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Design of A Solar MPP Charge Controller using Mamdani FIS with Generalized Bell-Shaped Membership Function

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Abstract**:** ***This research work proposes an innovative control technique for monitoring the maximum power point of the standalone photovoltaic system fast and precisely at variable solar cell temperature and insolation. In this work, the method uses a Mamdani FIS based fuzzy logic controller which uses bell shaped membership function to track MPPT of the off grid solar module. A sampling process is used to measure the PV array power and voltage that decides an optimal increment of sample which is required to get the optimal operating voltage that permits maximum power tracking. This method provides high accuracy and reliable result around the optimum point. This proposed controller has shown a better performance compare to existing methods with a power conversion efficiency of ~100%. Different steps of designed controller with the proposed method has been shown along with its simulation.***

Index Terms**:** ***Photovoltaic, fuzzy, Mamdani, bell shaped function, MPPT, FIS.***

I. INTRODUCTION

Mamdani fuzzy inference system (FIS) was first developed as a tool for constructing a control technique by simulating a collection of language command rules [1]. Because Mamdani systems are more intuitive and easier to understand, they are ideal for the intelligent systems where the rules are generated. Each rule produces a fuzzy set derived from the function of membership of the output and the FIS system of inference. Using the FIS aggregation process the fuzzy sets are aggregated to make a single fuzzy array. The combined output fuzzy array is then de-fuzzified using one of the methods described in the Defuzzification Methods to determine a final crisp output value. A typical Mamdani fuzzy interface system is described by Fig.1. The main advantages of Mamdani FIS are intuitive, well-suited to human input, more interpretable rule base, have widespread acceptance.

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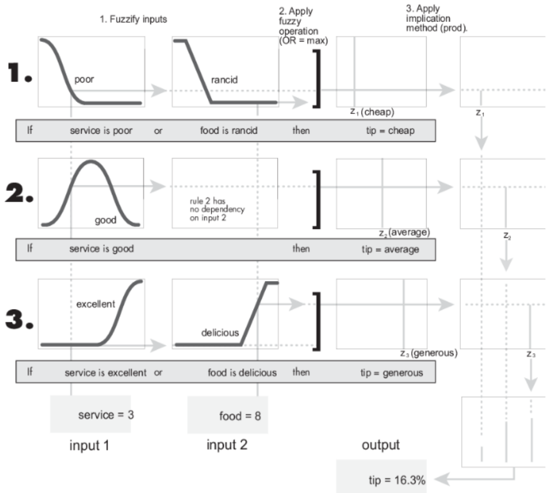

Fig. 1. Mamdani fuzzy interface system

A symmetrical structure similar to a bell is the generalized bell-shaped membership function (Gbellmf). This function uses three parameters as expressed by a specifies the bell's length as curve, b is a positive integer, while c sets the center of the curve in the discourse universe (Fig. 2).

