Design and Implementation of Fuzzy Unit Commitment of Maximum Power Point Tracking Designed for 1kW Solar Photovoltaic Converter

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Abstract- **Maximum power point trackers (MPPTs) play a** vital role in photovoltaic (PV) systems because they increase the efficiency of the solar photovoltaic system by increasing the power output. MPPT algorithms are necessary because PV arrays have a non linear voltage-current characteristic with a unique point where the power produced is maximum. The output power from the solar panel varies with solar irradiance, temperature and so on. To increase the power extracted from the solar panel, it is necessary to operate the photovoltaic (PV) system at the maximum power point (MPP).This paper presents the Matlab/simulink arrangement of fuzzy logic controller (FLC) MPPT algorithm which is responsible for driving the dc-dc boost converter to track maximum power point (MPP).This paper also presents the theoretical analysis of variable step size(VSS) of INC MPPT which can effectively improve the tracking speed and accuracy of maximum power

***Index Terms* — MPPT -DC-DC Converter- Fuzzy Logic Controller –Photovoltaic (PV) System**

I. INTRODUCTION

Energy is the prime mover of economic growth and is vital to the sustenance of a modern economy. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible and environmentally friendly. Government, industry and independent analyses have shown that cost-effective energy efficiency improvements could reduce electricity use by 27% to 75% of total national use within 10-20 years without impacting quality of life or manufacturing output. Besides India is world's 6th largest electrical energy consumer, accounting 3.4% of global energy consumption..the photovoltaic (PV) system technologies have increasing roles in electric power technologies, providing more secure power sources and pollution-free electric supplies [1]-[4]. Solar photovoltaic is a phenomenon where the solar irradiation is converted directly into electricity through solar cell [5]. The PV array can supply the maximum power to the load at a particular operating point which is generally called as maximum power point (MPP), at which the entire PV system operates with maximum efficiency and produces its maximum power.

A major challenge in the use of PV is posed by its nonlinear current-voltage (I-V) characteristics, which result in a unique maximum power point (MPP) on its power-voltage (P-V) curve. The high initial capital cost of a PV source and low energy conversion efficiency makes it imperative to operate the PV source at MPP so thatmaximum power can be extracted. The PV maximum output power is dependent on the operating conditions and varies from moment to moment due to temperature, irradiation and load so tracking and adjusting for this maximum power point is a continuous process. In general, a power source is operated in conjunction with a dc-dc power converter, whose duty cycle is modulated in order to track the instantaneous MPP of the PV source.

There are several methods and controllers that have been widely developed and implemented to track the MPP. In the last years researchers and practitioners in PV systems have presented survey or comparative analysis of MPPT techniques. The various MPPT techniques are Perturb and Observe (P&O) method [6]-[9], Incremental Conductance (IC) method [6]-[10], Artificial Neural Network method [11], Fuzzy Logic method [12], Constant Voltage [13], Three Point weight Comparison [14], short Current Pulse [15], Open Circuit Voltage [16], the temperature method [17]. The most commonly used methods are Perturb and Observe (P&O), incremental conductance and three-point weight comparison.

Among these, incremental conductance (I&C) method is dominantly used in practical PV systems for the MPPT control due to its simple implementation, high reliability, and tracking efficiency [5],[18],[19]. I&C technique applies perturbation to the buck-boost DC-DC controller by increasing or decreasing the voltage reference of the PWM (Pulse Width Modulation) signal, sub sequently observes the effect on the PV output power . Problem that arises in I&C MPPT method is that the operating voltage in PV panel always fluctuating due to the needs of continuous tracking for the next perturbation cycle.

Hence, in this paper a fuzzy logic based MPPT technique is proposed. The proposed MPPT controller is designed for 1kW solar PV system installed at Cape Institute of Technology. The fuzzy logic based MPPT can track the maximum power point faster and also it can minimize the voltage fluctuation after MPP has been recognized.

