MAXIMUM POWER POINT TRACKING OF SOLAR PHOTO VOLTAIC BY PERTURB & OBSERVE AND FUZZY LOGIC CONTROL – A COMPARATIVE STUDY"

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Abstract:

Power generation through Solar photovoltaic is a vitalmethod using non pollutant,renewable energy source. The power which is obtained directly from solar radiation by the Photovoltaic panel is not steady, because of variations in solar intensity. To maximize the Photovoltaic panel output power, maximum power point tracking (MPPT) has been introduced into the system. A buck-boost DC-DC converter is used to vary the Photovoltaic panel operating voltage and search for the maximum power that the Photovoltaic panel can produce. In this paper, the implementation of Perturb & ObserveMPPT and fuzzy logicMPPT control arecompared. Based on the change in power input and change in voltage with respect to change in power input, fuzzy can determine and facilitate the maximum power tracking faster and minimize the voltage variations, after the maximum power point is found. Simulation results exhibit that the performance of fuzzy based MPPT is better than conventional Perturb & ObserveMPPT.

Keywords—Photovoltaic, Maximum Power Point Tracking, Buck-Boost converter, Perturb & Observe, Fuzzy Logic

I. INTRODUCTION

Most of the countries, throughout the world, have the awareness now, thatthe solar photovoltaic is an important renewable energy source for electricity generation, where the solar density is relatively high. Solar photovoltaic is a phenomenon where the solar radiation is directly converted into electricity with the help of a solar cell. The advantage of this process is, it does not have any materials to be consumed or emitted. Solar electrification can be applied even in rural areas where stand-alone photovoltaic system can supply adequate electricity for certain area independently without the need of having connection with utility grid.The photovoltaic array has a particular operating point that can supply the maximum power to the load which is generally called maximum power point (MPP). The maximum power point has a non-linear locus where it varies according to the solar irradiance and the cell temperature. To boost the efficiency of photovoltaic system, the maximum power point has to be tracked followed by regulating the photovoltaic panel to operate at maximum power point operating voltage point, thus optimizing the production of electricity. This process can draw as much power as possible that the photovoltaic panel can produce. There are several methods that have been widely implemented to track the MPP. The most widely used methods are Perturb and Observe (P&O), Incremental Conductance (IC) and Three-point Weight Comparison. In this paper, P&O MPPT is investigated. P&O technique applies perturbation to the buck-boost DC-DC controller by increasing or decreasing the pulse width modulator (PWM) duty cycle, subsequently observes the effect on the PV output power. If the power at present state is larger than previous state, the controller's duty cycle shall be increased or vice-versa, until the MPP operating voltage point is identified. Problem that arises in P&O MPPT method is that the operating voltage in photovoltaic panel always fluctuating due to the needs of continuous tracking for the nextperturbation cycle.In this paper, fuzzy logic is proposed to be implemented in MPPT. Fuzzy logic is robust and relatively simple to design since fuzzy do not require information about the exact model. The photovoltaic power at the present state will be compared with the photovoltaic power at the previous state and the change of power will be one of the inputs of fuzzy. Another input is the change in power with respect to change in voltage. Based on these two inputs, fuzzy can determine the size of perturbed voltage. Therefore, fuzzy based MPPT can track the maximum power point faster. In addition, Fuzzy can minimize the voltage fluctuation after MPP has been recognized.

II. SYSTEM DESCRIPTION

The fuzzy based MPPT solar photovoltaic system is illustrated in Fig. 1. The system consists of a photovoltaic panel, buck- boost converter, fuzzy based MPPT control unit and a load. The power produced by photovoltaic panel is supplied to the load through a buck boost converter. The output voltage and current from the photovoltaic panel are fed to the fuzzy based MPPT control unit to determine the perturbed voltage reference for buck-boost converter.

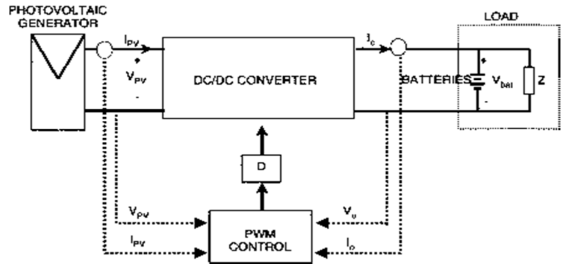

Fig. 1: Fuzzy based MPPT solar PV system

A. Modeling Of PV Panel

The general model of solar cell can be derived from physical characteristic called one diode model. The equivalent circuit of solar cell is shown as Fig. 2.

