[1] Anil N. Patel

[2] Dr. Rajendra R. Aparnathi

Comparative Analysis of Mppt Techniques for Grid Tie Solar Pv Applications

Abstract: - For effective energy harvesting, photovoltaic (PV) systems must produce their maximum amount of power. This is especially true for grid-tie applications, where the objective is to feed generated power into the grid. The different Maximum Power Point Tracking (MPPT) methods used in grid-tie solar PV systems are compared in this paper. In order to guarantee that PV arrays function at their maximum power point in a variety of environmental circumstances, MPPT algorithms are essential. A DC-DC boost converter is also used for interfacing the load and photovoltaic module. Result is simulated in MATLAB/Simulink environment, and all the condition is kept same for both techniques in simulation for the best outcomes of this comparative study. The efficiency, accuracy, convergence speed, and implementation complexity of several MPPT techniques—Perturb and Observe (P&O), Incremental Conductance (INC), Fractional Open Circuit Voltage (FOCV), and Particle Swarm Optimization (PSO)—are assessed and contrasted in this study. The performance of each technique under various operating conditions is demonstrated through MATLAB/Simulink simulation results, which help in the selection of the optimal MPPT method for grid-tie solar PV applications.

Keywords: Photovoltaic (PV), Particle Swarm Optimization (PSO), Grid-Tie Solar PV, Incremental Conductance (INC), Fractional Open Circuit Voltage (FOCV), Perturb and Observe (P&O), Maximum Power Point Tracking (MPPT), Matlab-Simulink, Charge Controller.

Introduction

Small-scale standalone photovoltaic systems are becoming more and more popular as a means of autonomous power supply, whether it be for routers, laptops, mobile devices, or other consumer electronics. PWM charge controllers are more cost-effective than MPPT ones, which is why small-scale systems frequently select them. Because solar photovoltaic (PV) systems are environmentally sustainable and have the potential to reduce dependency on fossil fuels, their use in the production of electricity has gained significant momentum worldwide. To maintain economic viability and effective use of renewable energy resources, optimizing the energy yield from PV arrays is essential in grid-tie solar PV applications, where the generated power is integrated into the utility grid. Grid-tie photovoltaic systems' performance is largely reliant on their capacity to track the solar panels' maximum power point (MPP) in a variety of environmental circumstances, including temperature, shade, and irradiance. A solar charge controller's primary duties include regulating the photovoltaic array's battery charging and guaranteeing the load's power supply. Additionally, it divides the PV array's current draw between the load and the battery. Finally, if the PV array is not producing power and the battery voltage drops below a specific threshold, it disconnects the load to prevent the battery from overdischarging. In PV systems, Maximum Power Point Tracking (MPPT) techniques have become essential for continuously adjusting the operating point of the solar panels. This ensures that the panels operate at their MPP regardless of changes in external factors. The goal of these MPPT algorithms is to transfer the maximum amount of power that can be obtained from the PV modules to the load or grid. Over time, a number of MPPT approaches have been put forth and put into practice; each has its own advantages, disadvantages, and operating principles. It can be difficult to choose the best MPPT technique for a given grid-tie solar PV application given the abundance of techniques available.

The PV system's cost-effectiveness and optimal performance depend on a number of factors, some of which need to be carefully taken into account. These include efficiency, accuracy, convergence speed, and implementation complexity. Thus, in order to enable well-informed decision-making concerning the selection and implementation of various MPPT techniques in grid-tie solar PV installations, a thorough comparative analysis of these techniques is required. This study suggests a technique for PV system maximum power point tracking (MPPT) that minimizes steady state oscillation and lessens the likelihood of losing the tracking direction of perturb and observed (P&O) events. To improve tracking efficiency, a modified P&O algorithm is developed in this project. The strategy is to minimize the loss resulting from the losing direction while concurrently reducing the steady state oscillation. The algorithm's ability to precisely identify oscillation and apply a boundary condition that keeps it from deviating uncontrollably from the MPPT is essential to its effectiveness. The updated plan keeps the traditional P&O structure while introducing a novel method for dynamically changing the perturbation size. Simultaneously, a dynamic boundary condition is incorporated to guarantee that the algorithm stays within its tracking locus. The standard MPPT efficiency (η MPPT) calculation is used to benchmark the performance of the modified P&O,

[1] Ph.D. Scholar, Electrical Department, Gokul Global University, Siddhpur, Gujarat, India. anpatelee@gmail.com

[2] Professor, Gokul Global University, Siddhpur, Gujarat, India. (raparnathi.ee.hcet@gokuluniversity.ac.in)

which is simulated using Matlab Simulink. This paper's primary goal is to review the top MPPT algorithms. Next, a thorough analysis is conducted on the most widely used methods, perturb and observe (P&O) [7], incremental conductance (IncCond) [3] [6] [7] [9]. Next, by simulating it in Simulink and comparing the efficiency, it is suggested that the P&O and IncCond algorithms be improved in order to succeed in the MPP tracking under conditions of changing irradiance[7][10]. Ultimately, it is determined that incremental conductance outperforms perturb and observe.

This study offers a thorough comparison of MPPT methods designed especially for grid-tie solar PV applications. Under varied operating conditions, the study assesses the performance of well-known MPPT algorithms, such as Particle Swarm Optimization (PSO), Incremental Conductance (INC), Fractional Open Circuit Voltage (FOCV), and Perturb and Observe (P&O). This analysis attempts to give insights into the advantages and disadvantages of each MPPT technique through simulation-based experiments carried out with MATLAB/Simulink, assisting researchers, engineers, and stakeholders in determining the best strategy for maximizing power extraction from grid-tie solar PV systems. This research advances grid-tie solar PV technology by illuminating the relative performances of various MPPT techniques. This, in turn, encourages the widespread adoption of renewable energy solutions and sustainable development in the energy sector.

