**Radak Blange[1],**
**A. K. Singh[1]**

# Study of PV Module for Characterizations Using MATLAB Simulink and Tracking of Maximum of PV Power

Journal of Electrical Systems

***Abstract: -*** Solar energy is the primary renewable energy source, and solar photovoltaic (PV) cells utilise sunlight to generate power for utility applications. The output of PV power varies as a direct current, depending on the intensity of the sunlight. Therefore, understanding the behaviour of PV power in terms of electrical power, voltage, and current is crucial to effectively tracking and extracting the maximum power from the PV system. In this paper, we have configured the parameters of the PV cell using a reference PV module and modelled it within the MATLAB Simulink environment, taking into account changing atmospheric conditions. We successfully simulated the PV characteristics, specifically maximum power, voltage, and current, through a stepwise variation of incoming irradiance and ambient temperatures. The results of these simulations were then compared with data from the actual reference PV cell. The PV model we employed has successfully verified and validated the parameters against the provided actual reference PV module in the MATLAB Simulink environment, yielding results that closely match the actual datasheet specifications.The PV power is Solar Insolation(S) and ambient temperature(T) dependence. Hence its Maximum power point is to be correctly tracked down. The Maximum power tracking using Perturb and Observe and Fuzzy Logic Based MPPT algorithms have been evaluated and compared.from the result it is seen that Fuzzy Logic MPPT is much better than that of conventional PO.

***Keywords:*** Solar Photovoltaic (PV), Solar Insolation(S), Cell Ambient Temperature (T), Matlab Simulink.

## INTRODUCTION:

Fossil fuels are extensively utilised, and the day is not long before fossil fuels are exhausted. Therefore, scientists and engineers have been exploring alternative uses of renewable energy. Solar energy, being the prime renewable energy source, has been the ultimate choice among other renewable energy sources. Hence, lots of active research has been carried out in recent years for power generation from PV owing to the sun's photon energy being the prime source of renewable resource on the earth, and it is also spotless and pollution-free, inexhaustible and can be freely harvested. PV power has vast applications ranging from power generation for electricity consumers, standalone power backup applications, electric vehicle charging applications, and powering solar vehicles to power satellite space programs [1,2]. However, PV cell systems have some energy problems, such as PV systems having approximate conversion up to 18 per cent and having peculiar non-linear characterizing DC power. So, the behavior of PV power under various magnitudes of changing solar insolation and the ambient temperature is analyzed because PV power solely depends on the intensity of sunlight, so-called solar isolation (S) and ambient temperature (T). So the solar isolation and cell ambient temperature creates changes in the I-V and P-V behavior characteristic concerning the advancement of time and accordingly change the scope of tracking the Maximum power point (MPP) using various techniques of many Maximum Power Tracking(MPPT) algorithms [3,6-7] The PV power is Solar Insolation(S) and ambient temperature(T) dependence. Hence its Maximum power point is to be correctly tracked down. Various methods of MPPT had been proposed by researchers. The three prominently conventional maximum power point tracking (MPPT) algorithms widely used are perturb and Observe(PO), Hill Climbing Technique and Incremental Conductance method. Out of these three PO is preferred over others owing to its simplicity, ease of implementation and much-cheaper[3,4].But PO also have some draws back of poor tracking, deviation of MPP at low value of solar irradiance

[1]Department of Electrical Engineering NERIST, Nirjuli-Arunachal Pradesh-791109, India
[2]Department of Physics, NERIST, Nirjuli-Arunachal Pradesh-791109, India
Corresponding author: radakblange@gmail.com

and hovering back-and forth around its MPP and fails to stick exactly besides slow-response [2,5].for the overcoming of these draw backs, researchers strongly strive to use the artificial intelligence control techniques such as fuzzy logics, neural networks, neuro-fuzzy and genetic Algorithms [6-7].FLC is one of the most popular among the artificial intelligent techniques since it is simple and practically easy to be implemented [6,7,8].

