A Project Report

on

Exploring Performance Enhancement of MPPT Techniques for Boost Converter in Solar PV System

submitted to

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR,

ANANTAPURAMU

in partial fulfillment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL AND ELECTRONICS ENGINEERING

By

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SREE VIDYANIKETHAN ENGINEERING COLLEGE

(An autonomous institution affiliated to JNTUA, Anantapuramu)

Sree Sainath Nagar, Tirupati – 517102

2020-2024

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CERTIFICATE

This is to certify that the Project report entitled "*Exploring Performance Enhancement of MPPT Techniques for Boost Converter in Solar PV System*" is the bonafide work done and submitted by

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In the department of EEE, **Sree Vidyanikethan Engineering College**, an autonomous institution affiliated to **Jawaharlal Nehru Technological University Anantapur, Anantapuramu** in partial fulfillment of the requirements for the award of the degree of **Bachelor of Technology** in **Electrical and Electronics Engineering**, during 2020-2024.

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EXAMINER – 1

EXAMINER – 2

SREE VIDYANIKETHAN ENGINEERING COLLEGE

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Department of Electrical and Electronics Engineering

VISION

To be one of the Nation's premier Engineering Colleges by achieving the highest order of excellence in Teaching and Research.

MISSION

- To foster intellectual curiosity, pursuit, and dissemination of knowledge.
- To explore students' potential through academic freedom and integrity.
- To promote technical mastery and nurture skilled professionals to face competition in ever increasing complex world.

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To become the Nation's premiere centre of excellence in electrical engineering through teaching, training, research and innovation to create competent engineering professionals with values and ethics.

MISSION

- Department of Electrical Engineering strives to create human resources in Electrical Engineering to contribute to the nation development and improve the quality of life.
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- Honing technical and soft skills for enhanced learning outcomes and employability of students with diverse background through comprehensive training methodologies
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B. Tech. (ELECTRICAL AND ELECTRONICS ENGINEERING)

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After few years of graduation, the graduates of B. Tech (EEE) will be:

PEO1. Have enrolled in an academic program in the disciplines of electrical engineering and multidisciplinaryareas.

PEO2. Become entrepreneurs or be employed as productive and valued engineers in reputed industries.

PEO3. Engage in lifelong learning, career enhancement and adopt to changing professional and societal needs.

Program Outcomes

On successful completion of the Program, the graduates of B.Tech. (EEE) Program will be able to:

PO1 **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO2 **Problem analysis**: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3 **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4 **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5 **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with anunderstanding of the limitations.

PO6 **The engineer and society**: Apply reasoning informed by contextual knowledge to assess societal,health, safety, legal and cultural issues and the consequent responsibilities relevant to professionalengineering practice.

PO7 **Environment and sustainability**: Understand the impact of professional engineering solutions insocietal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8 **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of engineering practice.

PO9 **Individual and teamwork**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10 **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11 **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12 **Lifelong learning**: Recognize the need for and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

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On successful completion of the Program, the graduates of B. Tech. (EEE) will be able to

PSO1. Demonstrate knowledge of Electrical and Electronic circuits, Electrical Machines, Power Systems, Control Systems, and Power Electronics for solving problems in electrical and electronics engineering.

PSO2. Analyze, design, test and maintain Electrical systems to meet the specific needs of the industry and society.

PSO3. Conduct investigations to address complex engineering problems in the areas of Electrical Machines, Power Systems, Control Systems and Power Electronics.

PSO4. Apply appropriate techniques, resources and modern tools to provide solutions for problems related to electrical and electronics engineering.

SREE VIDYANIKETHAN ENGINEERING COLLEGE

Department of Electrical and Electronics Engineering

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Declaration

We hereby declare that the Project report entitled ***"Exploring Performance Enhancement of MPPT Techniques for Boost Converter in Solar PV System"*** has been submitted by us under the guidance and supervision of *Dr. M.S. SUJATHA*, M. Tech, Ph.D., Professor & Head, Department of Electrical and Electronics Engineering, Sree Vaidyanathan Engineering College (Autonomous), Tirupati. This work / report has not been submitted either for the award of any degree or any other similar title.

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Date:

ACKNOWLEDGEMENTS

We are deeply indebted to our supervisor, ***Dr. M.S. SUJATHA, M. Tech, Ph.D., Professor & Head, Department of Electrical and Electronics Engineering,*** *for his valuable guidance, constant encouragement and keen interest evinced throughout the course of our Project work.*

We sincerely thank our Head of the Department, ***Dr. M. S. SUJATHA, M. Tech, Ph.D.,*** *for hersupport and constructive suggestions at various levels of the work.*

We express our gratitude to our Principal ***Dr. B.M. SATISH, Ph.D.,*** *and the* ***Management*** *of SVEC for providing all kinds of support. We express our heartfelt thanks to all our* ***teachers*** *in the department of EEE of Sree Vaidyanathan Engineering College for their moral support and good wishes.*

Finally, we would like to express sincere thanks to our parents, one and all those who guided, inspired, and helped us in completion of our Project work.

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Exploring Performance Enhancement of MPPT Techniques for Boost Converter in Solar PV System

ABSTRACT

The efficiency of photovoltaic (PV) systems will continue to heavily rely on meteorological conditions and load features, making maximum power point tracking (MPPT) methods even more essential for optimizing power delivery. Implementing MPPT will still require a DC-DC converter, and choosing the right MPPT technique will remain crucial for overall system efficiency. This project goes with comprehensive study on the analysis and performance of a step-up DC-DC converter topology paired with closed loop PI controller and with different MPPT techniques: Perturb and Observe, Incremental Conductance, Fuzzy Logic Controller with P&O and Incremental conductance method, Particle Swarm Optimization, and Adaptive Neuro Fuzzy Inference System.

Unlike existing literature, this project includes analyzing and comparing the performance of each MPPT method in terms of maximum power, settling time, rise time, steady state error and efficiency for power converter. The main contribution of this project will lie not only in identifying the optimal combination of converter and MPPT strategy for typical PV systems but also in presenting a methodology to support solar PV system design. Simulation results are to be achieved with Simulink/MATLAB environment for different methods.

The novelty of this project will lie in its focus on comparing the key characteristics and simulated results of all mentioned MPPT techniques, offering insights into their relative performances.

Keywords*-PV Module, DC-DC Boost converter, MPPT methods, MATLAB.*

CONTENTS

LIST OF ABBREVIATIONS

PV	Photo Voltaic
MPPT	Maximum Power Point Tracking
DC	Direct Current
P&O	Perturb & Observe
MPP	Maximum Power Point
ANFIS	Adaptive Neuro Fuzzy Interface System
PSO	Particle Swarm Optimization
FLC	Fuzzy Logic Control
Inc Cond	Incremental Conductance
PI	Proportional Integral
PWM	Pulse With Modulation

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Chapter-1
INTRODUCTION

Due to the depletion of fossil fuels and the increment in energy demand, a new era has begun with a huge welcome for renewable energy sources (RESs) all over the world. RESs, such as solar, tidal, and wind that are free from environmental pollution and with excess availability have become important during recent years. The worldwide concern about CO2 reduction has led to RES deployment [1]. A solar photovoltaic (PV) system has become a much more flexible RES due to its availability everywhere on the earth. The installation and operating costs of a PV system are reduced to a greater extent due to the development of semiconductor manufacturing technology. From the literature survey, many researchers have used different circuit topologies to model the PV array at different atmospheric conditions. Some researchers have focused on single-diode model PV panel modeling based on their application [1].

From the comparison results, a single-diode circuit PV panel was used to assess the maximum power point tracking (MPPT) techniques for controlling the boost converter duty cycle. From the literature survey, conventional DC-DC converters are available to control PV voltage such as Boost, The Boost converter is used to step up the DC voltage, compare without and with MPPT techniques using different MPPT methods [3]. There are without MPPT techniques are closed loop PI/PID control, and so many conventional and evolutionary MPPT techniques illustrated in the literature that are based on the technique of controlling the duty cycle and the output voltage of the boost converter. Among all the conventional techniques, However, these techniques suffer from MPP tracking that is inaccurate and are suitable only for low power applications [8]. Other conventional MPPT techniques such as perturb and observe (P&O), incremental conductance (IC), (dP/dI) variation of power with respect to current or power/voltage (dP/dV) feedback control, slider controller and incremental resistance (INR) are applicable for low, as well as high, power application where higher accuracy in MPP tracking is needed [4].

Over the years, a variety of MPPT techniques have been developed, such as Particle Swarm Optimization (PSO), Incremental Conductance (Inc Cond), Perturb and Observe (P&O), fuzzy logic controller (FLC) and Adaptive Neuro Fuzzy Interface System (ANFIS) among others. All those techniques vary in several respects, such as implementation complexity, effectiveness, tracking speed, tracking accuracy, rise time, settling time, steady state error and efficiency, after that Compare with the closed loop PI/PID control [5].