Maximum Power Point Tracking (MPPT) techniques

A crucial component of grid-tie solar photovoltaic (PV) systems is maximum power point tracking (MPPT), which modifies the operating point continuously in order to track the maximum power point (MPP) and maximize the power output of PV arrays. To accomplish this, a number of MPPT approaches have been created and put into practice, each using a different set of algorithms and control schemes. In PV applications, MPPT algorithms are essential because a solar panel's MPP fluctuates with temperature and irradiation. As a result, using MPPT algorithms is necessary to maximize the power output of a solar array[2][4][6].

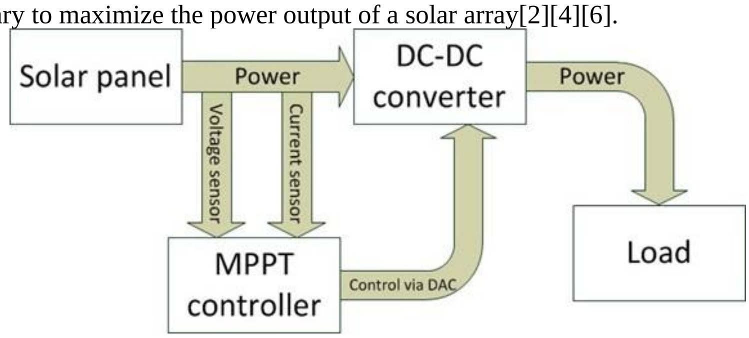

Figure 1. MPPT block diagram

There are numerous MPPT techniques. The most widely used and widely used are the P&O and IncCond algorithms due to their simplicity of implementation.[7][9]. The MPPT system block diagram is displayed below. The fundamental MPPT-P&O and MPPT-IncCond algorithms are now shown. An overview of the most popular MPPT methods for grid-tied solar PV applications is given in this section:

- **Perturb and Observe (P&O)**
- **Incremental Conductance (INC)**
- **Fractional Open Circuit Voltage (FOCV)**
- **Particle Swarm Optimization (PSO)**

Above fig.1 shows the block diagram of MPPT system. Here now we see basic two MPPT-P&O and MPPT-IncCond algorithm.

Perturb and Observe (P&O) Method

- The first one is P&O algorithm, which used to track maximum power point. It can calculate the power at PV array by determining value of voltage and current.
- P&O is one of the most popular MPPT methods because of its efficiency and ease of use.
- The P&O algorithm modifies the PV array's operating voltage or current and tracks the change in power output that occurs.
- The algorithm modifies the operating point in the direction of the power change to bring it closer to the MPP.
- Although P&O can be easily implemented and is appropriate for quickly changing environmental conditions, in some situations it can experience oscillations around the MPP.

This problem is common also to the IncCond method, as was mention earlier. A scheme of the algorithm is shown in the figure 2.

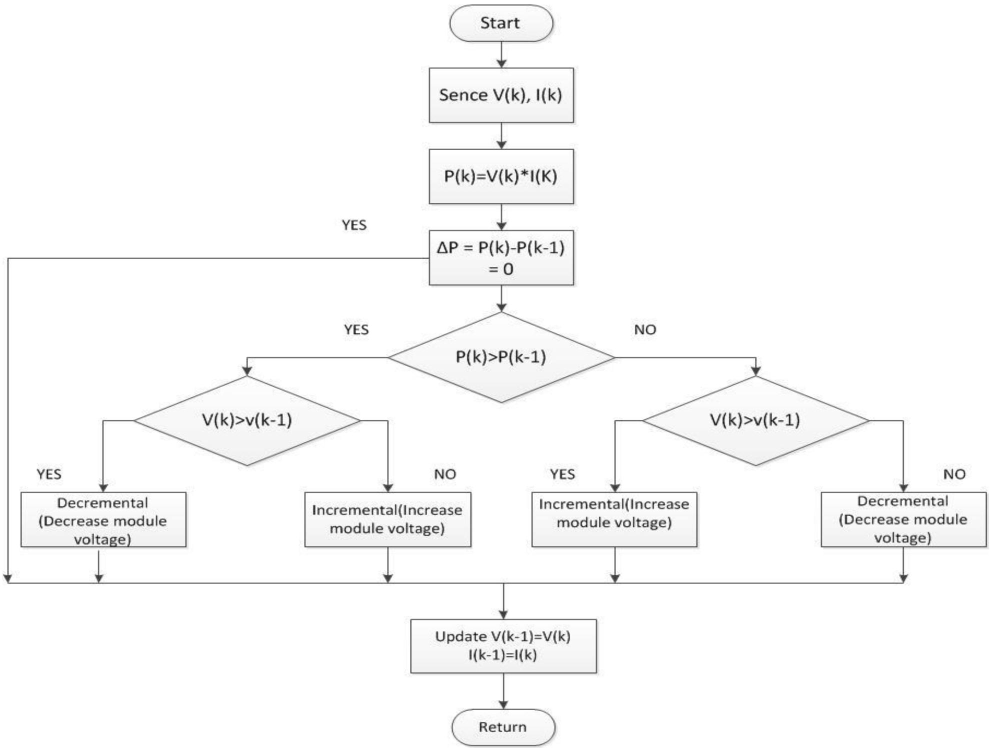

Figure 2.Perturb and Observe (P&O) flowchart

Incremental Conductance (IncCond)

- The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IncCond method.
- The INC algorithm operates on the basis of comparing the PV array's instantaneous conductance and incremental conductance.
- The algorithm determines which direction to adjust the operating point in order to track the MPP by continuously observing changes in conductance.
- Compared to P&O, INC provides faster and more accurate tracking, especially in situations with partial shading and dynamic weather.
- However, the algorithm's intricacy and the need for precise sensor readings could make implementation more expensive.