The Shockley diode equation which describes the I-V characteristic of diode is shown in equation (1)

$$I_D = I_0\left(\exp\left(\frac{V_D}{nV_T}\right) - 1\right) \quad (1)$$

Where, I_D is the diode current, I_0 is the reverse bias saturation current, V_D is the voltage across the diode, ηis ideality factor of the diode and V_T is the thermal voltage. Thermal voltage V_T however can be defined as in equation (2)

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

Where, K is Boltzmann constant (1.3806503×10^{-23} J/K), T is temperature in degree Kelvin and q is charge of an electron (1.60217646×10^{-19} C).

To model the I-V characteristic of photovoltaic array, equation (3) has been derived, based on the equivalent circuit in Fig. 2,

$$I = I_{PV} - I_0 \exp\left[\left(\frac{V_{PV} + IR_S}{nV_T}\right) - 1\right] - \frac{V_{PV} + IR_S}{R_P} \quad (3)$$

Where, I is the current at terminals of photovoltaic array, I_{PV} is the photovoltaic array current, V_{PV} is the photovoltaic array terminal voltage, R_S is the equivalent series resistance of the array and R_P is the equivalent parallel resistance. Unlike the electrical generators which are generally classified as either current source or voltage source, the photovoltaic device presents hybrid behavior. Photovoltaic panel acts as a current source when the panel operates at voltage smaller than MPP voltage point but it acts as voltage source when it operates at voltage larger than MPP voltage point. The series resistance R_S has a strong influence when photovoltaic panel acts as voltage source whereas the parallel resistance R_P has great influence when the photovoltaic panel acts as current source. R_S is the sum of structural resistance of PV panel however R_P exists due to leakage current of p-n junction depending on the fabrication method of the photovoltaic cells. Generally, R_P is very high and R_S is very low. High resistance R_P blocks the PV panel from short-circuited and low resistance of R_S allows the current flow to the load without resistance. Hence, these parameters can be neglected.

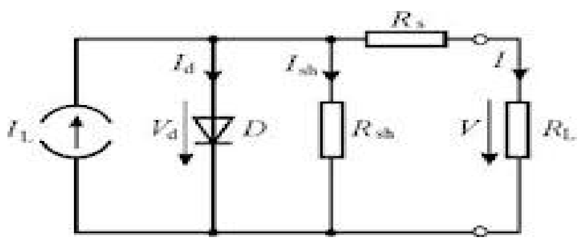

Fig. 2: Equivalent circuit of solar cell.

The characteristics of 80W SHARP NE-80E2EA multi crystalline silicon PV module has been studied. The SHARP NE-80E2EA is modeled in MATLAB-SIMULINK using equation (3) with the assumption that the PV module has constant temperature of 25^0C. Since R_S is very small and R_P is very high, it can be assumed that Ipv is equal to PV panel short circuit current (Isc). The parameters obtained from SHARP NE-80E2EA datasheet for PV panel modeling are shown in Table 1. Fig. 3 shows the P-V characteristic of the PV panel at different solar radiation. It can be noticed that the MPP operating voltage point of PV panel varies at different solar radiation. As the solar irradiance increased, the MPP voltage point is higher. Fig. 4 shows the P-V characteristic of PV panel at 600W/m^2 solar irradiance and the corresponding I-V curve. The PV panel modeled in MATLAB-SIMULINK has similar characteristics that described in SHARP NE-80E2EA datasheet.

Table 1

Parameters of SHARP NE-80E2EA PV

Array at 25 ^{0}C and 1000W/m^{2} solar irradiance

Parameters Symbol	**Typical value**
Open circuit voltage (Voc)	Voc 21.3V
Maximum powervoltage	17.1V
Short circuit current Isc	5.16A
Maximum power current	4.68A
Maximum power Pm	80W
No. of cells	36

B. Buck-Boost DC-DC Converter

Buck-boost DC-DC converter is an important element in PV system since buck-boost converter is able to regulate the output voltage that may be less or greater than the input voltage. Buck-boost converters allow more flexibility in modulating the energy transfer from the input source to the load by varying the duty cycle D. Fig. 5 shows the circuit diagram of buck-boost DC-DC converter. The operation of the buck-boost converter can be divided into two modes, namely "on" state and "off" state.

