Design & Evaluation of Various MPPT methods for Solar PV

(Comparison between Perturb & Observe Algorithm and AI based Fuzzy Logic Controller)

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Abstract—PV systems need to incorporate the Maximum Power Point Tracking System (MPPT) to optimize solar cell efficiency. To achieve the highest possible voltage output from PV modules in different climates, various strategies have been proposed. Among these, the Perturb & Observe (P&O) algorithm is a notable technique for maximum power point tracking. A model consisting of a PV module connected to a DC to DC step-up converter was used in this study. The performance of the PV system was evaluated under varying sun radiation and temperature conditions. Simulation results demonstrated the successful and accurate tracking of maximum power across all test scenarios using the maximum power tracker. The proposed method was found to have higher efficiency and better performance than traditional methods such as perturbation and observation, as evidenced by various operating parameters including tracking efficiency and response time. The P&O method measures the voltage, current, and power of the module and employs a fuzzy logic-based MPPT controller to step up the voltage. When there are variations in the voltage and current of the PV array, the proposed method uses fuzzy logic-based control (FLC) to issue control commands to the output step-up converter. The MATLAB/SIMULINK software was used to represent the Fuzzy Logic based MPPT controller for the PV module.

Keyword- PV System, Step-up converter, MPPT methods

INTRODUCTION

In the past decades, there has been an increase in both the global demand for energy and the number of distributed generation systems. Consequently, it has become essential to incorporate renewable energy systems alongside conventional ones. Among the most widely utilized sources of renewable energy is solar energy, which is abundant, pollution-free, and cost-effective. To convert solar energy into electrical energy, a solar cell is employed. Photovoltaic (PV) systems come in two varieties: disconnected from the grid systems and isolated systems. To increase the output voltage or current of a single solar cell, PV modules can be created by connecting solar cells in series or parallel. The output voltage of the PV module can be regulated using a DC/DC converter to achieve the maximum power point, while a DC/AC converter is employed to transfer energy to the AC side. Among the various DC/DC converter topologies available, this study utilizes a step-up converter to regulate the output voltage of the solar module as required. By manipulating the switch of the DC/DC converter, the input voltage necessary to track the MPP can be obtained.

SOLAR POWER PLANTS (PHOTOVOLTAIC PLANT)

A photovoltaic (PV) plant, also known as a solar power plant, is a service that produces electricity by utilizing the energy of the sun. It functions by turning solar energy into direct current (DC) electricity using PV cells made of semiconductors such as silicon. This direct current electricity is then transformed into alternating current (AC) electricity as needed by inverters and transmitted into the power infrastructure or used to power local loads. Solar power plants are becoming a popular renewable energy source due to their cheap running expenses and minimal environmental effect. They release no pollutants and require very little maintenance

PROBLEMS IN SOLAR SYSTEM

- Variations in solar irradiance: The intensity of sunlight incident on the solar panels varies throughout the day and varies with weather conditions, this can cause fluctuations in the output voltage and current of the solar panels.
- Temperature effects: The output of panels reduces with an increase in temperature, this leads to a reduced output power.
- Partial shading: Partial shading of panels can significantly decrease the power output of the panels.
- Non-linear voltage to current characteristics: The voltage to current characteristics of solar panels has non-linear characteristics, this makes it complex to determine the maximum power point of the panel.

IMPORTANCE OF MPPT

Maximum Power Point Tracking (MPPT) is an essential component of solar systems today because it improves efficiency and maximises power production. This method guarantees that the solar panels operate at their maximum power point independent of changing external circumstances such as shading, temperature, and panel alignment. As a result, solar system users benefit from increased energy output, increased system dependability, and a higher return on investment. As a result, MPPT is critical for optimising solar system efficiency and reaping the largest benefits from solar energy.

EFFECTS	BEFORE MPPT	AFTER MPPT
Energy Production	Limited	Increased, optimal output
Efficiency	Low	High
Return on Investment	Poor	Improved
Panel Lifespan	Shorter	Extended
Power Losses	Significant	Minimized
System Complexity	Simple	Complex
Maintenance Costs	High	Low

COMPONENTS OF SYSTEM

The irradiance and temperature of the surroundings are two important variables that influence the energy production of a PV panel. There is only one maximum power point (MPP) at which solar cells generate the most energy for a particular mix of solar radiation and temperature. Operating the PV system at the MPP results in increased system efficiency, making it critical to monitor the maximum power point using management techniques to optimize PV system performance and obtain the maximum power point under changing weather circumstances. The MPPT method computes the MPP for any irradiance and temperature combo at any point in time.