II. MATHEMATICAL MODEL OF PHOTOVOLTAIC MODULE

The general model of solar cell can be derived from physical characteristic of the diode, which is usually being called as one diode model. The equivalent circuit of solar cell is shown in Fig.1 [20], [21]. Equation 1 shows the Shockley diode equation which describes the I-V Characteristic of diode D,

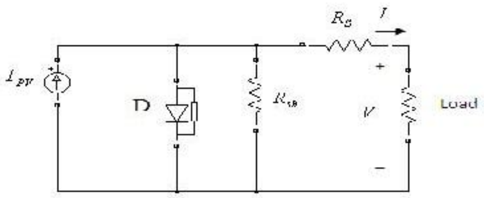


Fig.1. Equivalent circuit of a solar cell

where I_D is the diode current, I_{sat} is the reverse bias saturation current, V_D is the voltage across the diode, n is the solar ideal factor of the diode and V_T is the thermal voltage.

Thermal voltage V_T however can be defined as

$$V_T = \frac{KT}{q} \quad (2)$$

where K is Boltzmann constant (1.3806503*10^{-23} J/K), T is temperature in degrees Kelvin and q is electron charge (1.6021764*10^{-19} C).

To model the I-V characteristic of PV array, equation (3) can be derived from the circuit shown in Fig. 1,

$$I = I_{PV} - I_0 \left[\exp\left(\frac{V + R_S I}{V_t a}\right) - 1\right] - \frac{V + R_S I}{R_{sh}} \quad .....(3)$$

where I_{PV} is the light generated current, I_0 is the reverse saturation current, V is the PV array terminal voltage, R_S is the equivalent series resistance of the array and R_{sh} is the Equivalent parallel resistance .In addition, the I-V characteristic of the PV panel is also depending on the internal characteristics such as the series resistance Rs and parallel resistance Rsh.Theseries resistance is the sum of structural resistance of PV panel and it has strong influence when PV panel act as coltage source .The parallel resistance Rsh has great when PV panel act as Current source .

The light generated current of the photovoltaic cell depends linearly on the solar irradiation and is influenced by the temperature according to the following equation.

$$I_{pv} = (I_{pv,n} + K_i T)\frac{G}{G_n} \quad ....(4)$$

Where Ipv,n is the light –generated current at the normal condition(usually 25^0 C and 1000W/m^2),T=T-Tn (being T and T_n the actual and nominal temperatures [K]), G[W/m^2] is the irradiation on the device surface, and G_n is the nominal irradiation.

The diode saturation current I_0 and its dependence on the temperature is given by,

$$I_0 = \frac{I_{sc,n} + K_I T}{\exp\left(\frac{V_{oc,n} + K_V T}{\;}\right) - 1} \quad ....(5)$$

where a is the diode ideality constant. K_V and K_I is the current and voltage coefficients. $I_{sc,n}$ and $V_{oc,n}$ are the nominal short circuit current and nominal open circuit voltage. Fig. 2 and 3 shows the I-V and P-V characteristics for the XL 6P54G200 PV module at 25 °C and 1000W/m^2. Table 1 shows the parameter of the XL 6P54G200 PV module.

TABLE I

Parameters of the XL 6P54G200 PV module at 25 °C and 1000W/m^2

Peak Power (W), P_{MPP}	200
Peak Power Voltage (V), V_{MPP}	27.16
Peak Power Current (A), I_{MPP}	7.89
Open Circuit Voltage (V), V_{oc}	33.64
Short Circuit Current (A), I_{sc}	8.21
Temperature Coefficient of current (mA/ °C) , K_i	.003
Temperature Coefficient of voltage (mV/ °C) , K_v	-.123
Number of series cells, N_s	54