In this Paper, The Matlab Simulink Model for the PV module of 100W was developed for simulation in the Matlab Simulink platform. And the maximum power tracking of PV power using PO and FLC have evaluated.The paper further has been subdivided into sections for glances and easy analysis. Section II in the paper deals with the theoretical aspects of the PV model; Section III covers Matlab simulation for PV Power, Voltage and Current and their behavior; Section IV deals with the reference model of the PV Module and its validation and discussion, Section V deals with simulation results of PV power, Voltage and Current, section VI deals maximum power point tracking, section VII DC-DC Converter, section VIII simulation results of MPPT and Section IX explain the Conclusion respectively.

**Model For Photovoltaic Module:**

The PV cell is a p-semiconductor junction that directly converts light energy into electricity based on photoelectric effects. PV cells are arranged in a grouping way in larger units forming a PV module, and the interconnection of more PV modules in a parallel-series configuration forms PV arrays. The PV equivalent circuit is shown in Fig.1 [9].

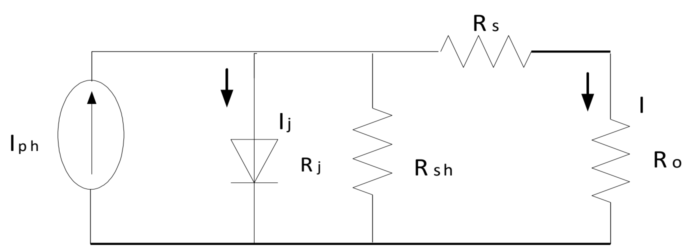



**Fig 1. Simple-Equivalent Circuit Model of PV Cell**

Usually, the value of $R_{sh}$ is very high, and that of $R_s$ is very low. In idealing cases, $R_s = 0$ (no series loss) and $R_{sh} = \infty\Omega$ (no leakage to ground). So, they may have neglected to simplify the analysis of the circuit. A set of equations can represent the output current (I), and accordingly, the PV model can be made by the set of equations given below[9-11].

$$I = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{q}{kTA}\frac{V}{n_s}\right) - 1\right] \quad (0.1)$$

In this paper, values have been taken as A =1.3, $n_s$ =36 and $n_p$ =1 The value of $I_{rs}$ varies with temperature according to the following equation

$$I_{rs} = \left[\frac{T}{T_r}\right]^3 \exp\left(\frac{q}{k}\frac{E_g}{A}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (0.2)$$

*E.g.* as a function of the temperature $T$ and is given by the equation[15]

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{(T + \beta)} \quad (0.3)$$

The equation of $I_{ph}$ is given as

$$I_{ph} = \left[ I_{scr} + K_i \left( T - T_r \right) \right] \frac{S}{100} \quad (0.4)$$

From eqn.(1.1) The PV array power P is given by.

$$P = VI = n_p I_{ph} V - n_p I_{rs} V \left[ \exp\left( \frac{q}{kTA} \frac{V}{n_s} \right) - 1 \right] \quad (0.5)$$

From eqn (1.4), the corresponding voltage at the Maximum power point, $V_{\max}$ can be calculated by taking $\frac{dP}{dV} = 0$.

By doing so, we get,

$$\exp\left( \frac{q}{kTA} \frac{V_{\max}}{n_s} \right) \left[ \left( \frac{q}{kTA} \frac{V_{\max}}{n_s} \right) + 1 \right] = \frac{I_{ph} + I_{rs}}{I_{rs}} \quad (0.6)$$

Solving the equation (1.5) above, $V_{\max}$ will be a function of $I_{ph}$ and $I_{rs}$ Which in turn are functions S and T.

III. MATLAB Simulation For Generation of PV Power, Voltage, Current and Characteristics.

Using the Matlab Simulation for PV module in the MATLAB Simulink Platform, the I-V and P-V characteristics of a Photovoltaic cell for different solar irradiance values and cell ambient temperature are compared with reference to the Alpex PV Cell Module. The following are the details of the power, voltage, and current generation of a PV cell for various solar insolation and temperatures.