$\frac{dI}{dV} = -\frac{I}{V}$ or $\frac{dP}{dV} = 0$ At MPP

$\frac{dI}{dV} > -\frac{I}{V}$ or $\frac{dP}{dV} > 0$ Left of MPP

$\frac{dI}{dV} < -\frac{I}{V}$ or $\frac{dP}{dV} < 0$ Right of MPP

A scheme of the algorithm is shown in figure-3 below.

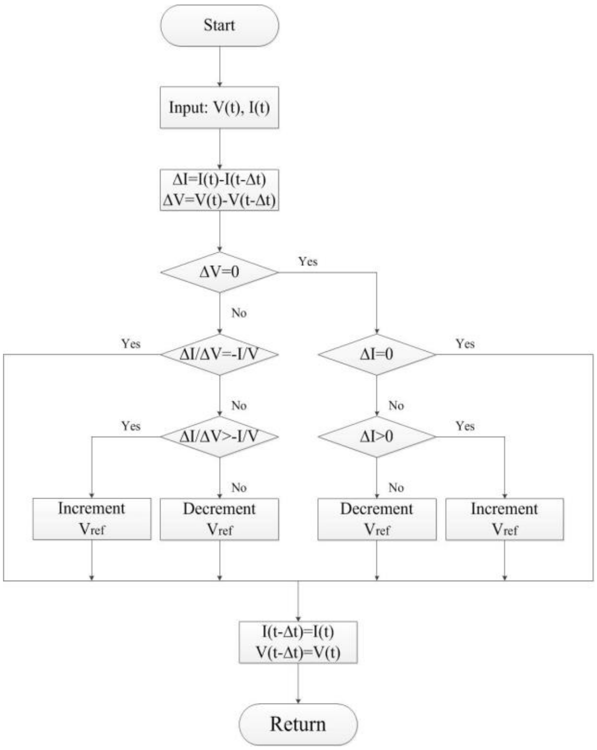

Figure-3 IncCond Flowchart

Fractional Open Circuit Voltage (FOCV)Method

- The derivative of the voltage of the PV array with respect to the irradiance is estimated using the derivative-based MPPT method known as FOCV.
- Without requiring precise power measurements, the algorithm predicts the MPP by extrapolating the PV array's open-circuit voltage.
- Applications where power sensors are either unavailable or prohibitively expensive can benefit from FOCV.
- On the other hand, FOCV may need to be calibrated for various PV module characteristics and may show decreased accuracy under quickly changing irradiance conditions.

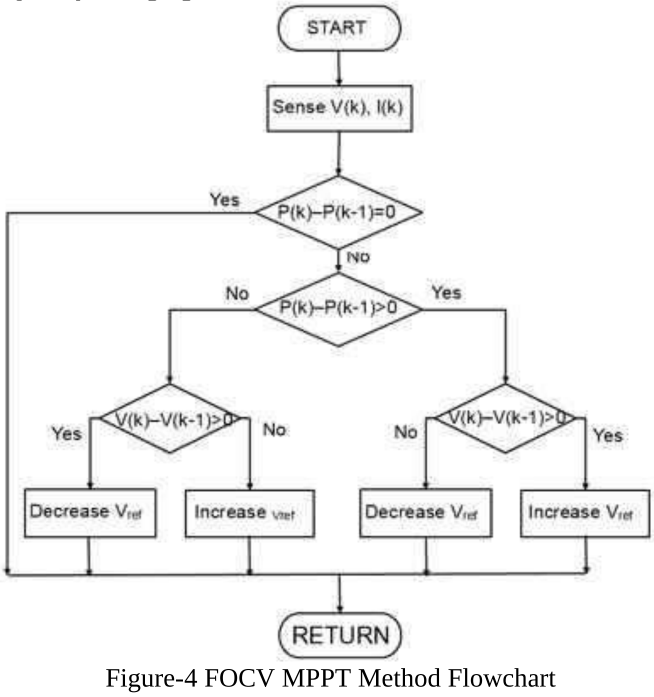

Figure-4 FOCV MPPT Method Flowchart

Particle Swarm Optimization (PSO) Method

- PSO is a metaheuristic optimization method that draws inspiration from fish schools and bird flocks' social dynamics.

- PSO searches for the MPP in MPPT applications by optimizing the parameters of a mathematical model that represents the PV array.
- PSO converges to the ideal operating point by iteratively updating the position and velocity of particles in the search space.
- PSO may need a large amount of computational resources, but it has the potential to provide robust performance and global optimization under a range of operating conditions.