The FLC method does not require any mathematical model. Furthermore, its implementation is simpler when compared to other MPPT techniques. They are mainly based on the designers' experience and knowledge about the system [8]. In PV systems, the use of an MPPT method requires for its implementation a DC-DC converter, which can be seen as an impedance adapter between the PV panel and the connected load. The DC-DC power converter is controlled through its electronic switch by a signal generated by the MPPT technique called the duty cycle. There are many DC-DC converters utilized for renewable energy applications and which can be classified into two categories, isolated, and non-isolated converters [18].

Chapter-2
LITERATURE SURVEY

1. "Modelling of PV based DC-DC boost converter using P&O algorithm under varying environmental conditions". Raunak Das, Shoubhik De, Saikat Sinha, Somnath Hazra. 2021 Innovations in Energy Management and Renewable Resources (IEMRE).
   This paper explains that the Solar PV systems efficiently harness free solar energy, but their output power fluctuates based on factors like cell temperature and sun irradiation. To optimize power extraction, we implemented a DC-DC boost converter and an MPPT algorithm for panels in series. Simulation results validate the effectiveness of adjusting operating parameters to maximize power output. Specifically, we employed the Perturb and Observe algorithm alongside a boost converter to reach the maximum power point. This approach offers simplicity and cost savings compared to complex data management systems. By showcasing the efficacy of MPPT in extracting maximum power from solar panels, we underscore the practicality and efficiency of our solution for maximizing solar energy utilization.

2. "Implementation of Perturb & Observe MPPT Technique using Boost converter in PV System". Shivendra Singh, Mohd Imam Hasan Mansoori, Saibal Manna, Dr. A.K. Akella. International Conference on Computational Intelligence Smart Power System and Sustainable Energy (CISPSSE).
   The paper talks about the MPPT maximizes electricity extraction from a PV array, utilizing the Perturb and Observe (P&O) algorithm to optimize solar power production while reducing output oscillations. This straightforward algorithm enhances PV system conversion efficiency. By integrating a DC-DC boost converter and the MPPT algorithm, simulation-based MATLAB models demonstrate improved performance. Sim Power System blocks emulate the PV array and boost converter. The boost converter adjusts PV voltage via duty cycle modulation. The P&O algorithm effectively responds to varying irradiance and constant temperature conditions, ensuring efficient power extraction.

3. "Comparative Study of P&O and Incremental Conductance method for PV System". S. Uma Ramani, Sathish Kumar Kollimalla, B. Arundhati .2017 International Conference on circuits Power and Computing Technologies (ICCPCT).
   The research work in this paper is photovoltaic panels often operate below peak efficiency due to their inability to consistently reach the maximum power point. While the Perturb and Observe (P&O) algorithm is commonly used for MPPT, it exhibits drawbacks such as slow response and oscillations under varying atmospheric conditions. To address these issues, incremental conductance algorithms are preferred. A comparative evaluation of tracking capabilities and performance, including oscillations, was conducted between incremental conductance and P&O techniques. The incremental conductance method, requiring an additional sensor, demonstrates rapid response with minimal oscillations even under dynamic conditions, making it advantageous for effectively tracking changes in irradiance and temperature.

4. “Incremental Conductance MPPT Technique for PV System”. Srushti R. Chafle , Uttam B. Vaidya. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering.
   This paper speaks that MPPT techniques are essential for improving solar system efficiency, with many studies delving into different strategies. Among these, incremental conductance shines for its superior steady-state accuracy and adaptability to environmental shifts. This method precisely governs power extraction from the PV by determining maximum power. overpower ages comprise high tracking efficiency, rapid response time, and meticulous control over power extraction, rendering it a favored option for maximizing solar energy utilization. Its ability to swiftly adjust to changing conditions and maintain optimal performance distinguishes incremental conductance as an effective choice in the quest for efficient solar power generation.

5. “Fuzzy logic based MPPT controller for high conversion ratio quadratic boost converter”. Saban Ozdemir , Necmi Altin , Ibrahim Sefa. International Journal of Hydrogen Energy.
   The paperwork shows that a high-conversion-ratio DC-DC quadratic boost converter is proposed, featuring a fuzzy logic-based MPPT controller for demanding applications. The system integrates a quadratic boost converter with a high step-up ratio and a fuzzy logic based MPPT controller. Fuzzy variables representing changes in PV power and voltage are utilized to generate the converter reference signal. Through determined membership functions and fuzzy rules, the MPPT of the PV system is tracked, enhancing efficiency. With better voltage conversion ratio and reduced duty cycle compared to traditional boost converters, it minimizes voltage stress and achieves a steady state MPPT efficiency of 99.10 percent, facilitated by the FLC-based MPPT controller.

6. “Fuzzy Logic Controller Based Maximum Power Point Tracking of Photovoltaic System Using Boost Converter”. Shilpa Sreekumar, Anish Benny. 2013 Fourth International Conference on Computing, Communications and Networking Technologies (ICCCNT).
   This paper introduces an intelligent control method for maximizing power point tracking (MPPT) in solar systems under variable insolation conditions. Employing a Fuzzy Logic Controller (FLC) with a DC-DC converter, it contrasts outcomes with those of the Perturb & Observe (P&O) approach. Conventional MPPT algorithms face challenges in swiftly adapting to changing atmospheric conditions. Findings indicate the superiority of the fuzzy logic controller over the conventional technique. Simulation compares the maximum power attained using the FLC-based method against the P&O algorithm.

7. “Implementing boost converter algorithm with PSO for photovoltaic system during partial shading condition”. K.Burhanudin, N.A.Kamarzaman, A.A.A.Samat, A.I.Tajudin, S.S.Ramli, N.Hidayath.
   This study targets enhancing the output voltage of a photovoltaic (PV) system via maximum power point tracking (MPPT) techniques and boost converter integration. A challenge arises as the boost converter initially matches input and output voltages, contrary to its design principle. To address this, a new boost converter algorithm is developed using Particle

Swarm Optimization (PSO) for MPPT control, overcoming obstacles like partial shading. This novel approach optimizes power extraction even under challenging conditions, improving overall system efficiency.

8. "An Improved Particle Swarm Optimization (PSO)-Based MPPT Strategy for PV System". Tianmeng Wei, Dongliang Liu and Chuanfeng Zhan.
   The paper study shows that under partial shading, the PV array's P-U curve exhibits multiple extreme points, challenging general MPPT methods prone to local MPP misjudgment and low efficiency. While traditional PSO tracks MPP accurately, its optimization process fluctuates and could be faster. An enhanced PSO algorithm is proposed, initializing particles closer to the MPP using I-U and P-U characteristic curves. This modification significantly improves PSO efficiency, ensuring rapid and precise MPP tracking under partial shading conditions.

9. "Dynamic Behaviour Analysis of ANFIS Based MPPT Controller for Standalone Photovoltaic Systems". Dilovan Haji, Naci Genc.
   This paperwork explains that Solar energy, a clean and abundant renewable source, is harnessed via photovoltaic systems, offering promise for electric power generation. However, drawbacks such as low efficiency and high fabrication costs persist. Maximum Power Point Tracking (MPPT) controllers mitigate these limitations by optimizing power extraction. Coupled with DC/DC converters, MPPT ensures optimal power production despite varying environmental conditions. Various MPPT techniques exist, from traditional methods like hill climbing to advanced approaches like ANFIS, which combines fuzzy logic and neural networks for efficient power point tracking.

10. "Anfis as a Method for Determinating MPPT in the Photovoltaic System Simulated in Matlab/Simulink". D. Mlakić and S. Nikolovski.2016 39th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO).
    The paper study involves a solar system employing a DC-to-DC boost converter with an Adaptive Neuro-Fuzzy Inference System (ANFIS) Maximum Power Point Tracking (MPPT) algorithm optimizes energy conversion. ANFIS dynamically adjusts the boost converter's parameters based on input data like solar irradiance and temperature, maximizing power output from the solar panel. This smart control system enhances efficiency by continuously aligning the panel's output with the maximum power point, ensuring optimal energy harvesting in varying environmental conditions.

Chapter-3

SOLAR PHOTOVOLTAIC SYSTEM

Solar photovoltaic (PV) systems represent a transformative technology in the quest for sustainable energy solutions. By converting sunlight into electricity, these systems offer a renewable alternative to traditional fossil fuels, contributing to a cleaner environment and energy independence. In this comprehensive exploration, we delve into the workings of solar PV systems, their components, advantages, limitations, and the broader implications for our energy landscape. At the heart of a solar PV system lies the solar panel, comprised of individual solar cells [2].

