A

Project Report

on

A STUDY, MODELLING AND COMPARATIVE ANALYSIS OF MPPT ALGORITHMS

Submitted in partial fulfilment of the

requirement for the award of the

Degree of

BACHELOR OF TECHONOLOGY

in

ELECTRICAL ENGINEERING

by

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May, 2020

DECLARATION

We declare that the work presented in this report titled "**A Study, Modelling and Comparative Analysis of MPPT Algorithms**", submitted to the Department of Electrical Engineering, Galgotias University, Greater Noida, for the Bachelor of Technology in Electrical Engineering is our original work. We have not plagiarized unless cited or the same report has not submitted anywhere for the award of any other degree. We understand that any violation of the above will be cause for disciplinary action by the university against us as per the University rule.

Place:

Date:

Signature of the Student

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CERTIFICATE

This is to certify that the project titled **"A Study, Modelling and Comparative Analysis of MPPT Algorithms''** is the bonafide work carried out by Divyanshu Singh, Shreyash Sinha during the academic year 2019-20. We approve this project for submission in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Electrical Engineering, Galgotias University.

Mr. D. Saravanan
Project Guide(s)

The Project is Satisfactory / Unsatisfactory.

Internal Examiner (s) External Examiner

Approved by

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ABSTRACT

This paper presents the modelling and comparative analysis of three well known MPPT algorithms for solar photovoltaic (PV) systems. The analysis addresses the energy decision makers and researchers for the selection of MPPT algorithm. The electrical characteristics of PV system fluctuates with the change in irradiation level, temperature, aerosol deposits and partial shading. The maximum power point tracker (MPPT) helps in harvesting the maximum power available from the photovoltaic system. In this paper perturb and observe (P&O) algorithm, incremental conductance (IC) algorithm and fuzzy logic controller (FLC) techniques were simulated using Matlab Simulink. The variable irradiance and constant temperature were considered as an environmental parameter in this simulation work to extract the maximum power from PV system. The duty cycle for the DC-DC converter is generated with the help of PV voltage and PV current. The generated duty cycle was converted to PWM signal to drive the MOSFET switch of DC-DC converter. The simulation was carried out on all the three algorithms and efficiency of each was presented here. The 7 precise analysis and comparison of the steady state and dynamic behavior of each algorithm also carried in this study.

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GLOSSARY

MPPT	Maximum Power Point Tracking
PV	Photovoltaic
P & O	Perturb and Observe
IC	Incremental Conductance
FLC	Fuzzy Logic Controller
PWM	Pulse Width Modulation

1. INTRODUCTION

The energy generated by the sun is sufficient to fulfill the vitality needs of the whole world and it won't be done, unlike other fossil derivatives. With the exponential growth of global warming throughout the decades, it has become more important than ever to find the alternate source of energy which can fulfill the energy demand. *Annette Evans [2008]* Sun's energy Being a renewable source and the most accessible sustainable wellspring of vitality, the solar photovoltaic framework has become the most significant and standard wellspring of vitality. There is no nursery gasses are discharged into the air while producing power, by photovoltaic system. The growth of individual country is also depending on the energy generation and satisfying the demand. As a green energy source, the PV system can fulfill the needs of nations who imports the derivatives of fossil fuels from others. But harvesting energy from the solar was tedious because of production cost of energy and efficiency of conversion system, though it does not require much maintenance as compared to other conventional methods of energy generation. *S. Gosh [2015]* In order to change the face of PV system, the researchers and policy makers made the initiatives on PV system as available to all the individuals across the world with conversion efficiency up to 22%. But this efficiency is not consistent due to environmental condition which includes installation location, panel inclination angle, variable irradiance and temperature, aerosol deposit, and physical problems associated with PV panel by *Wasynezuk, O [2008]***.** The Impact of partial shading leads to power loss addressed y *R N Shaw. Et al.,[2019]*, the reduced power loss and enhanced efficiency under partial shading can be obtained using novel array formation *RN Shaw, et al.[2019].*

Above all maximum power harvesting efficiency from solar photovoltaic system can be improved through Maximum power point tracker. There are two ways of tracking the sun power, i.e. one is mechanical tracker which tracks the position of sun and other is electrical tracking through tracing the maximum voltage and current point. The maximum point is traced in order to derive the maximum power. This phenomenon is known as maximum power point tracking. There are various techniques are available for MPPT and many scientists have worked on that techniques to improve further.

1.1 Current Challenges

In the area of solar power monitoring and production, there are certain difficulties we are currently facing. Compared to other renewable energy sources, the performance of the solar PV network is poor (wind energy = 50% and hydro energy = 90% whereas solar power is still at 11.22%). Responses to traditional solar power monitoring and recovery approaches were slow and inefficient.

In the event of sudden changes in solar temperature and irradiance conditions, conventional MPPT methods are also slow and inefficient, and sometimes they are unable to track the maximum power point.

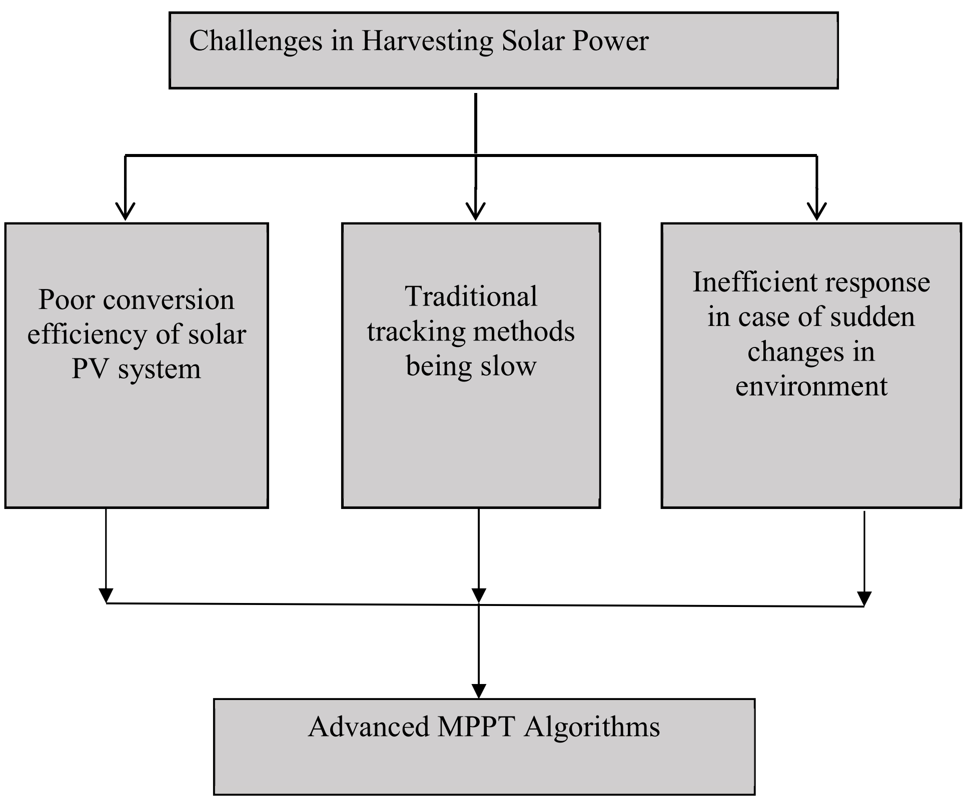

Fig1. Challenges in harvesting solar Power

1.2 Applications Of Solar PV System

The photovoltaic based force framework finds applications in various fields.

- The roadways are a sun based fueled light, which is made out of PV system-oriented parts, lighting circuits, charge-release controller, batteries, and shafts and so forth.
- Automobile sector: In the 21st century, the automotive industry advances vehicular technology and developing in energy saving & electric car which is environment friendly. And it will be future alternative to the hybrid and electric vehicles.
- Electricity for remote areas: - Some zones are very a long way from the dissemination system to set up association with the power grid. PV frameworks are an appealing alternative for these remote locations.

2. LITERATURE SURVEY

L. Piegariet al [2010] proposed an adaptive P&O method. The author validated by means of simulations and experimental tests, which confirms the effectiveness of the method. The result shows the faster dynamics and improved stability compared to the traditional P&O. *S. M. Ferdous et al [2012]* presented an article on Design and Simulation of an Open Voltage Algorithm based Maximum Power Point Tracker for Battery Charging PV System. The system results the efficiency of the MPPT circuit was more than 95% and the system, with the buck converter, was 86% efficient.

D. K. Sharma et al [2012] and Ashwin Chandwaniet al. [2016] reported an article on design, simulation and implementation of maximum power point tracking (MPPT) for solar based renewable systems. This article presents holistic view in the concept of maximum power point tracking (MPPT) implemented in MATLAB environment and the same results were reproduced in hardware using Perturb and Observe (P&O) algorithm. Improvement in the performance of a solar power conversion was reported. *Mei, Q., Shan [2011]* discussed automatic step adjustment incremental resistance algorithm to track the power, this automatically generate variable duty cycle with respect to change in environmental effect.

Weiping Luo et al. [2009] and Shristi Das et al [2017] has applied fuzzy based control to the controller in PV system. A solar photovoltaic charging controller design had a direct impact on the reliability and efficiency of the overall system represented the paper on analysis and design of fuzzy based PWM controller for solar power generation. The simulation results of designed system were validated and compared with the conventional PID controlled system during constant and varying irradiance and load by the later.

Vineeth Kumar P.K. et al. [2018] presented an article on comparative analysis of most popular MPPT algorithms used in SPV systems of Incremental Conductance Algorithm (ICA) and P&O Algorithm (POA). *Dehlia Canny [2018]* presented a technique to extract the maximum power under slow and dynamic variation of irradiance using fuzzy based algorithm. *K Karthik Kumar [2014]* reported an article by comparing the incremental conductance and short circuit method of extracting the maximum power from PV system. The reported result shows that incremental conductance performs better in variable atmospheric condition.*A. Varnham [2007]* reported neuro-fuzzy based controller which results 8.6% increase in power extraction as compared to conventional PI based controller. *XunGe [2020]* presented a BAT-Fuzzy based optimized algorithm to converge and precise the duty cycle production based on environment changes. *Abdeghani Harrag [2015]* reported an improved performance during dynamic and steady state performance of offline system using hybrid MPPT based on P&O and GA algorithm. *Abdeghani Harrag [2019]* reported reduced power loss through variable step size neuro-fuzzy IC based maximum power point tracking. *Hua Chih-Chiang [2016]* proposed a hybrid MPPT to adopt the fast changing of input using fractional open-circuit voltage technique and current sensor less technique to track the maximum power. *K. Loukil [2019]* modeled and proposed the reconfigurable Fuzzy based MPPT for variable atmospheric condition. Which proves the stability speed of response and adapt to rapid change in input.

3. SCHEMATIC MPPT MODEL

3.1 Introduction

In this article following schematic is used which describes the model of solar PV system fed DC-DC boost converter. As like a various models of solar charge controllers, the proposed one has three main parts:

a. Solar PV array
b. Pulse Generation Circuit
c. Power Circuit

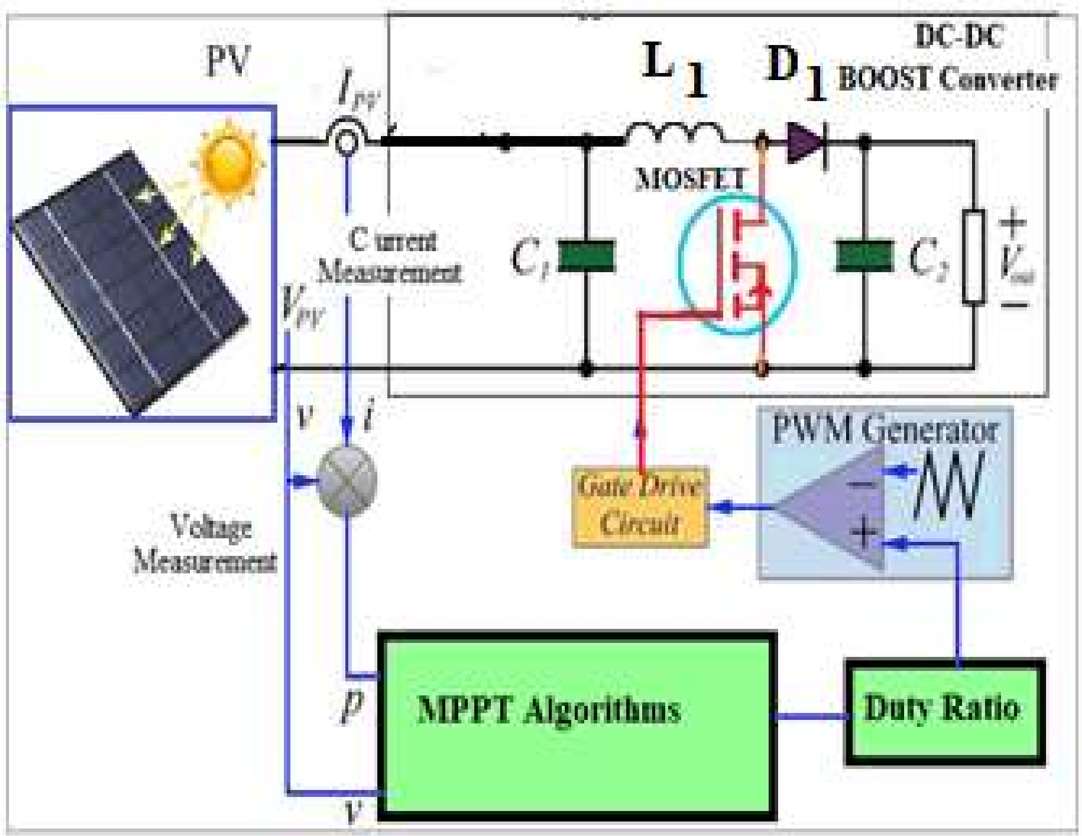

Fig 2. Schematic representation of MPPT Model

3.2 PV Array

The PV Array block implements an array of photovoltaic (PV) modules. The array is built of strings of modules connected in parallel, each string consisting of modules connected in series.PV array was designed based on available product in the market in MATLab simulink. The PV array performance is based on the two-diode model of solar cell.