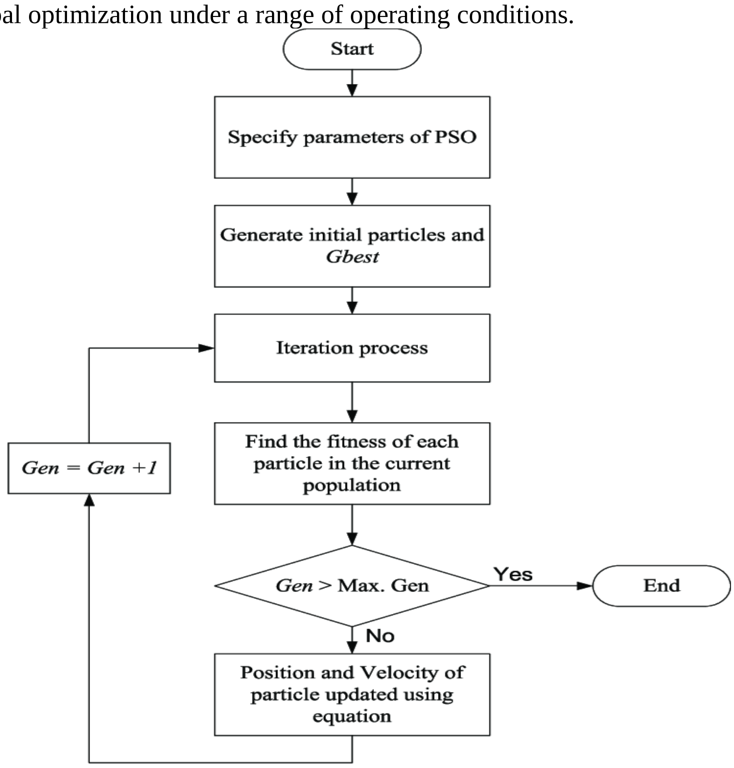

Figure-5 PSO MPPT Method Flowchart

Requirement of MPPT

Because each of these MPPT methods has pros and cons, they can be used for various grid-tie solar PV applications based on things like system requirements, cost considerations, and environmental factors. The performance of these methods will be compared in the following sections of this research paper in order to assess their efficiency, accuracy, convergence speed, and implementation complexity. The results will provide valuable information that will help determine which MPPT approach is best suited for a given grid-tie solar PV installation. From the below fig.6 for Solar PV I-V characteristics, we can understand the requirements of MPPT for maximum power tracking.

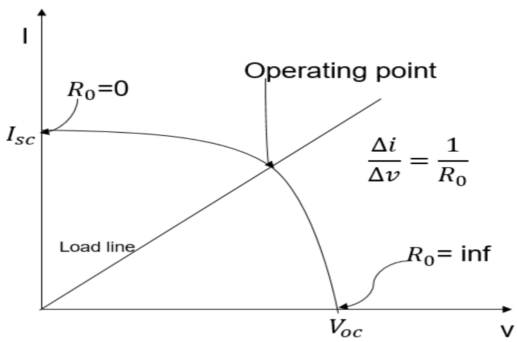

Fig.6- Solar P.V. Cell I-V Characteristic

Every time R_0 is not variable, so we add a power interface between R_0 and R_T.So by very the value of R_T We can gate maximum output power from the P.V. panel. As a power interface, we use a DC-DC converter.

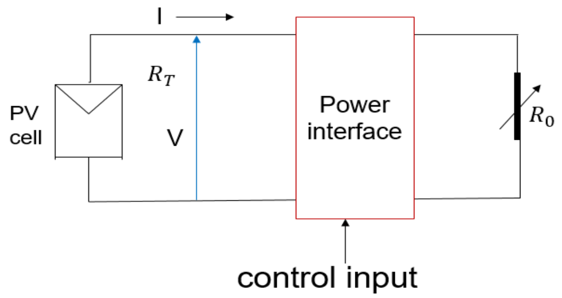

Fig.7- MPPT Operation Concept

Operational Mechanism of MPPT in P.V.

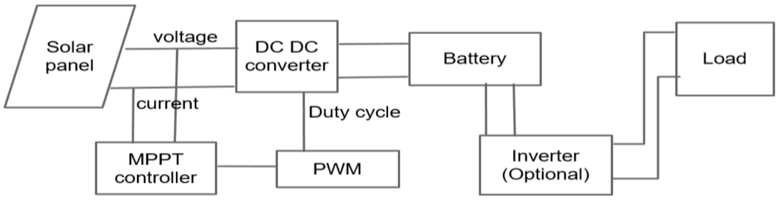

Fig.8- Basic Operational Block Diagram of MPPT

As shown in fig.8, the MPPT is used as the primary control device for solar P.V. output parameters regulation. The duty cycle selected from the MPPT algorithm is used for the PWM block to give triggering pulses to the converter operation. The regulating D.C. voltage from the proposed controller circuit is sued for the Battery for charging, and an optional inverter mechanism is also provided in this project. To develop the simulation of different MPPT techniques, it is vital to understand the boost converter operation and decide the converter's parameters.

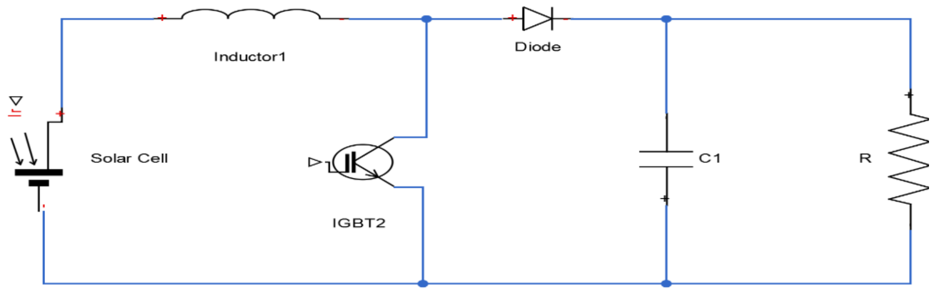

Fig.9- Boost Converter Operational Mechanism

Input and output voltage relation

$V_{o}=(\frac{1}{1-D})V_T$ ………… (1)

Input and output current relation

$I_{o}=I_T(1 - D)$………… (2)