These cells are typically made of silicon, a semiconductor material capable of converting sunlight into electricity through the photovoltaic effect. When photons from sunlight strike the solar cells, they excite electrons, generating an electric current. This direct current (DC) electricity is then sent to an inverter, a critical component that converts it into alternating current (AC) electricity, compatible with most household appliances and the electrical grid. Beyond the solar panels and inverters, a solar PV system encompasses several other components. Mounting structures secure the solar panels in place, typically on rooftops or ground-mounted arrays, optimizing exposure to sunlight [6]. Electrical wiring connects the solar panels to the inverter and other system components, ensuring the smooth flow of electricity. Additionally, monitoring systems track the performance of the solar PV system, providing valuable data on energy production and efficiency.

3.1 Solar PV Cell

A photovoltaic cell or photoelectric cell is a semiconductor device that converts light to electrical energy by photovoltaic effect. If the energy of photon of light is greater than the band gap, then the electron is emitted, and the flow of electrons creates current [4]. However, a photovoltaic cell is different from a photodiode. In a photodiode light falls on n-channel of the semiconductor junction and gets converted into current or voltage signal but a photovoltaic cell is always forward biased. Fig.3.1 shows the model of Photovoltaic Cell in solar system.

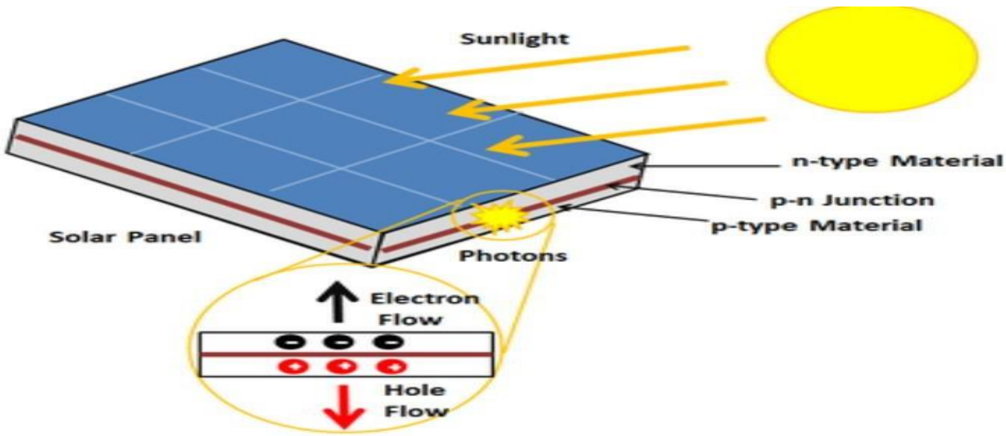

Fig.3.1 Photovoltaic Cell

3.2 PV Module

For the prediction of the behavior of a real solar cell under various environmental conditions and further to obtain its current-voltage (I-V) and power-voltage (P-V) characteristic curves, modeling of solar cell is necessarily required. The common approach is to utilize the electrical equivalent circuit, which is primarily based on a light generated current source connected in parallel to a p-n junction diode. Many models have been proposed for the simulation of a single solar cell or for a complete photovoltaic (PV) system at various solar intensities and temperature conditions [16]. There are different kinds of parametric models presented in various literatures in the past few decades, like single-diode model, two-diode model, three diode models, etc. The most used models are single diode and two diode model, as they provide better relations with a practical solar cell keeping in mind the simplicity and the speed in the extraction of parameters as well as I-V and P-V curves also gives minimum error with respect to characteristics of solar PV cell.

3.2.1 Ideal Single Diode Model

The below Fig.3.2 shows the ideal single diode model for the solar PV cell.

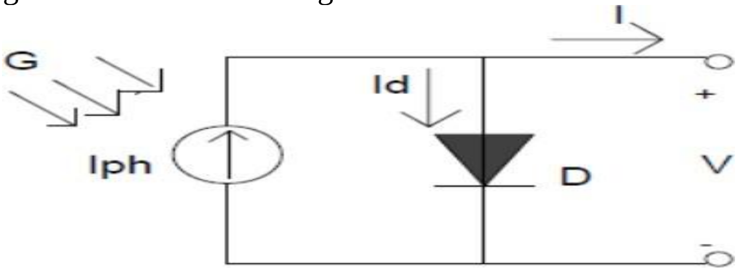

Fig.3.2 Ideal single diode model

This one is the most simplified form of an ideal PV cell through which the output voltage equation (3.2.1.3) and current equation (3.2.1.1) relations comes out to be, also diode current can be calculated by equation (3.2.1.1)

$$I = I_{ph} - I_d \tag{3.2.1.1}$$

Where $$I_d = I_0\left(e^{\frac{V}{n_s v_T}} - 1\right) \tag{3.2.1.2}$$

And $$V_T = \frac{nkT}{q} \tag{3.2.1.3}$$

3.2.2 Practical Single Diode Model

The below Fig.3.3 shows practical single diode model of solar cell.

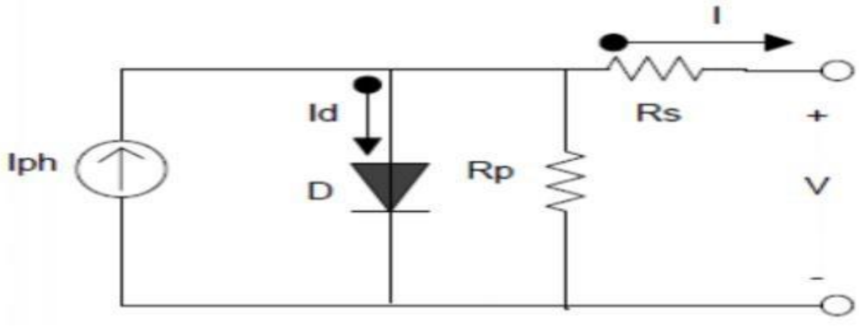

Fig.3.3 Practical Single diode model of solar cell

This one is an equivalent circuit of a practical PV cell. In many literatures it is also termed as a five parameters model (I_o, n, R_s, R_p, I_{ph}). It considers different properties of solar cell as:

- R_s is introduced as to consider the voltage drops and internal losses in due to flow of current.
- R_p considers the leakage current to the ground when diode is in reverse biased.
- But this model has neglected recombination effect of diode, which is why it is still not the mostaccurate model. The equation (3.2.2.1) for PV Model current is given by,

$$I = I_{ph} - I_0\left(e^{\frac{V+IR_S}{n_S V_T}} - 1\right) - \frac{V+IR_S}{R_p} \tag{3.2.2.1}$$

Whereas,

I – PV module current (A)

I_{ph} - Photocurrent (A)
I_d - Current through the diode
I_o - Diode saturation current (A)

V – PV module voltage (V)

n_S- Number of cells in series
V_T- Thermal voltage equivalent

k – Boltzmann Constant (1.3865×10^{-23} J/K)

q – Electronic Charge (1.6021×10^{-19} C)
R_S- Series Resistance (Ω)
T – Operating Temperature (Kelvin)
R_P- Parallel Resistance (Ω)
n – Diode factor ($1 \leq n \leq 2$)

3.2.3 PV Panel Configuration's

The specifications of the solar PV module are detailed in Table.3.1.

Table.3.1 PV Module Specifications

S. No.	Parameter	Value
1	Parallel strings	1
2	Series-connected modules per string	1
3	Series-connected modules per string	60
4	Voltage generated per cell	0.5v
5	Short-circuit current (Isc)	8.84A
6	Open circuit voltage (Voc)	37.6V
7	Voltage at maximum power point (Vmax)	30.6V
8	Current at maximum power point (Imax)	8.33A
9	Maximum Output Power (Pmax)	255w

Fig.3.4 shows the variable irradiance signal graph given to the solar PV panel, which is used in all the MPPT methods.