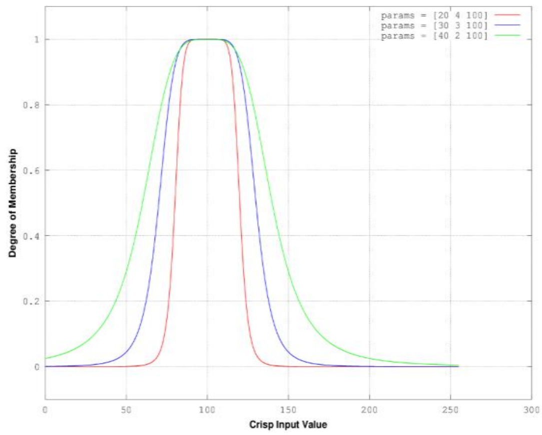

Fig. 2. Bell shaped membership function

A bell shaped function can be defined as,

$$bell(x,a,b,c)=\left(\frac{1}{1+\left|\frac{x-c}{a}\right|^{2b}}\right)$$

II. DESIGN OF THE CONTROLLER

The block diagram of proposed scheme is shown in Fig.3. This system is made up of a PV panel (P_{max}= 130W approx..), Fuzzy Logic Controller (FLC) and a boost converter.
A Dc link capacitor is connected in shunt with the PV module. The specification of the module is elaborated in Table 2. The output The FLC has been used to peak power point of PV modules because of its robust nature, simple to design and also not requires knowing of exact model. Typical FLC-based MPPT controller involves three fundamental parts, i.e. module of fuzzification, inference engine and module of defuzzification. [3]. The main FIS block (Fig. 4) contains the main fuzzy logic controller unit along with other circuitry components. The output voltage (V_{pv}) and current (I_{pv}) are taken as inputs to this block. To generate dV and dP, memory blocks are used to incorporate delay. Finally, these two signals re fed to the fuzzy logic controller unit. This unit is defined by the FIS file. This is defined by the Fig. 7. In that file the rules are defined accordingly.

A. Fuzzification module

The fuzzification allows the transition from real data to fuzzy data. It is possible to measure the real voltage (V) and present (I) of the PV generator continually and to calculate the energy (P= V×I). The control is determined on the grounds of the fulfillment of two requirements pertaining to the suggested controller's two input factors, namely error E (representing the slope of the trait P-I) and shift of this error (CE), at instant sampling k [4]. The followings are expressed in variable E and CE,

$$E(K) = \frac{P(k)-P(k-1)}{I(k)-I(k-1)}$$

$$CE(k) = E(k) - E(k-1)$$

Where P(k) and I(k) are the PV generator's power and current, respectively.