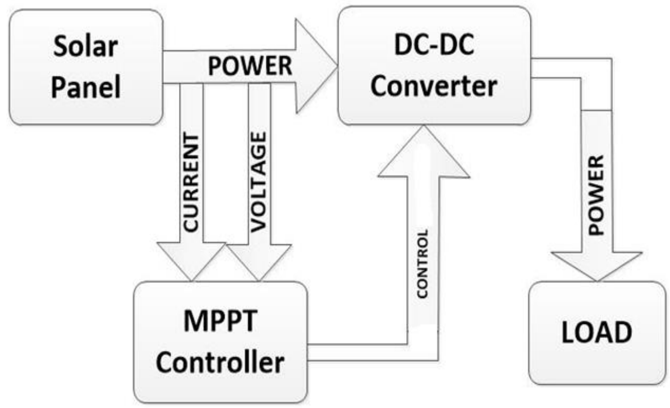

Fig: 1 Basic block diagram of MPPT in PV System

The photovoltaic system architecture, which consists of PV panels and a DC/DC converter, is described in this part. The device is linked to a direct current load, allowing management of the voltage that generates the MPP. The PV model outlined in this part is based on the paper cited in [2].

A. SOLAR CELL

Solar radiation is turned into electrical energy by a solar cell by utilizing the photovoltaic effect. To achieve this, the solar cell includes a p-n junction made of a semiconductor material. As shown in Figure2, the electrical components of the solar cell's corresponding circuit model include a current source, a diode, and two resistors (one in series and one in parallel).

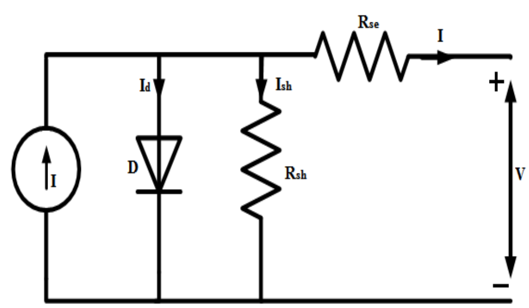

Fig: 2 Basic solar cell circuit

The equation that describes the I-V characteristic curve of a solar cell is :

$$I = I_{Ph} - I_O [\mathrm{Exp}((V + I R_S)/ V_T) - 1] - [(V + I R_S)/ R_P]$$

Where,
Iph = The PV module saturation current (A)

I = Output Current of a PV modules (A)

Io= Reverse Saturation Current

V = Output Voltage of a PV modules (V)

Rs = Series Resistance of PV modules

Rp = Parallel Resistance

VT = Thermal Voltage

A solar cell's voltage output, V, is measured in volts, whereas the current produced by photons, Iph, and saturation current, Io is measured in amperes. To allow for losses, two resistors were added to the model. Rs denotes parallel current leaks and ohmic losses, which are both quantified in ohms. Since a single solar cell generates only about 1 V, PV modules are built by joining cells in series and parallel to accomplish the required power production.

B. STEP-UP CONVERTER

The Step-up converter is also called boost converter and it is used to alter input voltage to some higher level. A simple circuit of a DC-DC Step-up converter is illustrated below in Figure 3. This converter operates in two modes.

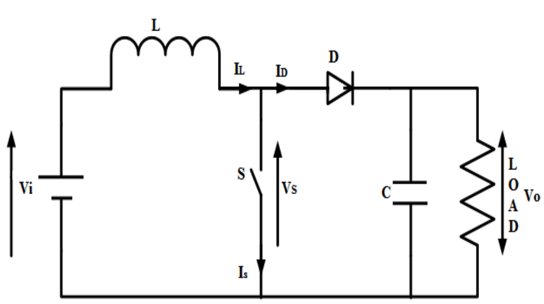

Fig: 3 Basic circuit of Step-up Converter

This converter operates in two modes. In the first mode, while the switch is closed, the inductor is used to store the energy from the PV cell, and the load is supplied by the capacitor only.

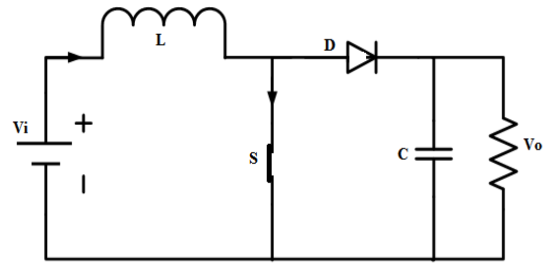

Fig: 4 Operation of Step-up Converter (Switch On)

When the switch is open, the current in the inductor flows to the load, and the energy that is stored in the inductor is transferred to the capacitor and the load. This is illustrated in Figure 5.