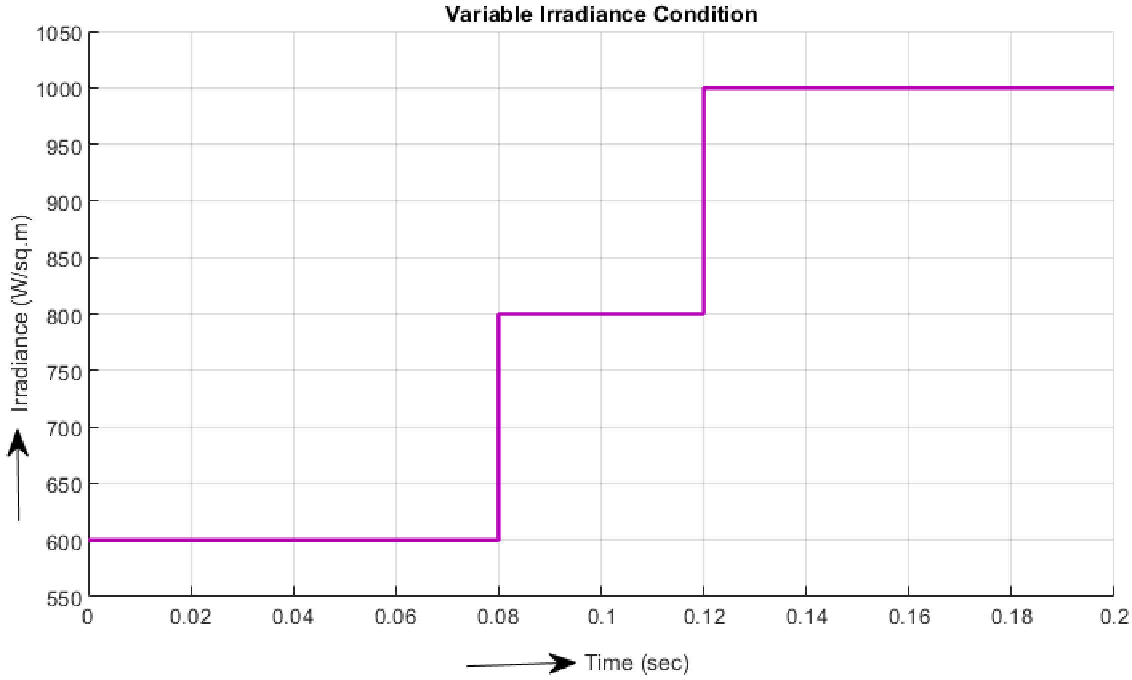

Fig.3.4 Variable irradiance signal graph given to the solar PV panel.

Fig.3.5 shows the I-V and P-V curves of solar panels at irradiance levels of 1KW/m^2 0.8KW/m^2 and 0.6KW/m^2 at a temperature of 25^{o}C.The panels were designed for the power of 1019.59watts.

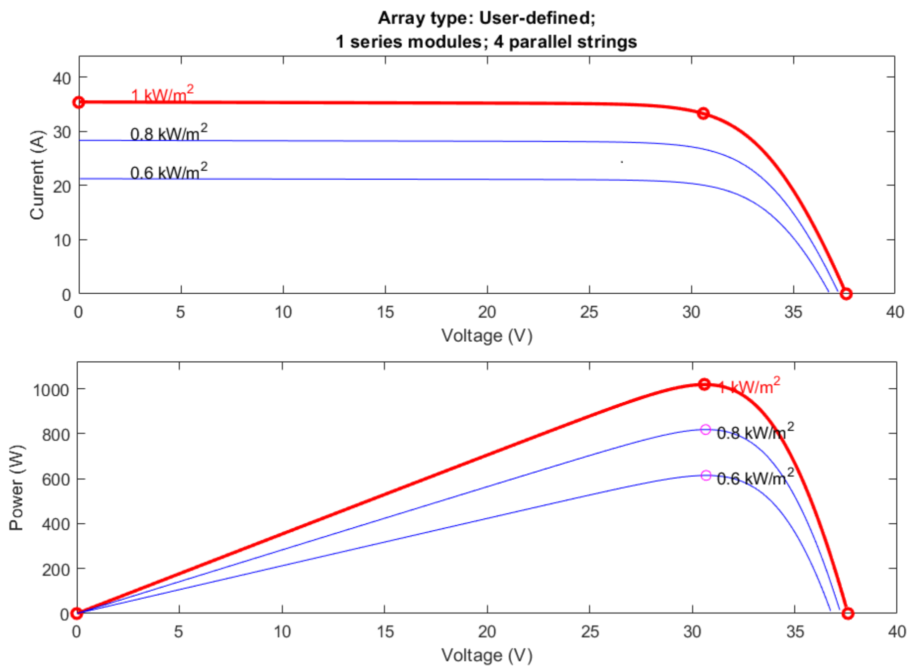

Fig.3.5 I-V and P-V curves of solar panel at a different irradiance level of 1000W/m^2,800W/m^2 and 600W/m^2

3.4 DC-DC Boost Converter

A boost converter, also known as a step-up converter, is an electronic circuit used to increase the voltage of a DC power source. A boost converter takes a lower voltage DC input and increases it to a higher voltage output. It consists of an inductor, a switch (usually a transistor), a diode, and a capacitor [5]. When the switch is closed, energy is stored in the inductor, and when the switch is open, the inductor releases energy, raising the output voltage[6]. Boost converters are commonly used in applications where a higher voltage is required, such as in LED drivers, battery charging circuits, and renewable energy systems. Fig.3.6 shows the DC-DC Boost converter consisting of inductor, capacitor, diode and MOSFET switch.

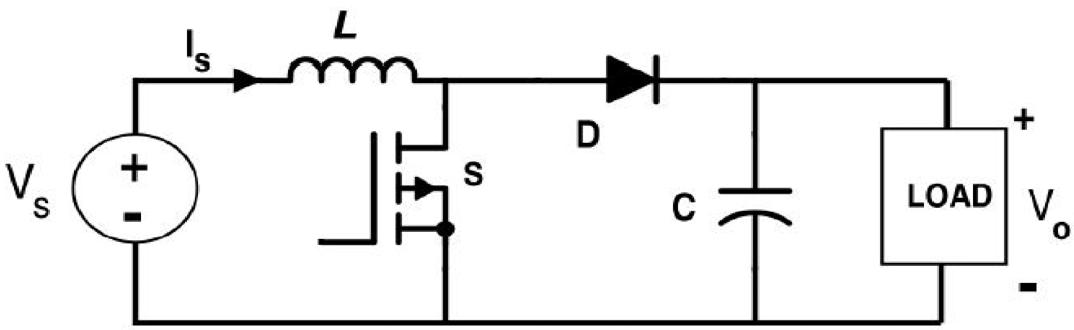

Fig.3.6 DC-DC Boost Converter

The basic principle of operation for a boost converter can be understood through the following two stages:

Switch-on period (S1 closed, S2 open): During this stage, the input voltage (V_{in}) is applied across the inductor (L), causing the current through the inductor to increase linearly. The energy stored in the inductor builds up, and the diode (D) is reverse-biased, preventing current flow to the load. The inductor current can be expressed by the equation (3.4.1),

$$\Delta I_L = \frac{V_{in}}{L}.t_{on} \tag{3.4.1}$$

where ΔI_L is the change in inductor current, L is the inductance, and t_{on} is the duration of the switch-on period.

Switch-off period (S1 open, S2 closed): When the switch S1 opens, the inductor current must continue to flow. This forces the diode D to become forward biased, and the inductor releases its stored energy to the load (R) and the output capacitor (C). During this period, the voltage across the inductor (V_L) is equal to the difference between the output voltage (V_{out}) and the input voltage (V_{in}). The inductor current decreases linearly as the energy is transferred to the load, and the equation (3.4.2) for the inductor current becomes:

$$\Delta I_L = \frac{(V_{out}-V_{in})}{L}.t_{off} \tag{3.4.2}$$

where t_{off} is the duration of the switch-off period,

By equating the inductor current equations for both stages and rearranging the terms, we can derive the voltage conversion relationship for the boost converter is given by equation (3.4.3):

$$V_{out} = \frac{V_{in}}{(1-D)} \tag{3.4.3}$$

where D is the duty cycle, defined as the ratio of the switch-on time (t_{on}) to the total switching period (T) is given by equation (3.4.4) as below,

$$D = \frac{t_{on}}{(t_{on}+t_{off})} \tag{3.4.4}$$

This equation (3.4.4) shows that the output voltage can be controlled by adjusting the duty cycle of the switching waveform, allowing for a higher output voltage than the input voltage.

3.4.1 Design Calculations of Boost Converter

The design calculations for the boost converter given as,
Consider, the switching frequency as (f_s) = 40KHZ
The input voltage for the converter (V_{in}) = 30v
Consider, the Duty cycle (D) = 0.7

$$D = 1-\frac{V_{in}}{V_0} \tag{3.4.1.1}$$

$$0.7 = 1-\frac{30}{V_0}$$

Take output voltage (V_0) =100
Let us consider,
The resistance (R) =10Ω
The output current (I_0) = V_0 /R (3.4.1.2)

$$=100/10$$

$$I_0 = 10A$$

The change in Current ($\triangle I_L$) = $0.2\times I_0\times\frac{V_0}{V_i}$ (3.4.1.3)

$$= 0.2\times10\times100/30$$

$$= 6.66A$$

The inductance of a Inductor (L) = $\frac{V_{in}(V_0-V_{in})}{\triangle I_L \times f_{sw}\times V_0}$ (3.4.1.4)

$$= \frac{30(100-30)}{6.66\times40\times10^3\times100}$$

$$L=78.75\times10^{-6}H$$

The Change in output voltage ($\triangle V_0$) = $0.1\times V_0$ (3.4.1.5)

$$= 0.1\times100$$

$$\triangle V_0 = 10V$$

The capacitance of a Capacitor (C) = $\frac{I_0\times D}{f_s\times\triangle V_0}$ (3.4.1.6)

$$= \frac{10\times0.7}{40\times10^3\times10}$$

$$C=17.5\times10^{-6}F$$

3.5 Solar PV System with Closed loop Proportional Integral Control

3.5.1 Introduction

The surging demand for energy has led to a rapid depletion of fossil fuels, potentially leaving future generations energy deprived. In response, solar energy emerges as a specific solution, being abundantly available and reliable [25]. This project suggests enhancing solar energy system efficiency through advancements in conventional boost converters. A Proportional-Integral (PI) controller is integrated to ensure a consistent output voltage despite variable input, with parameters determined using the Ziegler-Nichols method. Modeling and simulation of the PV Module and Boost Converter are conducted via MATLAB/Simulink [26]. This approach aims to bridge the energy gap, ensuring uninterrupted power supply to meet consumer demands while mitigating environmental concerns associated with fossil fuel consumption.