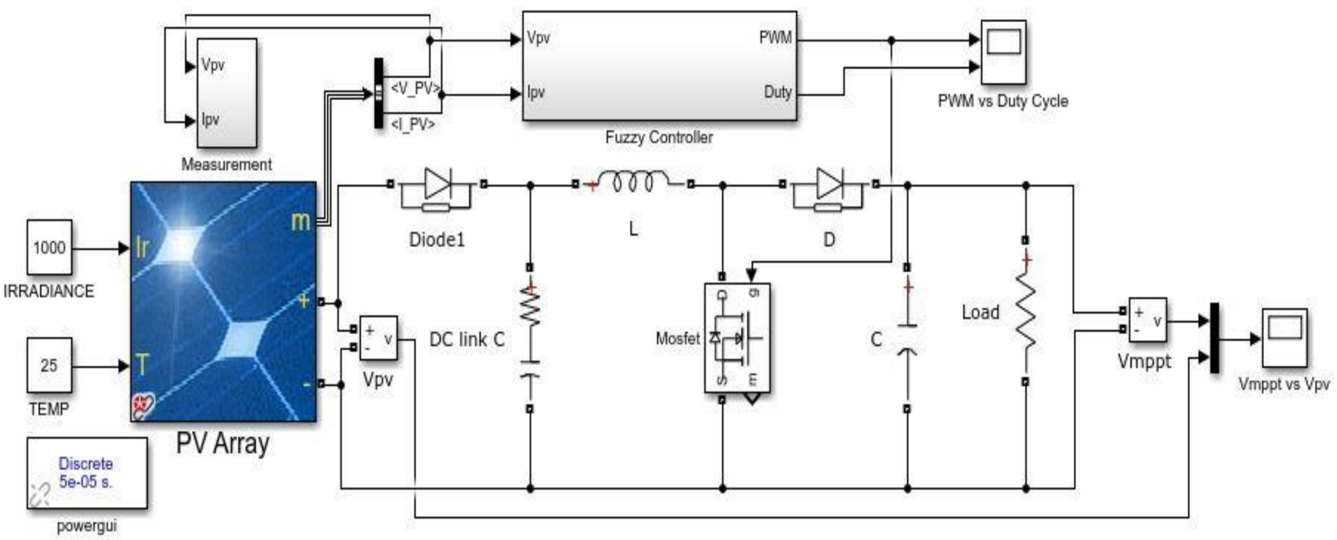

Fig. 3. Simulink Model of the MPPT model based on Mamdani FIS

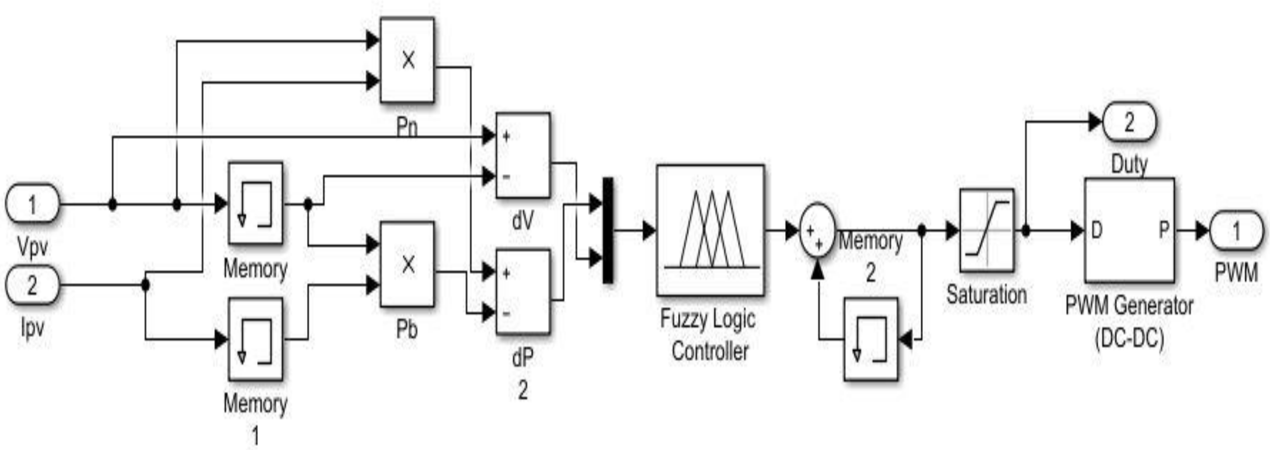

Fig. 4. Design of the Mamdani FIS block based on bell shaped membership function

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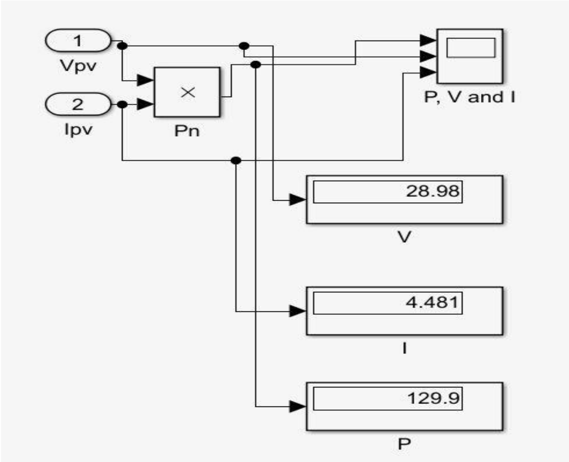

Fig. 5. Output voltage, current and power of the controller

The duty ratio change of the DC-DC converter is used as the suggested output of the controller. The control is therefore performed by altering this duty ratio according to the slope E(k) to return the operating point to the ideal level where the slope is zero. As depicted in Fig. 6, The input variables of the fuzzy controller (P, dV) are acquired from the actual signals (e, ce) by multiplying the corresponding rises in scale (S_E, S_{CE}) and then converting to semantic factors such as NB, NM, NS, ZE, PS, PM, PB using the basic fuzzy subset. Fig.6 demonstrates the affiliation grades for input and output factors of five fundamental fuzzy subsets.

B. Interference engine

Inference Engine determines fuzzy output by applying rules to the fuzzy input that generated from fuzzification process [5-6]. To acquire the respective linguistic value (which is essential to determine fired or active laws), the crisp input value must be flushed after the rules can be assessed and the degree to which each portion of the precedent has been satisfied for each rule. [7]. The rule table of fuzzy controller has shown in Table 1, where all the enters of the matrix are fuzzy sets of P, dV and change of duty ratio D of the controller (Fig. 10). The 26 control fuzzy rules that shown in table can be presented in 3-dimensions (3-D) graph as described in fig. 8. When the DC-DC boost converter reaches the PV generator's MPP, the rules are used to control that converter. As shown in the Table 1, the target is to operate MPP simply by increasing or decreasing the duty ratio depending on MPP's position. With the increasing distant of MPP from operating point, the duty ratio also increased or decreased eventually. An example of control rule demonstrates in Fig. 9 below.