III.1 Voltage at open circuit ( $V_{OC}$ ) and Current at short circuit(ISC) of PV

PV power is non-linear in its output, so the nature of voltage and Current needs to be studied. The significant parameters that usually describe PV cell performance are $V_{OC}$ and $I_{sc}$. Short-Circuiting the terminal of wire, $I_{sc}$ is achieved and then measuring the current of the terminal by simply neglecting the small leakages current of the diode under Zero volt of terminal voltage, and at this condition, the short-circuiting current is the $I_{ph}$ .The maximum PV voltage is obtained with opened-circuited voltage. The $V_{oc} = V + IR_{sh}$ Of cell [14] is achieved at zero value of load-current that is $I$=0

III.2 Characteristics of Current(I)-voltage(V) and power(P)-voltage of PV.

The behaviour or the characteristics of PV cells understood by its I-V and P-V characteristics of PV and the nature of I-V and P-V curves at constant irradiance(S) of sunlight and continuous cell ambient temperature(T) are shown below in Fig.2 and Fig.3, respectively. Generally, on the left top of the current-voltage curve, Short-Circuit-Current(Isc) is obtained at zero Voltage and on the bottom right of the current-voltage graph, Open-Circuit-Voltage ($V_{oc}$) is received at zero value of current.

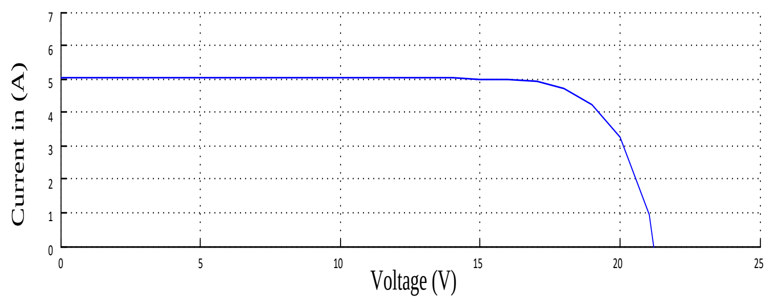



**Fig 2. I-V Curve of PV module**

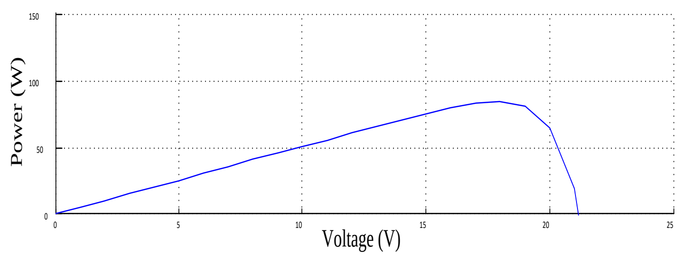



**Fig 3. P-V characteristics of PV module**

Concurrent with the Alpex PV model, the parameters of the PV Model have been configured, and accordingly, the simulation at the MATLAB-Simulink platform under varying values of Solar Irradiance(S) and ambient Temperature (T) at stepwise of S and T is provided in Fig.4, Fig.5, Fig.6, and Fig.7, respectively.