Eq. 1 divided by Eq. 2, we gate

$R_T = R_O(1-D)^2$

Parameter	Value
Inductor	3mH
Capacitor	100 micro F
Resistance	30 Ohm

Table-1 Boost Converter Calculated Parameters for Simulation

$\frac{1}{R_0} = \frac{1}{30}$ = 0.0333333

At maximum point $\frac{1}{R_T} = \frac{I_{mpp}}{V_{mpp}} = \frac{3.555}{17.0458}$ = 0.2085

Grid-tie solar photovoltaic (PV) systems allow solar energy to be seamlessly integrated into the utility grid, marking a significant advancement in renewable energy technology. In order to meet consumer energy demands, these systems use solar panels to convert sunlight into electricity, which is then fed directly into the electrical grid. Numerous benefits of grid-tied solar PV systems include decreased carbon emissions, cheaper electricity costs, and greater energy independence. All things considered, grid-tie solar PV systems provide a dependable and affordable way to capture solar energy and incorporate it into the current electrical grid infrastructure. The optimization of system performance and the maximization of energy yield are contingent upon the effective implementation of Maximum Power Point Tracking (MPPT) techniques. This, in turn, facilitates the shift towards a more environmentally friendly and sustainable energy landscape. We will compare several MPPT strategies designed for grid-tie solar PV applications in the following sections of this research paper in order to offer important insights into their effectiveness and suitability for real-world implementation.