3.5.2 Theory

Renewable energy sources, such as solar power, offer a compelling alternative to conventional sources due to their abundant availability and reliability. Solar photovoltaic (PV) systems, known for their eco-friendliness, exhibit moderate efficiency levels ranging from 9% to 20%, with variability based on irradiation conditions [27]. To enhance PV system efficiency, especially in low irradiation, boosting the low-level DC voltage output becomes essential. This task is accomplished through a Boost converter, a DC-to-DC converter that ensures the output voltage surpasses the input voltage. Control over the boost converter output is achieved using a Proportional-Integral (PI) controller, which adjusts MOSFET driving pulses' width. This integrated approach aims to optimize the performance of solar PV systems, mitigating the impact of weather-induced fluctuations on electricity generation [28].

3.5.3 Simulink Model

The Simulink model for closed loop proportional integral control is shown in Fig.3.7.

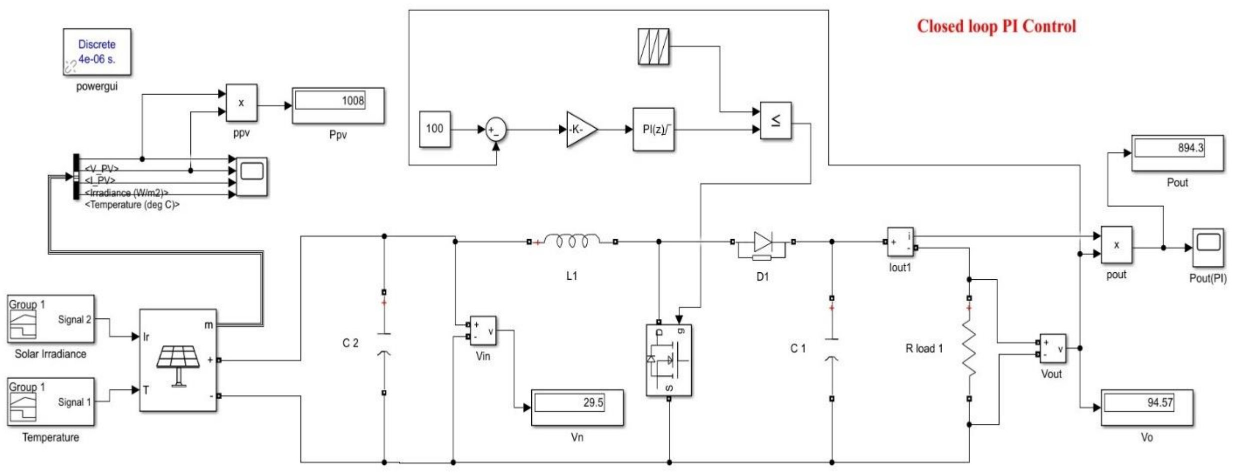

Fig.3.7 Simulink Model for Closed loop PI Control

3.5.4 Results

Fig.3.8 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for PI control. The maximum power obtained for PI control is 894.3W, the settling time is 0.198sec, rise time is 60.855ms, steady state error is 1.136% and efficiency is 88.72%.

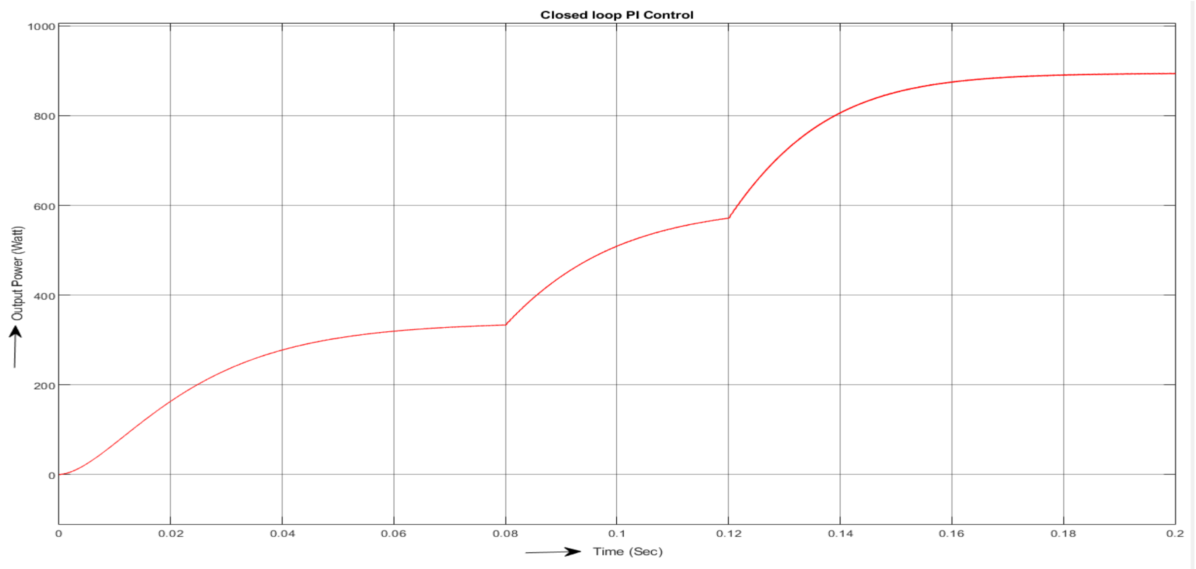

Fig.3.8 Output Power Vs Time for Proportional Integral Control

3.5.5 Advantages and Disadvantages

Advantages:

- ***Stability:*** The PI controller enhances system stability by continuously adjusting its output based on both present error (Proportional) and past error (Integral), ensuring a smoother response to disturbances or setpoint changes.
- ***Accurate Setpoint Tracking:*** By incorporating integral action, PI controllers can eliminate steady-state errors, ensuring that the system reaches and maintains the desired setpoint accurately over time.
- ***Compatibility:*** PI controllers are widely compatible with various control systems and processes, making them versatile for use in different industries and applications.

Disadvantages:

- ***Limited Adaptability:*** PI controllers may struggle to adapt to dynamic changes in system parameters or operating conditions. They are less effective in systems with highly nonlinear or time-varying dynamics, potentially leading to suboptimal performance.
- ***Slow Response:*** The integral action in PI controllers introduces a time delay in the control loop, which can result in slower response times compared to controllers with derivative action. This may affect the system's ability to track rapid changes in the reference signal.
- ***Tuning Challenges:*** Tuning PI controllers for optimal performance can be challenging, especially in systems with complex dynamics or uncertain parameters. Finding the right balance between proportional and integral gains requires careful analysis and experimentation.

Chapter-4

MAXIMUM POWER POINT TRACKING TECHNIQUES

4.1 Overview of MPPT

There are two major barriers for the use of PV systems, low energy conversion efficiency and high initial cost. To improve energy efficiency, it is important to always work the PV system at its Maximum Power Point (MPP). The Maximum Power Point Tracking (MPPT) is a technique used in power electronic circuitsto extract maximum energy from the Photovoltaic (PV) Systems, wind energy systems or thermoelectric generators. In recent decades, photovoltaic power generation has become more important due to its many benefits such as low maintenance and being environmentally friendly [2].

So far, a lot of research has been conducted and many papers have been published that suggested different methods for extracting maximum power point. To produce maximum power and to get maximum efficiency, the entire photovoltaic panel must operate at the MPP. To maximize the utilization of large arrays of photovoltaic modules, maximum power point tracker is normally employed in conjunction with the power converter (DC–DC converter and/or inverter) [3]. However, due to the varying environmental conditions, namely temperature and solar insulation, the power–voltage characteristic curve exhibits an MPP that varies nonlinearly with these conditions — thus posing a challenge for the tracking algorithm. Here, the Fig.4.1 shows the block diagram of Solar PV System with MPPT Controller.