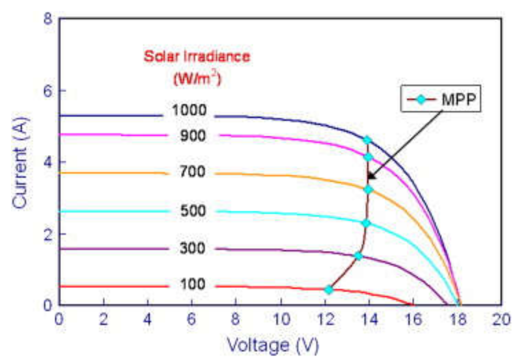

Fig. 3: Power-voltage characteristic of PV panel at different solar irradiance

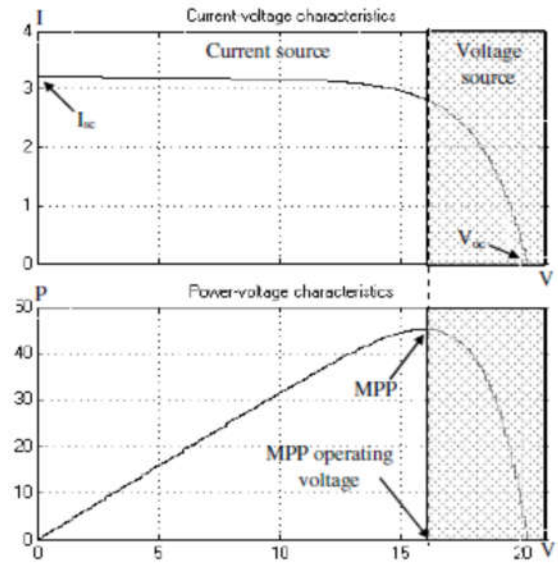

Fig. 4: Current-voltage characteristics power and voltage characteristics of PV panel for solar irradiation of 600W/m^2

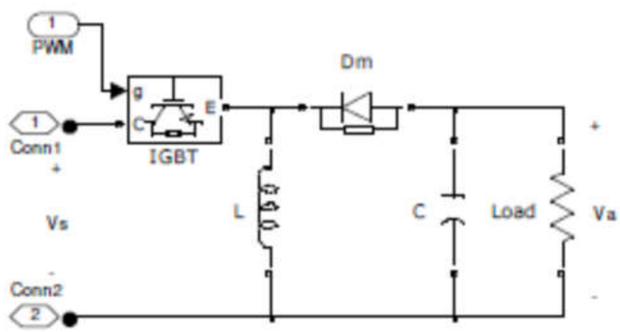

Fig. 5: Circuit diagram of Buck Boost converter

During the "on" state, the IGBT is turned on and the diode D_M is reverse biased. The current from the input source flows through the inductor L. When IGBT is turned off, during "off" state, the energy stored in the inductor L will be transferred to the load until the next "on" state. By varying the duty cycle D, the output voltage is changed accordingly. The duty cycle D however can be delivered by MPPT control unit.

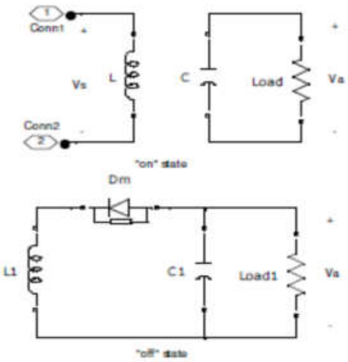

Fig. 6: The operation of buck-boost converter.

In buck-boost converter, the output polarity is opposite to the input polarity. Fig. 6 is the operation of buck-boost converter. The relationship among the load voltage V_a, input source voltage V_S and duty cycle D can be described as equation (4).

$$D = \frac{V_a}{V_a - V_s} \quad (4)$$

C. Perturb And Observe MPPT

Perturb and Observe (P&O) MPPT has widely been used to track the MPP by continuously changing the operating voltage point of solar panel. This method applies a little increase or decrease in operating voltage to the panel and compare the PV output power at present with previous perturbation cycle. Fig. 7 shows the operation of P&O.The operation of P&O MPPT is started with the measurement of voltage (V) and current (I). Comparison has been made among two parameters (voltage and power) between actual state k and previous state k-1.