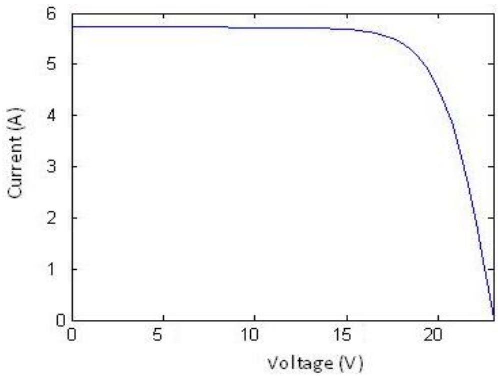


Fig.2 I-V Characteristics of 1kW solar PV system

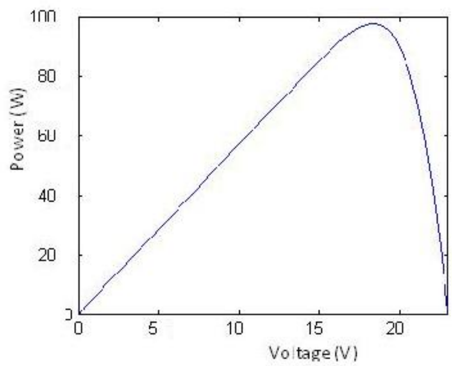


Fig.3 P-V Characteristics of 1kW Solar PV System

The PV array contains seven series assemblies with seven series connected PV modules, each with 54 solar cells assemblies of XL 6P54G200 PV Modules. When the modules are wired in parallel, their current rating is increased while the voltage remains constant. When the modules are wired together in series, their voltage is increased while the current remains constant. Hence, in this paper a fuzzy logic based MPPT technique is proposed.. The fuzzy logic based MPPT can track the maximum power point faster and also it can minimize the voltage fluctuation after MPP has been recognized

III. INCREMENTAL CONDUCTANCE

The incremental conductance (INC) method is based on the fact that the slope of the PV array power curve is zero at the MPP also positive on the left of the MPP and negative on the right, as given by the following equation and corresponding characteristics is shown in fig.4

$$\frac{dP}{dV} = 0 \quad \text{,at MPP}$$

$$\frac{dP}{dV} > 0 \quad \text{, left of MPP}$$

$$\frac{dP}{dV} < 0 \quad \text{, right of MPP}$$

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V.\frac{dI}{dV} = I + V.\frac{\Delta I}{\Delta V}$$

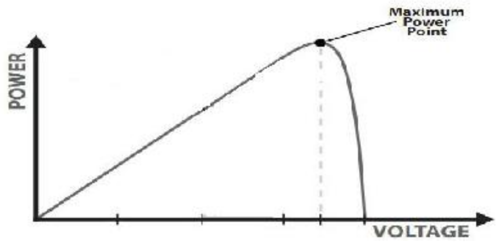


Fig.4Typical power-voltage characteristics of PV array

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V}, atMPP$$

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V}, atMPP$$

$$\frac{\Delta I}{\Delta V} < -\frac{I}{V}, atMPP$$

Fig.5 represents the flowchart for INC MPPT algorithm. The PV array terminal voltage can be adjusted relative to the MPP voltage by measuring the incremental conductance (I/V*)* and instantaneous conductance (*ΔI/ΔV*). Once the MPP is reached, the operation of thePV array is maintained at this point unless a change in Δ*I* is noted. Incase of dP/dV>0, the voltage is increased and in case of dP/dV<0, the voltage is decreased to select the MPP.

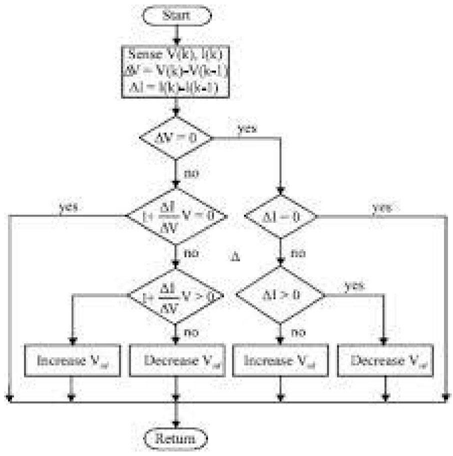


Fig.5 Flow chart of INC MPPT Algorithm

A maximum power point (MPP) tracker is designed by the combination of incremental conductance algorithm [4],[11] Which triggers the duty cycle of the DC/DC converter. Bychanging the duty cycle of converter, the PV panel is made to deliver the maximum power at that irradiance to the load. The Matlab/simulinkmodel of Incremental conductance algorithm to track maximum power output, along with a DC/DC boost converter is shown in Fig.6