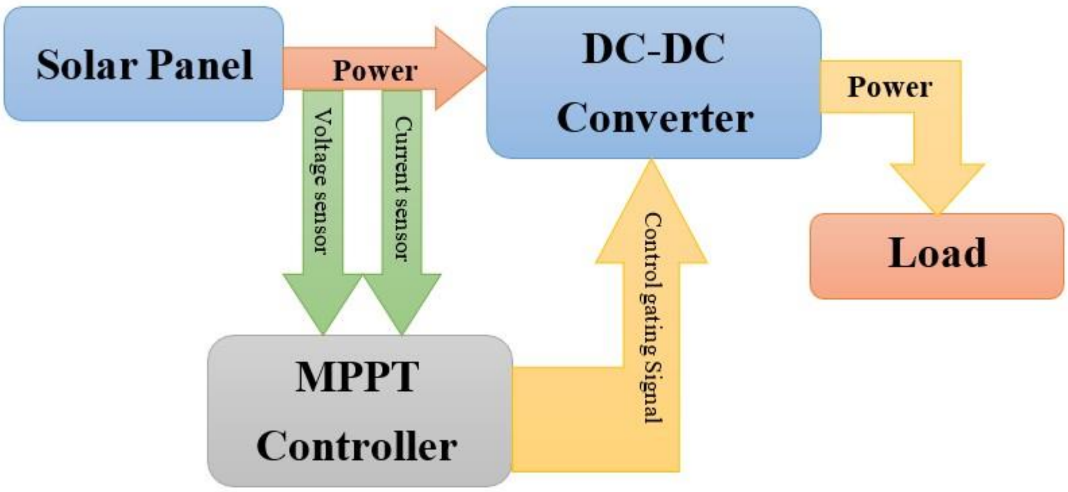

Fig.4.1 Solar PV System with MPPT Controller

This project report presents in detail the implementation of Perturb and Observe MPPT using Buck- Boost converter. Some results such as output power for various irradiances have been recorded. The simulation has been accomplished in software of MATLAB MathWorks. The MPPT is responsible for extracting the maximum possible power from the photovoltaic and feeding it to the load via the buck-boost converter which steps up the voltage to the required magnitude. The main aim will be to track the maximum power operating point of the photovoltaic module so that the maximum possible power can be extracted from it. In this report, we examine a schematic to extract maximum obtainable solar power from a PV module and use the energy for a DC application.

Also, to maximize the generation capacities of sources, Maximum Power Point Tracking (MPPT) techniques must be designed specifically for the characteristics of the source. For best performance, MPPT techniques should be tailored to the generator's capabilities and responses to environment. Choosing an MPPT scheme that does not fit the generator's characteristics will lead to increased losses [18].

The maximum power point tracking (MPPT) of the PV output for all sunshine conditions is a key to keeping the output power per unit cost low for successful PV applications. In this perturb and observe (P&O) method described initially in this report, the module voltage is periodically given a perturbationand the corresponding output power is compared with that at the previous perturbing cycle. With perturbation, power can either be increased or decreased. Sampled voltage and current value are used to calculate power.

4.2 Various types of MPPT Techniques

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

- Perturb and Observe method.
- Incremental Conductance method.
- Fuzzy logic control with P&O.
- Fuzzy Logic Control with Incremental Conductance.
- Particle Swarm Optimization
- Adaptive Neuro Fuzzy Interface System

The choice of the algorithm depends on the time complexity of the algorithm takes to track the MPP, implementation cost and the ease of implementation.

4.2.1 Perturb and Observe MPPT Method

4.2.1.1 Introduction:

The P&O (Perturb and Observe) method is a widely used algorithm in the field of maximum power point tracking (MPPT) for photovoltaic (PV) systems. Its primary function is to optimize the output power of a solar panel by continuously adjusting the operating point to track the maximum power point (MPP) under varying environmental conditions such as changes in sunlight intensity and temperature [4]. The basic principle of the P&O method involves periodically perturbing the operating point of the PV system and observing the resulting change in power output. By analyzing this change, the algorithm can determine whether the operating point needs to be adjusted further towards the MPP or if it has overshot the optimal point [5].

4.2.1.2 Theory:

The P&O method is typically used to track the Maximum Power Point (MPP) of a photovoltaic (PV) system. This technique involves introducing a minor perturbation to induce power variation in the PV module. Periodic measurements of the PV output power are taken and compared with previous readings. If there is an increase in output power, the perturbation process continues; otherwise, the perturbation is reversed. In this algorithm, perturbations are applied to either the PV module or array voltage [6]. Adjusting the PV module voltage allows the algorithm to check for corresponding changes in power output. An increase in voltage leading to increased power indicates that the operating point of the PV module is to the left of the MPP, necessitating further perturbation towards the right to reach the MPP. Conversely, if an increase in voltage results in decreased power, it suggests that the operating point is to the right of the MPP, requiring perturbation towards the left.

When the MPPT charge controller is connected between the PV module and battery, it monitors their voltages. After assessing the battery voltage, it determines if the battery is fully charged. If so (e.g., at 12.6 V), charging is halted to prevent overcharging. If the battery is not fully charged, charging begins by activating the DC/DC converter [22]. The microcontroller calculates the current power output (P_{new}) by measuring voltage and current, comparing it with the previously measured power (P_{old}). If p_{new} exceeds p_{old}, the PWM duty cycle is increased to extract maximum power from the PV panel; otherwise, the duty cycle is decreased to revert to the previous maximum power level. This MPPT algorithm is characterized by its simplicity, ease of implementation, low cost, and high accuracy.

The tracking time constitutes an essential performance evaluation parameter for the MPPT algorithm as defined according to t as the time taken by an MPPT algorithm to reach 95% within the maximum average power at MPP is given by the equation (4.2.1.1) as below,

$$\eta_{MPPT} = \frac{\int_{t1}^{T} p(t)d(t)}{\int_{0}^{T} p_{max}(t)d(t)} \tag{4.2.1.1}$$

where:

- T_t is the tracking time.
- t_1 is the time when the algorithm reaches 95% of the maximum average power at MPP.
- t is the total time taken by the algorithm.
- p(t) is the power output of the PV system at time t.
- p_{max}(t) is the maximum available power output of the PV system at time t.

4.2.1.3 Algorithm

Fig.4.2 shows the algorithm for Perturb & Observe technique. It is also known as the hill climbing algorithm. Based upon the algorithm, P&O code was developed in a MATLAB function block.