$I_d = I_0 \left[\exp\left(\frac{V_d}{V_T}\right) - 1\right]$.....................................(1)

$V_T = \frac{kT}{q} \times nI \times Ncell$......................................(2)

Where,

V_T-Thermal Voltage (volts)

I_d-Diode Current(mA)

I_0-Saturation Current(mA)

V_d-Voltage across diode(volts)

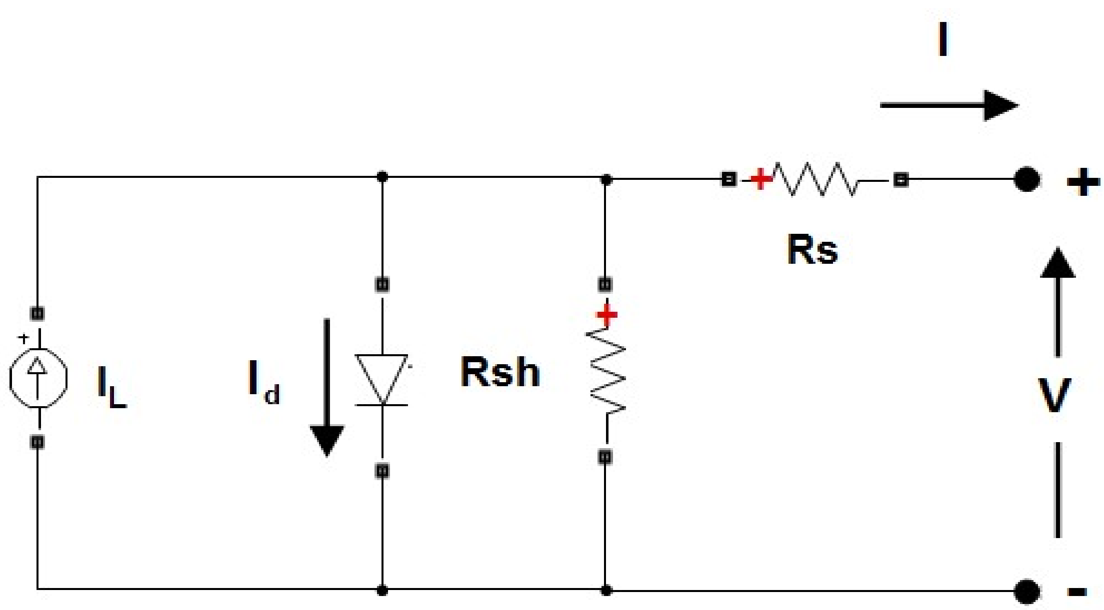

Fig 3. Two-Diode model equivalent cicuit of PV cell

The PV aaray was designed in Matlab simulink using the following paramaters.

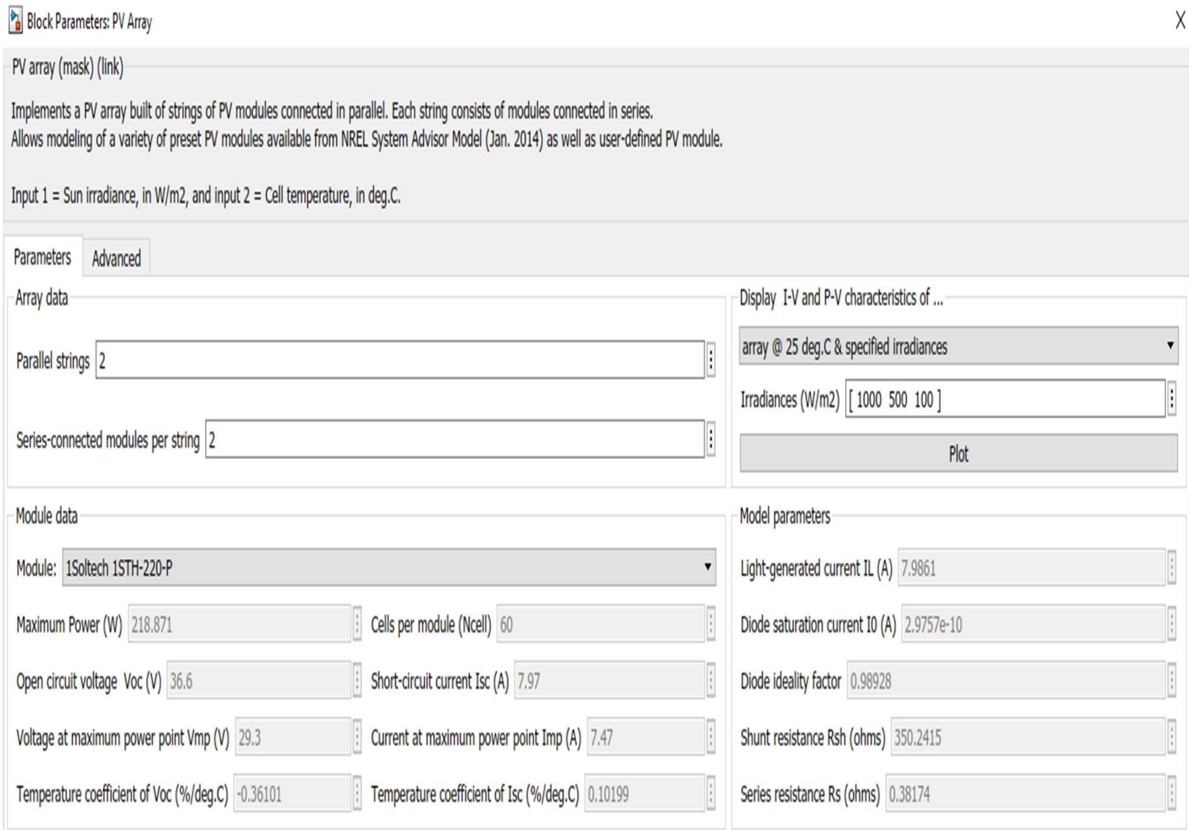

Fig 4. PV Array Parameters

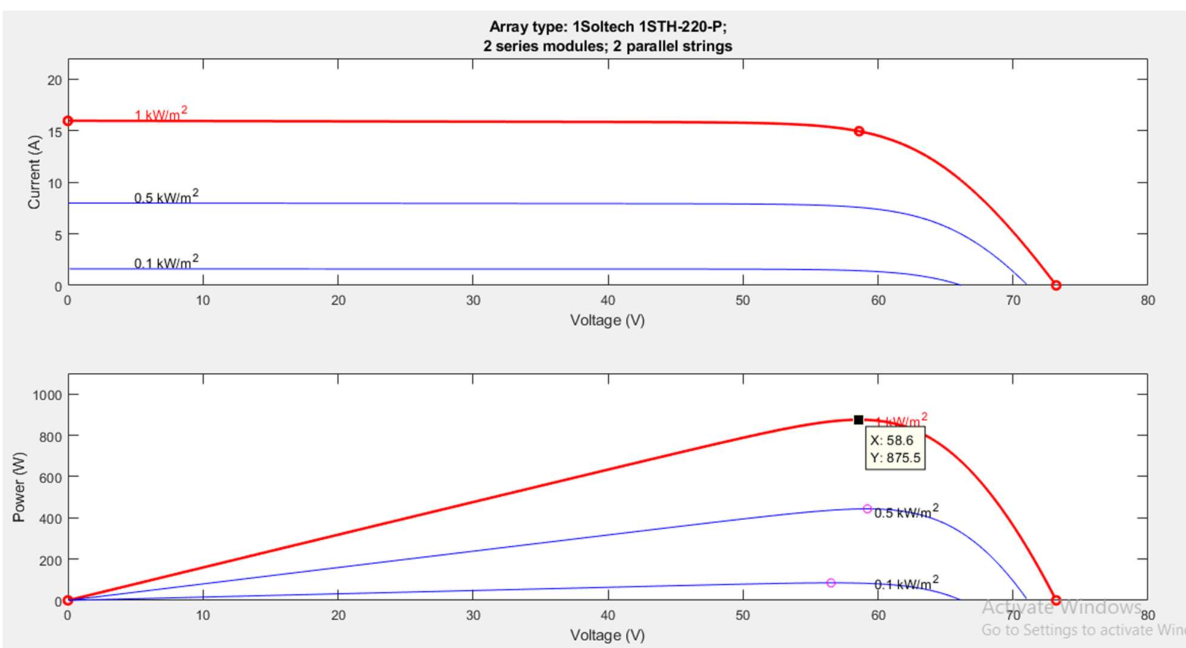

Fig 5. I-V and P-V characteristics of PV array with defined parameters

3.3 DC-DC Converter

In this article DC-DC boost convert conventional circuit utilized for the analysis. The MOSFET switch is utilized in this DC-DC controlled converter, which helps to obtain the smooth DC-DC conversion at very high switching frequency.

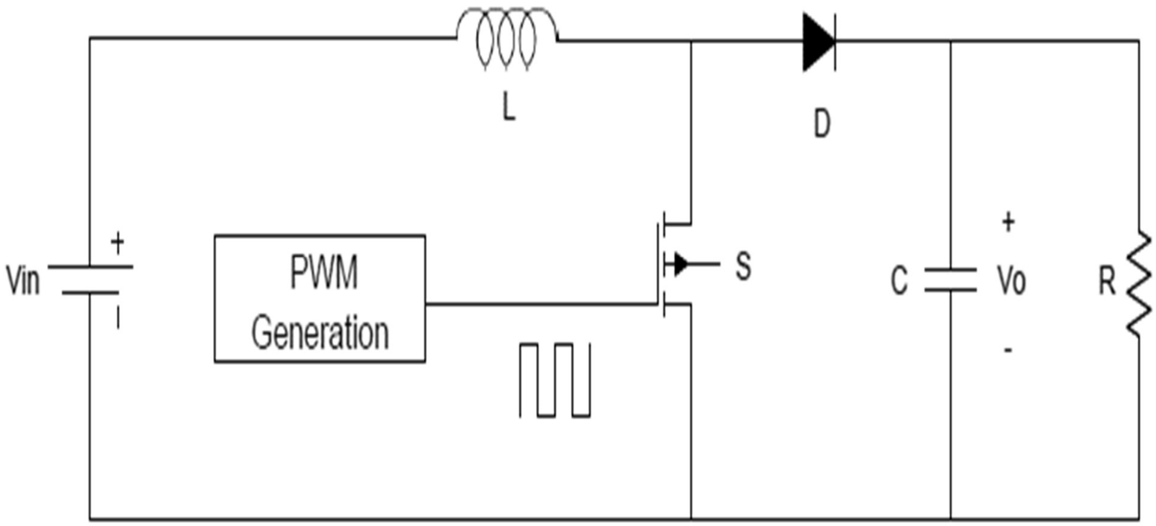

Fig 6. Power Circuit with Resistive Load

The values of various components in the DC-DC converter is obtained based on the input and output voltage. The filter component is connected in the proposed circuit to obtain the ripple free input and to produce the ripple free steady state output.

$L = \frac{D \times V_{in}}{\Delta i_L \times f_s}$…………………………………………...(3)

$C = \frac{D}{\left(\Delta V_0 / V_0\right) \times R \times f_s}$………………………………...(4)

Where,

D-Duty Ratio

L-Inductor (Henry), C-Capacitor (µF)

3.4 Pulse Generation Circuit

The pulse generation circuit is majorly focused in this article. The pulse is a logical or digital wise signal, helps to turn-ON or turn-OFF the switch of the power circuit. There are various methods to generate pulses in general, but in this article Perturb and Observe (P&O) Algorithm, Incremental Conductance (IC) Algorithm and Fuzzy rule-based algorithm are employed. Among these algorithms, fuzzy based rules are more effective and adopts to the environmental changes.

In this project, values of current and voltage measured from solar panel and supplied to MPPT controller which generates the duty ratio. This duty ratio is utilized to generate the modified PWM signal based on change in environmental parameter as input.

The duty ratio is generally defined as

$$D = T_{ON} / (T_{ON} + T_{OFF}) \quad \text{..(5)}$$

But in the case of Power circuit, the duty ratio is defined based on constant output voltage and variable input voltage.

$$V_0 = \frac{V_{in}}{(1-D)} \quad \text{...(6)}$$

4. MPPT ALGORITHM

The Maximum Power Point Algorithm is an important tool to obtain the maximum electrical output from the PV systems. There are two type different tracking mechanism are available, i.e.