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation intoelectrical energy. Maximum power point tracking technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximumwhen the source impedance matches with the loadimpedance. In the source side a boost converter is connected to a solar panel in order to enhance the output voltage. By changing the duty cycle of the boost converter appropriately the source impedance is matched with that of the load impedance. Several approaches have been proposed for tracking the MPP [4]. Among those methods, the perturb and observe (P&O) and incremental conductance (INC) methods are widely usedalthough they have some problems such as the oscillation around MPP and confusion by rapidly changing atmospheric conditions [6,7]. In general, these tracking approaches use a fixed iteration step size, which is determined by the accuracy and tracking speed requirement.

The left hand side is the instantaneous conductance of the solar panel. When this instantaneous conductance equals the conductance of the solar then MPP is reached. Here we are sensing both the voltage and current simultaneously. Hence the error due to change in irradiance is eliminated. However the complexity and the cost of implementation increases. As we go down the list of algorithms the complexity and the cost of implementation

Goes on increasing which may be suitable for a highly complicated system. This is the reason that Perturb and Observe and Incremental Conductance method are the most widely used algorithms. Owing to its simplicity of implementation we have chosen the Perturb & Observe algorithm for our study among the two.

III. PROPOSED METHOD

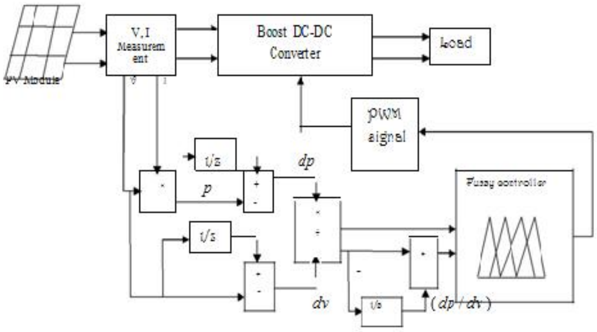


Fig. 6 Fuzzy logic based MPPT solar PV panel

The output voltage and current of the PV panel are measured and fed to the fuzzy based MPPT control unit foMPPtracking. Based on the change of power with respect changeof voltage and , fuzzy determines the voltage $dV\ dV$ reference of the PWM (Pulse Width Modulation) signal. The proposed fuzzy logic based MPPT technique is discussed in section V.

IV.REVIEW OF FUZZY LOGIC

Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership. Fuzzy logic allow us to emulate the human reasoning process in computers, quantify imprecise information, make decision based on vague and in complete data, yet by applying a "defuzzification" process, arrive at definite conclusions.

The FLC mainly consists of three blocks

- Fuzzification
- Inference
- Defuzzification

(i) Fuzzification

The fuzzy logic controller requires that each input/output variable which define the control surface be expressed in fuzzy set notations using linguistic levels. The linguistic values of each input and output variables divide its universe of discourse into adjacent intervals to form the membership functions. The member value denotes the extent to which a variable belong to a particular level. The process of converting input/output variable to linguistic levels is termed as Fuzzification.

(ii) Inference

The behavior of the control surface which relates the input and output variables of the system is governed by a set of rules. A typical rule would be

If x is A THEN y is B

When a set of input variables are read each of the rule that has any degree of truth in its premise is fired and contributes to the forming of the control surface by approximately modifying it. When all the rules are fired, the resulting control surface is expressed as a fuzzy set to represent the constraints output. This process is termed as inference.

(iii) Defuzzification

Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. There are several methods available for defuzzification. The most prevalent one is centroid method, which utilizes the following formula:

$$\frac{\int (\propto (x)\, x) dx}{\int \propto (x) dx} \qquad (6)$$

where $\propto$ is the membership degree of output x.