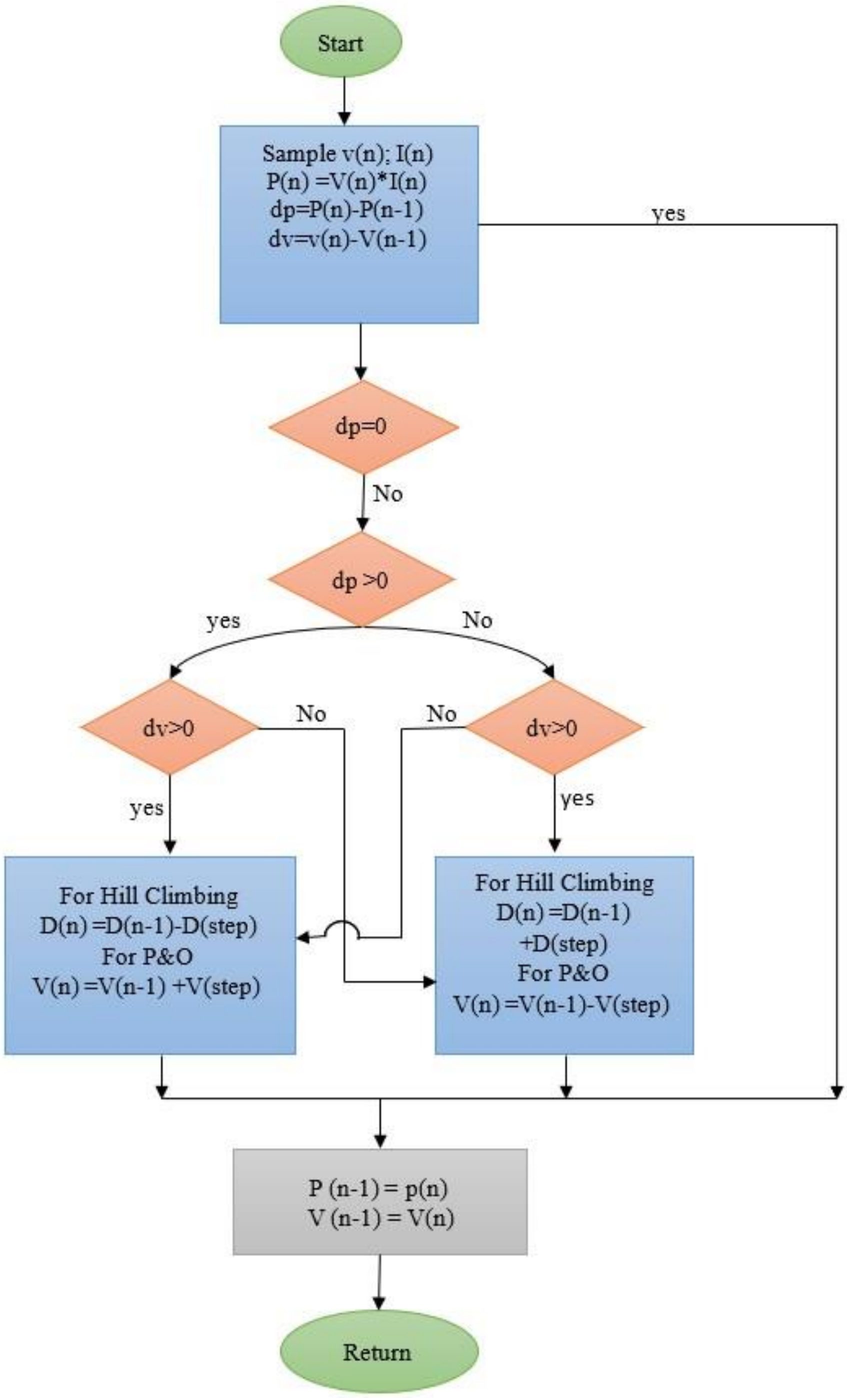

Fig.4.2 Perturb and Observe Algorithm

4.2.1.4 Simulink Model

The Simulink model for MPPT technique using Perturb & Observe is shown in Fig.4.3. It consists of P&O code in a MATLAB function block.

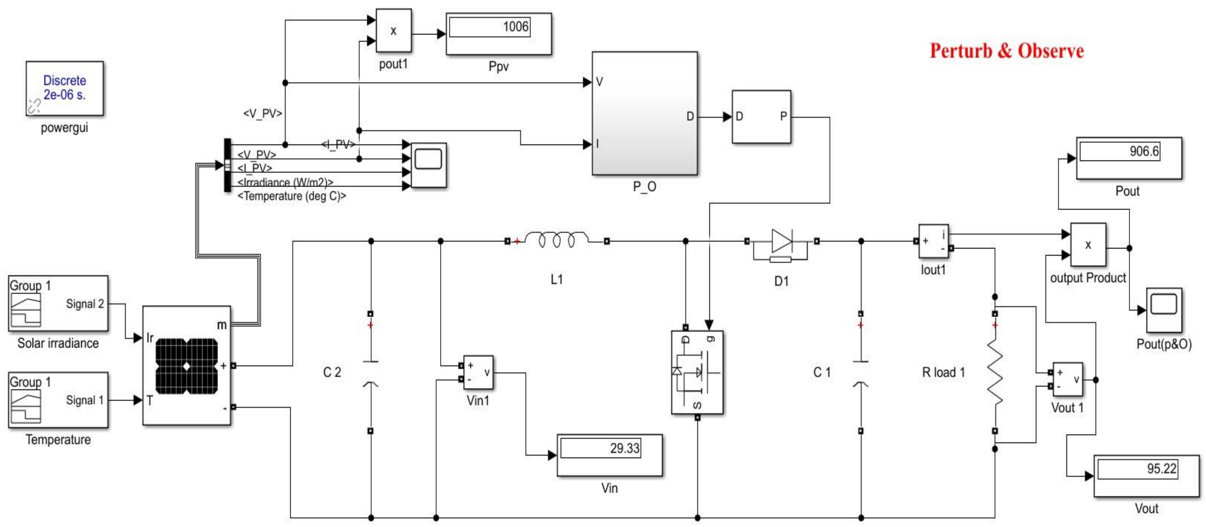

Fig.4.3 Simulink Model with Perturb and Observe Technique

4.2.1.5 Results

Fig.4.4 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for P&O. The maximum power obtained for P&O is 906.6W, the settling time is 0.196sec, rise time is 60.754ms, steady state error is 1.132% and efficiency is 90.119%.

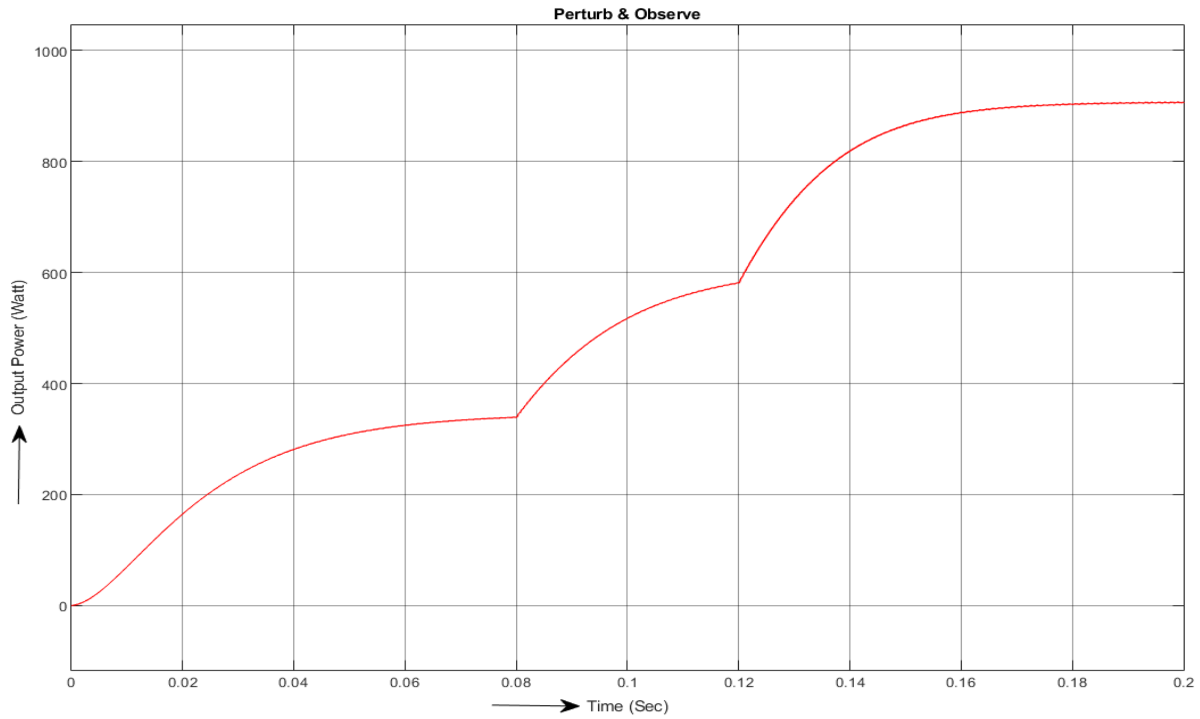

Fig.4.4 Output Power Vs Time for Perturb and Observe Technique

4.2.1.6 Advantages and Disadvantages

Advantages:

- ***Simplicity:*** The P&O method is relatively simple to implement compared to some other MPPT algorithms. It involves perturbing (changing) the operating point of the PV array and observing the resulting change in power to determine the direction in which to adjust the operating point.
- ***Cost-Effectiveness****:* Because of its simplicity, the P&O method typically requires less complex hardware and software compared to more sophisticated MPPT algorithms. This can lead to cost savings in system design and implementation.
- ***Suitability for Uniform Irradiance Conditions****: The* P&O method performs well under uniform irradiance conditions where the PV array is exposed to consistent levels of sunlight. In such scenarios, it can effectively track the Maximum Power Point (MPP) and optimize power output.

Dis-advantages:

- ***Oscillatory Behaviour****:* One significant drawback of the P&O method is its tendency to exhibit oscillatory behaviour around the MPP, particularly under rapidly changing environmental conditions or partial shading. This oscillation can lead to inefficient operation and reduced system stability. The P&O method is not suited in fast changing environmental conditions.
- ***Inefficiency under Partial Shading****:* In scenarios where the PV array experiences partial shading, the P&O method may struggle to accurately track the MPP. This is because the method relies on observing changes in power output, which can be misleading in partially shaded conditions where multiple local maxima or minima exist.
- ***Slow Response Time****:* The P&O method typically has a slower response time compared to some other MPPT algorithms. This slower response can result in slower convergence to the MPP.

4.2.2 Incremental Conductance MPPT Method

4.2.2.1 Introduction

The Incremental Conductance method is another widely used algorithm for Maximum Power Point Tracking (MPPT) in photovoltaic (PV) systems. Like the Perturb and Observe (P&O) method, its primary objective is to continuously adjust the operating point of a solar panel to track the Maximum Power Point (MPP) under varying environmental conditions. The Incremental Conductance method operates based on the rate of change of the PV panel's power with respect to voltage (dP/dV). Unlike the P&O method, which only considers the sign of the power change to determine the direction of adjustment, Incremental Conductance utilizes the slope of the power-voltage (P-V) curve to make more precise adjustments [7].

