



A Hybrid Maximum Power Point Tracking (MPPT) with Interleaved Converter for Standalone Photo Voltaic (PV) Power Generation System

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P. Manimekalai ^{*1}, R. Harikumar ⁺ and S. Raghavan [#]

Abstract – The PV system converts solar energy into electrical energy but the changes in the radiation from sun in varying weather conditions influence the generation of solar power. To provide impedance matching between PV systems and load a dc-dc converter with maximum power point tracking (MPPT) technique is used between PV system and the load. This paper incorporates hybrid P and O (perturb and observe) fuzzy MPPT as a maximum power point tracker in dc-dc converter of a standalone photo voltaic system. For P and O algorithm previous knowledge of the PV array characteristics is not required and its procedure is simple. But the oscillations of the operating point around MPP under steady state conditions and the inability to respond for the rapid changing atmospheric conditions are the drawbacks of this system. In fuzzy logic MPPT system the problems associated are slow transient response and fluctuations in the output power. The hybrid P and O fuzzy system gets rid of the muddles of P and O and fuzzy MPPT systems. The conventional P and O MPPT, fuzzy logic MPPT and P and O fuzzy MPPT methods were applied to interleaved boost converter and their performance in terms of the rising time, oscillating time, output voltage, ripple in output voltage were analyzed using Matlab/Simulink software.

Keywords – Comparison of MPPTs, fuzzy MPPT, hybrid P and O and fuzzy MPPT, interleaved boost dc-dc converter, perturb and observe MPPT.

1. INTRODUCTION

Energy becomes the essential part of human life. The substantial increase in the energy requirement and the fast depletion of fossil fuels in the globe drives mankind towards the usage of nonconventional energy sources such as wind, solar, geothermal, etc. Among all non conventional energy sources solar energy is suiting up because of its reusable; non exhaustible and non polluting nature [1]-[3]. It has the added advantages of incurring no fuel cost, static and noise free operation and hence less maintenance requirements. It attracted the interest of the government, industries and researchers because of its zero greenhouse emission during its operation. The life cycle of the PV panel will be around 20 years [4]-[5]. Solar panels from the highest standard manufacturing companies could convert 23% of the solar energy into electricity [2] and it reduces to 9-17% at low solar irradiation conditions [6].

The electric power generation by the PV panel depends on the factors such as weather conditions, solar radiation level, ambient temperature, type of solar cell and array design quality [1], [7]. The power transfer from PV array to AC load is carried out through power conditioning systems. Since the efficiency of the solar panel is poor, the power conditioning system should have high efficiency. The power conditioning system includes two conversion stages. A dc-dc converter with

maximum power point tracking constitutes the first stage and a dc-ac inverter supplying power to the load is the second stage [8], [9]. The power output of the PV system can be increased either by increasing the solar irradiation using sun trackers or by MPPT methods.

The MPPT tracks the maximum power point of the PV array under all atmospheric conditions and transfers up to 97% of the maximum power generation of the PV array to the next stage. Implementation of the MPPT techniques increases the output power from PV array by 45.2% for a clear sunshine day [9]. This can be achieved by the utilisation of advanced power electronic devices and by the implementation of soft switching converter topologies [10]. In dc-dc conversion stage it is necessary to step up the voltage for most of the applications. For this boost converter is the optimum choice. But to obtain high voltage, the duty cycle of the converter must be greater than 0.95 which is difficult to achieve due to operational constraints [11].

The interleaved boost converter (IBC) brings down the conduction loss by the distribution of the input current and in turn increases the efficiency. IBC has low current stress, reduced passive component size, small input current ripple and output voltage ripple. Figure 1 represents the basic block diagram of the PV power generation system.

2. PV CHARACTERISTICS USING SOLAR SIMULATOR

The non linear variation of PV output with the variation of irradiance and temperature can be observed from the current-voltage (I-V) and power-voltage (P-V) curves illustrated in Figures 2 and 3. On the P-V curve a point known as maximum power point exists, where the efficiency of the array will be maximum and maximum output power will be produced by the PV array as

^{*}Electrical and Electronics Engineering, Selvam College of Technology, Namakkal, 637001, India.

⁺Electronics and Communication Engineering, Bannari Amman Institute of Technology, Erode, 638401, India.

[#]Electronics and Communication Engineering, National Institute of Technology, Trichy, 620015, India.

¹Corresponding author; Tel: + 91 428 622 7938, Fax: + 914286244602
E-mail: manikarthiee@yahoo.co.in.

marked in Figure 3.

The readings for these characteristics were obtained by using solar simulator. For tracking the maximum power point and extracting maximum power

under varying environmental conditions different maximum power point tracking techniques were used to control the duty cycle of the dc-dc converter.

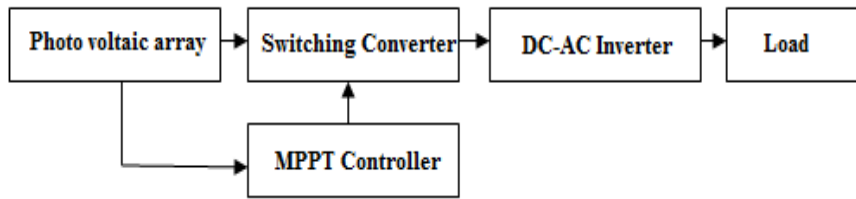


Fig. 1. Block diagram of a MPPT controlled PV system.