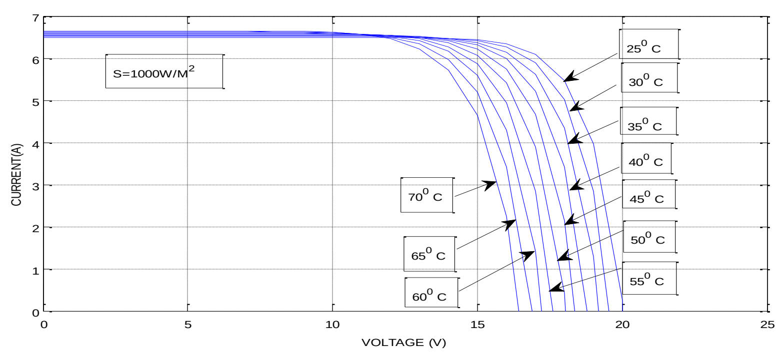



**Fig 4. I-V Characteristic with varying *T* at constant *S*.**

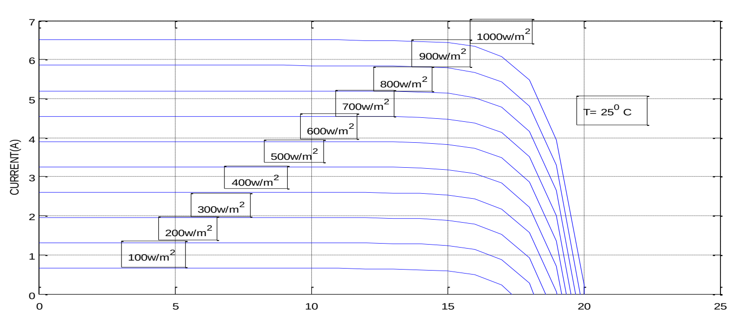



**Fig 5. I-V Characteristic with varying *S* at constant *T*.**

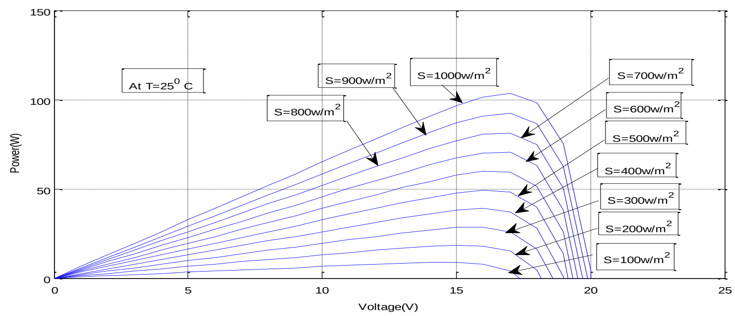



**Fig 6. P-V Characteristic with varying *S* at constant *T*.**

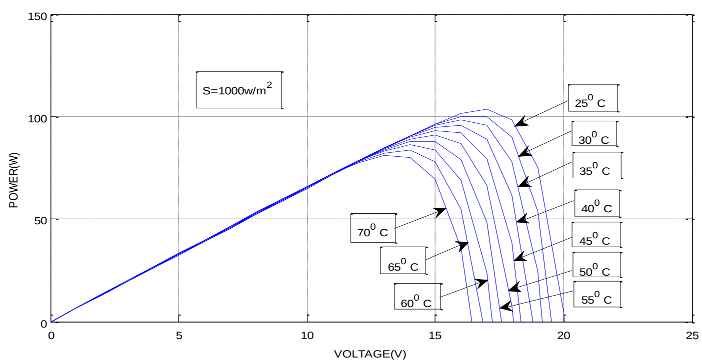



**Fig 7. P-V Characteristic with varying *T* at Constant S.**

IV. Reference Model of PV Module, its validation and Discussion.

A PV model of 100 watts, as shown in Table I, had been considered the reference module for simulation. The details of PV parameters are provided in Table. I

**TABLE I: PV Module-Parameters (Alpex-1552P-3613G)**

| | |
|---|---|
| Maximum PV power | 100W |
| Voltage at maximum power | 17.5V |
| Current at maximum power | 5.6A |
| Open-circuit- voltage ($V_{oc}$) | 21.3V |
| Short-circuit- current($I_{sc}$) | 6.45A |
| The co-efficient of Temperature (Ki) of $I_{sc}$ | 0.065%/K |
| PV cell temperature | 25$^0$ C |

V. SIMULATION RESULTS OF PV POWER, VOLTAGE AND CURRENT

The simulations in MATLAB Simulink results under various values of solar isolation and different values of PV cell ambient temperature were carried out with step variations. The I-V and P-V characteristics are provided in Fig.4, Fig.5, Fig.6, and Fig.7, respectively.

Then, the simulation results were analysed and compared with the PV module's reference data. The simulation results are recorded in Table II, and a comparison of the simulated results and specifications data of the given PV module is provided in Table III, respectively.

**Table II: The Simulation results of PV power voltage and current.**

| Parameter | Simulated results | Remarks |
|---|---|---|
| Maximum PV Power (Pmax) | 103W | Higher than the PV module datasheet, slightly |
| Voltage at $P_{max}$ | 17V | Slightly less but almost matched with the PV module |
| Open circuit voltage ($V_{oc}$) | 20V | slightly lesser than the datasheet -the value of the PV |
| Short-circuit- current($I_{sc}$) | 6.45A | almost nearing matching with the PV module |