Simulation & Analysis of Different Techniques

Solar PV with MPPT Control with Variable Radiation using P&O Algorithm

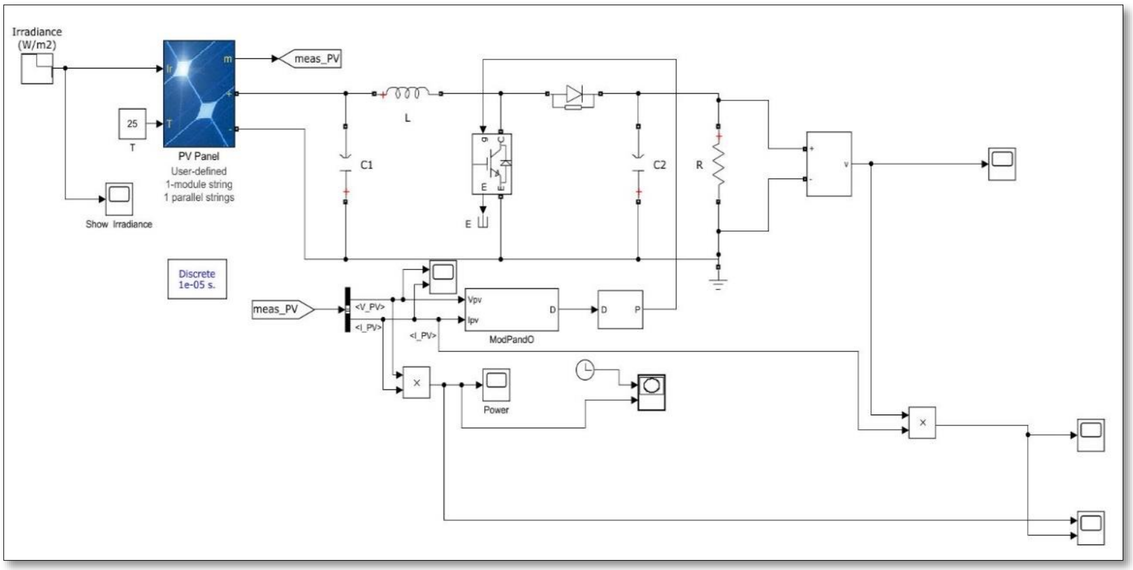

Fig 10- Solar PV System with variable Radiation with P&O Algorithm

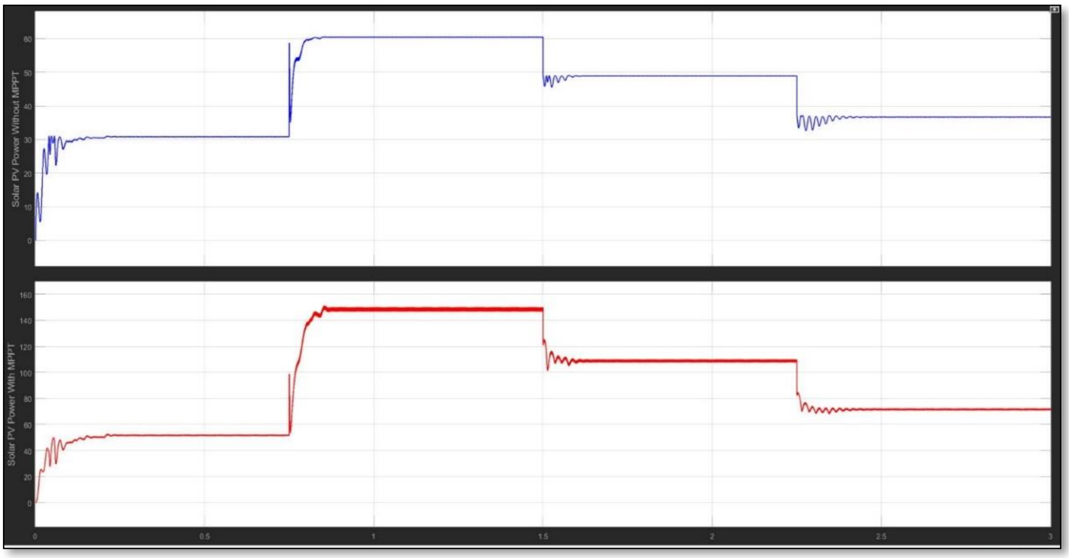

Fig.11- Solar output Power without and with MPPT

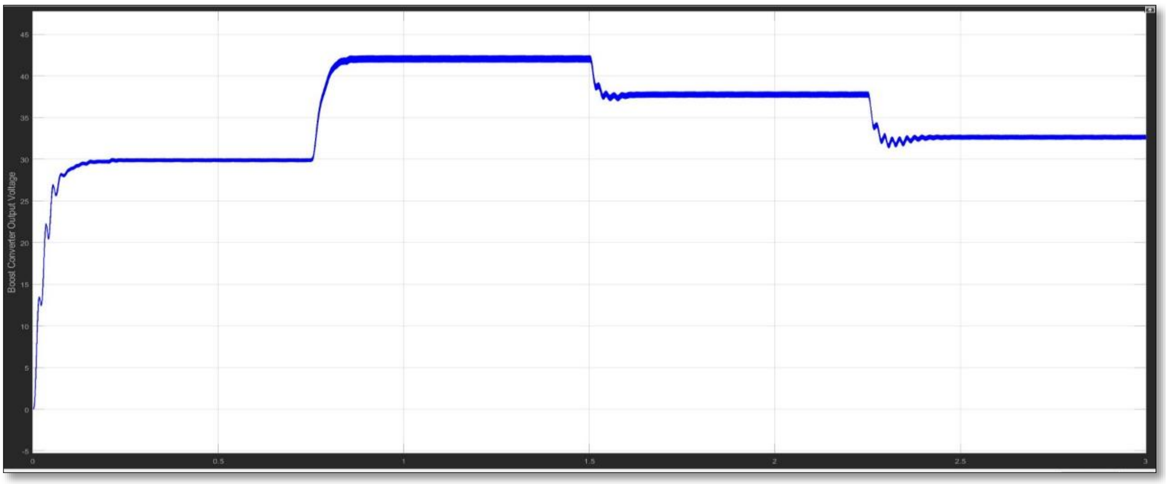

Fig 12- Solar PV output voltage using Boost converter

Solar PV with MPPT Control with Variable Radiation using INC Algorithm

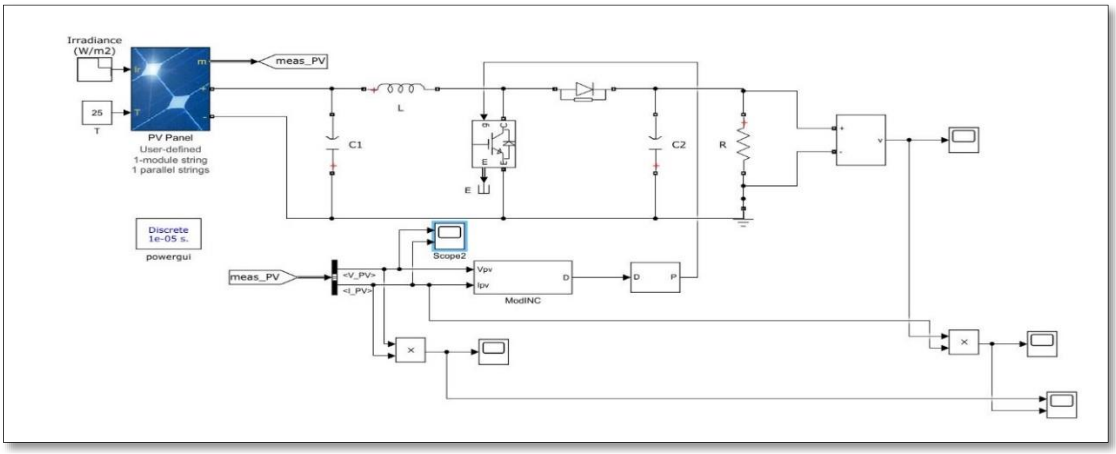

Fig 13- Solar PV System with variable Radiation with INC Algorithm

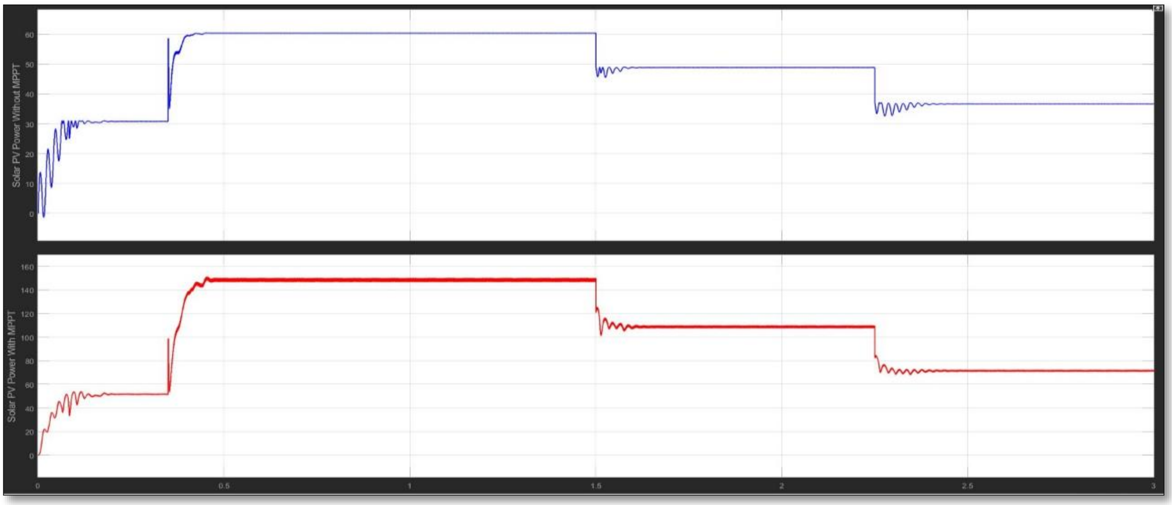

Fig.14- Solar output Power without and with MPPT (INC)