V.PROPOSED FUZZY LOGIC CONTROLLER

Fuzzy logic is implemented to assist the conventional MPPT technique to obtain the MPP operating voltage point faster and also it can minimize the voltage fluctuation after MPP has been recognized [21],[22].

The proposed fuzzy logic based MPPT controller, shown in Fig. 7, has two inputs and one output.

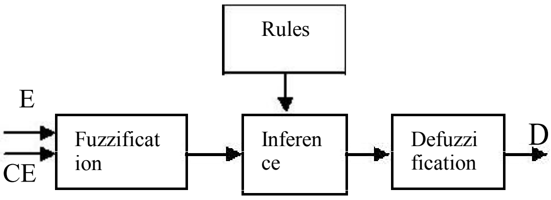


Fig. 7 General diagram of a fuzzy controller

In the proposed fuzzy logic based technique the error (E) and changing error (CE) are taken as input variables which are as below for k^{th} sample time.

$$E(k) = \frac{dP}{dV} = \frac{P_{ph}(k) - P_{ph}(k-1)}{V_{ph}(k) - V_{ph}(k-1)} \qquad (7)$$

$$CE(k) = E(k) - E(k-1) \qquad (8)$$

where $P(k)\,ph$ is the power of the photovoltaic generator. The input E (k) shows the change of power with respect to the change of voltage. Another input CE (k) expresses the change of error.

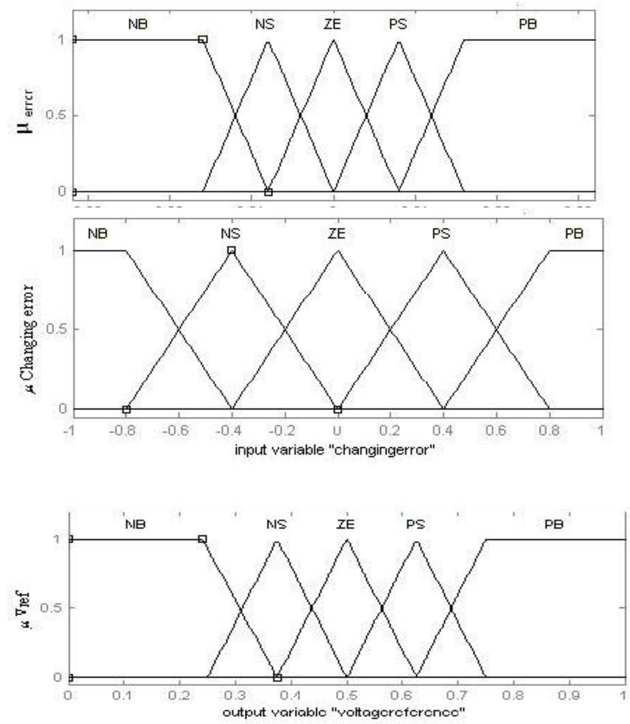


Fig. 8 Membership functions of (a) error E (b) Changing error

CE (c) Voltage reference V_{ref}

Table II: Fuzzy Rule Table.

CE \ E	**NB**	**NS**	**ZE**	**PS**	**PB**
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NS	NB	NB	ZE	ZE

To design the FLC, variables which can represent the dynamic performance of the system to be controlled, should be chosen as the inputs to the controller. In the proposed method, the derivative of the change of power with respect to change of voltage (dP/dV) and change of (dP/dV) are considered as the inputs of the FLC and the voltage reference for modulated signal generation is taken as the output of the FLC. The input and output variables are converted into linguistic variables. In this case, five fuzzy subsets, NB (Negative Big), NS (Negative Small), ZE (Zero), PS (Positive Small) and PB (Positive Big) have been chosen. Membership functions used for the input and output variables are shown in Fig.8. As both inputs have five subsets, a fuzzy rule base formulated for the present application is given in table 2. The performances of fuzzy logic based MPP tracking are able to reduce the perturbed voltage after the MPP operating voltage has been recognized.