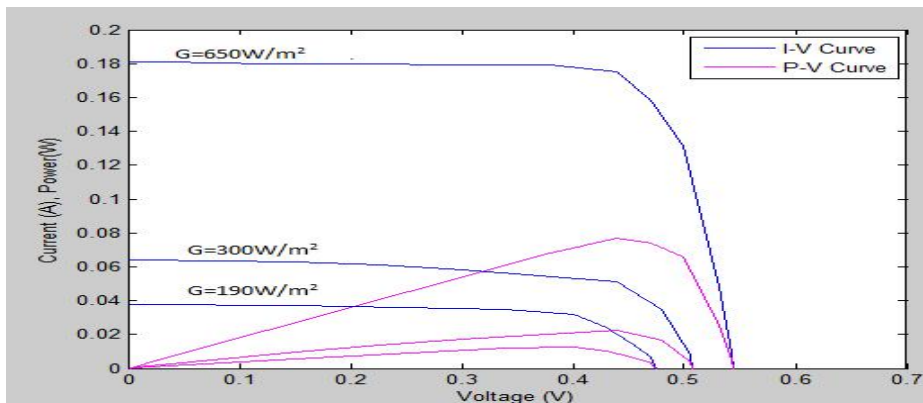


Fig. 2. Output I-V curve and P-V curve under varying illumination.

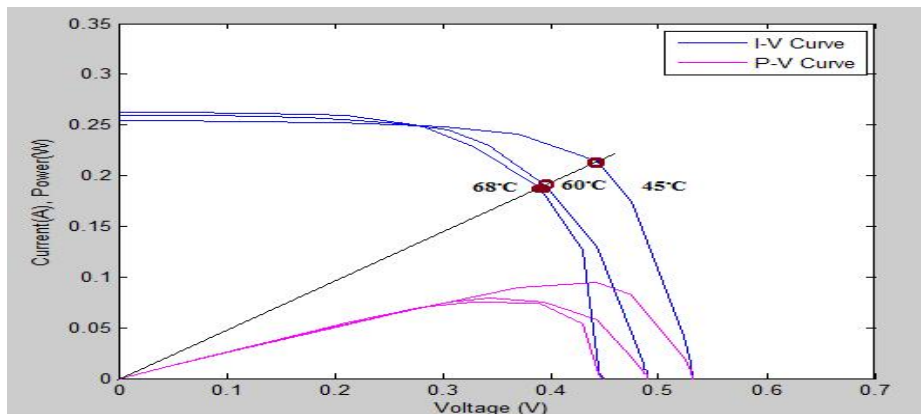


Fig. 3. Output I-V curve and P-V curve under varying temperature.

3. DC-DC CONVERTERS

DC-DC boost converters with MPPT control were used at the output of the PV array to provide power to the load. Boost converters are used in PV power applications because of its simple topology, fast transient response and continuous input current. For providing high output voltage dc-dc converters has to be operated at extreme duty cycle, which would subjects switching devices to short pulse which leads to reverse recovery and EMI (Electromagnetic

interference) problems [13], [14]. Converters with coupled inductors can provide high output voltage and less switching voltage stress without extreme duty cycle. But the leakage energy loss in the coupled inductor reduces the efficiency of the converter [15].

4. INTERLEAVED CONVERTERS

To improve the performance of the boost converter interleaving technique can be used. Interleaving is the process of connecting two or more switching converters

in parallel as illustrated in Figure 4.a. In interleaved boost converters the input current ripple is reduced because of the summation of the inductor current i_{L1} and i_{L2} to get the current i_L as in Figure 4.b. Because of interleaving the volume of the inductor can be reduced by a factor of four and current rating of the switching devices can be reduced by half for a two phase interleaved boost converter compared to conventional converter [16]. The increase in the number of phases reduces the ripple content by a factor of 9% in a two

phase interleaved converter compared to conventional boost converter. But increasing the number of phases without restriction will increase the number of components and hence the device cost without significant reduction in ripple. In all phases the number, type and ratings of the components should be the same. The phase difference between the PWM controls signals applied for different phases should be $360/n$ where n is the number of phases. For a two phase converter it would be 180 degrees.

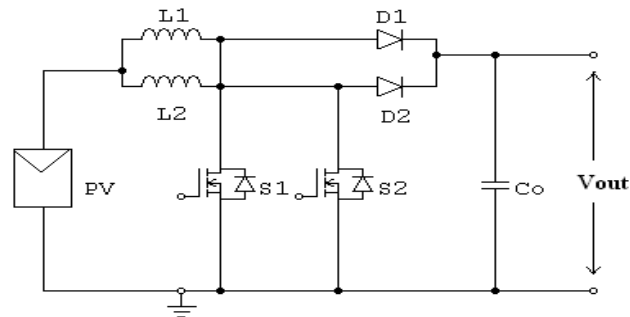


Fig. 4. a. Interleaved converter.

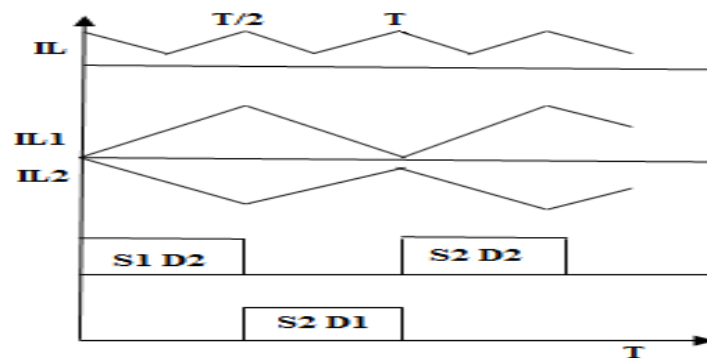


Fig. 4. b. Wave forms.