**TABLE.III: comparison of simulation results with the reverence datasheet of PV Cell.**

| $S=1000W/m^2$ | Specification of Solar AlpexPV Module | Simulation Results of PV Model | Error in (%) |
|---|---|---|---|
| $P_{max}$ | 100W | 103W | 0.03 |
| $V_{mpp}$ | 17.7V | 17V | 0.039 |
| $I_{mpp}$ | 5.7A | 6.5A | 0.008 |
| $V_{oc}$ | 21.4V | 20.10 | 0.012 |
| $I_{sc}$ | 6.5A | 6.5 | 0.000 |

From the simulation results, it is observed that in the curves of Current Voltage and PV Power Voltage under varying values of solar insolation and cell ambient temperature at the fixed temperature, the maximum power increases with increasing solar insolation(S) and decreases when S decreases with negligible changes in PV voltage. However, at a fixed value of S with increasing temperature, maximum power decreases with essential decreases in the voltage.

It is also observed that at the fixed or constant T, PV output current increases or decreases when S is increased or decreased, with voltage slightly increasing or decreasing when S is increased or decreased.

It is also observed that the maximum current remained almost constant with an increase in temperature, but the PV voltages decreased when T was increased. However, the maximum current depends upon the intensity of solar insolation; when S is increased, the maximum current increases, or when S is decreased, the maximum current also increases. Hence, in PV Characteristic curves, it is observed that the overall efficiency is reduced drastically with a high increase in ambient temperature.

Tables II and III provide the simulation results and compare them with the reference apex PV module specification. The comparison shows that the simulation results almost match the PV module specification, with the error being less than 0.04 percent.

## VI. MAXIMUM POWER TRACKING OF PV POWER

There are various types of maximum power point tracking. In this paper two type of maximum power point tracking (MPPT) are discussed and compared and they are discussed below.

VI.(a) Perturb & Observe Method.

In this techniques the PV voltage is changing in such as way either increase or decrease the array voltage from time to time till the MPPT is achieved. On the P-V curve. The flow chart algorithms of Perturb & Observe (PO) is provided Fig.8 below.

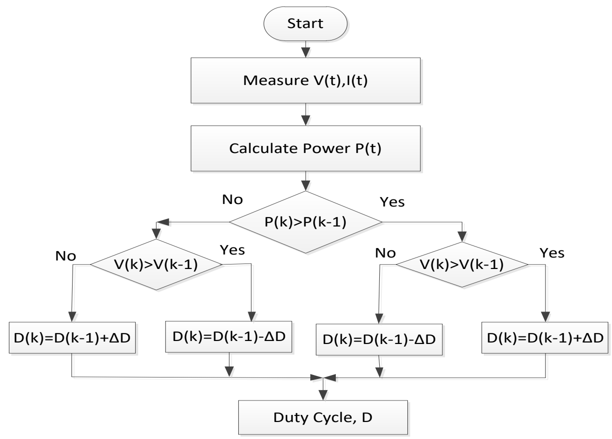
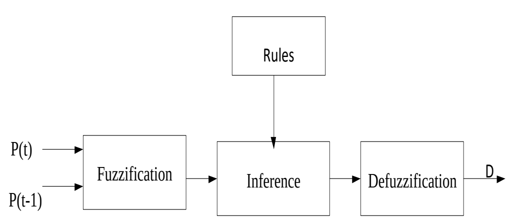



**Fig.8 The flow chart algorithms of Perturb & Observe**

VI.(b) Fuzzy logic controlled maximum Power point tracking .

The fuzzy logic controller technique is very simple but very effective for the non-linear system like PV system. In this technique and FLC does not require the exact PV system. The Block-diagram of FLC and the proposed FLC algorithms are provided in Fig.9 and Fig.10 respectively.