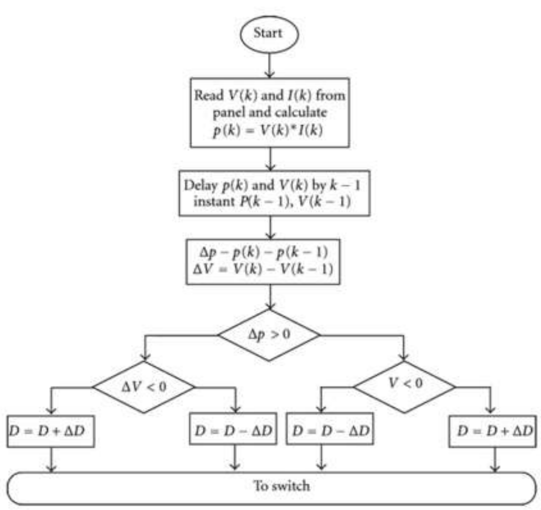

Fig. 7: Flowchart of P&O MPPT

There are total of four cases to be considered in P&O MPPT. Fig. 8 is the power-voltage characteristic of SHARP NE-80E2EA for the four cases under discussion. The PV module is operated at $600W/m^2$ solar irradiance at 25^0 C.

Case I, where P(k)>P(k-1) and V(k)>V(k-1), the situation can be described as path A in Fig.8. Therefore, a small voltage ΔV need to be added on the present voltage in order to approach MPP operating point.

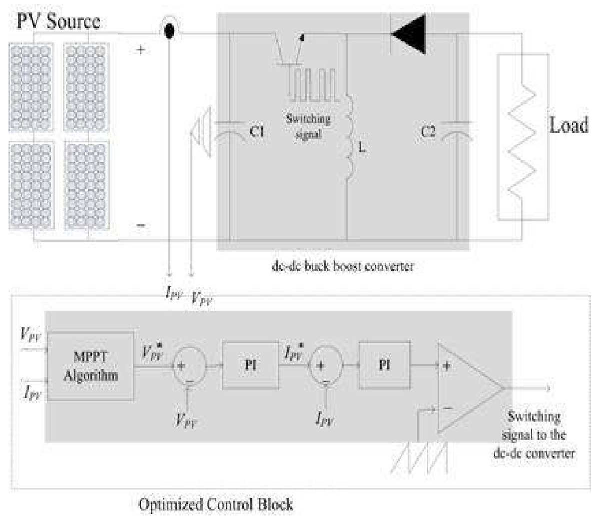

Fig. 8: Principle for MPP tracking.

Case II, where P(k)>P(k-1) and V(k)<V(k-1) can be illustrated as path B in Fig. 8. It should have reducing of ΔV on the present voltage.

Case III, where P(k)<P(k-1) and V(k)>V(k-1) can be described as path B in Fig. 8, should have reduction ΔV on the present voltage.

Case IV, where P(k)<P(k-1) and V(k)<V(k-1) can be illustrated as path A in Fig. 8, having addition ΔV on Vk.

A common problem that arises in P&O MPPT algorithm is the PV array operating voltage being perturbed every cycle. In general, the tracking of MPP will never be ended unless the PV system is stopped for operation. Even if the MPP is reached, P&O MPPT is still continually changing the operating voltage for PV module, hoping the next cycle has higher output power. The oscillation of the operating voltage has caused in the power loss in the PV system. Thus, the implementation of fuzzy logic is expected to reduce the oscillation of the operating voltage and hence minimize the power loss in the PV system.

III. Fuzzy Logic MPPT

Fuzzy logic has been introduced in MPP tracking in photovoltaic system lately. Fuzzy logic is easy to use due to their heuristic nature associated with simplicity and effectiveness for linear and non-linear systems. Among the advantages are fuzzy does not need accurate mathematical model; fuzzy can work with imprecise inputs; fuzzy can deal with non-linearity; and fuzzy are more robust than conventional non- linear controller.