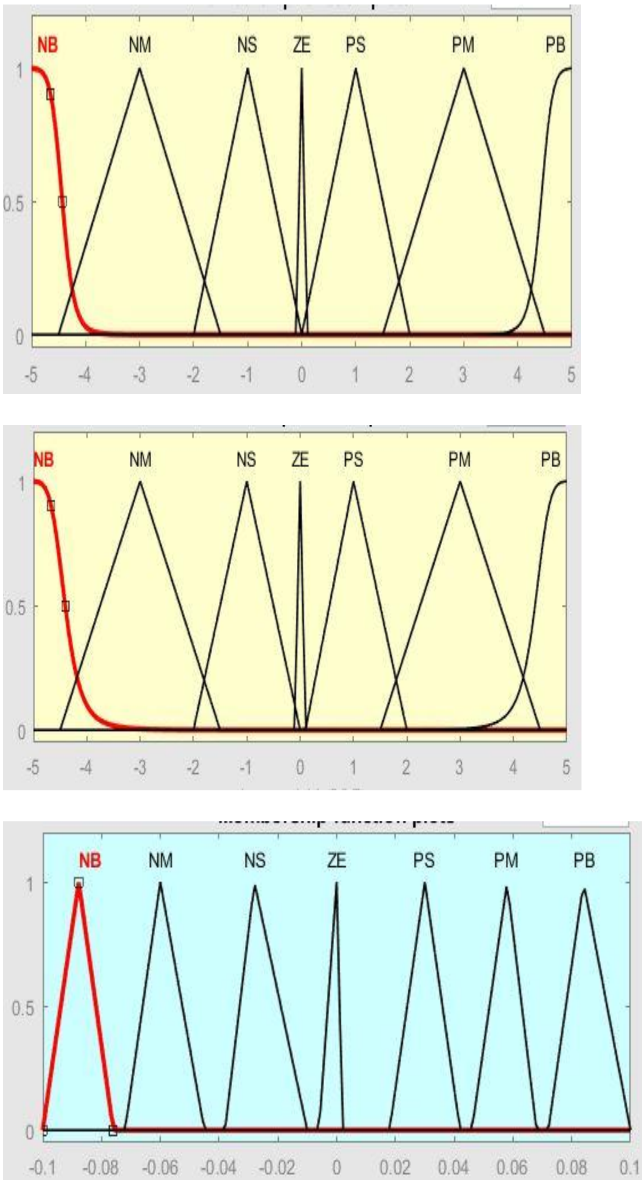

Fig. 6. Membership functions for: (a) dP (b) dV and (c) D.

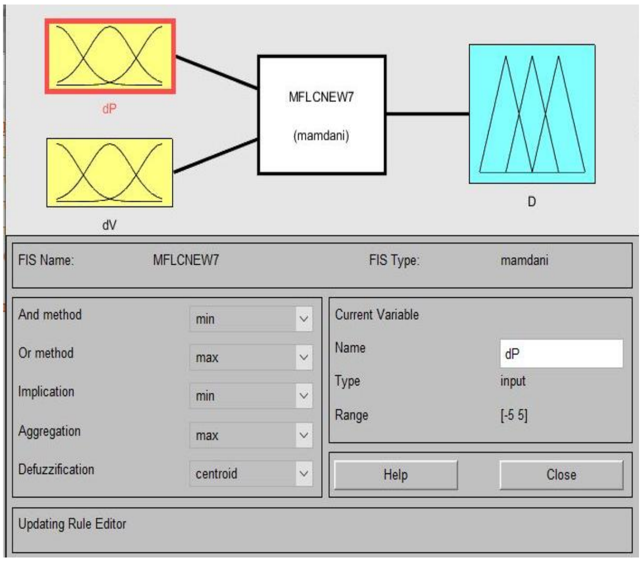

Fig. 7. Fuzzy logic designers based on Mamdani logic.