1. Mechanical Tracking Mechanism
2. Electrical Tracking Mechanism

4.1 Mechanical Tracking System

A mechanical based system was the first one to track the SUN direction on own axis. The mechanical system involves the physical moving portion to track the sun based on its intensity of irradiation falls on it, where it having a motor and gear arrangements. The Mechanical Tracking mechanism is made available to the users based on axis, as follows:

i. Single Axis Tracking system

ii. Dual Axis Tracking system

4.2 Electrical Tracking System

In electrical tracking mechanism, there is no moving system attached with the PV system. The electrical tracking is based on its output terminal voltage and current. At every instantaneous time the terminal voltage and current is measured that is compare with the previous values and predicts the direction to move ahead or laid back in the tracing path. There are various unique algorithms were discussed in the literature to extract the maximum power. In this article following algorithms are considered for the analysis based on literature, most of the authors were used in these algorithms for the implementation.

i. Perturb and Observe (P and O)

ii. Incremental Conductance (IC)

iii. Fuzzy Rule Based Algorithm

i. Perturb and Observe Algorithm

Perturb and observe algorithm plays significant in the development of various maximum power point tracking process. From literature we all know that there are several environmental factors that affects electrical output characteristics of PV system. By measuring the voltage and current from the PV system, the power is calculated and path is outlined to observe the changes. *T. Esram.et.al.,* has shown that Perturb is calculated by observing the changes in power ΔP with corresponding change in voltage ΔV. This process helps to trace the peak value of power by associating the subsequent and preceding value of the tracking path. The perturbation oscillates in regular interval of time around the peak value of power which is mentioned in following table 1.

Perturbation	**Variation in Power**	**Next Perturbation**
Constructive	Positive	Constructive
Constructive	Negative	Undesirable
Undesirable	Positive	Undesirable
undesirable	Negative	Constructive

Table 1. Steps of P&O process

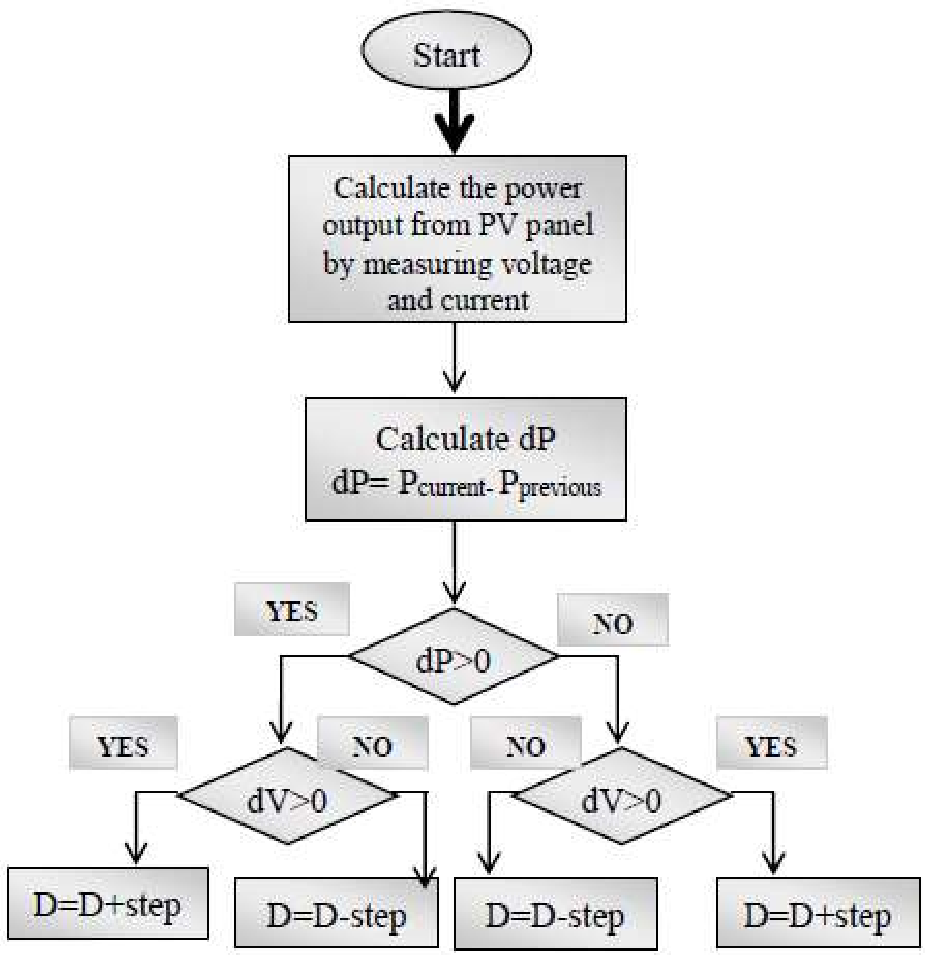

Fig 7. P & O Algorithm Flow chart

ii. Incremental Conductance Algorithm

The Incremental Conductance algorithm is based on slope of change in power with respect to change in voltage(ΔP/ΔV).

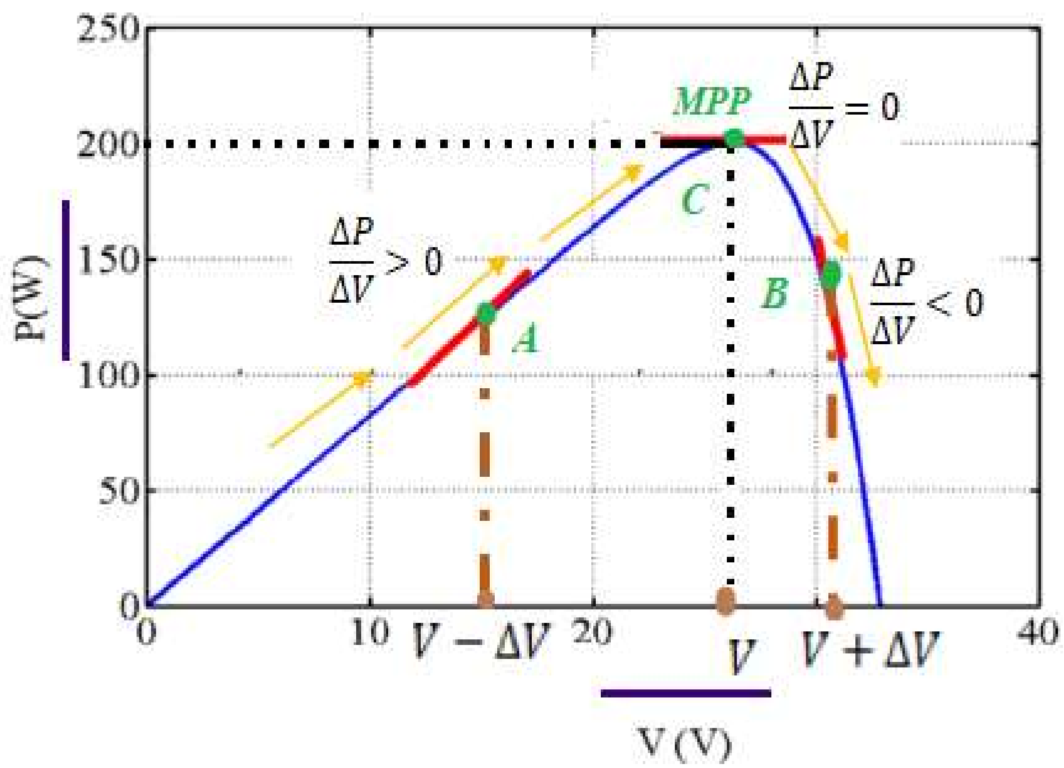

Fig.8 Divergence of Incremental Conductance and P&O

The mathematical expression of process is stated from PV characteristics as:

$P = V * I$……………………………………………………(7)

$\frac{\Delta P}{\Delta V} = \frac{\Delta(IV)}{\Delta V} = I + V\frac{\Delta I}{\Delta V}$……………………………………..(8)

$\frac{\Delta I}{\Delta V} = -\frac{I}{V}$…………………………………………………(9)

Slpoe Vlaue of PV curve	Slope value of IV curve	Position of Peak Power
$\frac{\Delta P}{\Delta V} = 0$	$\frac{\Delta I}{\Delta V} = -\frac{I}{V}$	At Maximum Point
$\frac{\Delta P}{\Delta V} > 0$	$\frac{\Delta I}{\Delta V} > -\frac{I}{V}$	Left of the Maximum Point
$\frac{\Delta P}{\Delta V} < 0$	$\frac{\Delta I}{\Delta V} < -\frac{I}{V}$	Right of the Maximum Point

Table 2. Tracing mechanism of Incremental Inductance

The peak power can be traced using this process with the help of instantaneous value of conductance$({}^{I}/_{V})$ with change in conductance$({}^{\Delta I}/_{\Delta V})$ as shown in flowchart.

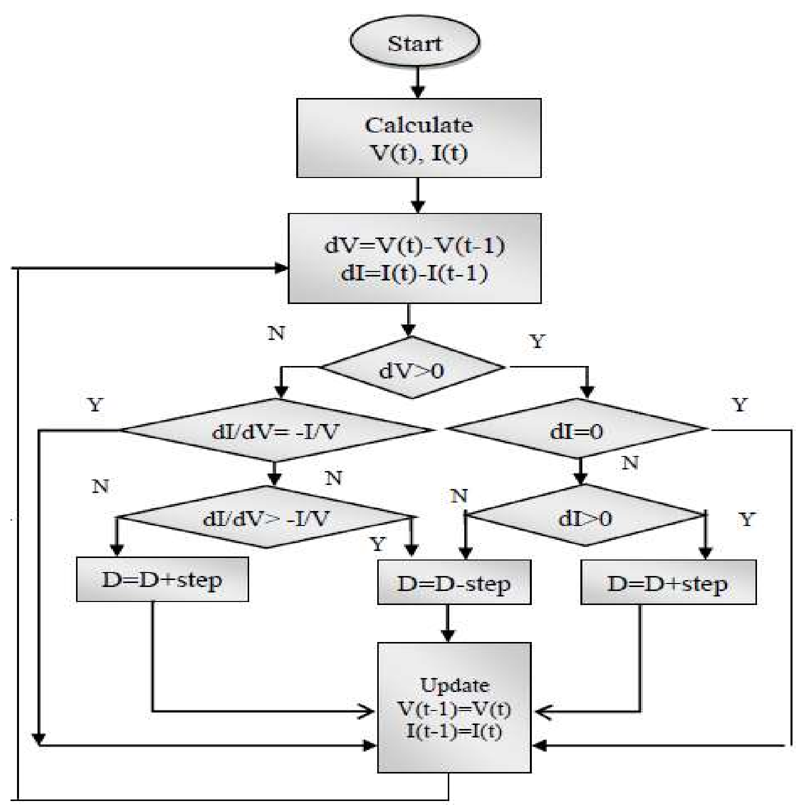

Fig. 9. Flow chart of incremental conductance (IC) algorithm.

iii. Fuzzy Rule Based System

Fuzzy Rule based system works with uncertainties, does not require precise numerical model and treating the nonlinearity. Fuzzy system works in the flow of fuzzification, rule base query table and defuzzification. In this fuzzy controller, numerical value of voltage and current from PV system is considered as input.

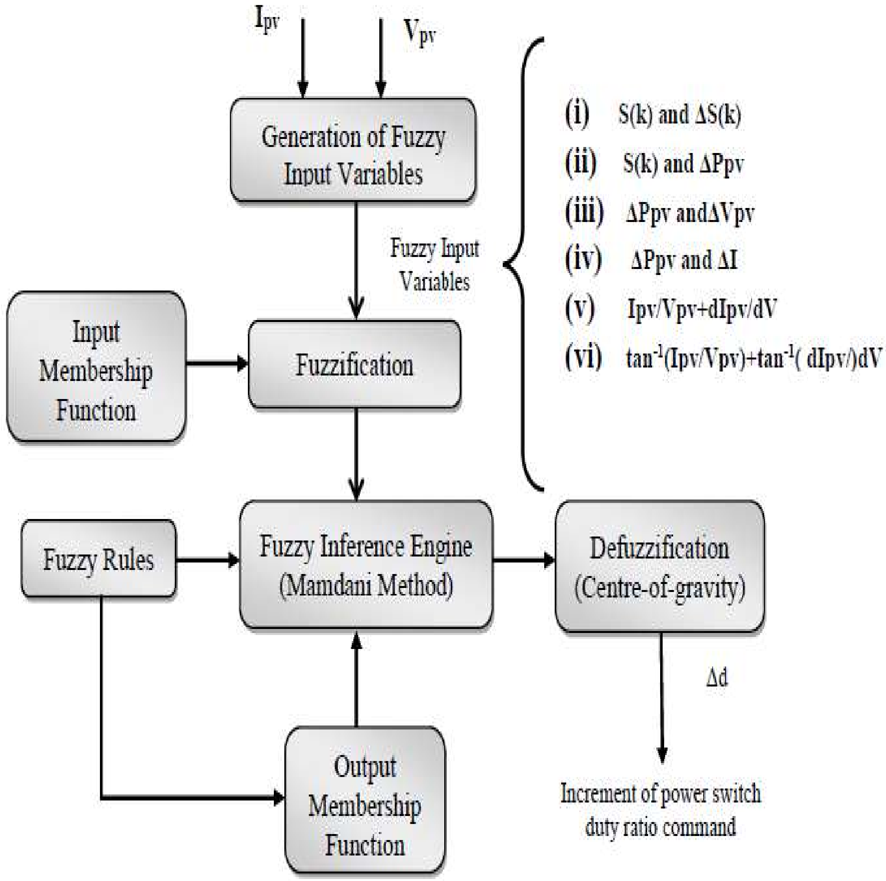

Fig. 10. Block diagram of fuzzy logic controller.

During fuzzification this numerical value will be converted into linguistic forms based on membership function. Based on membership function the change in duty ratio is generated with reference to the assigned rules. In the defuzzification process the linguistic variable of duty ratio is converted to numerical value.