5. MAXIMUM POWER POINT TRACKING TECHNIQUES

Keeping the operating point of the PV panel at maximum power point for the corresponding radiation is known as MPPT which could be achieved by changing the duty cycle of the power electronic converters in the PV system. In conventional MPPT methods, the Interruptive type (off line) employs constant voltage control method or constant current control method which necessitates the measurement of open circuit voltage or short circuit current by delinking the panel from the power electronics converters, which leads to the loss of output power [19]. In non interruptive (on line) type, such as P and O method, modified P and O method and incremental conductance method, the power calculation was carried out by the measurement of voltage and current by using sensors, which makes the system a little bit complicated. The duty cycle of the dc-dc converters were adjusted till reaching the maximum power. In this method there is no need for delinking of

the panel from the converters, and hence no loss in the output power [19].

The soft computing techniques like fuzzy logic control, adaptive fuzzy logic control, neural network control, and ant colony optimization are flexible, fully digitized and effective in handling non linear problems and are suitable for the MPPT implementations of PV system. Among these soft computing techniques fuzzy logic control can be implemented using simple, less expensive microcontrollers [20].

6. LITERATURE SURVEY

Though there are several MPPT techniques, the most commonly used techniques are P and O MPPT and fuzzy MPPT in most of the research articles. The random analysis carried out from IEEE papers for the year 2012, out of 27 seven papers, P and O and modified P and O MPPT used in nine papers, fuzzy in three papers, incremental conductance in two papers, fuzzy combined with other conventional methods four papers

and all other MPPT techniques in nine papers were used. From the survey it was found the simplest and most commonly used conventional type MPPT was P and O MPPT and the soft computing type MPPT was fuzzy logic MPPT. Hybrid MPPT controls were formulated by combining the conventional and soft computing techniques for obtaining better performance.

7. EXISTING SYSTEM

The simplest conventional P and O MPPT technique and soft computing fuzzy logic MPPT technique were analyzed based on their concept, advantages and disadvantages.

7.1. P and O MPPT Technique

In this algorithm the array terminal voltage and current were sensed and processed and power output is calculated. The present PV output power is compared with the power of previous perturbation cycle as shown

in the flow chart numbered as Figure 5.

The PV voltage and current is perturbed periodically after comparing. If the PV operating voltage varies and change of power is greater than zero $dP/dV > 0$, the algorithm moves the operating point in the same direction, and if the change of power is less than zero $dP/dV < 0$, the algorithm moves the operating point in the opposite direction and if the change of power is equal to zero $dP/dV = 0$ that represents the condition of maximum power point. The operation of P and O algorithm can be summarized as in Table.1

The advantages of P and O algorithm is previous knowledge of the PV array characteristics is not required and its simple procedure. But the oscillation of the operating point around MPP under steady state conditions as in Figure 6 and inability to respond for the rapid changing atmospheric conditions are the drawbacks of this system [21]-[25].

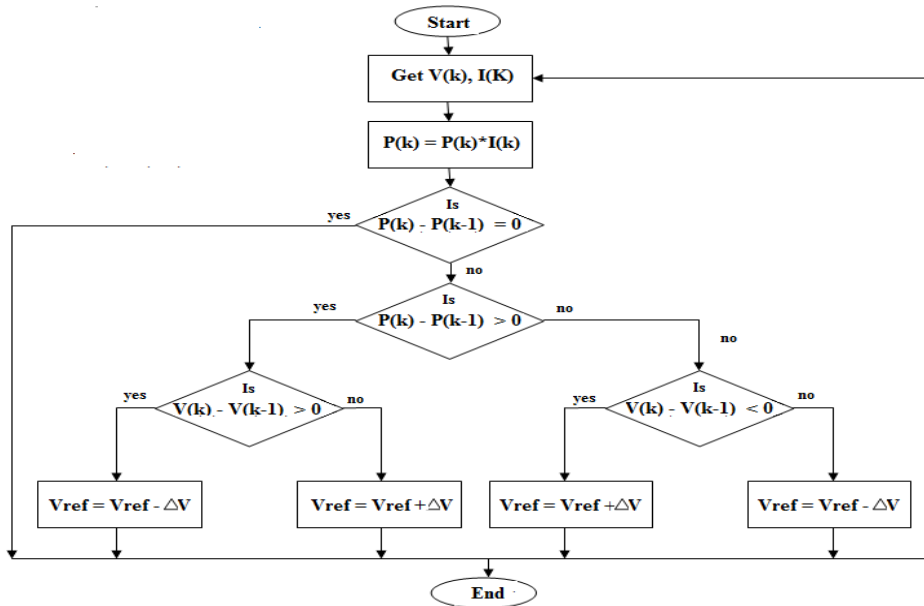


Fig. 5. Flow chart for P and O MPPT technique.