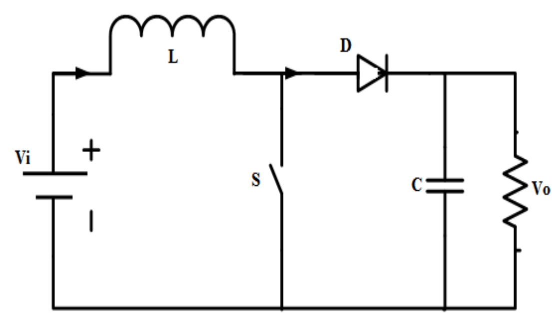

Fig: 5 Operation of Step-up Converter (Switch Off)

C. MPPT BASED DIFFERENT TECHNIQUES

D.

The algorithms of MPPT play a major role in maximizing the efficiency of PV systems, particularly when there are fluctuations in environmental conditions. The Perturbation & Observation (P&O) algorithm is a commonly used method for tracking the maximum power point tracking of a PV system. However, it has limitations such as slow tracking and oscillations in certain scenarios. Fuzzy Logic Control (FLC) has been proposed as an alternative to P&O, which can provide faster and more accurate tracking, especially when there are abrupt changes in environmental conditions.

1. PERTURB AND OBSERVE (P&O)

Recognizing the simplicity to apply, the Perturbation & Observation (P&O) algorithm is frequently employed in MPPT. The algorithm alters the output voltage of the PV module by changing the duty cycle of the DC/DC converter.

The power production of the solar cells is then compared to the prior cycle's power output. If the present power output is greater, the voltage is increased in the same way; if it is less, the voltage is decreased. This algorithm has a tendency to oscillate around the highest power point, resulting in delayed tracking and decreased effectiveness. The flowchart for the P&O algorithm is depicted in Figure 6.

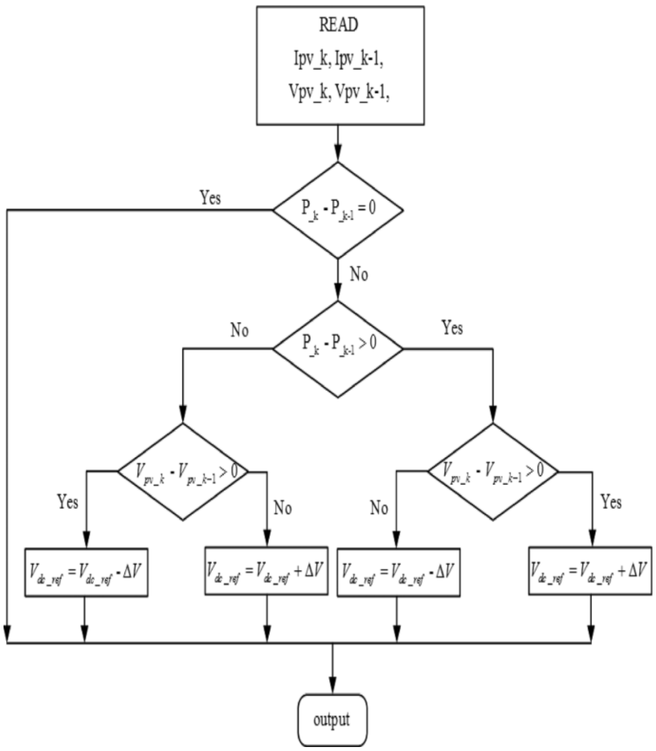

Fig: 6 Flowchart of Perturb and Observe

1. FUZZY LOGIC CONTROL (FLC)

FLC has gained popularity in various fields, including renewable energy sources such as PV systems. The advantage of FLC lies in its simplicity and ability to handle imprecise inputs without requiring a precise mathematical model. FLC can effectively deal with non-linear situations that arise in PV systems, which is crucial for extracting the maximum power from PV modules under varying environmental conditions. Unlike other MPPT algorithms, FLC can function under any weather conditions, including changes in temperature and irradiance levels. Fuzzy Logic Control for MPPT not only offers higher performance but also has a robust and straightforward architecture. Moreover, it does not require a precise model of the system, making it easier to implement. FLC consists of four primary components, namely fuzzification, rule-base, inference, and defuzzification, as shown in Fig. 7.

