is the reason why the choppers have good yields [4].The switch is turnedON and turned off by thepulses givenbyMPPT controller. The voltage gain of this converter can be expressed as:

$$\frac{V_{out}}{Vin} = \frac{1}{1-d} \qquad (4)$$

Where d is the duty cycle.

III. FUZZY LOGIC MPPT CONTROLLER

The fuzzy regulator has the same objectives of regulation and tracking such as a classic regulator used in automatic control theory [2].This control technique provides faster results compared to other Artificial Intelligent control methods such as Genetic Algorithm and Neural Networks[5].In this study the inputs to the fuzzy logic MPPTcontroller will be error (E) and change in error (CE)at sample time k, which are defined by (4) and (5). The output will be the duty cycle (d). The fuzzy logic controller consists of three parts as shown in Fig. 7.

$$\mathrm{e}(\mathrm{K}) = \frac{\mathrm{P}(\mathrm{k}) - \mathrm{p}(\mathrm{k}-1)}{\mathrm{V}(\mathrm{k}) - \mathrm{V}(\mathrm{K}-1)} \tag{4}$$

$$\mathrm{ce}(K) = \mathrm{e}(K) - \mathrm{e}(K-1) \tag{5}$$

Where p(k) and v(k) are the power and the voltage of the PV panel, respectively.

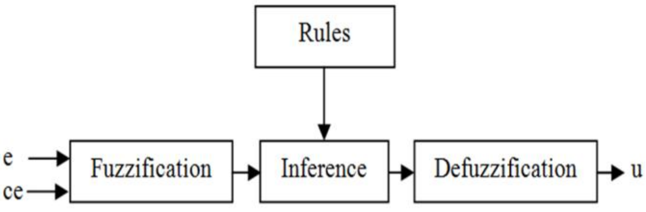

Fig. 7. General diagram of a fuzzy controller[6].

The fuzzification block transforms the input variables e(k) and ce(k) into a linguistic variables composed of membership functions such as NB (Negative Big), ZE (Zero) and PB (Positive Big).The fuzzy subsets and the shape of membership function are depicted in fig. 8.

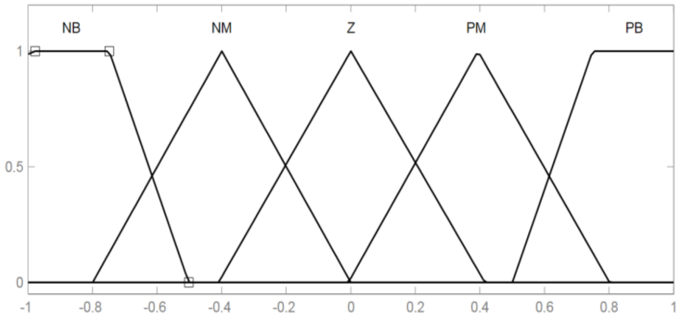

Fig. 8. Membership function plots for error (e) and change of error (ce).

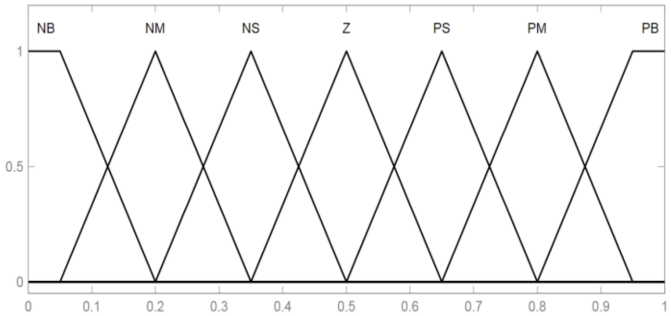

Fig. 9. Membership function plots for duty cycle (d).

The composition operation by which a control output can be generated. Several composition techniques such as MAX–MIN and MAX–DOT have been proposed in fuzzy tool box in Matlab/Simulink.In this studya MAX–MIN(maximum-minimum) method is used. The output membership function of each rule is given by the MIN operator and MAX operator. The rule table is designed and shown in Table II.

For example, the rule given by the blue cell of table II is interpreted as follows:

If error is Negative Small and change of error is Positive Big then d is Positive Small.

TABLE II. RULE BASE OF FUZZY CONTROLLER.

Error(e)	**Change of error(ce)**				
	NB	**NS**	**Z**	**PS**	**PB**
NB	NB	NB	NB	NB	NM
NS	NB	NM	NS	Z	PS
Z	NM	NS	Z	PS	PM
PS	NS	Z	PS	PM	PB
PB	PM	PB	PB	PB	PB

The present system uses the centre of gravity to compute the output of this fuzzy logic controller which is the duty cycle. The centre of gravity technique is both very simple and very fast method. The centre of gravity defuzzificationtechnique in a system of rules by formally given by:

$$d = \left(\frac{\sum_{j=1}^{n} \mu(d_j).d_j}{\sum_{j=1}^{n} \mu(d_j)} \right) \tag{6}$$

Where d is the fuzzy controller output and d_j is the center of max–min composition at the output membership function.