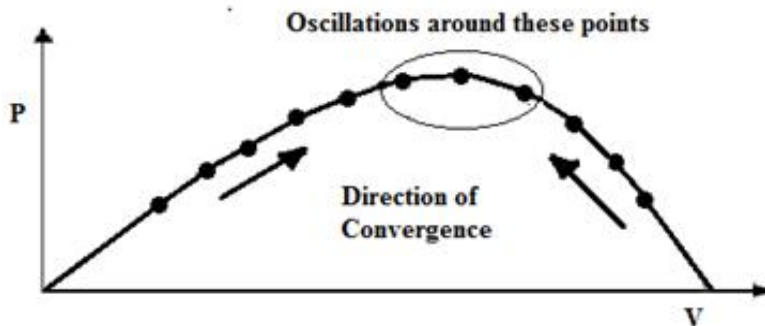


Fig. 6. MPPT convergence.

7.2 Fuzzy Logic Systems (FLC)

FLC provides an automatic control algorithm by using linguistic variables which may take any value between 0 and 1 [26]. This algorithm does not require an accurate mathematical model hence the uncertainties such as non linear operating characteristics and unexpected changes in the operating point can be dealt easily, hence more suitable for handling non-linear problems [26]-[31].

The FLC system as in block diagram of Figure 7 has three processing stages namely fuzzification, rules inferences and defuzzification. It has a rule table to store the fuzzy rules and calculations of FLC are performed by rules inference. The system consists of two linguistic input variables namely error (E) and change in Error (CE) and one output variable duty cycle (D) as in Figure 8.

7.2.1 Fuzzification

The input variables of the FLC are divided into five subsets namely positive big (PB), positive small (PS), zero (Z), Negative small (NS) and negative big (NB). The partition of the fuzzy subsets and shape of the

membership functions are shown in Figure 9. The input error and change in error values are normalized by an input scaling factor such that the input values lie between -1 and 1. To get only one dominant output for a particular input triangular shape of membership functions were chosen.

The error (E) and change in error (CE) are calculated using the following formulae:

$$P(k) = V(k) * I(k) \tag{1}$$

$$E(k) = P(k-1) - P(k) \tag{2}$$

$$CE(k) = \frac{I(k-1) - I(k)}{P(k-1) - P(k)} \tag{3}$$

- V(k) Voltage of the PV panel
- I(k) Current of the PV panel
- P(k) Power of the PV panel
- E(k) Error value
- CE(k) Change in error value

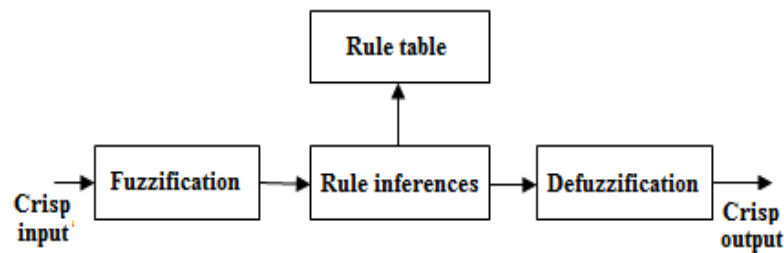


Fig 7. Block diagram of fuzzy system.

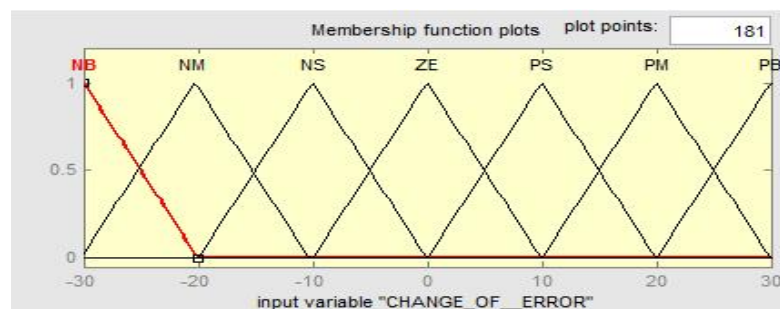


Fig. 8. Input variable membership function.

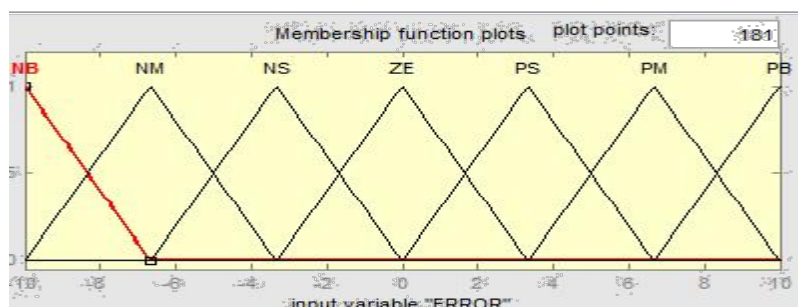


Fig. 9. Change in error membership function.

The voltage and current of the PV panel are measured and power is calculated. The values of the error (E), and change in error (CE) are calculated and used by the fuzzy inference system (FIS). The inputs are processed by fuzzy set of rules. The output of the inference system is subjected to defuzzification. The defuzzifier output in Figure 10 is the change in the duty cycle. The change in the duty cycle is given to dc-dc converter to track the maximum power point of the PV panel.

7.2.2 Inference method

The Mamdani fuzzy inference method is used in this analysis. Though several composition methods such as MAX-MIN and MAX-SOT are in fuzzy tool box, the MAX-MIN method is commonly used and the same is used in this analysis also. The rule table for the FLC is given by Table 2.