Table 1: Fuzzy Set to obtain D

dP	dV					
	NB	**NM**	**NS**	**ZE**	**PS**	**PB**
NB	**NB**	**NB**	**NB**	**NB**	**NB**	-
NM	**NM**	**NM**	**ZE**	**ZE**	**NS**	-
NS	**ZE**	**PS**	**ZE**	**PS**	**ZE**	-
ZE	**PS**	**PS**	**ZE**	**ZE**	**PS**	-
PS	**PM**	**PM**	**PM**	**PM**	**PM**	-
PB	-	-	-	-	-	**PB**

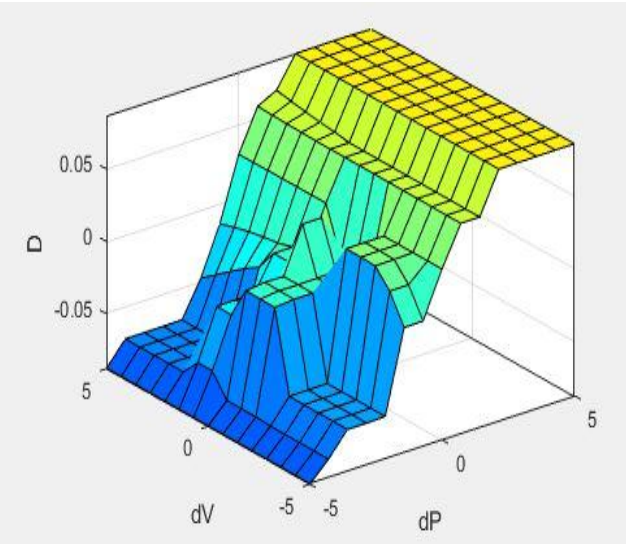

Fig. 8. 3-dimensions (3-D) Surface view for fuzzy inputs (P,dV) vs output (D)

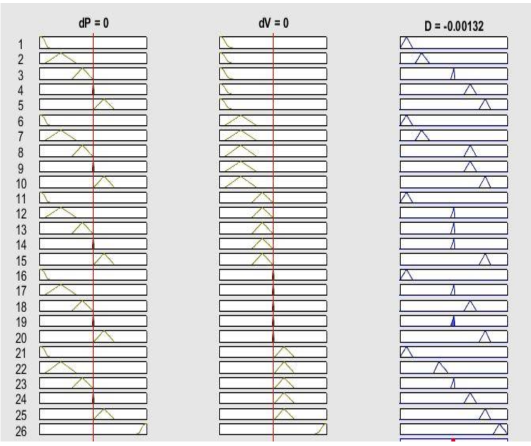

Fig. 9. Rule viewer in MATLAB windows of Fuzzy logic controller for dP, dV and D.

C. Defuzzification

The inference techniques generate resultant membership function that functions as fuzzy data. [8-9]. As the desired output is non fuzzy value thus, conversion of the fuzzy value to non-fuzzy value with in a proper process is needed which is called defuzzification. Centroid is one of the existing methods. The center of mass of the aggregated membership function is calculated to de-fuzzify the crisp value from the fuzzy controller. This crisp value is the changing signal duty cycle that turns the IGBT on in the circuit.

D. Simulation model

The PV was constructed and simulated in MATLAB / Simulink to evaluate the efficiency of the suggested FLC [10-11]. Using the Simscape toolbox, PV system simulation is introduced while the boost converter is applied. Controlled current source is used to link the booster converter to the PV system. Each module is permitted to obtain distinct irradiation levels. The voltage signal is saved in a memory to subtract present and past values to enter the block of the fuzzy controller. Fuzzy block logic controller calls to the fuzzy system and transfers the inputs. This s model also passes the fuzzy engine output straight to the converter from the fuzzy system. Connected to a boost converter, a fuzzy controller controls the PV system.

Table 2: The specification of the solar panel in STC condition used in simulation

Maximum power	129.94 W
Open circuit Voltage (Voc)	36.3 V
Short circuit current (Isc)	4.82 A
MPP voltage	29.2 V
MPP current	4.45 A