The structure of the fuzzy logic MPPT controller is presented in Fig.10; where the inputs are the power variation and the voltage variation of the PV panel and the output is the duty cycle of the DC-DC boost converter.

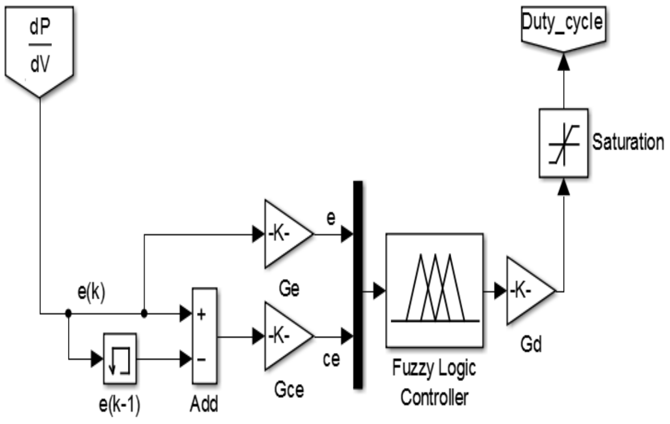

Fig. 10. The configuration of fuzzy logic MPPT controller.

IV. SLIDING MODE MPPT CONTROLLER

Sliding mode control (SMC) is one of the effective nonlinear robust control techniques since it provides system dynamics with an invariance property to uncertainties once the system are controlled in the sliding mode[7]. A sliding mode control has two modes of operation. The first is the approaching mode, where the systemstate converges to a pre-defined manifold called sliding function in finite time. The second mode is named the sliding mode, where the system state is confined on the sliding surface and is driven to the origin [8]. In this section, a sliding mode controller with a boost converter is used to track MPPT of PV module.According to [9], the output power of photovoltaic panel is given by.

$$P_{pv} = V_{pv} . I_{pv} \qquad (7)$$

From the P-V characteristic curve of PV panel, as shown in Figure 11.the switch function can be selected as:

$$S = \frac{dP_{pv}}{dV_{pv}} = I_{pv} + V_{pv}\frac{dI_{pv}}{dV_{pv}} \qquad (8)$$

Based on the observation of duty cycle versus operation region as presented in Fig. 11, the duty cycle output control is given by:

$$d_{k+1} = \begin{cases} d_k + \Delta d & for \quad S > 0 \\ d_k - \Delta d & for \quad S < 0 \end{cases} \qquad (9)$$

The duty cycle of the boost converter must lies in $0 \le d \le 1$, the real control signal can be chosen as:

$$d = \begin{cases} 0 & for \quad d_{eq} + ksat(s) \le 0 \\ d_{eq} + ksat(s) & for \quad 0 < d_{eq} + ksat(s) < 1 \\ 1 & for \quad d_{eq} + ksat(s) \ge 1 \end{cases} \qquad (10)$$

Where d_{eq} is the required effort for $\dot{s} = 0$ and $ksat(s)$ can be considered as the effort to achieve the maximum power point.

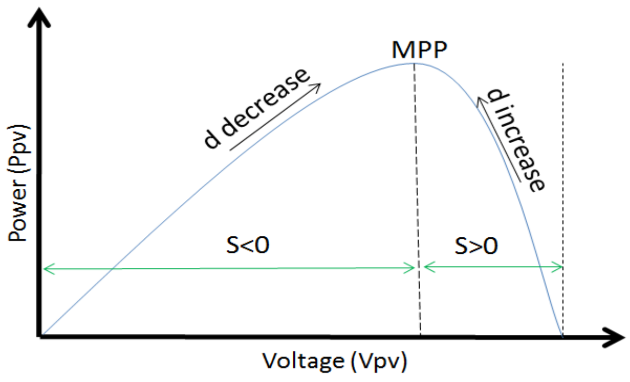

Fig.11.Duty cycle versus operation region [8].

V. SIMULATION RESULTS

The simulation results were achieved considering a KD135GX-LP photovoltaic panel supplying a resistive load via a boost converter. The PV panel parameters used in this simulation are given in Table I. this section presents also the simulation of the both techniques of maximum power point tracking (fuzzy logic and sliding mode control).