The operation of fuzzy logic control can be classified into four basic elements, namely fuzzification, rule base, inference engine and defuzzification. The fuzzification is the process of converting the system actual value into linguistic fuzzy sets using fuzzy membership function. The membership function is a curvature that describes each point of membership value in the input space. Fuzzy rule base is a collection of “if-then” rules that contains all the information for the controlled parameters. It is set according to professional experience and the operation of the system control. Fuzzy inference engine is an operating method that formulates a logical decision based on the fuzzy rule setting and transforms the fuzzy rule base into fuzzy linguistic output.

In References [1], [3] and [5], the derivative dp/dv and change of dp/dv become the inputs of fuzzy controller duty cycle tuning. In [2], the author has selected the change of power and change of voltage as the inputs and a voltage reference as the output of fuzzy controller. The inputs of fuzzy in [4] are change of PV power and change of PV current whereas the output is the converter current reference. In [8], the two inputs of fuzzy controller are dp/dv and the previous duty cycle D_{k-1}. The fuzzy decides the output duty cycle D_k based on the fuzzy inputs. In [10], fuzzy works by tuning the duty cycle according to voltage error and change of voltage error.

In this paper, change of power (dp) and change of power with respect to change of voltage (dp/dv) has been selected as the inputs of fuzzy controller.

$$d_p = P_k - P_{k-1} \quad (5)$$

$$\frac{dp}{dv} = \frac{p_k - p_{k-1}}{v - v_{k-1}} \quad (6)$$

Where, k is the current state and k-1 is the previous state. Based on these two inputs, fuzzy will decide the size of perturbed voltage Cv to P&O MPPT for further process. The membership function of input dp has the range of [0 to 1.3] and input dp/dv has the range [0 to 5], whereas the range of output Cv is set [0 to 1.2]. In this paper, fuzzy is set to work according to the magnitude of inputs and decide the magnitude of output for P&O MPPT. Fig. 9 shows the membership function output Cv. It can be noticed that the membership function is set not to be averaged along the range. The output Cv has total of six membership functions for the range [0 to 0.5] whereas only three membership functions for the range [0.4 to1.2]. The main purpose of this setting is that the fuzzy been expected to be more sensitive at range [0 to 0.5]. At this range, the PV panel operating voltage is expected approaching the maximum power. Hence it should have minimum perturbed voltage reference to minimize the voltage fluctuation. However, the range [0.4 to 1.2] of output 6 aims to lead P&O MPPT track the maximum power operating voltage point faster.

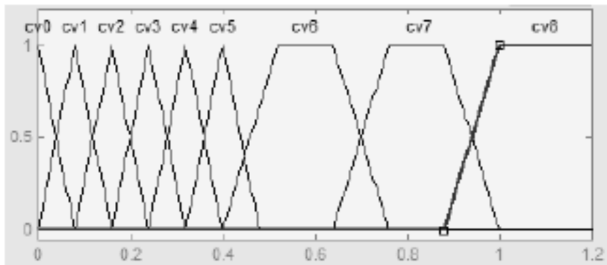

Fig. 9: Membership functions of fuzzy output Cv

Fuzzy rule base is an important element in fuzzy logic controller. Fuzzy rule base collects all the data which fuzzy inference engine will determine a logical conclusion based on the collected data. Fuzzy rule viewer is a tool to verify, if the rules are set properly. Fuzzy rule viewer is shown in Fig.10. Each row of plot in fuzzy viewer represents one rule. The fuzzy is set to have 19 rules and hence there are 19 rows in rule viewer. Row 15 in Fig.10 declares that, if the change of power is very low, regardless of the dp/dv the perturbed voltage reference is set to be the lowest.The output decision of fuzzy can be checked via adjusting index line of fuzzy inputs. Fig.10 shows the index line of input dp has been adjusted to 0.44 and the index line of input Cv is set to 2.3. Through fuzzy inference engine calculation, the output perturbed voltage is 0.348. Subsequently, the output Cv can be checked to validate the tuning parameter. The defuzzification method used in fuzzy based MPPT is centroid, which computes the centre of arc under curve. From Fig. 10, the areas of row 4,5,8 and 9 are accumulated and the area under curve is calculated as 0.348.