VI. SIMULATION RESULTS

The PV module is modeled in MATLAB-SIMULINK using equation (3) with the assumption that the PV module has constant temperature of 25^{o}C. The PV array contains seven series assemblies with seven series connected PV modules, each with 54 solar cells assemblies of XL 6P54G200 PV Modules. The ratings of PV modules are $P_{MPP} = 200W$, $V_{MPP} = 27.16V$, $V_{OC} = 33.64V$ and $V_{OC} = 7.89\,A$ at an Insolation level of $1000W/m^2$ and 25 $°C$ temperature. A pure resistive load is connected to the PV module through the buck boost dc-dc converter. The performance of the proposed technique has been examined for fixed solar radiance at $1000W/m^2$.

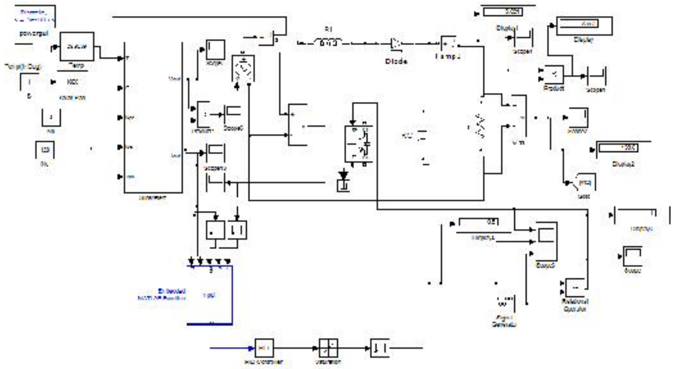
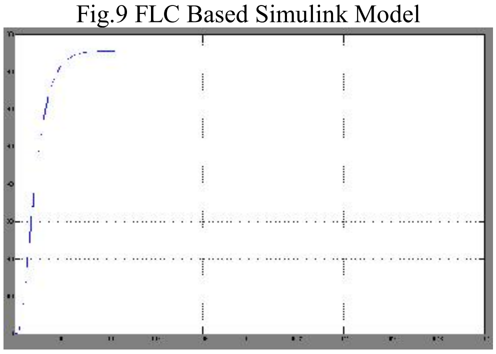
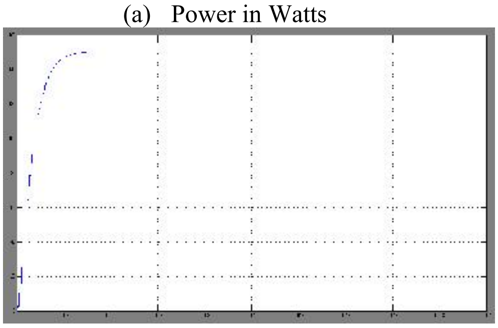


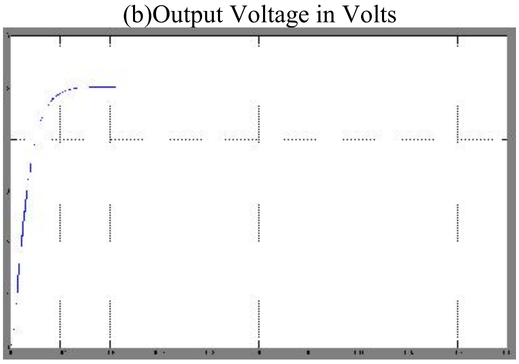
Fig.9 FLC Based Simulink Model



(a) Power in Watts



(b)Output Voltage in Volts



(b) Output Current in Amps

Fig.10 I&C, responses for standard conditions of temperature 25 $°C$ and irradiation $1000W/m^2$