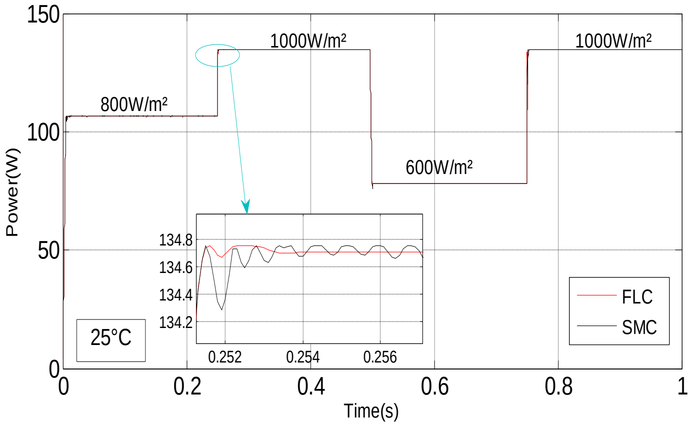

Fig. 12.The output power of PV panel under rapidly changingirradiation.

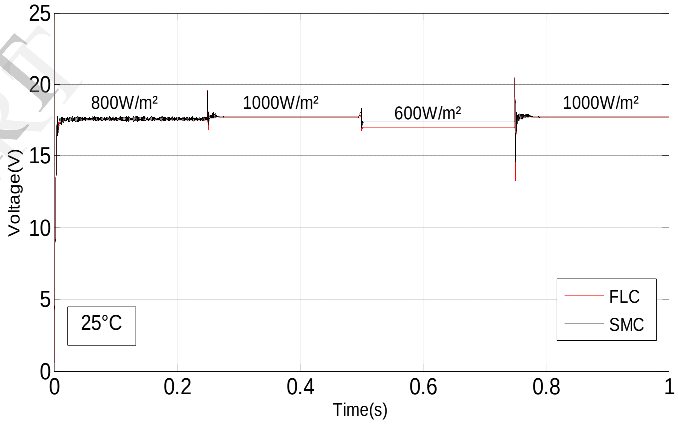

Fig. 13.The output voltage of PV panel under rapidly changingirradiation.

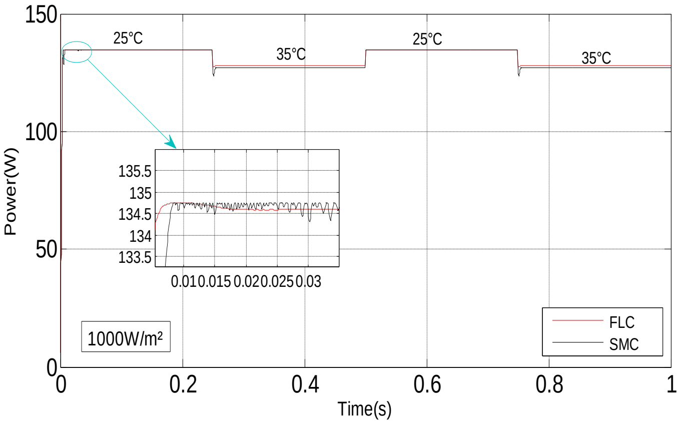

Fig. 14.The output power of PV panel under rapidly changing temperature.

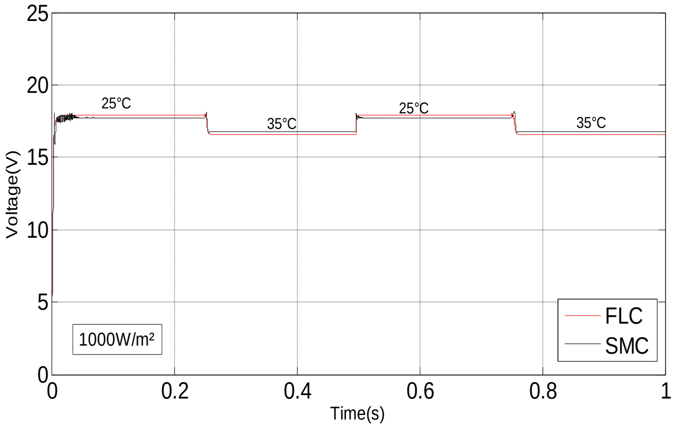

Fig. 15.The output voltage of PV panel under rapidly changing temperature.

A rapid increase in irradiance from 800W/m^2 to 1000W/m^2 respectively a decrease from 1000W/m^2 to 600W/m^2 with a time period of 0.25 seconds was simulated. The cell temperature was maintained at a constant value of 25°C.A second simulation was made to show the response the two techniques of MPPT to rapid change in temperature from 25°C to 35°C,It is observed thatboth fuzzy logic MPPT and sliding mode MPPT can track the maximum power point. We can also confirm with these tests thatthe PIfuzzy controller has better response time, less oscillation and much more accurate trackingat each step.

VI. CONCLUSION

This study presents P-V and I-V characteristics of KD135GX-LPphotovoltaic panel, the comparison of fuzzy logic MPPT and sliding mode MPPT have been elaborated to test the performance of both controllers.The simulation results showthat the fuzzy logic technique provides a better response than a sliding mode controller in terms of the maximum power tracking performance.

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