IV. Simulation Results And Discussion

The performances of P&O MPPT and fuzzy based P&O MPPT have been investigated and compared. Fig. 11 shows the results of PV maximum power operating voltage point versus time and maximum power versus time at 1000W/m^2 and 600W/m^2 solar irradiance.

From Fig. 11, it is noticed that both P&O MPPT and fuzzy based P&O MPPT can track the maximum power operating voltage point. However, fuzzy based P&O MPPT can track the maximum power operating voltage faster than conventional P&O MPPT. The MPP tracking of fuzzy MPPT is approximated 56% faster than P&O at 1000 W/m^2 solar irradiance and approximated 45% faster at 600W/m^2 solar irradiance. Fast tracking MPP can lead to more production of electrical energy from PV module.

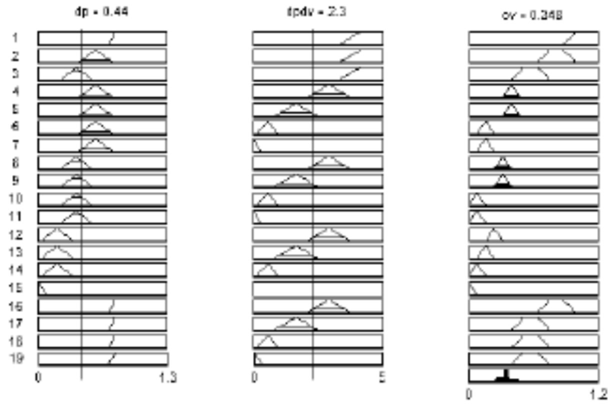

Fig. 10: Fuzzy rule viewer for parameter verification

In addition, the perturbed voltage around MPP operating voltage of both controllers have been analyzed. When photovoltaic system has identified the MPP,both controllers are able to direct PV module to oscillate around MPP operating voltage. However, fuzzy based MPPT can provide less perturbed voltage compared to P&O MPPT for both 1000W/m2 and 600W/m2 cases. Less perturbed voltage will lead to a more steady PV output power. Through the observation of P&O MPPT and fuzzy based P&OMPPT on single solar irradiation (600W/m2 and 1000W/m2) the performance of fuzzy MPPT is better than conventional P&O MPPT.

Both controllers have been tested under variable solar irradiance. Fig. 12 is the results of P&O MPPT whereas the results of fuzzy MPPT have been shown in Fig. 13. Initially, the solar irradiance is set to 800W/m2 for 18s. Both controllers are able to approach the maximum power voltage operating point and achieve the maximum power gaining. The reference of MPP voltage operating point and maximum power of each solar irradiation can be obtained from P-V characteristics as in fig. 3. However, P&O MPPT consumes more time to track the MPP operating voltage point. Fuzzy MPPT can track the MPP voltage operating point at least 30%faster than P&O. The fact that fuzzy MPPT can track MPP faster is evident at time equals to 18s and 47s of Fig. 13, where fuzzy MPPT reaches maximum power ahead than P&O MPPT.

When the maximum power has been successfully tracked, fuzzy based MPPT will reduce the perturbed voltage. Comparing the MPP operating voltage point in Fig. 12 and Fig.13, Simulation diagram for PV system using Matlab /Simulink are obtained. The larger perturbed voltage will lead to an unstable output power. The maximum power is still continuously being tracked in both P&O MPPT and fuzzy MPPT cases even after the maximum power has been discovered. P&O MPPT has larger oscillation around the MPP operating voltage. However in the fuzzy based MPPT, there are only small perturbed voltage being increased or decreased to the system.