7.2.3 Defuzzification

The fuzzy inference system output is a fuzzy set. But non fuzzy value is necessary to control the dc-dc converter. For that many defuzzification methods are available such as the centroid method, mean of maximum method, first of maxima method and last of

maxima method. The centroid method is used in our system. The formula for defuzzification using centroid method is given by equation 4.

$$D = \frac{\sum_{j=1}^n \mu(D_j) \cdot (D_j)}{\sum_{j=1}^n \mu(D_j)} \tag{4}$$

Where D is the duty ratio.

The major problems using fuzzy logic system are its slow transient response and fluctuations in the output power [27].

8. PROPOSED SYSTEM

The proposed system is a combination of P and O and Fuzzy system which posses the boon of minimum settling time and reduced harmonics. Fuzzy logic control can be implemented with simple less expensive controllers like PIC 16F872 and PIC 16C74 and Tricore TC1796 controllers [25]. The flow chart of the hybrid system is shown in Figure 11.

The hybrid system is formed by the two simple effective methods. This system is blessed with the less settling time and harmonics thus improves the performance of the system [29]-[32].

Table 2. Rule table of fuzzy logic.

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



Fig. 11. Flow chart for P and O fuzzy MPPT.

9. SIMULATIONS

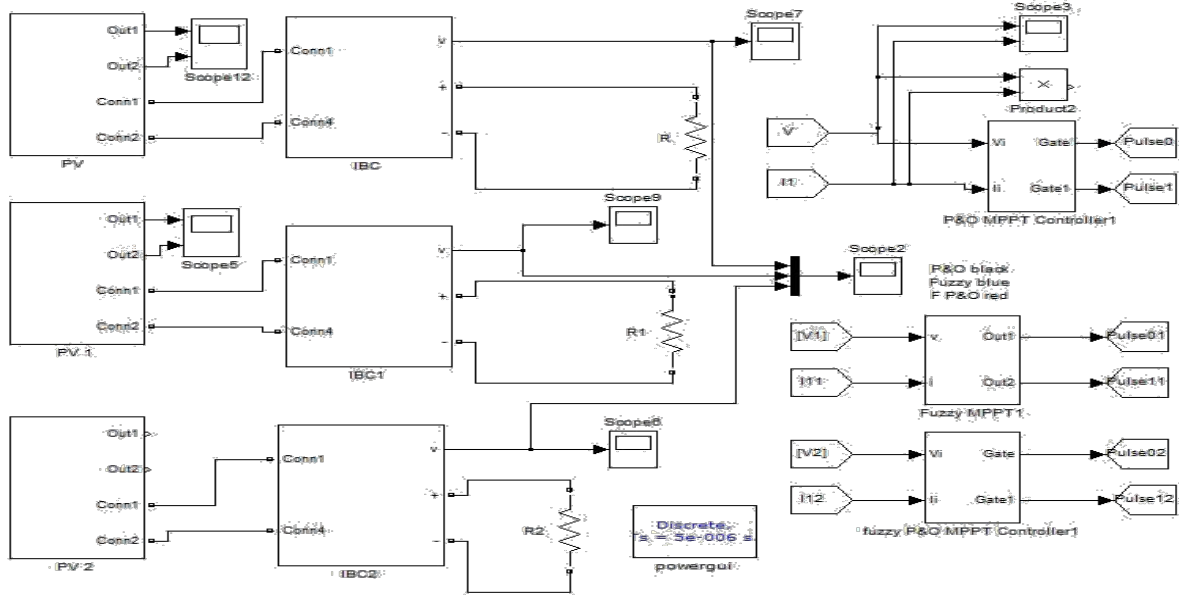


Fig. 12. Simulation of interleaved converter using P and O, fuzzy and fuzzy P and O.

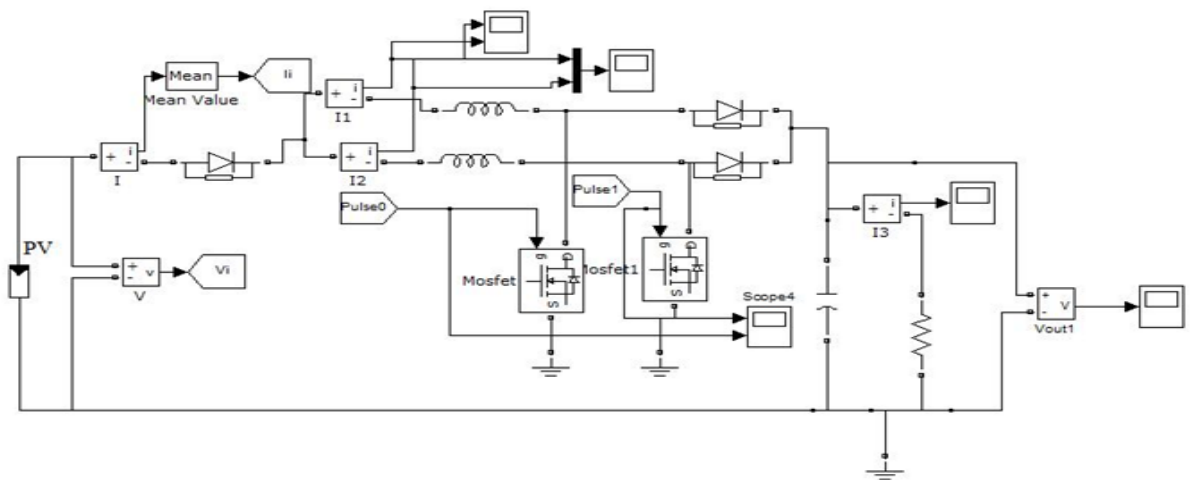


Fig. 13. Simulation of interleaved converter.