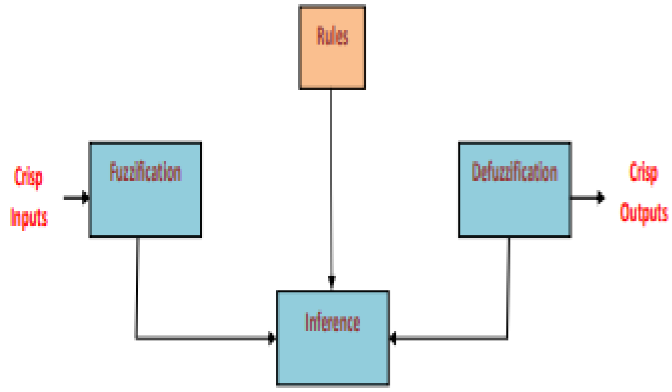

Fig: 7 Components of Fuzzy Logic Controller

In the suggested system, the input variables for the FLC are the changes in PV array power (Ppv) and PV current (Ipv), while the output variable is the change in step-up converter current reference (Iref). The proposed method employs seven fuzzy subsets, denoted by the acronyms NB (negative big), NM (negative medium), NS (negative small), Z (zero), PS (positive small), PM (positive medium), and PB (positive big), to define the universe of discourse for the first input variable (Ppv). The membership functions for this variable are depicted in Figure 8. Reference papers [2] and [7] provide clear explanations and equations for the FLC used in this system.
The error equations for ΔPpv and ΔIpv are given as follows:

$$E = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \quad \text{....(1)}$$

$$\Delta E = E(k) - E(k-1) \quad \text{....(2)}$$

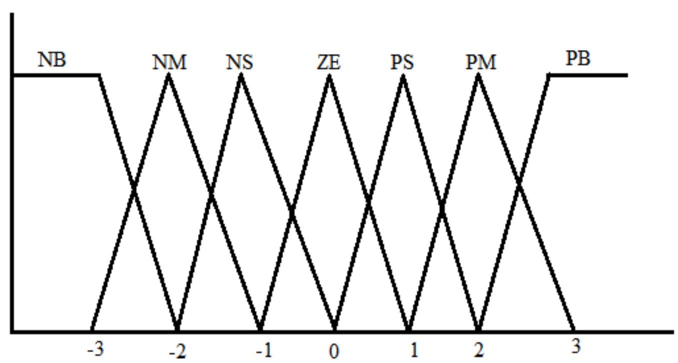

Fig: 8 Membership Functions

P & O BASED MPPT TECHNIQUE

The system incorporates a straightforward MPPT controller that employs the Perturbation and Observation algorithm, and the controller's output is utilized to regulate the gate duty cycle of a DC to DC buck-boost converter. Fig. 9 illustrates the input signal supplied to the PV module.

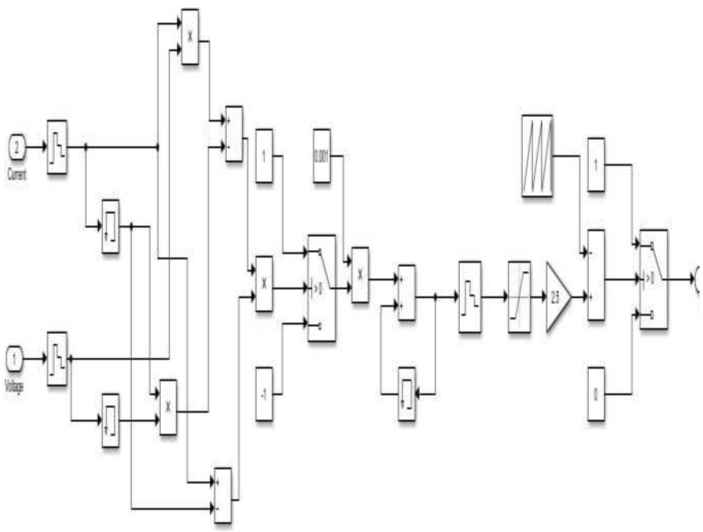

Fig: 9 P & O Matlab/Simulink

The Perturb & Observe method model illustrated in Fig. 9 uses voltage and current as inputs, and the output of the model is used to control the gate duty of a DC to DC buck-boost converter. Fig. 10 shows the current, voltage and power signals output from the PV Module, which are provided to the Perturb & Observe algorithm. The technique's efficient use was confirmed with the help of reference papers [1] and [2], from which Fig. 9 was also collected.