IV. RESULTS AND DISCUSSION

The system was tested for STC condition (G=1000 W/m^2, T= 25° C). A off grid solar module which had a maximum power of 129.94 W was used. The specification of the module is described in the table above. The MPP voltage (V_{mpp}) and current (I_{mpp}) of the module was defined as 29.2 V and 4.45 A respectively for STC condition. The controller tracked the MPP precisely with an output power of 129.9 W at V_{pv}= 28.98V and I_{pv}= 4.48A which is almost equal to V_{mpp} and I_{mpp} respectively (Fig. 5). The output efficiency of the controller was calculated as almost 100% which is really impressive. The V_{pv} vs V_{mpp} graph is depicted by Fig. 11(a) and the V_{pv}, I_{pv} and P_{pv} graphs are represented by Fig. 11(b). Further the system was tested for variable irradiance (G) with the help of signal builder block in MATLAB. This variable irradiance conditions signify how fast and precisely a controller attains the MPP in changing ambient condition in real time scenario. A set of changing irradiances (100, 250, 500, 750, 1000) W/m^2 was fed in time intervals of (0.5, 1, 1.5, 2, 2.5) s to the module. In each case, the fuzzy controller was able to track the corresponding MPPs for different irradiances (Fig. 12 (a)) and the V_{pv}, I_{pv} and P_{pv} graphs are represented by Fig. 12(b). So, the controller is not only efficient to get the MPP for a fixed irradiance but it precisely tracks the MPPs for different values of irradiances even when change rapidly with high accuracy.