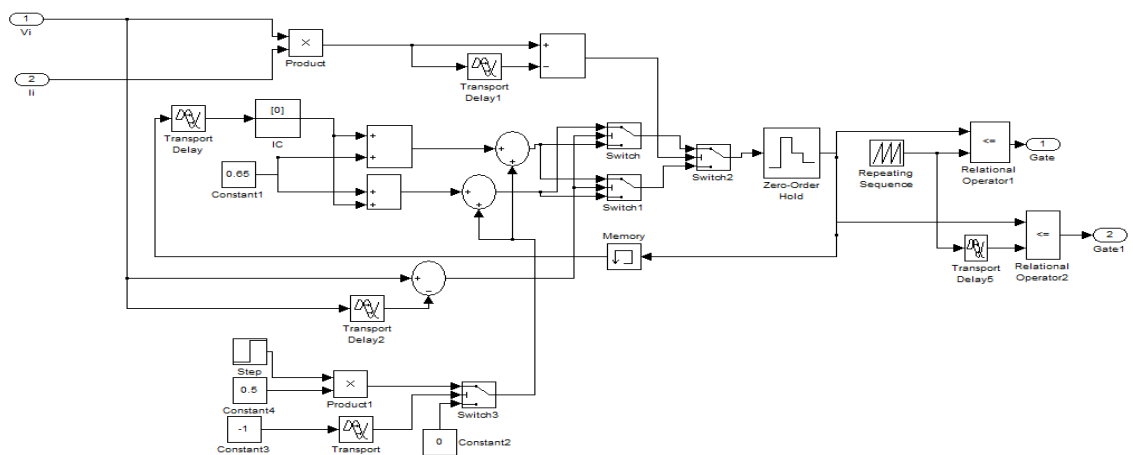


Fig. 14. Simulation for P and O MPPT technique.

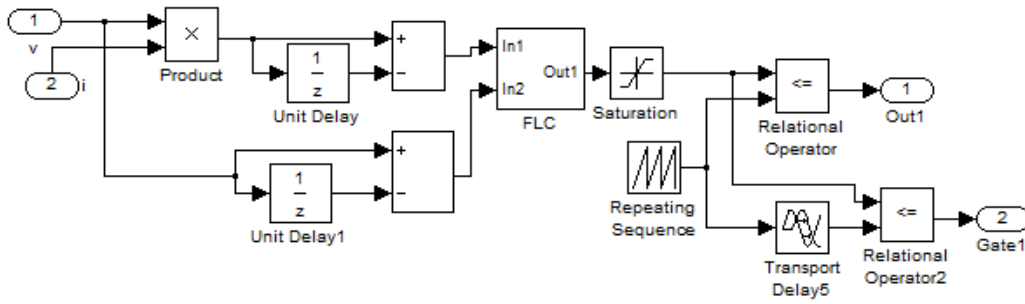


Fig. 15. Simulation for fuzzy MPPT technique.

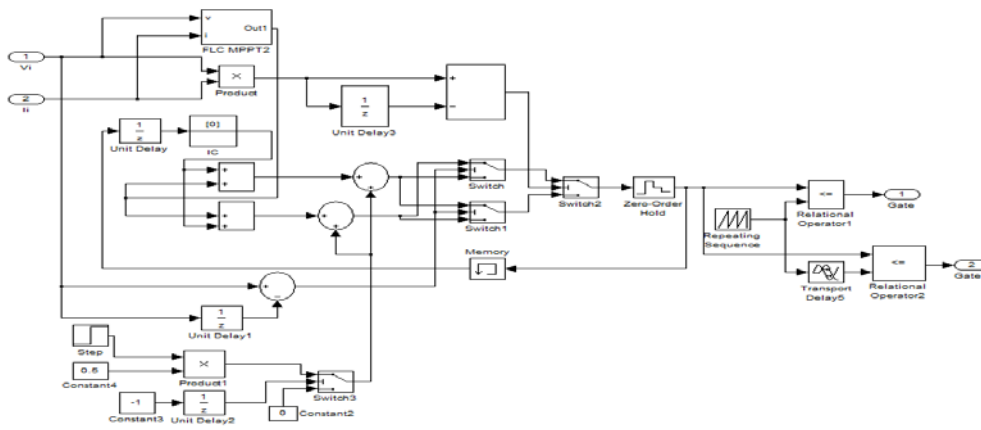


Fig. 16. Simulation for Fuzzy P and O MPPT technique.

Simulations Results for P and O MPPT Technique



Fig. 17. Interleaved converter output with P and O MPPT at constant illumination.

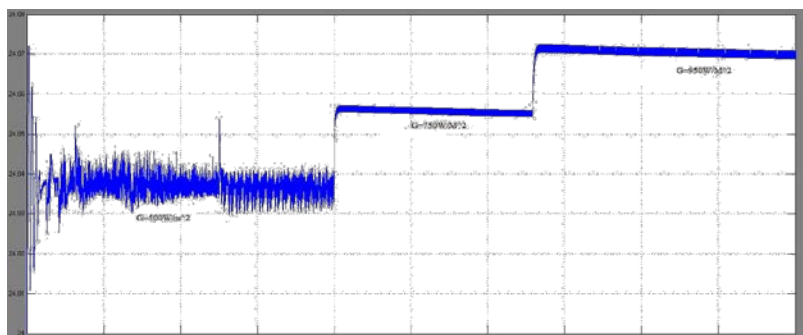


Fig. 18. Interleaved converter output with P and O MPPT at varying illumination.