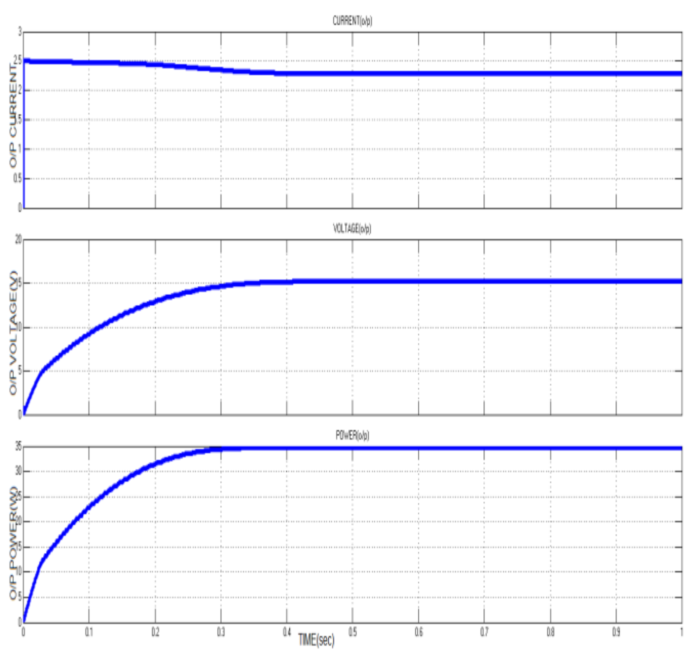

Fig: 10 Output current/voltage/power for P&O Controller

FUZZY LOGIC CONTROLLER BASED MPPT

The integration of the MPPT algorithm with the fuzzy logic controller is a crucial element of this concept. The MPPT file stored in the controller consists of the necessary fuzzy rules and membership functions used to optimize the solar PV module's output voltage. As shown in Figure 11, the input signal block provides the fuzzy logic controller with signals of changes in voltage and power. The fuzzy logic block processes this input, and its output is then directed to the output block, which modifies the signal using the appropriate repeated sequencing signal. The output is finally provided to the gate drive of the buck-boost converter. The fuzzy logic controller's output is determined by the stored membership function and rule assessments. The integration of the fuzzy logic controller and MPPT algorithm was clarified by reference paper [3].

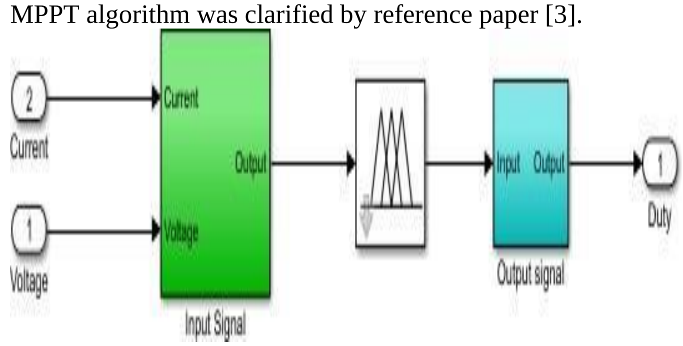

Fig: 11 FLC Based Method

Applying a fuzzy logic-based MPPT controller leads to the achievement of maximum power from a solar PV system. By using an MPPT controller to compare the actual solar power output with the claimed power, it becomes evident how effective the controller is in achieving this goal.