5. DESIGN AND IMPLEMENTATION

5.1 Perturb and Observe Algorithm Based Pulse Generation

The P&O algorithm is employed in the MATLab environment using function block. We are giving input from PV array, where V_pv is PV array voltage, I_pv is PV array current and Duty block is the duty cycle. PWM generator block is used to convert the duty ratio to Pulses. The duty ratio is generated using algorithm with minimum 0% and maximum 100%. Based on the input changes the duty ration automatically get updated.

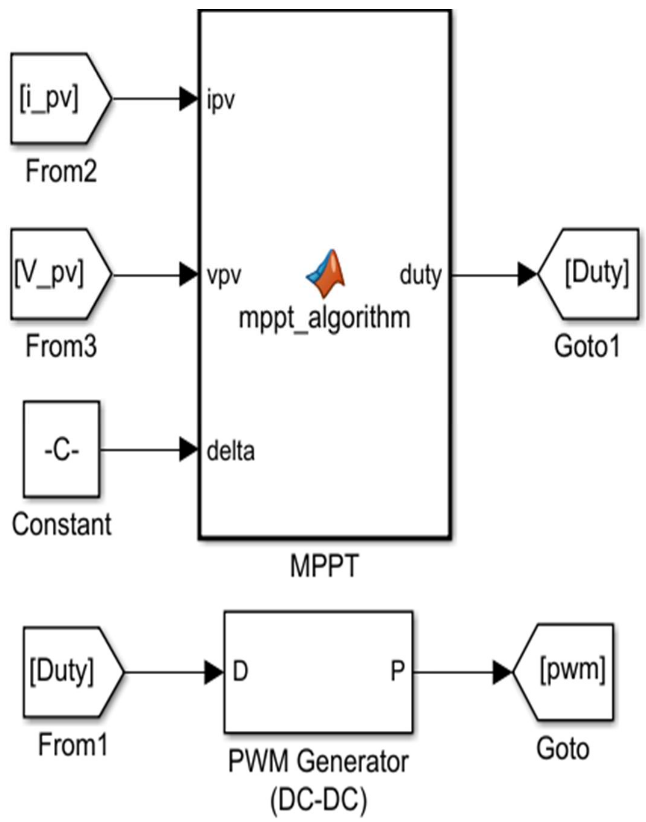

Fig. 11. Pulse generation simulation circuit of perturb and observe (P&O) algorithm.

5.2 Incremental Conductance Algorithm Based Pulse Generation

Incremental conductance algorithm was employed in MATLab environment using function block. Voltage and current were measured form PV system and fed as input to the function block which generates the conductance and compare the succeeding value of the same to generate change in conductance. Based on difference between instantaneous value of conductance and succeeding value, it generates the duty ratio. PWM generator block is used to convert the duty ratio to Pulses. The duty ratio is generated using algorithm with minimum 0% and maximum 100%. Based on the input changes the duty ration automatically get updated.

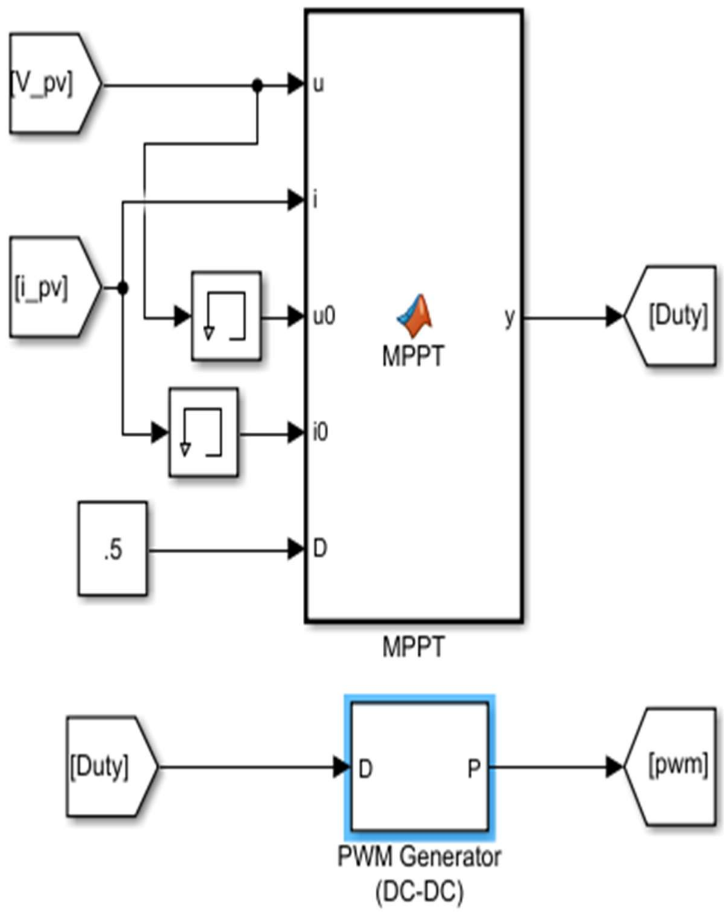

Fig. 12. Pulse generation simulation circuit of incremental conductance (IC) algorithm.

5.3 Fuzzy Logic Based Pulse Generation

The following Part describes the implementation of Fuzzy rule based system in the MATLab environment to generate the duty cycles.

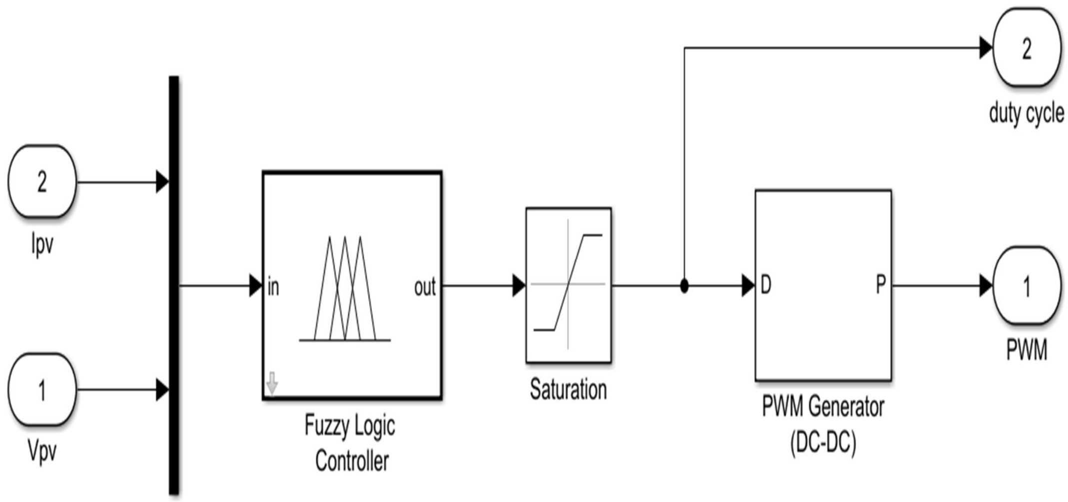

Fig 13. Optimum duty cycle generation system

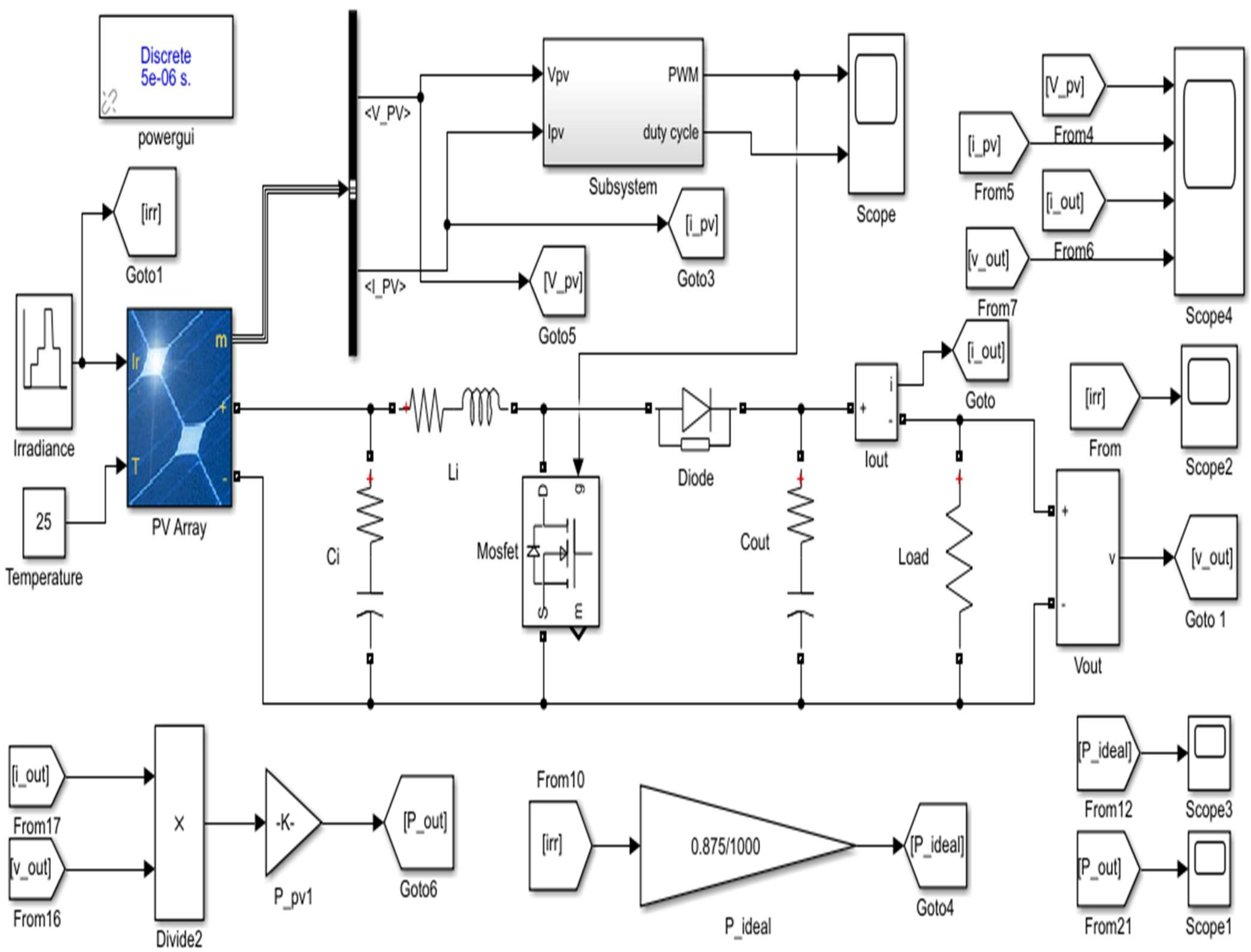

Fig. 14. Complete simulation circuit.

The fuzzy system was designed by considering two input parameters such as voltage and current of the photovoltaic system and one output parameter as a duty ratio.

The Fuzzy member ship function is defined for each parameter which includes both input and output. The membership combination was selected on the basis of permutation combination.