Simulation Results for Fuzzy MPPT Technique

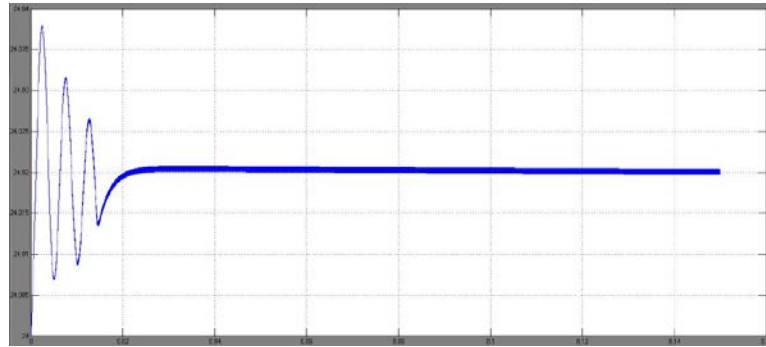


Fig. 19. Interleaved converter output with Fuzzy MPPT at constant illumination.

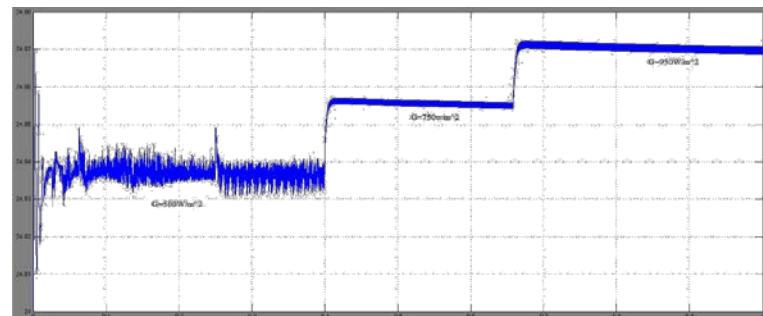


Fig. 20. Interleaved converter output with Fuzzy MPPT at varying illumination.

Simulation Results for Fuzzy P and O MPPT Technique

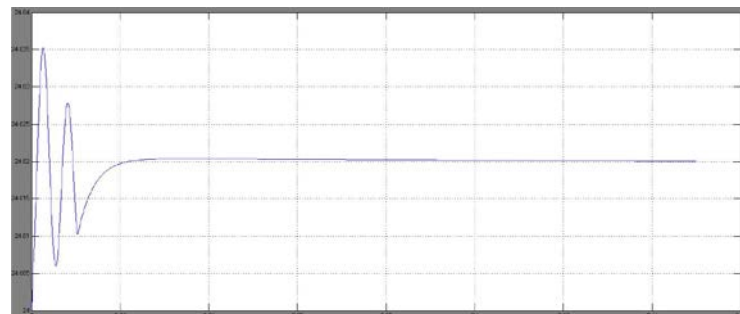


Fig. 21. Interleaved converter output with fuzzy P and O MPPT at constant illumination.

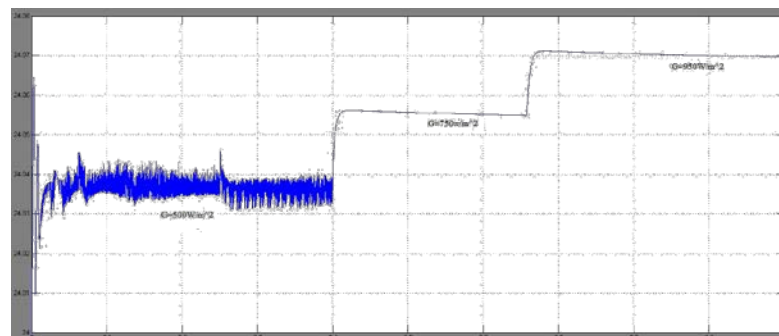


Fig. 22. Interleaved converter output with Fuzzy P and O MPPT at varying illumination.

Simulation Results for P and O, Fuzzy and Fuzzy P and O MPPT Technique

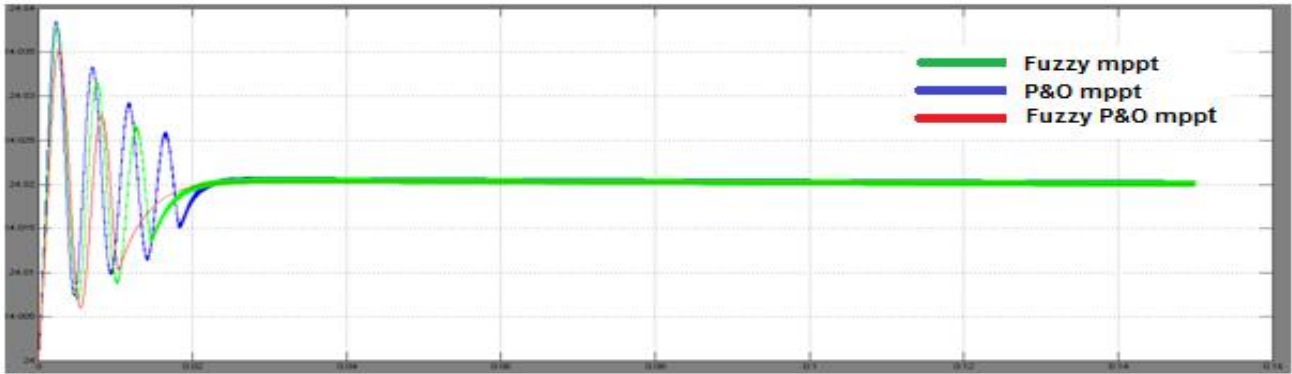


Fig. 23. Interleaved converter output at constant illumination.