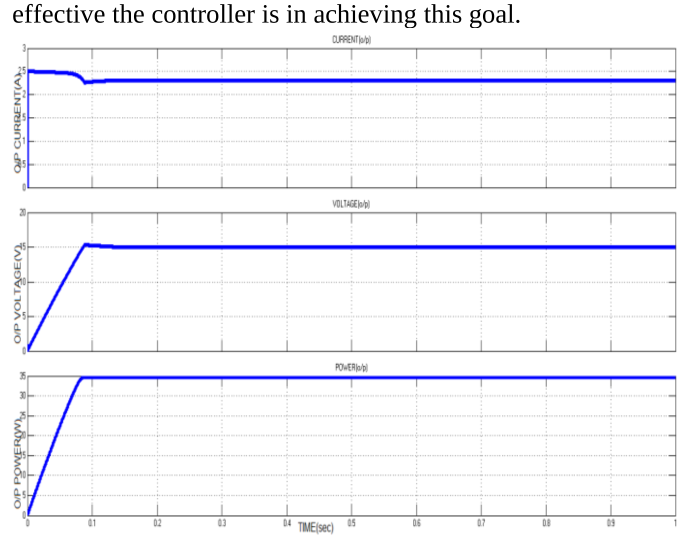

Fig: 12 Output current/voltage/power with FL Controller

EVALUATION OF MPPT TECHNIQUES ON THE BASIS OF DESIGN

Design Aspect	Perturb and Observe (P&O)	Fuzzy Logic Control (FLC)
Control Method	Hill-climbing algorithm	Fuzzy logic controller
Mathematical Model	Based on the slope of the power-voltage curve	Based on fuzzy rules and membership functions
Algorithm Complexity	Simple	complex
Efficiency	Low efficiency at high irradiance variations	High efficiency at high irradiance variations
Oscillation Issues	Suffers from oscillations around MPP under rapidly changing environmental conditions	Less prone to oscillations due to the use of fuzzy control rules
Response time	Fast response time	Relatively slower response time
Adaptability	Not suitable for systems with fast-changing environmental conditions	Suitable for systems with fast-changing environmental conditions
Implementation	Relatively easier to implement	Suitable for systems with fast-changing environmental conditions

EVALUATION OF MPPT TECHNIQUES ON THE BASIS OF FUNCTIONS PERFORMED

FUNCTIONS	PERTURB AND OBSERVE (P&O)	FUZZY LOGIC CONTROL (FLC)
Control Objective	Adjusts the PV array operating point to track the MPP based on the power-voltage curve	Adjusts the PV array operating point to track the MPP based on fuzzy control rules
Perturbation Direction	Alternates between increasing and decreasing the array voltage to track the MPP	Based on fuzzy control rules, perturbation direction is determined based on the error between the actual and reference operating points

Control Action	Calculates the voltage change required to track the MPP, which is a function of the slope of the power-voltage curve	Uses fuzzy control rules to determine the optimal voltage change required to track the MPP based on inputs such as PV array voltage, current, and irradiance
Convergence	Converges to the MPP, but may exhibit oscillations under rapidly changing environmental conditions	Exhibits stable and smooth convergence to the MPP under varying environmental conditions
Performance	Performs well under steady-state conditions, but may experience tracking issues under rapidly changing environmental conditions	Performs well under varying environmental conditions, including fast-changing conditions
Implementation	Simple implementation using a Hill-climbing algorithm	Complex implementation requiring expertise in fuzzy logic control and programming

OUTPUT POWER EVALUATION OF MPPT TECHNIQUES

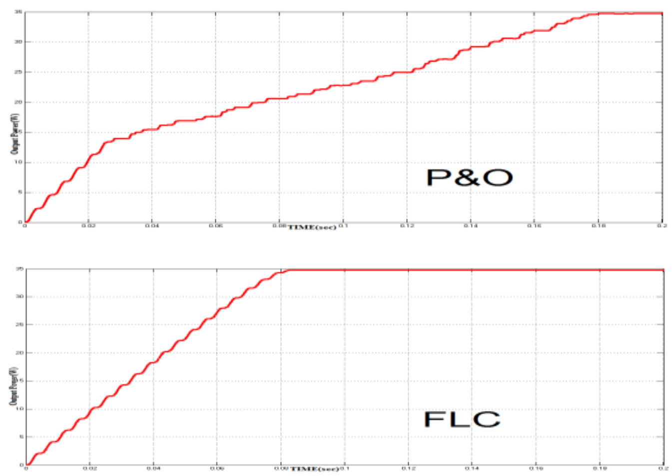

Fig: 13 Evaluation for Output Power of P&O and FL Controllers

CONCLUSION

The P&O algorithm and the fuzzy logic controller (FLC) were simulated and contrasted as two MPPT algorithms in this research. Both techniques showed rapid tracking in a variety of environments. However, the P&O method has a few drawbacks: owing to signal ripple, it sometimes achieves a local maximum rather than a global maximum, resulting in small oscillations around the MPP voltage and power losses. The FLC technique, on the other hand, prevents local maximums, has smooth transient reactions, and generates more output power. When compared to other methods, the FLC strategy performed better in MPPT.

When compared to the conventional P&O technique, the model created with Matlab/SIMULINK showed greater responsiveness and less oscillation around the maximum power point. By evaluating the effectiveness of maximum power tracking in PV modules, it was found that the proposed approach is more efficient than previous P&O-based MPPT methods.

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