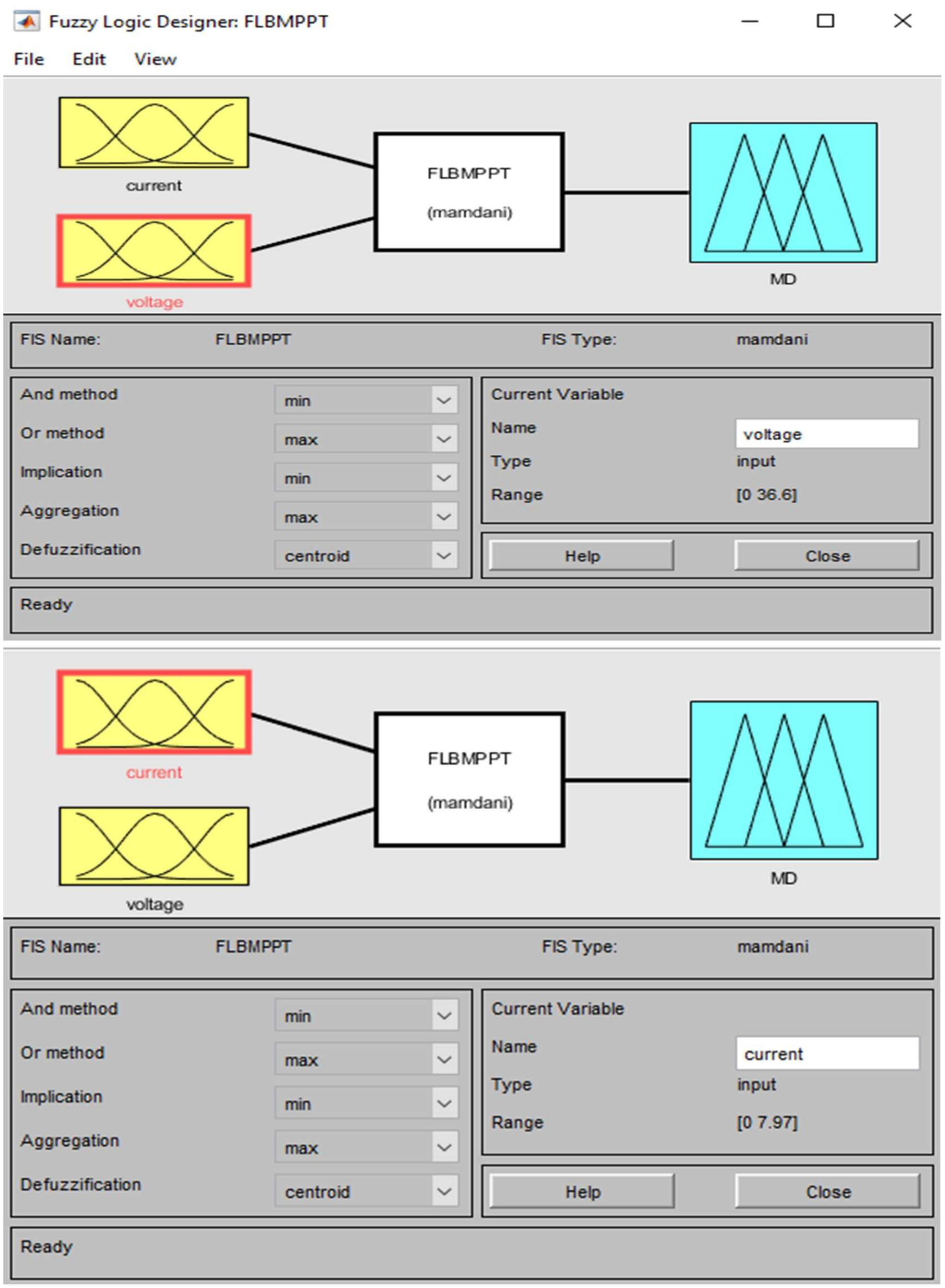

Fig15. Fuzzy Logic Designer

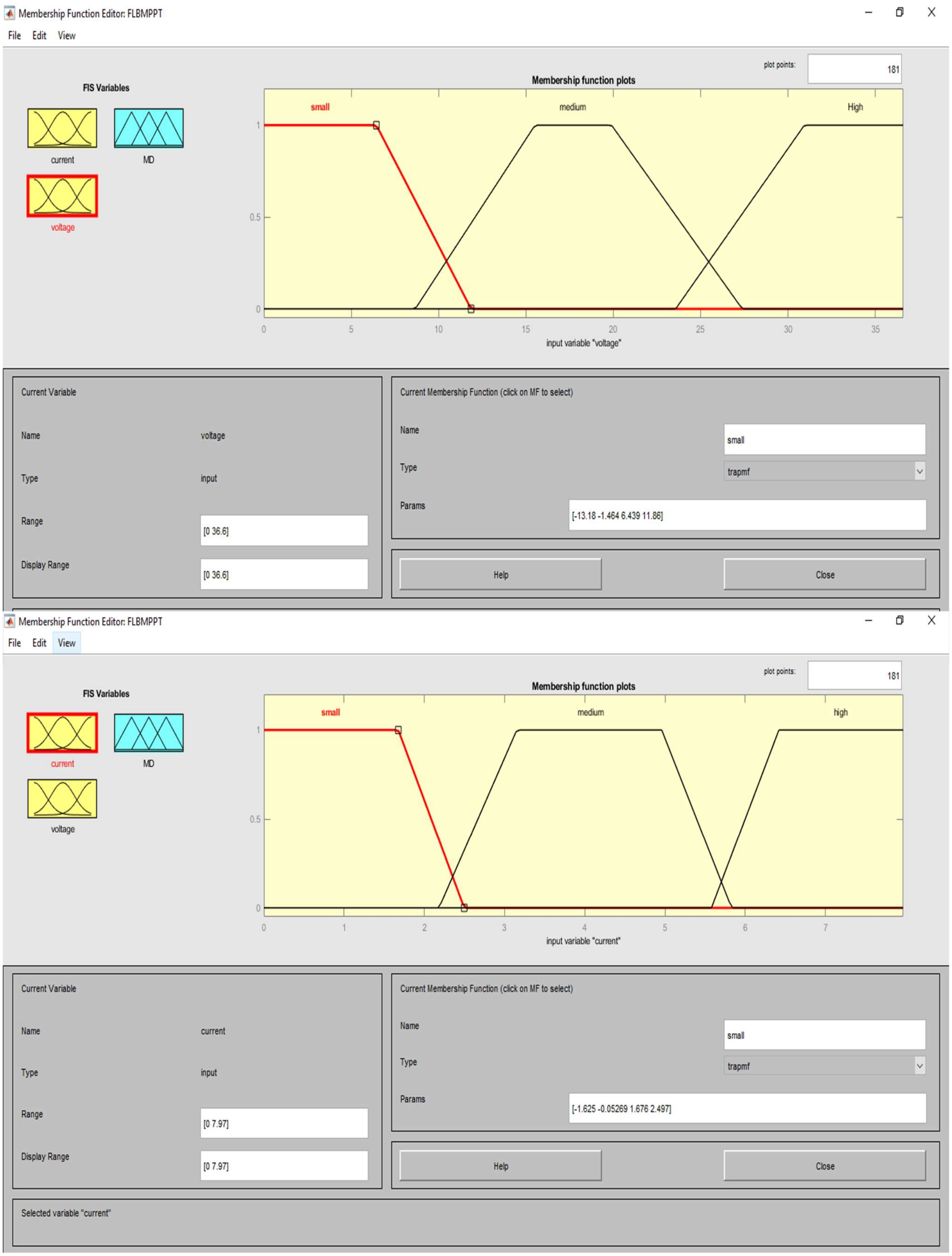

Fig 16. Membership Function Definition

The following figure describes the rules defined in fuzzy environment for optimal pulse generation with variable input. The designed system was capable to accept the any discrete change input and it will reproduce the change in duty cycle.

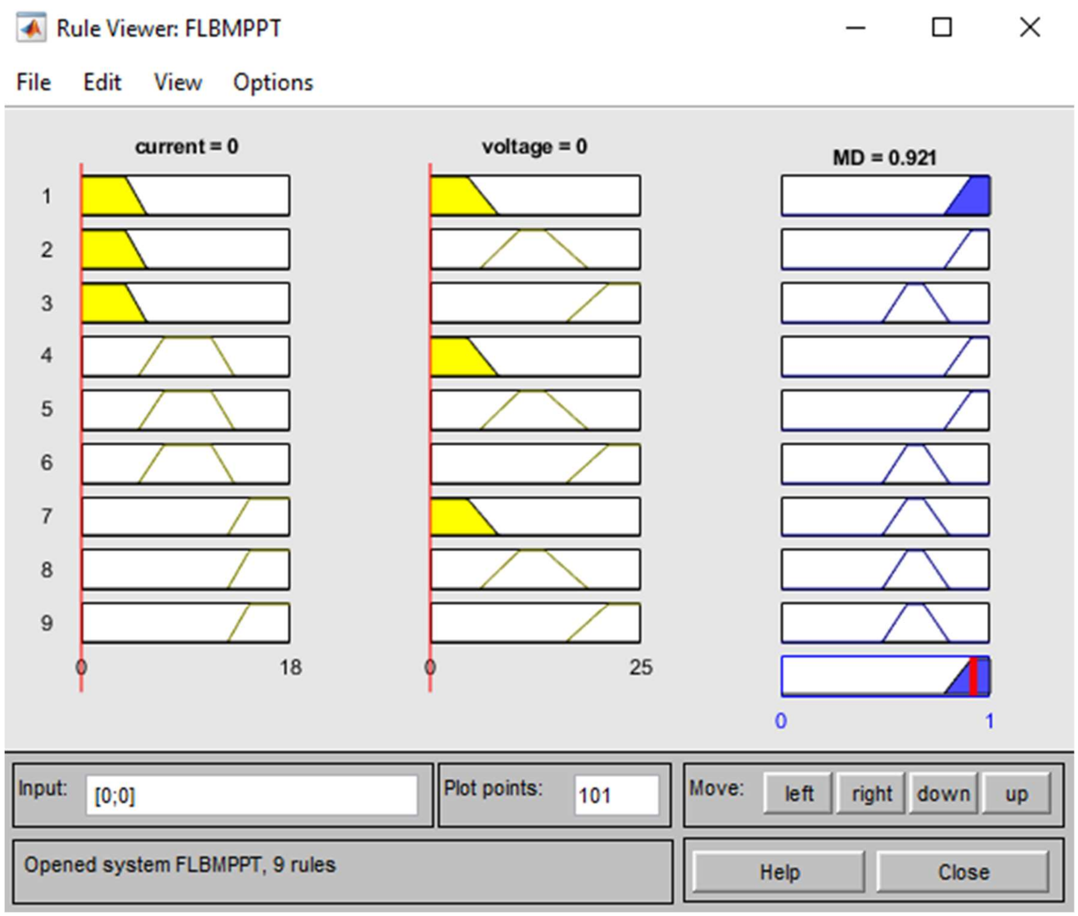

Fig 17. Fuzzy control Rule Viewer

6. RESULT & DISCUSSION

Each algorithm was modelled and simulated in Matlab Simulink environment. The outputs of all the three algorithms are described in this section in every level.

The following output describes the Dutycycle and PWM generated for the variable input. The duty cycle was about 50% in this case and corresponding PWM signal was generated through DC-DC PWM generator.

6.1 PWM & Duty Cycle

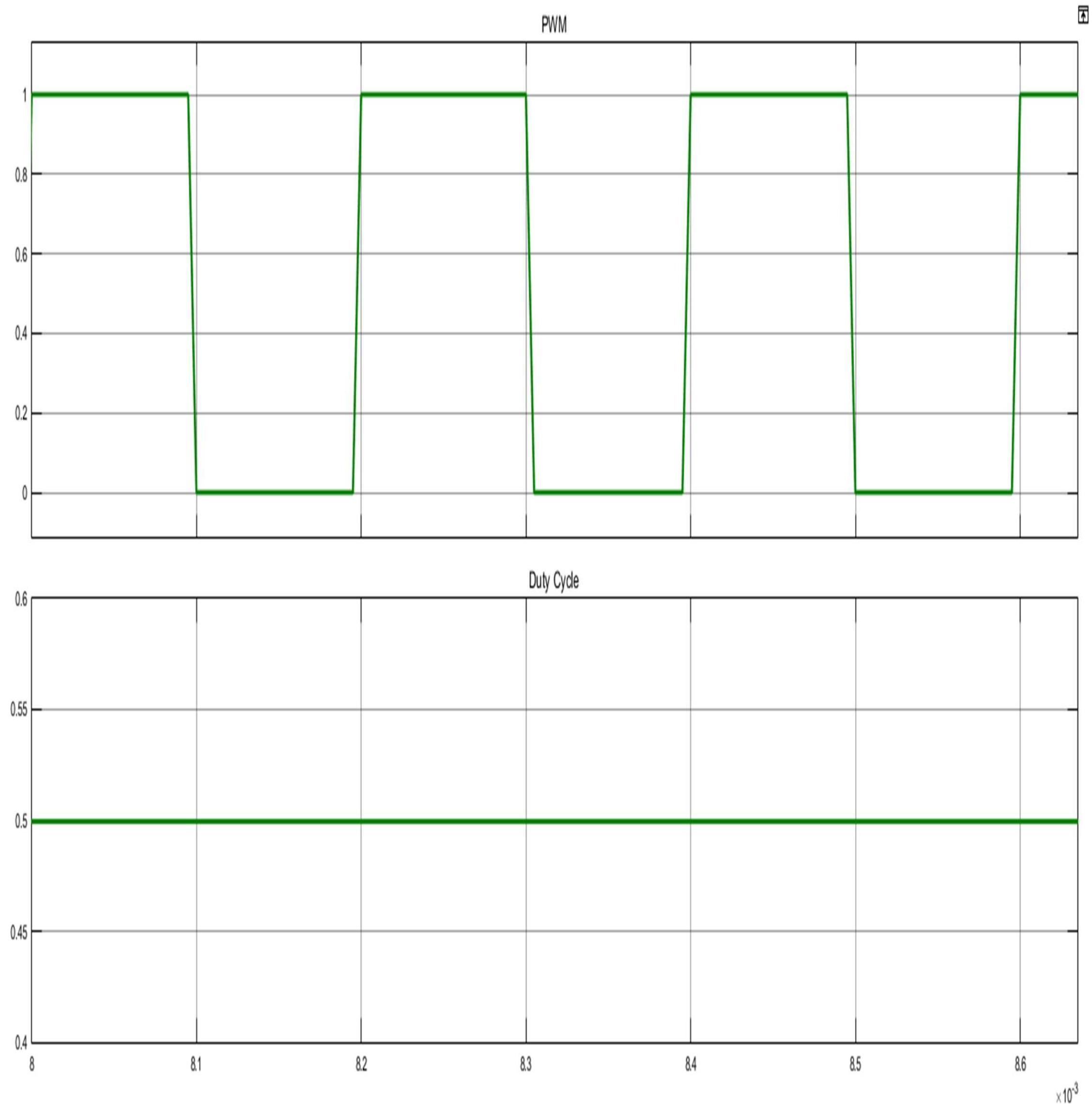

Fig 18. PWM signal and Duty Cycle generated by Fuzzy Rule Based controller.

In this simulation model, the PV system is supplied with two environmental parameters as temperature and irradiance, among these two temperatures is constant and irradiance is variable in different steps between 0 and 1000 W/m^2.

6.2 Irradiance

It is the total amount of light energy or power coming from sun obtained per unit area by a given surface. The SI unit of irradiance is W/(m*m). For a clear day the value of irradiance is approximately equal to 1000 W/(m*m).

Here we have taken different values of irradiance like 0, 300, 500, 1000, 500, 0. These values of irradiance are directly giving to PV array.