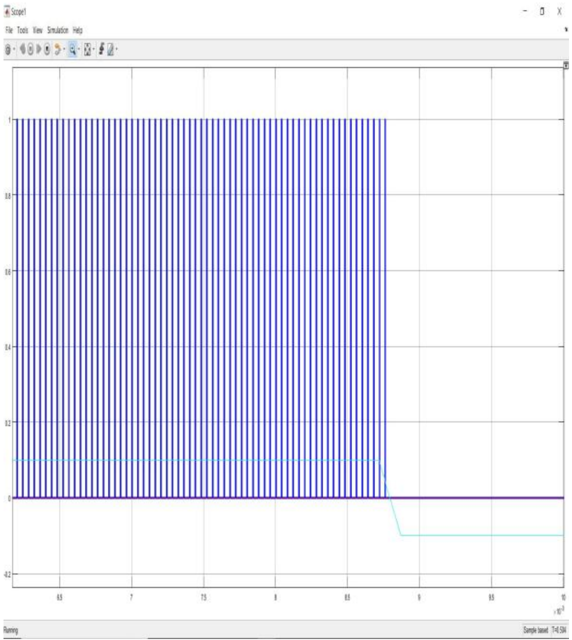

Fig. 10. PWM signal that is generated by the fuzzy logic controller

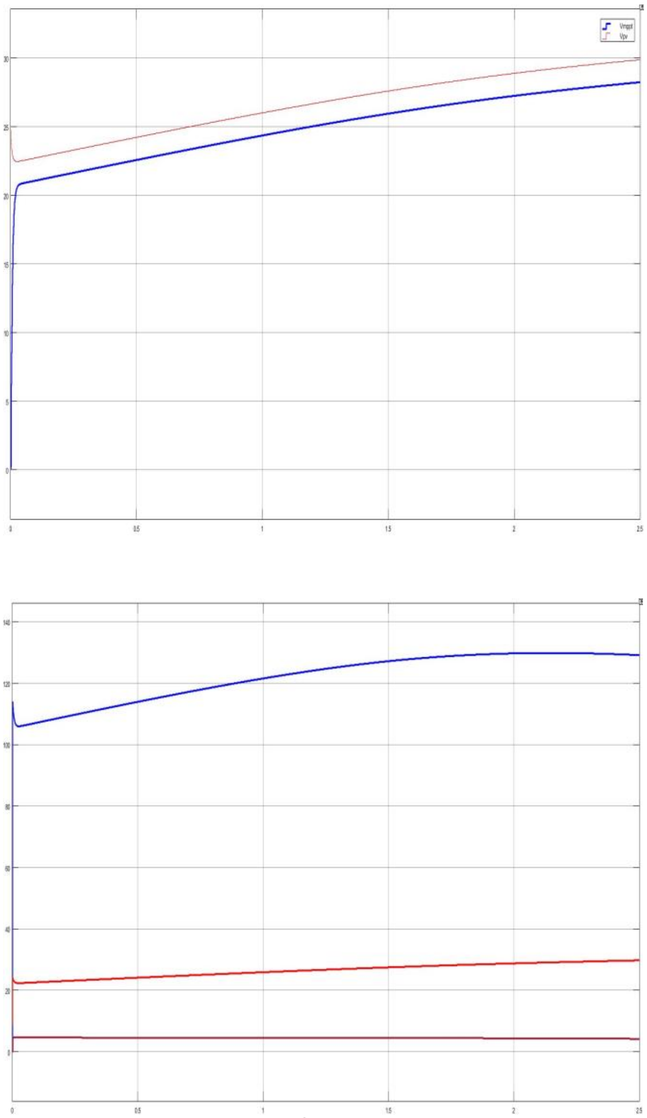

Fig. 11. At G= 1000 W/m^2, (a) tracking of MPP voltage (V_{mpp} vs V_{pv}) by the controller. (b) output voltage, current and power.

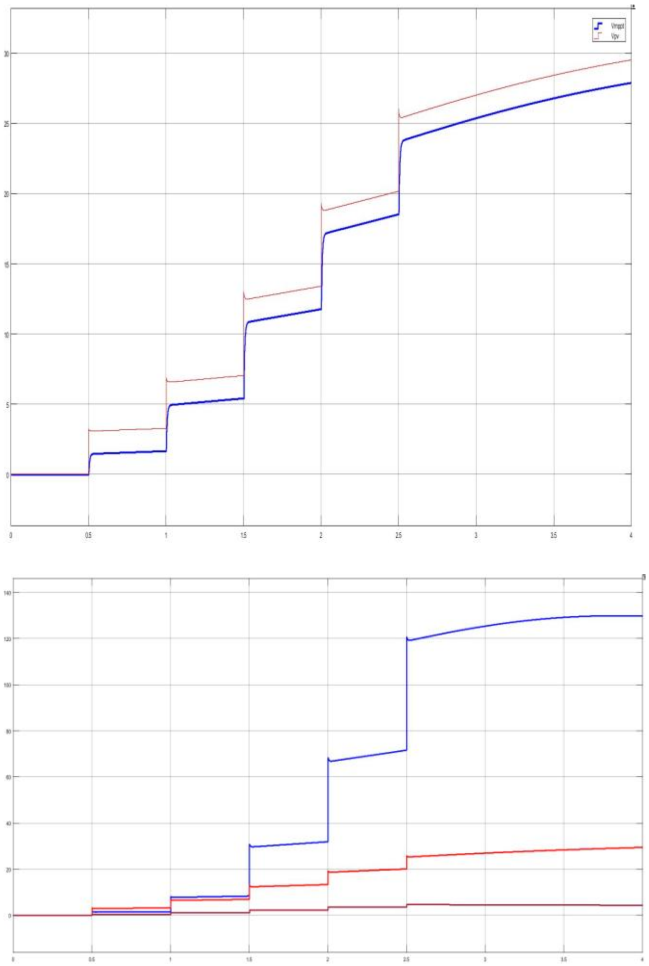

Fig. 12. At variable G, (a) tracking of MPP voltage (V_{mpp} vs V_{pv}) by the controller. (b) output voltage, current and power.

V. CONCLUSION

In this research work, a maximum power point tracking solar charge controller was designed based on Mamdani fuzzy interface system with generalized bell-shaped membership function. The model was simulated MATLAB/Simulink. The inbuilt fuzzy controller block was used to simulate. The Mamdani FIS system was incorporated instead of Takagi-Sugeno fuzzy model as the earlier one has some advantages over the later one. Out of different membership functions, the bell-shaped function was chosen due to its added features and accuracy. The input and output functions were defined using the function based on 26 rules set. The rules were made logically to detect changes in input voltage and output power of the solar module. Based on this voltage and power of the module, the duty cycle was generated. The voltage and power were fed as input and the duty cycle was generated as output of the interface engine. This duty ratio was further converted to a PWM signal to switch IGBT of the proposed controller. So, the controller acted independently and as per the rules defined in the engine. The system was capable to track the MPP of the solar power precisely both for constant irradiance and even in a condition when the ambient condition changes rapidly due to change in irradiance. The controller delivered output efficiency of almost 100%.

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