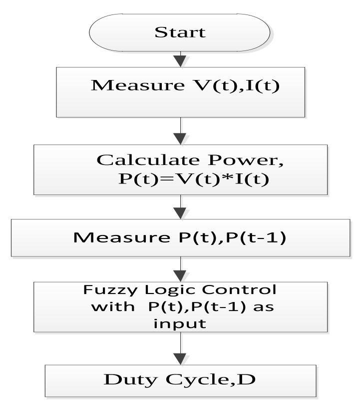




**Fig.9 Block- Diagram of FLC**

**Fig.10 Algorithms of FLC**

**VI.(b).1 Fuzzy Membership Functions.**

The Fuzzy Membership functions have been taken based on the proposed algorithms. The present power p(t) and the previous power p(t-1) on P-V curve have been taken as input variables and the duty cycle (D) as output variable. Converting input variables unitary. The membership function (mf) of input and output variables are provided in Fig.11, Fig.12 and Fig.13 Respectively.The denotation are VS-very small, S-small, M-Medium , H-High for input variables and VL-Very Low,L-Low, M-Medium and H-high for the output variable. The fuzzy rules in line with Mamdani-method is taken and the defuzzification is done the center of gravity for achieving the value of D.The fuzzy control rules in tabular format is provided in Fig.14

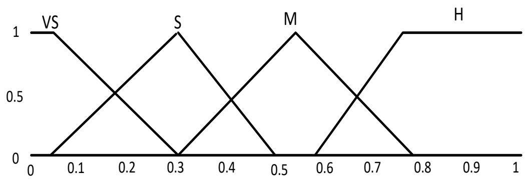



**Fig.11 mf of input variable p(t)**

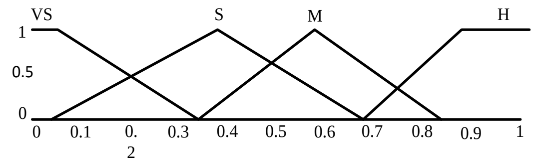



**Fig.12 mf of input variable p(t-1)**

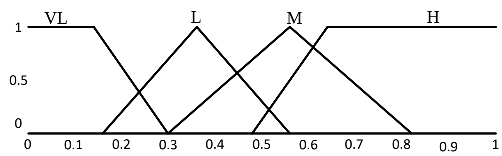



**Fig.13 mf of output variable(D)**

| P(t-1) \ P(t) | VS | S | M | H |
|---|---|---|---|---|
| VS | VL | L | M | L |
| S | L | M | H | M |
| M | M | M | M | H |
| H | M | H | H | M |

**Fig.14 Fuzzy Control Rules**

VII. DC-DC CONVERTOR.

These day battery charging is incorporated with dc-dc converter. This is paper DC-DC Buck-Boost converter is taken as switching mode regulator of output voltage for converting the unregulated to regulated DC-output voltage by means of pulse width modulation(pwm) technique[16]. The Buck-Boost Dc-Dc converter is provided in Fig.15. The duty cycle of the converter have been taken as $D = \frac{T_{on}}{T_s}$

And relation between the output voltage and the input voltage have been taken as $V_{out} = -\frac{D}{1-D} V_{in}$

The parameter of the buck Boost DC-DC Converter DC-DC taken is provided in Fig.16

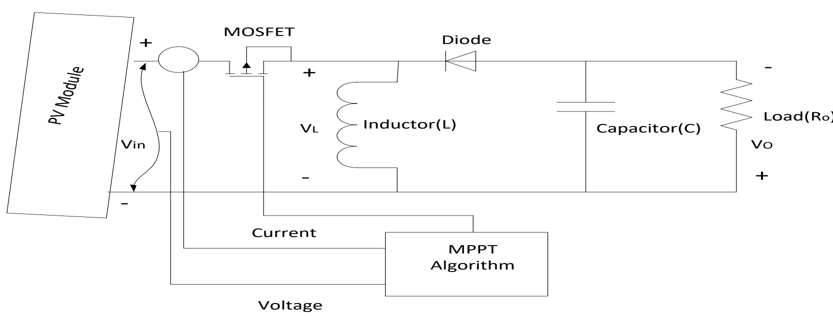



**Fig.15 Block-Diagram of Buck-Boost DC-DC Converter**

| Table: Buck-Boost Converter Parameters | |
|---|---|
| Inductance(L) | 1mH |
| Capacitance(C) | 300µF |
| Frequency | 100kHz |
| Load(Resistor) | 3Ω |

**Fig.16 Buck-Boost Converter Parameters**

VIII – SIMULATION RESULTS OF MPPT.