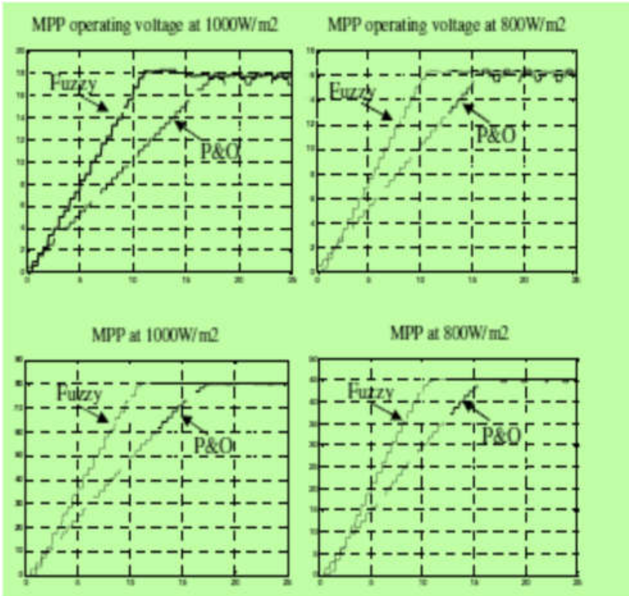

Fig. 11: Comparison of performance P&O MPPT and fuzzy based MPPT

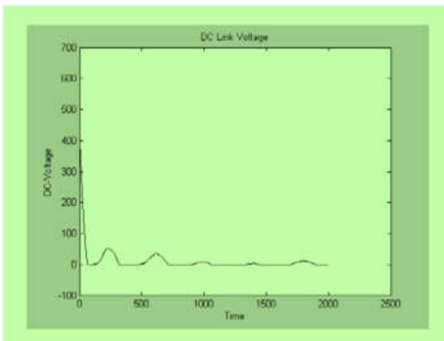

Fig .12. Simulation results

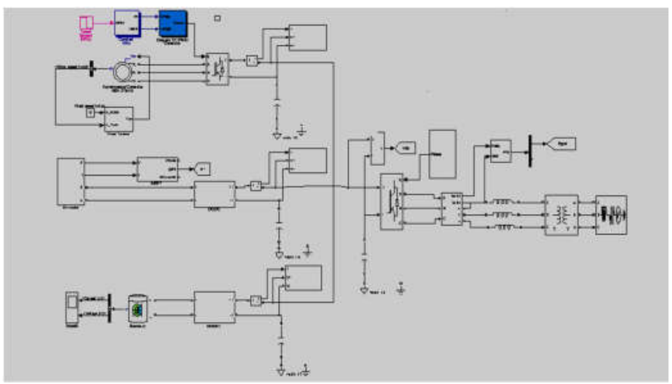

Fig. 13: Simulation diagram for PV system using Matlab/Simulink

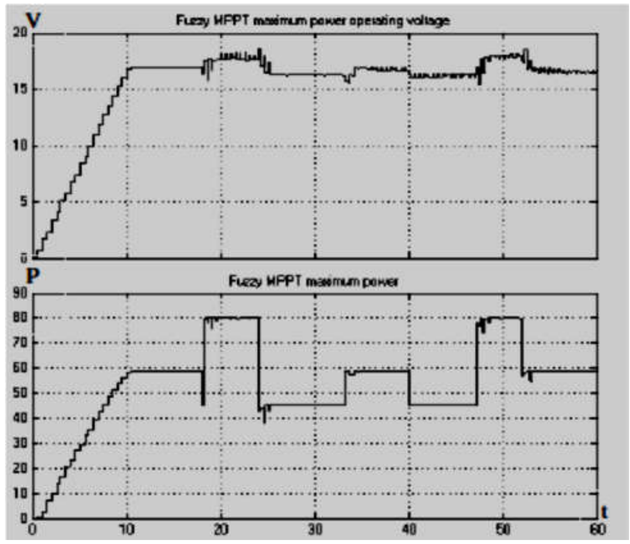

Fig. 14: Fuzzy MPPT maximum power operating voltage and maximum power against time

V. CONCLUSION

This paper compares fuzzy based MPPT and conventional P&O MPPT. The P-V characteristics and I-V characteristics have been modeled in MATLAB-SIMULINK to examine the performance of both controllers. Based on the simulation results, it can be concluded that, both controllers can assist PV panel to deliver maximum power. However, the performance of fuzzy MPPT is better. Fuzzy MPPT can track MPP faster than conventional MPPT even in variation/changes of solar irradiance. In addition, fuzzy MPPT has the capability of reducing the perturbed voltage when MPP has been recognized. This action directly preserves a more stable output power compared to the conventional MPPT where the output power fluctuates due to larger perturbed voltage around MPP voltage point.

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