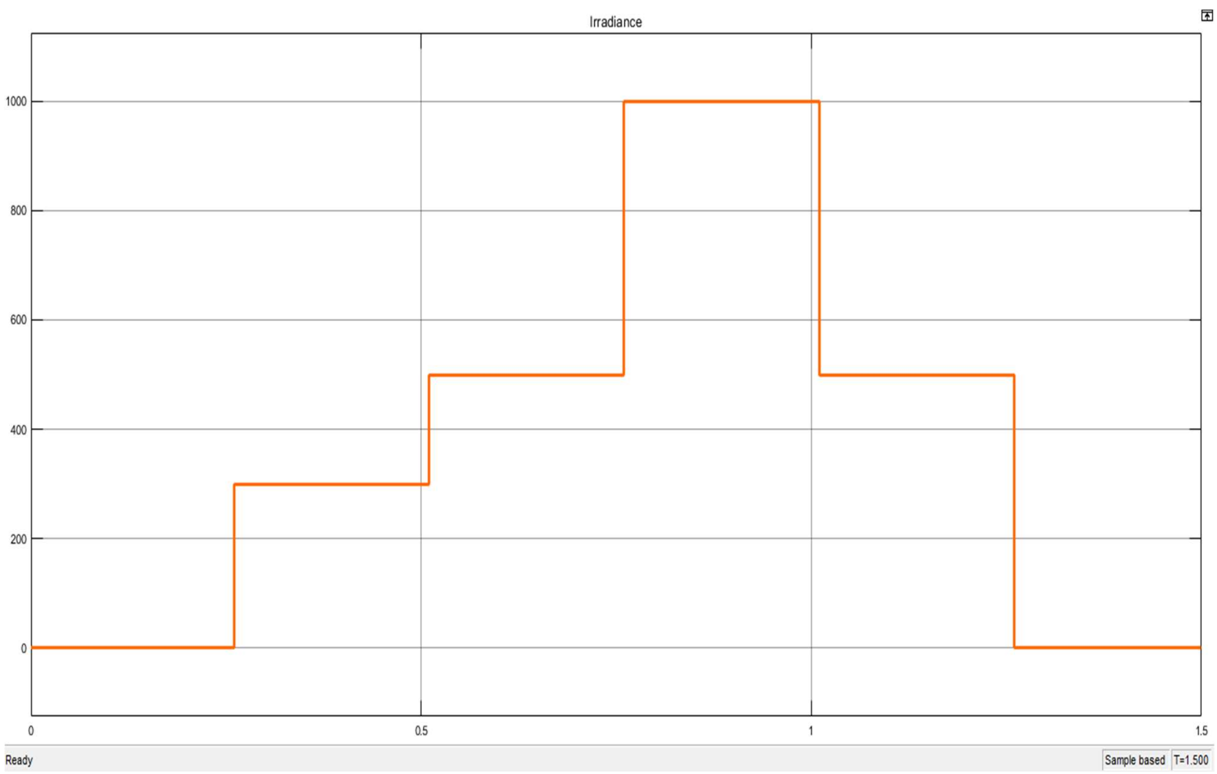

Fig 19. Step Variable Irradiance input to PV system.

6.3 Output Voltage & Output Current

V_pv is the value of voltage coming out from the PV array & I_pv is the value of current coming out from the PV array. And V_out is the value of voltage coming out from the controller & I_out is the value of current coming out from the controller.

Here, we are getting the different values of voltage and current at different values of irradiance. The graphs of output voltage and output current of P&O, IC and Fuzzy Logic Based algorithms are given below:

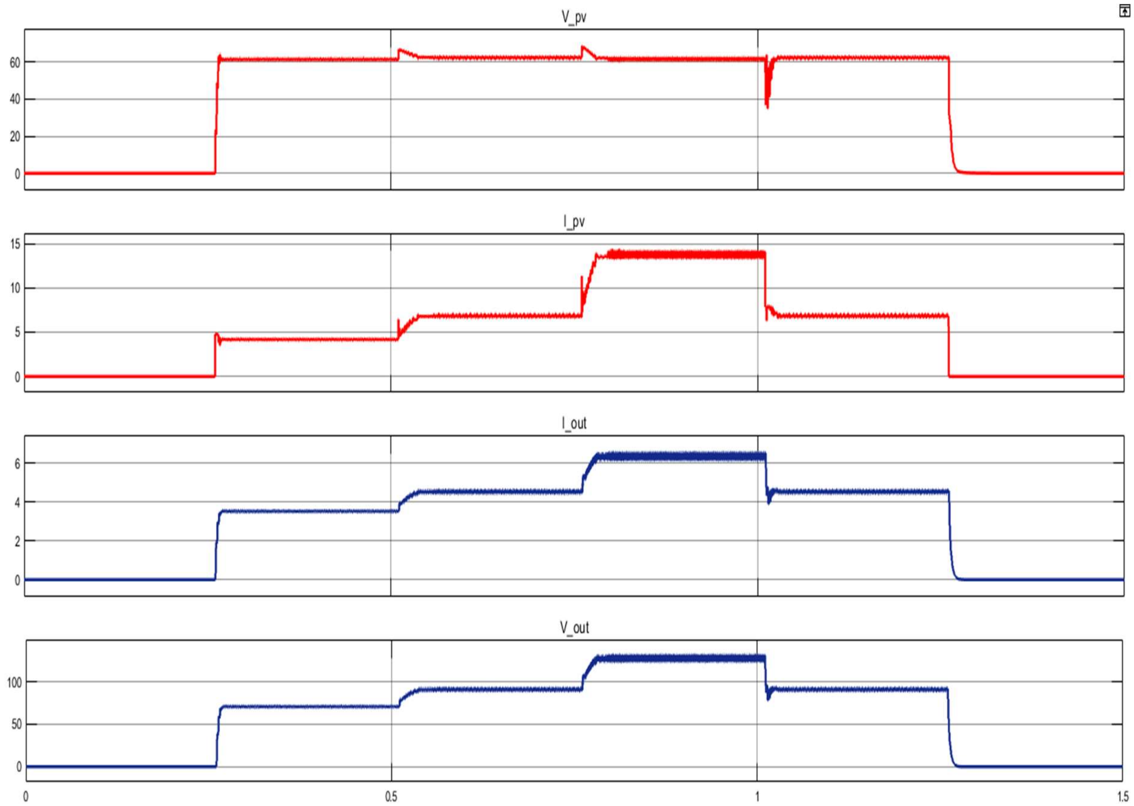

Fig 20. Output voltage & output current of P&O algorithm

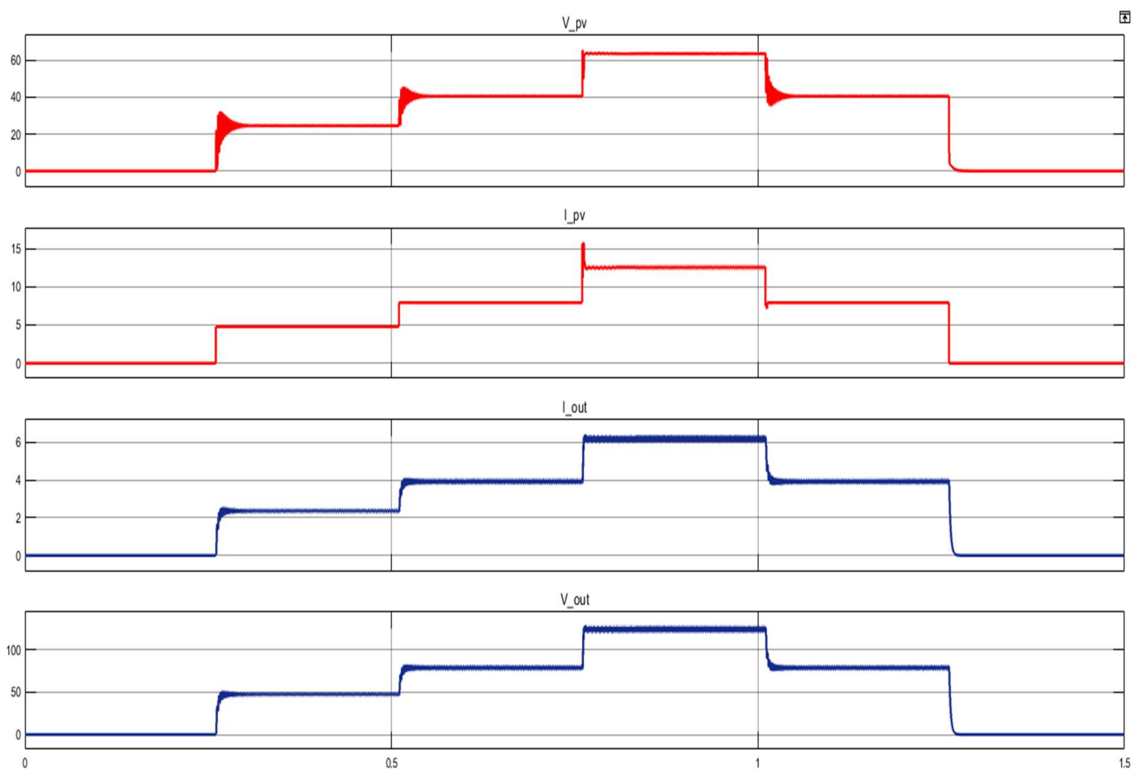

Fig 21. Output voltage & output current of IC algorithm

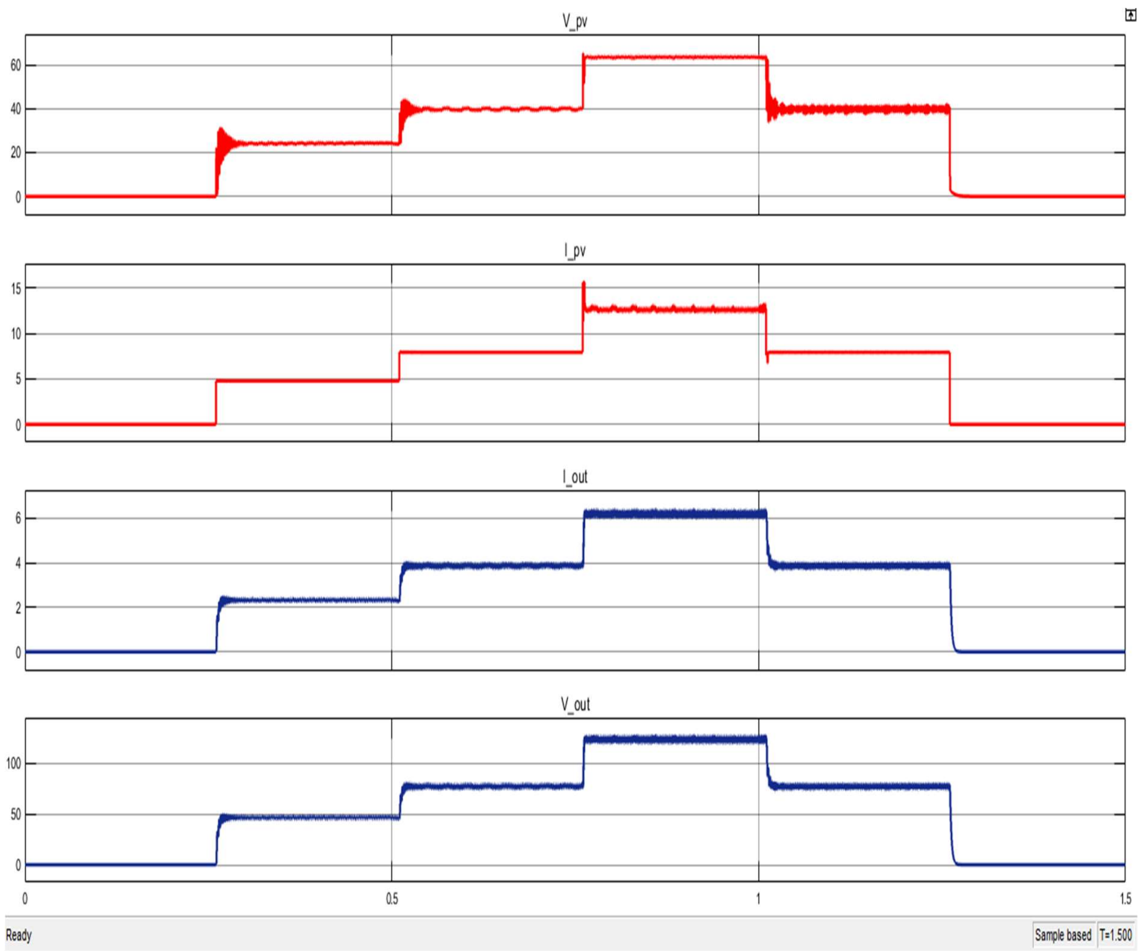

Fig 22. Output voltage & output current of Fuzzy Rule Based algorithm

6.4 Output Power

Output power is the product of the output voltage and output current.

Here, the system output is coming out from the controller. That's why we are using the values of voltage and current, which are coming out from the controller for finding the output power. The ideal value of power is 875.5 watt at irradiance of 1000 W/(m*m). The output powers are approximately equal to 860 watts, 810 watts and 800 watts of P&O, IC and Fuzzy Logic Based algorithms at irradiance of 1000 W/(m*m).