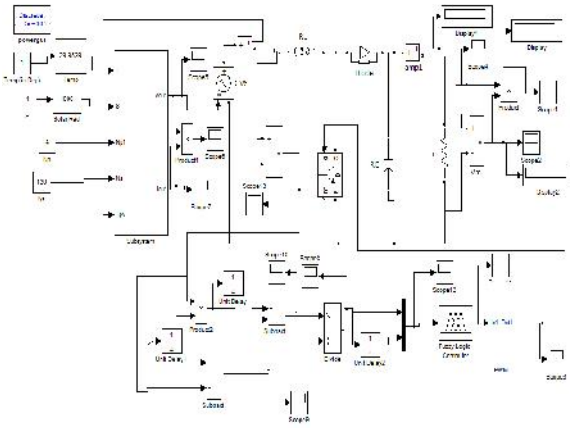
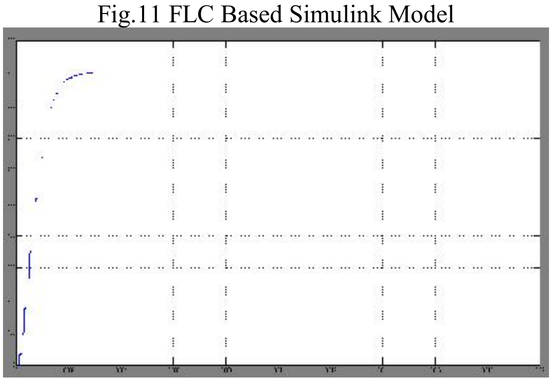
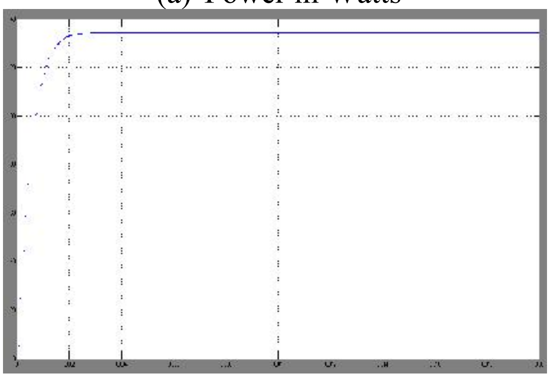


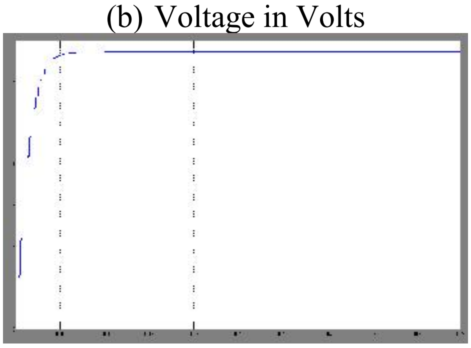
Fig.11 FLC Based Simulink Model



(a) Power in Watts



(b) Voltage in Volts



(c) Current in Amps

Fig.12 Fuzzy and I&C, responses for standard conditions of temperature 25 $°C$ and irradiation 1000W/m^2

Fig.10 (a), (b) and (c) shows the results of PV operating power, voltage and current of the triangular and Gaussian membership functions, respectively. From this figure, it is observed that the fuzzy can track the maximum power point at 0.01s and also it generates constant voltage without any deviations. The performance of the fuzzy based MPPT technique is compared with the conventional I&C MPPT. It shows that the conventional I&C MPPT tracks the maximum power point at 0.015s and also it does not have the ability to reduce the perturbed voltage.

Hence from the investigation, it is clear that the PV power which is controlled by the proposed fuzzy controller is more stable than the conventional MPPT techniques. From the data given in Table 3, it is observed that the fuzzy can track the maximum efficiency compared to the conventional I&C MPPT techniques.

TABLE III

Power generated as a function of MPPT technique

MPPT METHOD	CURRENT(A)	VOLTAGE(V)	POWER(W)
FUZZY MPPT	6.8	133	905
I&C Method	5.1	151	770

VII. CONCLUSION

This paper has presented an intelligent MPPT control strategy for the PV system using fuzzy logic controller. The maximum power point tracking technique was simulated using MATLAB/Simulink. The proposed fuzzy logic based MPPT technique can track the maximum power point faster compare to the I&C based mppt technique. It has the capability of reducing the voltage deviations after MPP has been recognized. The simulation results show the efficiency of the fuzzy logic controller in maintaining the stable maximum power point.

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