Using the proposed algorithm and taken the parameter of buck-boost converter as shown in Fig.16, the simulation on Matlab Simulink were carried for two level of solar irradiation(S) one being for S= 1000W/m$^2$ and S= 800 W/m$^2$ respectively. The simulation results of both PO and Fuzzy Logic Controller for MPPT are provided on Fig.17 and Fig.18 respectively

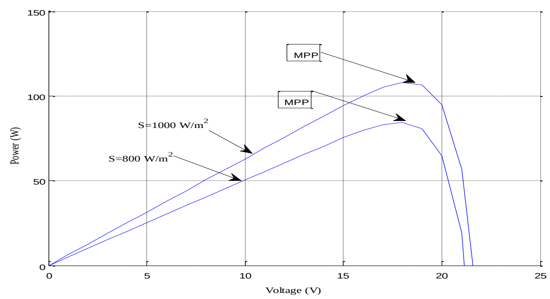



**Fig.17 P-V Curve showing the Solar Irradiation of for S= 1000W/m$^2$ & S= 800 W/m$^2$ respectively.**

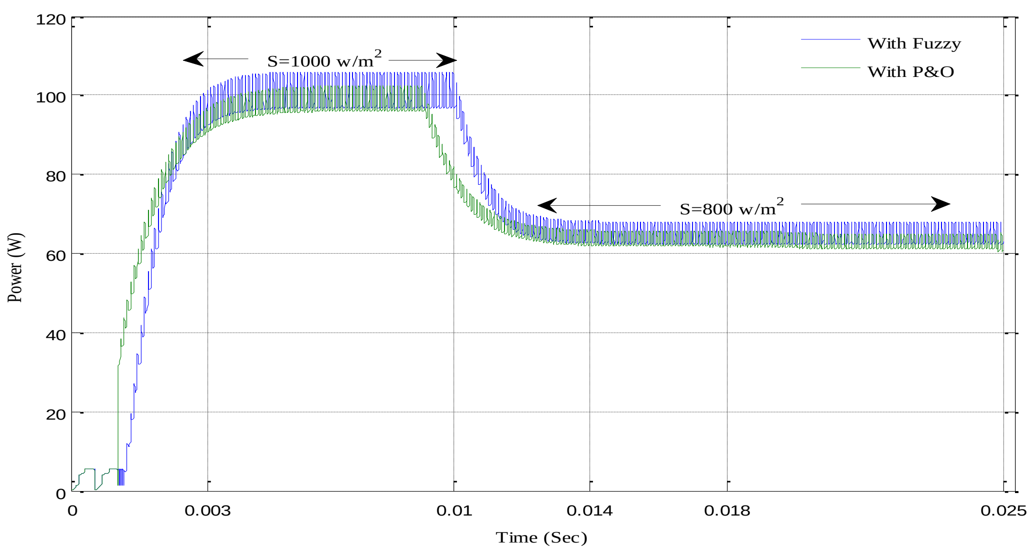



**Fig.18 Maximum Power tracked using PO and Fuzzy Logic Algorithms for S= 1000W/m$^2$ & S= 800 W/m$^2$ respectively.**

It is seen from the results of simulation that MPPT based on Fuzzy logic algorithm tracks and achieve higher value of MPP than that of conventional Perturb and Observe Method. The FLC technique provides better performance in term of time response, overshoot, oscillation and stability.

IX CONCLUSION

In this paper, the PV-cell parameters have been configured concurrently with the reference PV module and modelled and simulated in MATLAB Simulink environment under the changing atmospheric conditions. With the step-wise variation of incoming irradiance and ambient- temperatures, the simulations of PV characteristics in terms of maximum power, voltage and current were successfully carried out with voltage ranging from short-circuit voltage to open-circuit voltage and from open-circuit current to short-circuited current under varying solar insolation and ambient temperature and the results has been compared with the reference actual PV cell, Hence, the PV-Model so adopted have been verified the parameters and validated the same with the given actual reference PV module successfully in MATLAB Simulink environment provides results accurately matching with the actual datasheet parameters. And results of simulation that MPPT based on Fuzzy logic algorithm tracks and achieve higher value of MPP better performance in term of time response, overshoot, oscillation and stability than that of conventional Perturb and Observe Method.

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