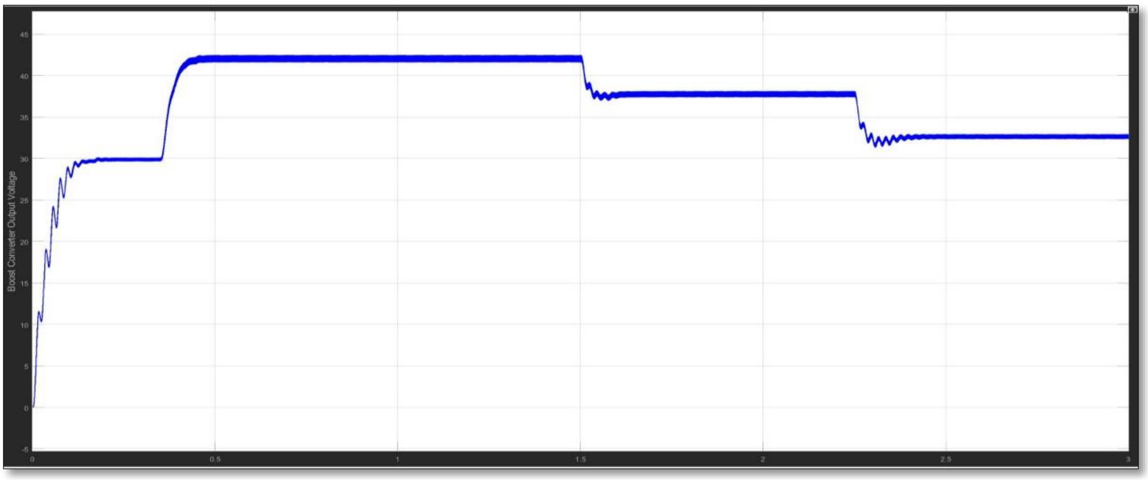

Fig.15- Solar PV output voltage using Boost converter (INC)