The graphs of output power of P&O, IC, Fuzzy Logic Based algorithms are given below:

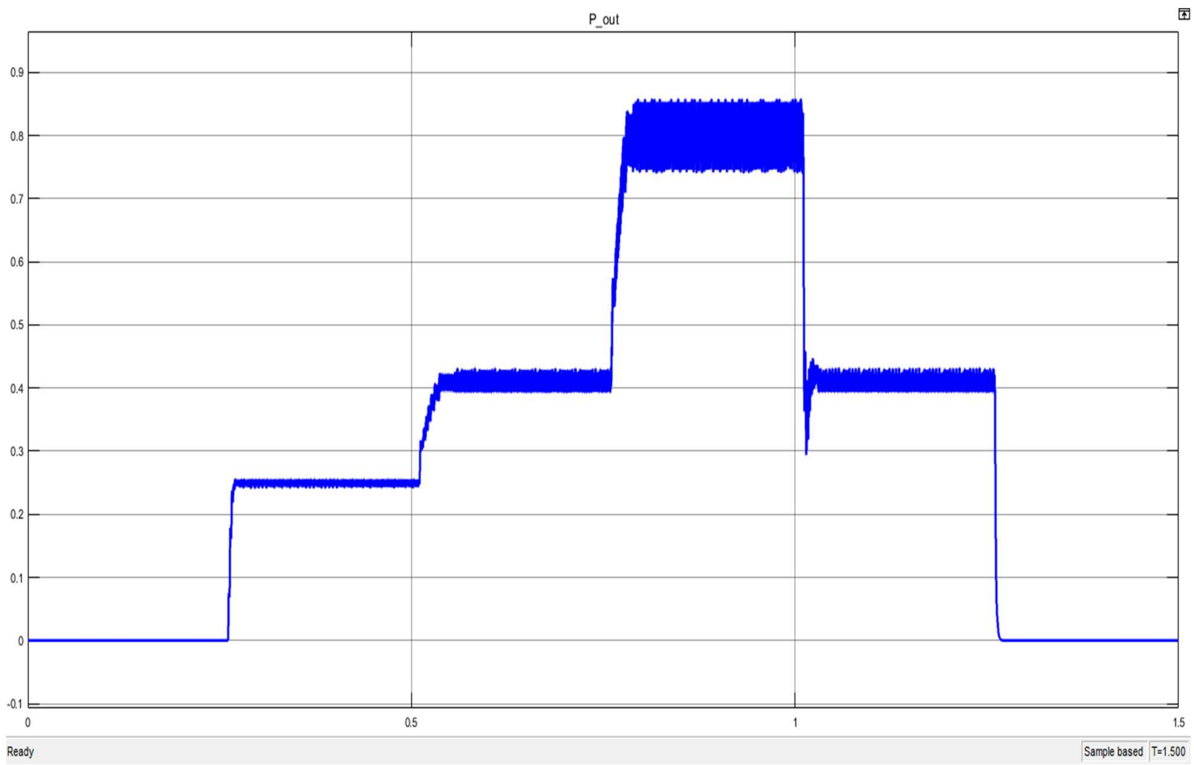

Fig 23. Extracted power from P&O algorithm

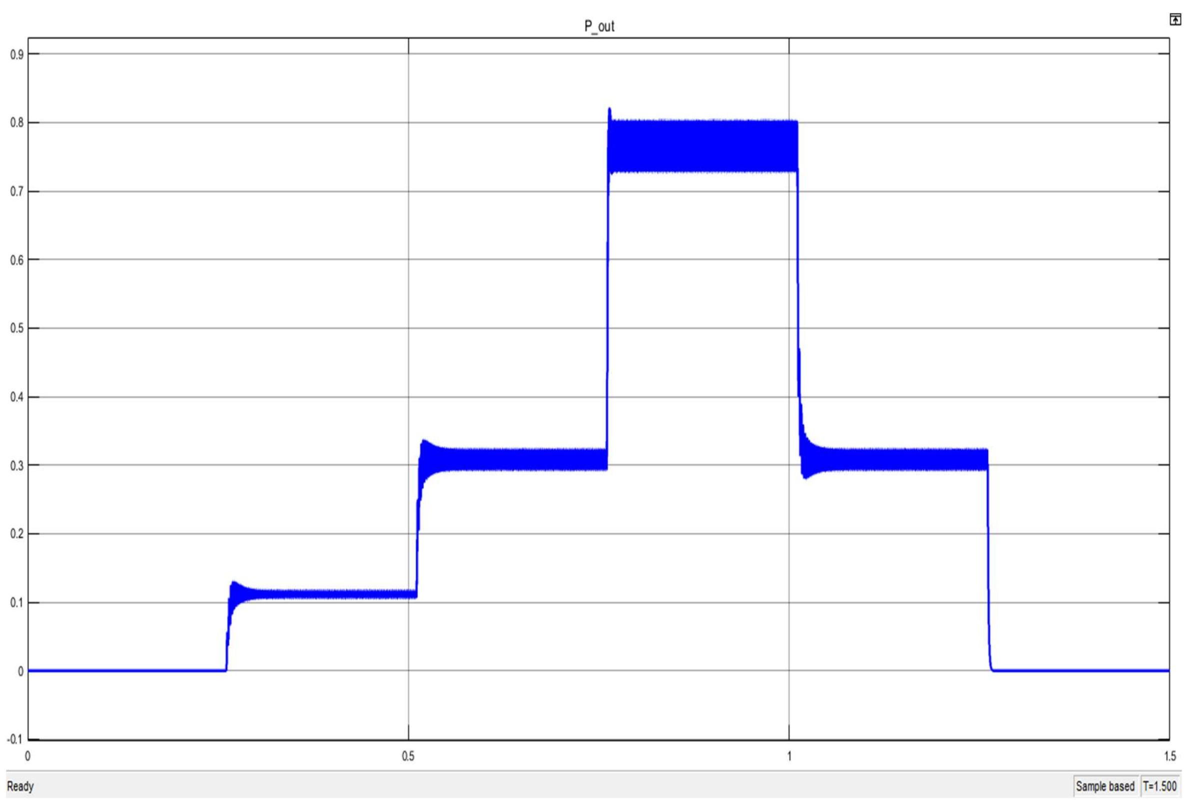

Fig 24. Extracted power from IC algorithm

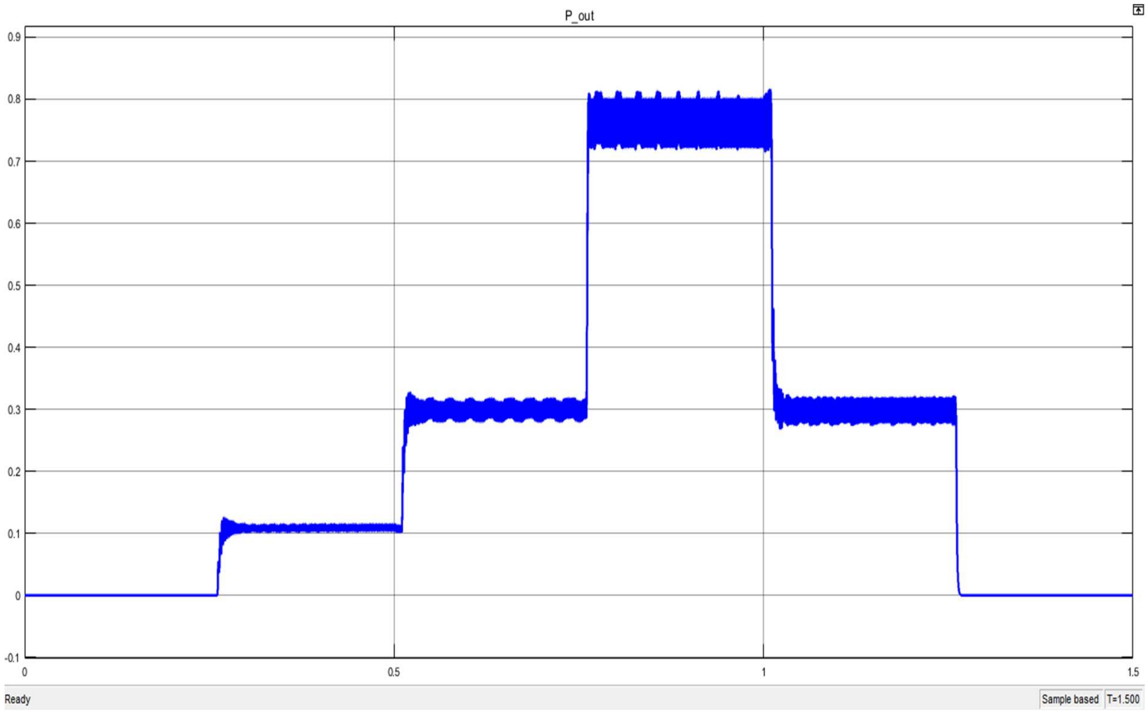

Fig 25. Extracted power from Fuzzy Rule Based algorithm

6.5 Tracking Efficiency

Tracking efficiency is the ratio of difference between ideal power and PV array power to the ideal power. The maximum value of tracking efficiency of P&O algorithm is more than 98%, IC algorithm is about 93% and the Fuzzy Logic Based algorithm is about 90%.