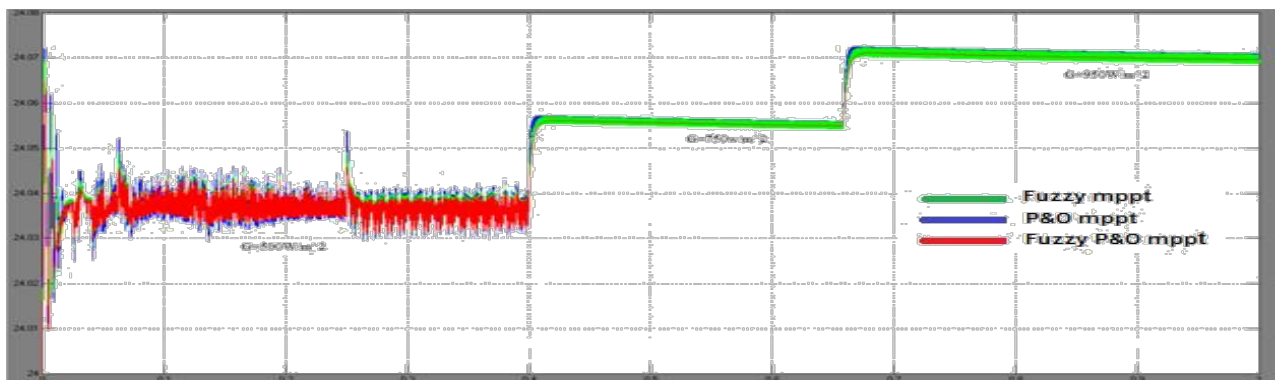


Fig. 24. Interleaved converter output at varying illumination.

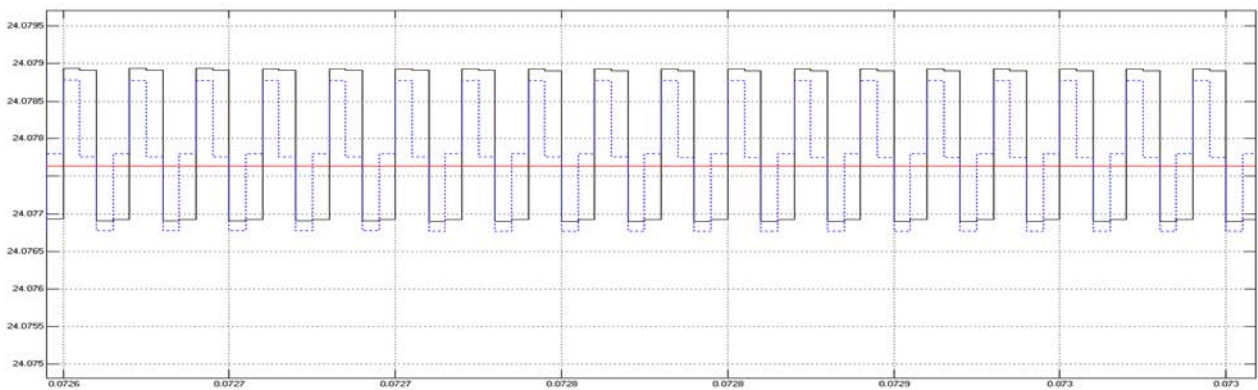


Fig. 25. Interleaved converter output ripple variation for the three MPPTs.

Table 3. Performance comparison of P and O, fuzzy and fuzzy P and O MPPT.

S.NO	TYPE OF MPPT	RISING TIME	SETTLING TIME	RIPPLE
1	P and O MPPT	0.0030sec	0.23sec	0.033V
2	Fuzzy MPPT	0.0025sec	0.22sec	0.002V
3	Fuzzy P and O MPPT	0.0030sec	0.20sec	0.000V

10. RESULTS AND DISCUSSION

The simulation was carried out under the same specifications of PV system and interleaved converter. The simulation for P and O, fuzzy and fuzzy P and O systems were shown in Figures 12-16. It was found that

P and O MPPT has the highest oscillations and minimum rising time of 0.002 sec as illustrated in Figures 17 and 18, but it's settling time is 0.23 sec having a ripple in the output of 0.033V. The fuzzy MPPT waveforms of Figures 19 and 20 have less oscillations and the rising time is 0.0025 sec with a

ripple of 0.022V and settling time of 0.22 sec. The fuzzy P and O MPPT in Figures 21 and 22 has the minimum oscillations and a rising time of 0.0030 sec. Its settling time is 0.2 sec with no ripple in the output voltage. The wave forms of Figures 23 and 24 gives an illustration of variation of outputs for P and O, fuzzy and fuzzy P and O MPPT techniques under constant and varying illumination. From the Figure 25 it was found that hybrid fuzzy P and O MPPT have the minimum ripple content.

11. CONCLUSION

Among P and O MPPT, fuzzy MPPT and fuzzy P and O MPPT the fuzzy P and O MPPT can be used to have a better output with minimum ripple. The performances of the three MPPT methods were put in Table 3. From the Table 3 it was observed that the fuzzy P and O MPPT ripple is minimum compared to the other two methods.

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