Matlab Simulation of MPPT with Fuzzy Logic Control

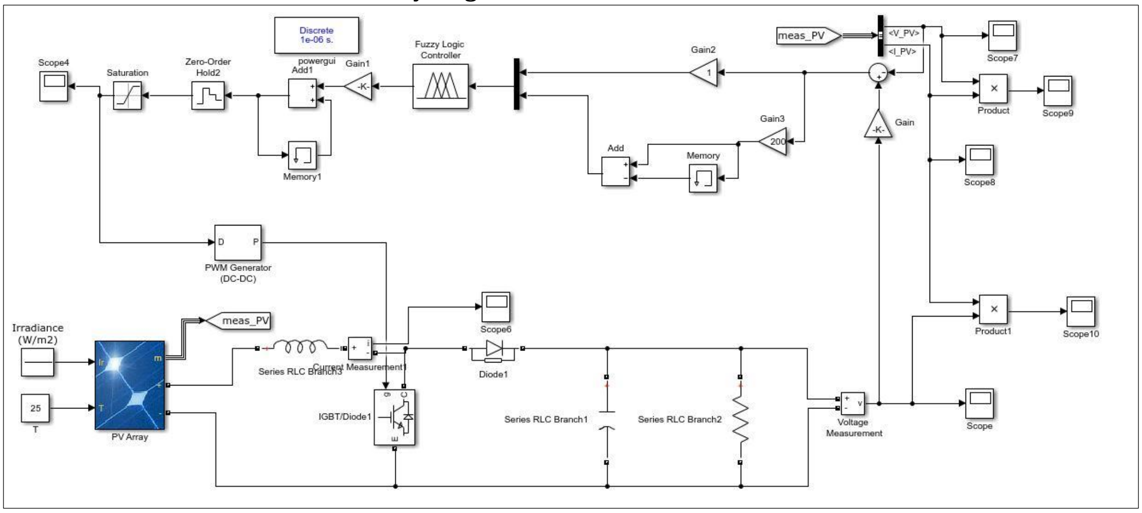

Fig.16- Solar PV System with FLC based MPPT Control

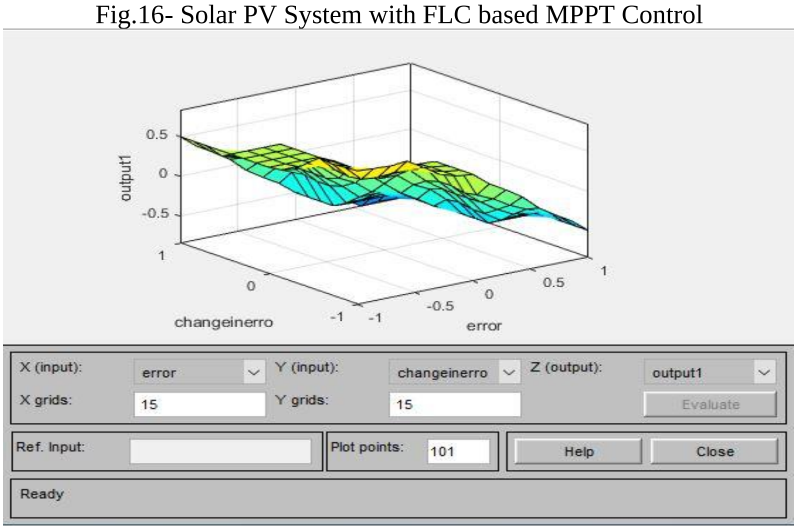

Fig.17- Surface viewer of FLC based MPPT Control

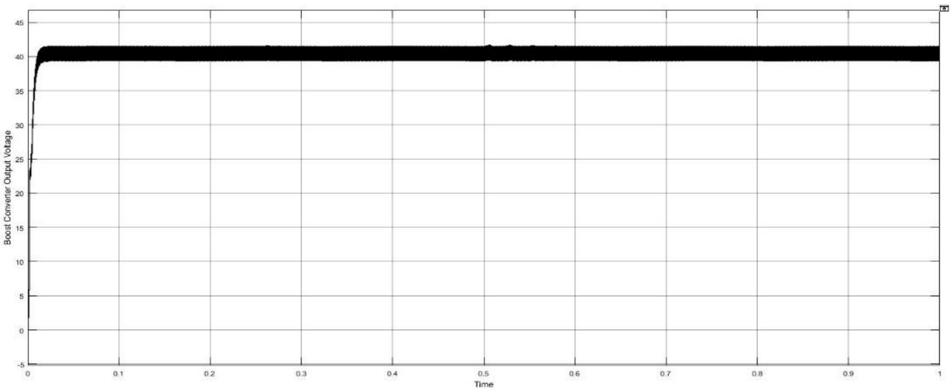

Fig.18- Solar PV Boost Converter output Voltage using FLC

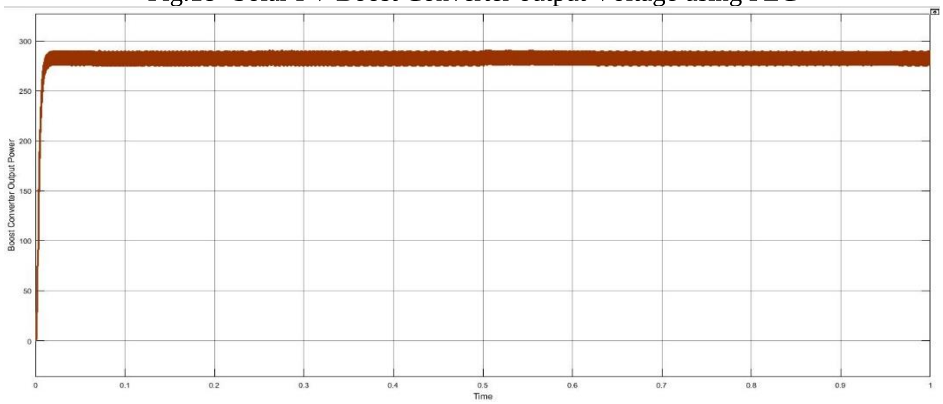

Fig.19- Solar PV Boost Converter output Power

Comparison of MPPT Techniques

MPPT Method	Output Voltage	Output Current	Power	Time Response	Accuracy
P & O	40 Volt	3.5 Amp	145 Watt	0.0017 Sec	Less
INC Method	41 Volt	3.5 Amp	150 watt	0.001 Sec	More
FLC Method	45 Volt	7.0 Amp	270 watt	0.01 Sec	Very Fast

Table-2 P&O and NIC methods with Fuzzy Logic Control Method comparison

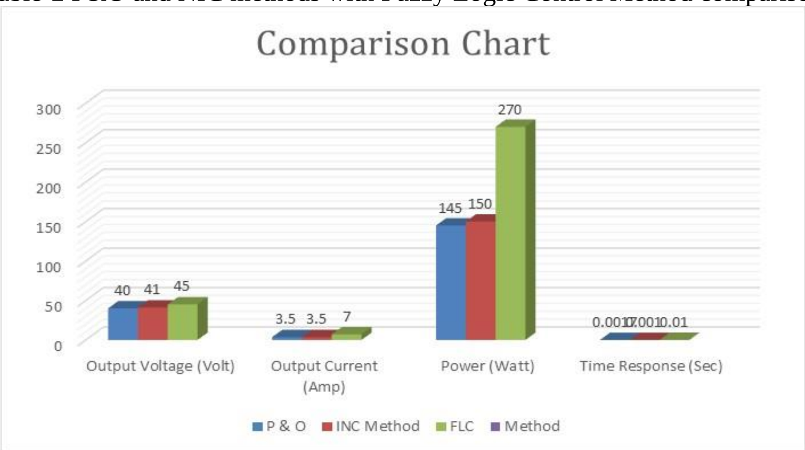

Fig.20-Result Summary of MPPT Techniques

Result Summary:- Incremental conductance in time response is significantly less means the steady condition is fast compared to P&O. Fuzzy Logic control is a more advanced control technique than these two techniques. The Maximum power tracking is also more accurate in FLC control, but its operation and design are a little complex compared to the other two methods of MPPT.

Conclusion

This paper concludes that P&O and I&C are so simple to implement, they are more appropriate than all other methods in a wide range of applications. The comparative analysis emphasizes how crucial it is to choose the best MPPT method for grid-tie solar PV installations based on their unique requirements and limitations. The design, implementation, and operation of MPPT algorithms in real-world PV systems can be made with greater knowledge by researchers, engineers, and stakeholders by utilizing the insights gained from this study. This will maximize energy yield, increase system efficiency, and hasten the shift to sustainable energy sources. The goal of this research may be to improve the scalability, resilience, and real-time performance of MPPT methods in order to meet new opportunities and challenges in grid-tie solar PV applications. The suggested solar PV system uses the MPPT Control methods P&O and INC at a fixed radiation level. The simulation and results of the proposed system's fuzzy logic controller-based MPPT are also completed in Matlab. These three approaches are also compared.The suggested charge controller is also used to regulate the battery's voltage level. The pure sinusoidal regulating A.C. output voltage and current is indicated in the simulation results of the A.C. load side.

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