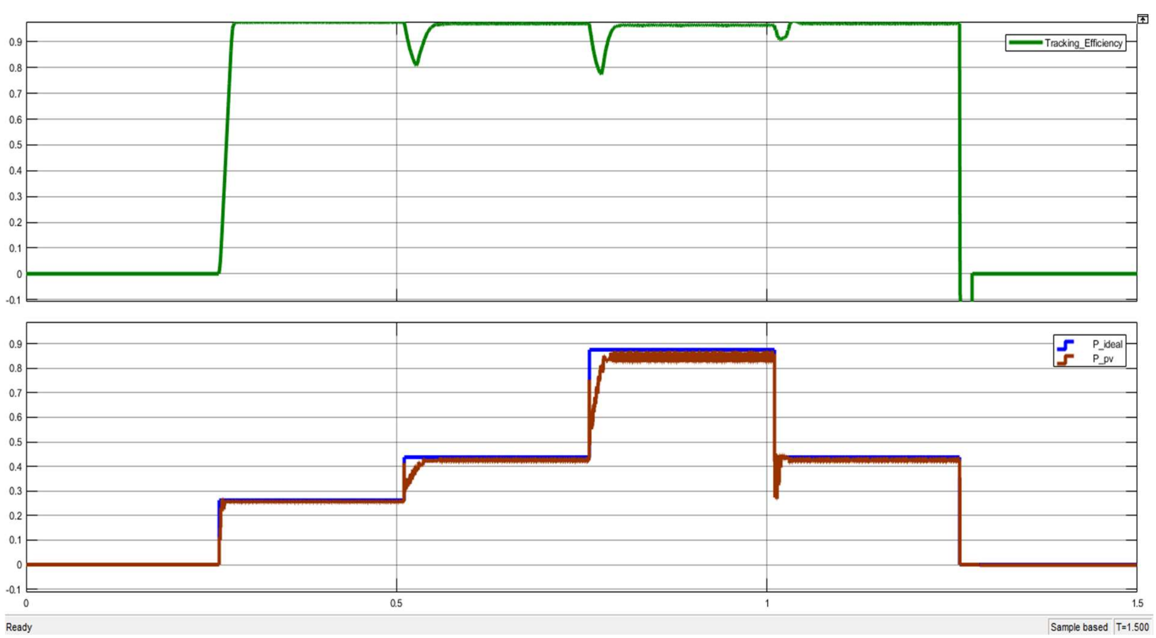

Fig 26. Tracking Efficiency using P&O algorithm

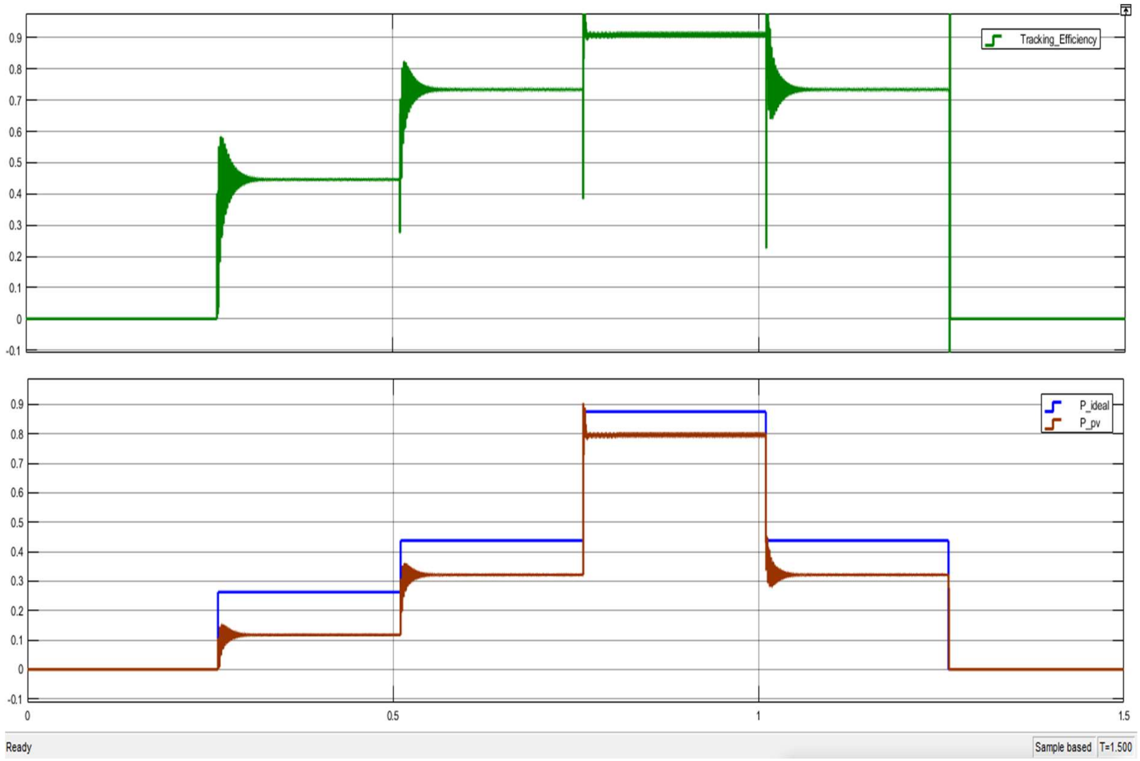

Fig 27. Tracking Efficiency using IC algorithm

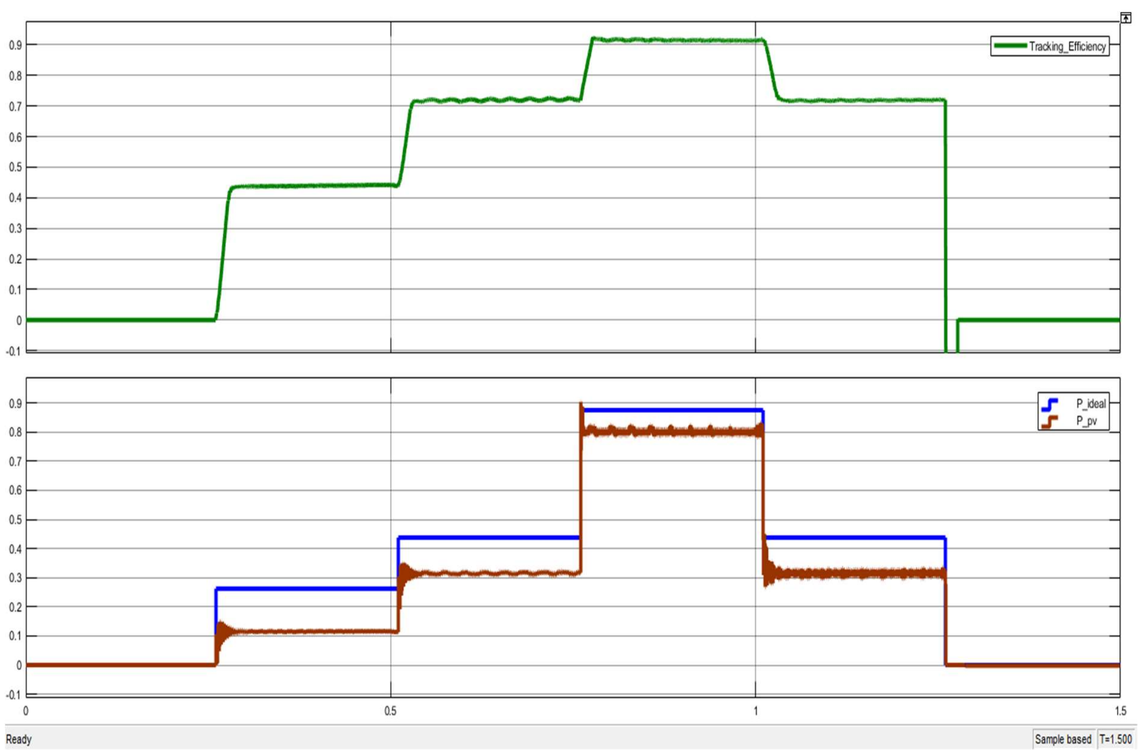

Fig 28. Tracking Efficiency using Fuzzy Rule Based algorithm

6.6 System Efficiency

System efficiency is the ratio of difference between ideal power and output power to the ideal power.

The maximum value of tracking efficiency of P&O algorithm is more than 95%, IC algorithm is about 90% and the Fuzzy Logic Based algorithm is about 88%.

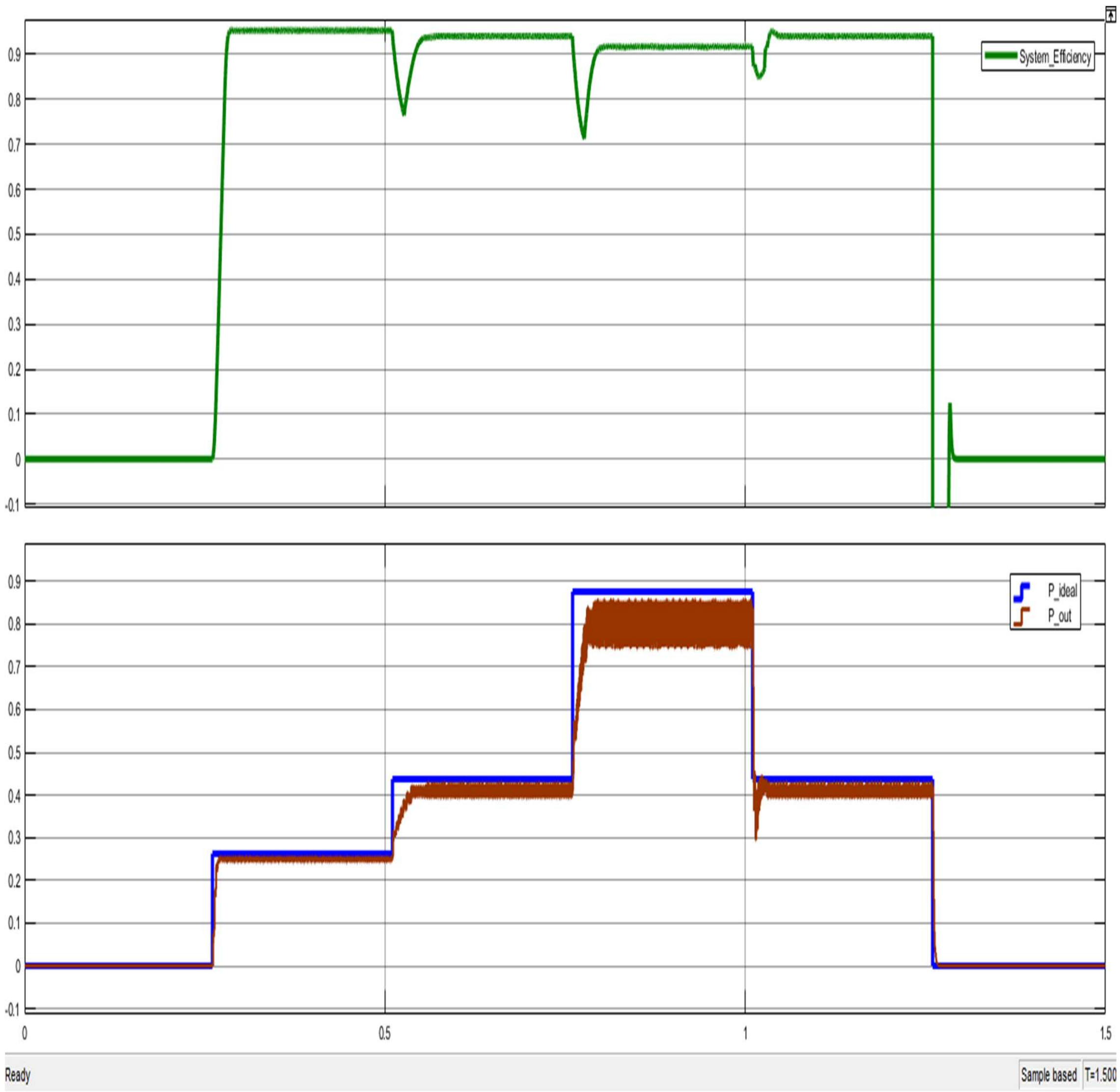

Fig 29. System Efficiency using P&O algorithm

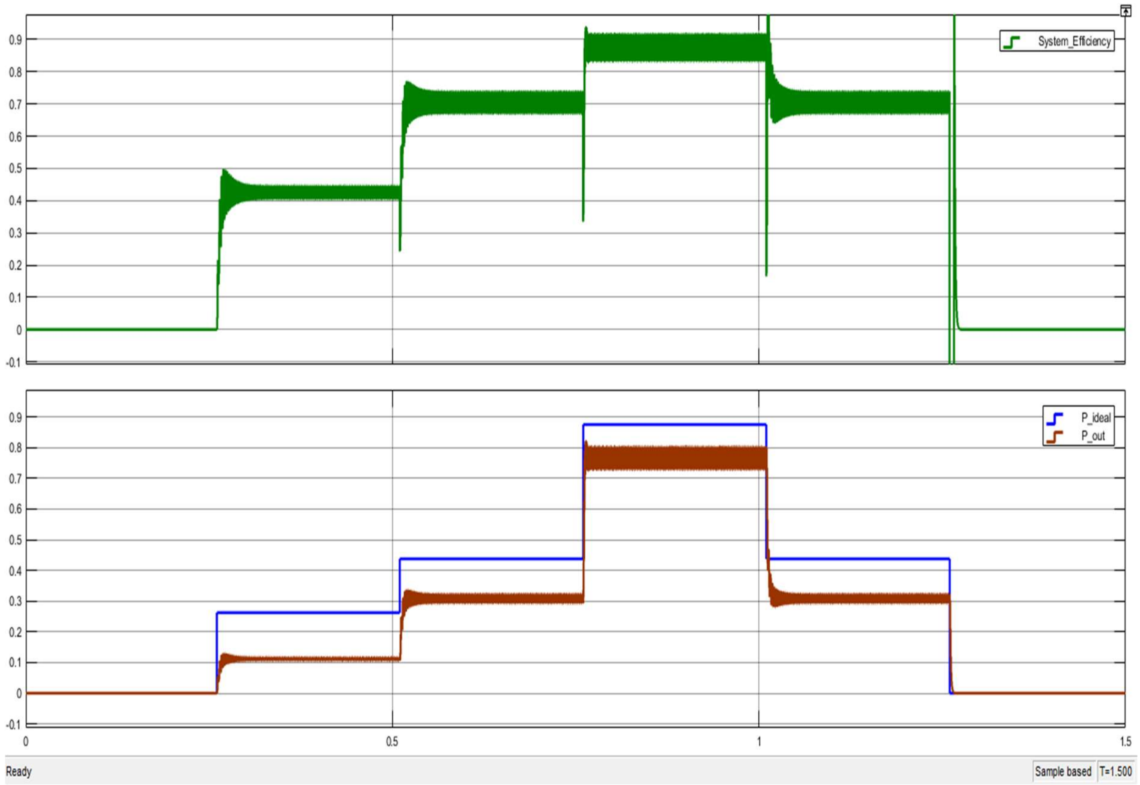

Fig 30. System Efficiency using IC algorithm

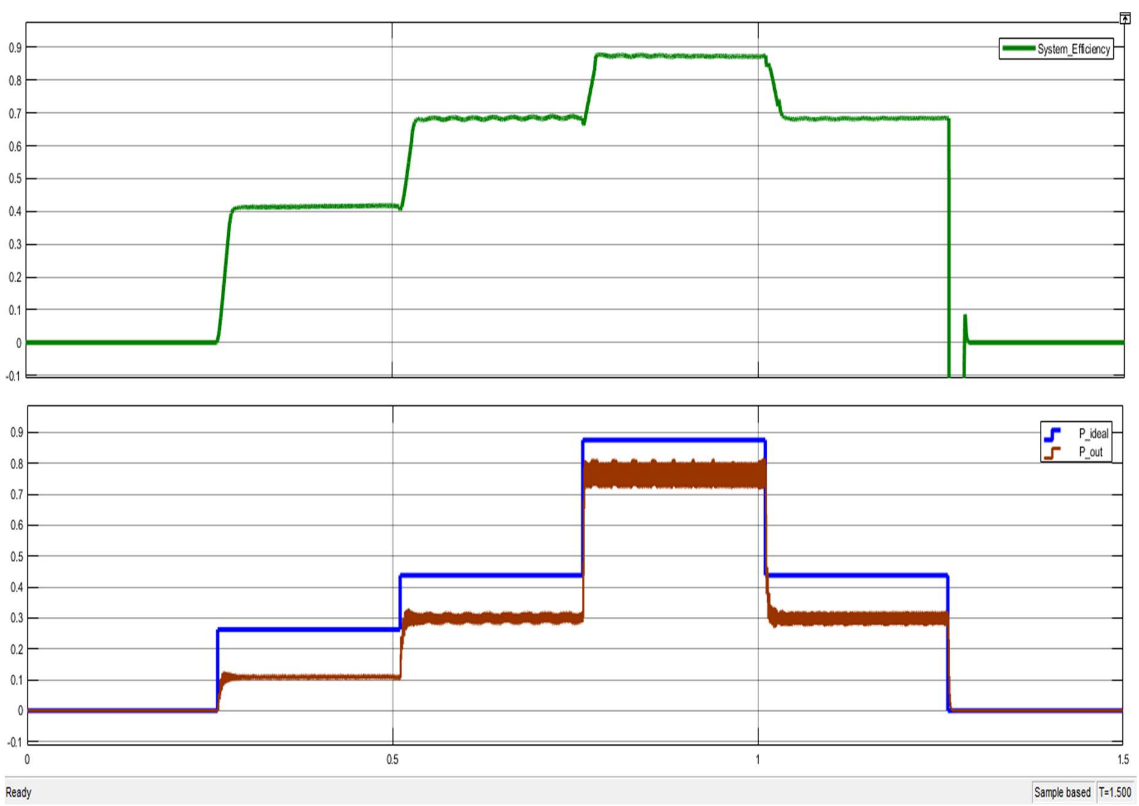

Fig 31. System Efficiency using Fuzzy Rule Based algorithm

7. CONCLUSION

The key function of this article was to analyse the performance of three most versatile MPPT. The analysis shows the difference in performance of all three in steady state and dynamic behavior. The major observation from the results were power extraction efficiency and tracking efficiency. In point of dynamic behavior, the P&O algorithm shows the smooth transition and steady state behavior was better in fuzzy based system. But system conversion efficiency shows that P&O is superior than others from the performance characteristics.

The value of irradiance can vary according to the weather. The output voltage and output current having same waveform because we are using resistance as a load. The output power of the system is changing due to change in the value of irradiance.

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