4.2.2.2 Theory

The incremental conductance (INC) method is a sophisticated technique employed in Maximum Power Point Tracking (MPPT) systems within photovoltaic (PV) setups. Its purpose is to optimize the power output of solar panels by continuously adjusting the operating point of the PV array to coincide with its maximum power point (MPP). At its core, the incremental conductance method relies on comparing the incremental conductance (dI/dV, where I is the current and V is the voltage) of the PV system with its instantaneous conductance. When these two values align, it indicates that the system is operating at the MPP. The process unfolds in a continuous cycle. Initially, the system captures measurements of voltage (V) and current (I) from the PV array. It then calculates through the equation (4.2.2.1) of instantaneous conductance (G)

using the formula $G_{inc} = \frac{dI}{dV}$ (4.2.2.1)

Where:

- G_{inc} represents incremental conductance.
- I denote the current.
- V signifies the voltage.

Next comes the comparison phase. If the calculated incremental conductance surpasses the instantaneous conductance, it signifies that the operating point is to the left of the MPP. Consequently, the system adjusts the operating voltage upwards to progress towards the MPP. Conversely, if the calculated incremental conductance falls short of the instantaneous conductance, it suggests that the operating point lies to the right of the MPP. In this scenario, the system reduces the operating voltage downwards to steer towards the MPP. This iterative adjustment process persists until the incremental conductance equals the instantaneous conductance, signaling that the system has reached the MPP. By dynamically adapting the operating point of the PV array, the incremental conductance MPPT method maximizes power extraction from solar panels, even amidst fluctuating environmental conditions like changes in irradiance and temperature. In essence, the incremental conductance technique plays a pivotal role in enhancing the efficiency and performance of PV systems by ensuring they consistently operate at their peak power output levels.

4.2.2.3 Algorithm

The Fig.4.5 shows the algorithm fo Incremental conductance. It consists of many conditional statement blocks inside the algorithm.

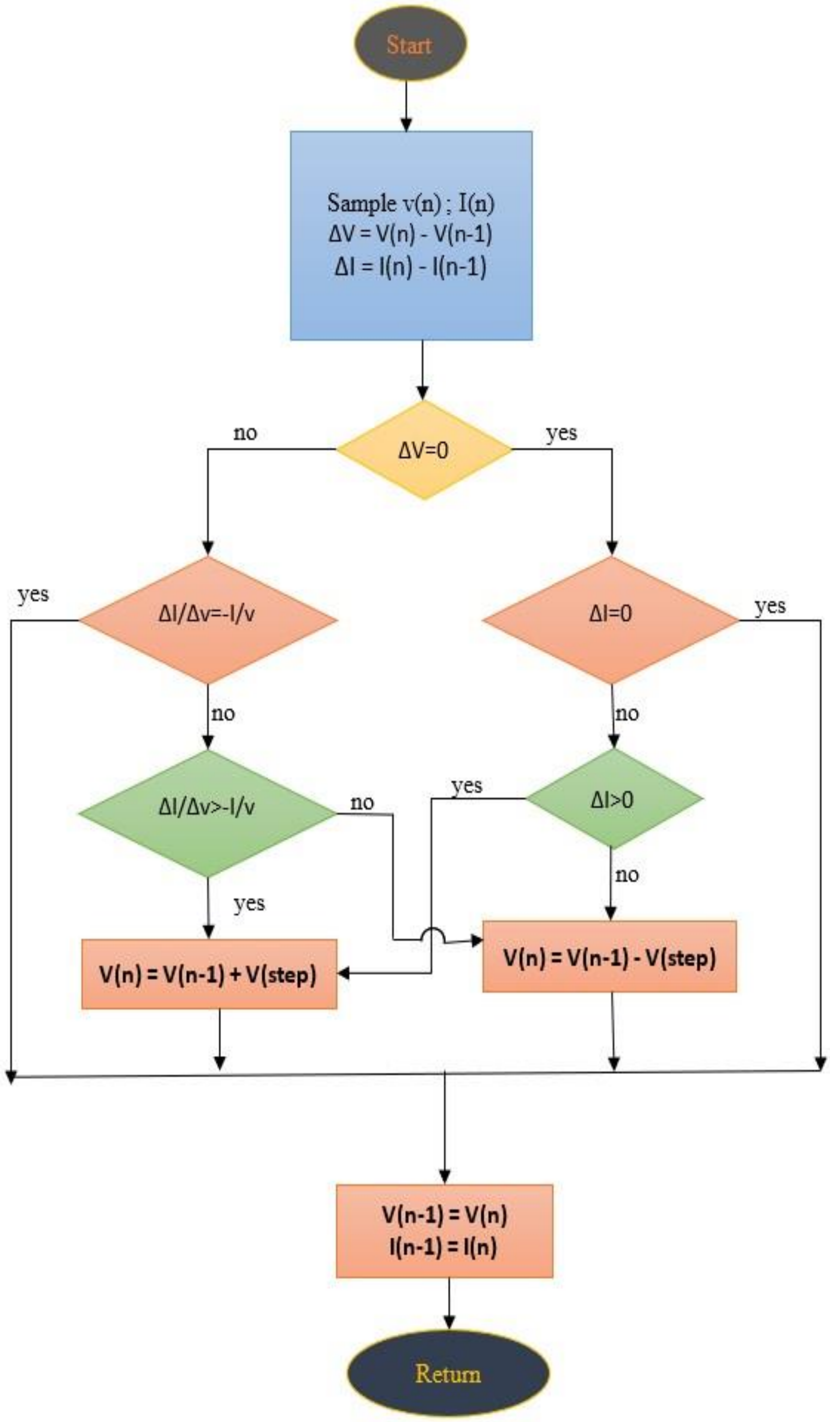

Fig.4.5 Incremental Conductance Algorithm

4.2.2.4 Simulink Model

The Simulink model for MPPT technique using Incremental Conductance is shown in Fig.4.6. It consists of Incremental Conductance code in a MATLAB function block.

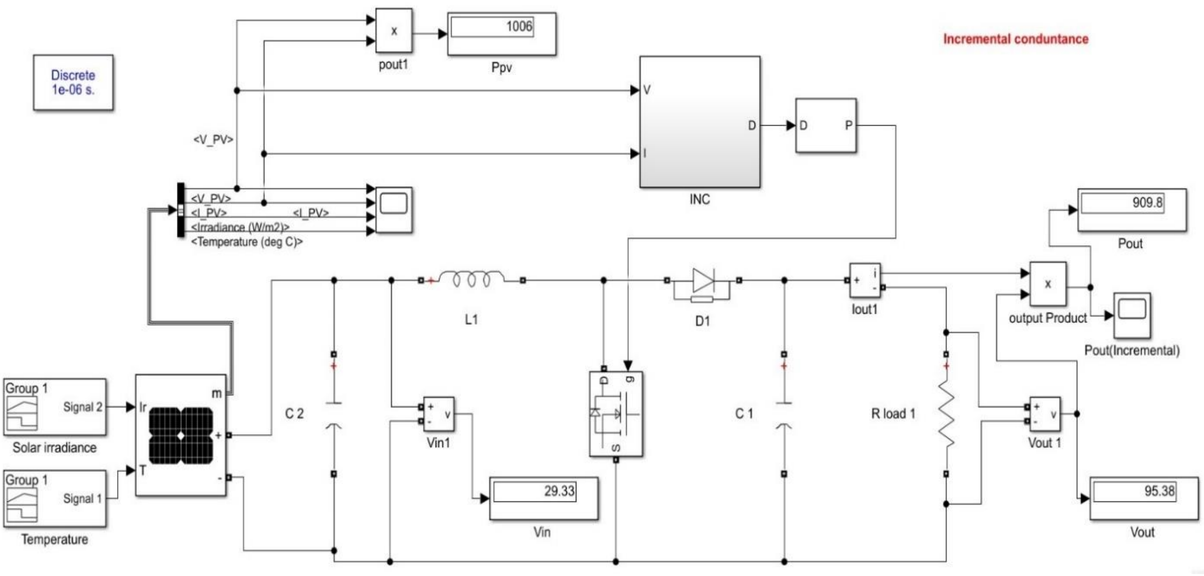

Fig.4.6 Simulink Model with Incremental Conductance Technique

4.2.2.5 Results

Fig.4.7 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for Inc Cond. The maximum power obtained for Inc Cond is 909.8W, the settling time is 0.189sec, rise time is 60.681ms, steady state error is 1.132% and efficiency is 90.437%.

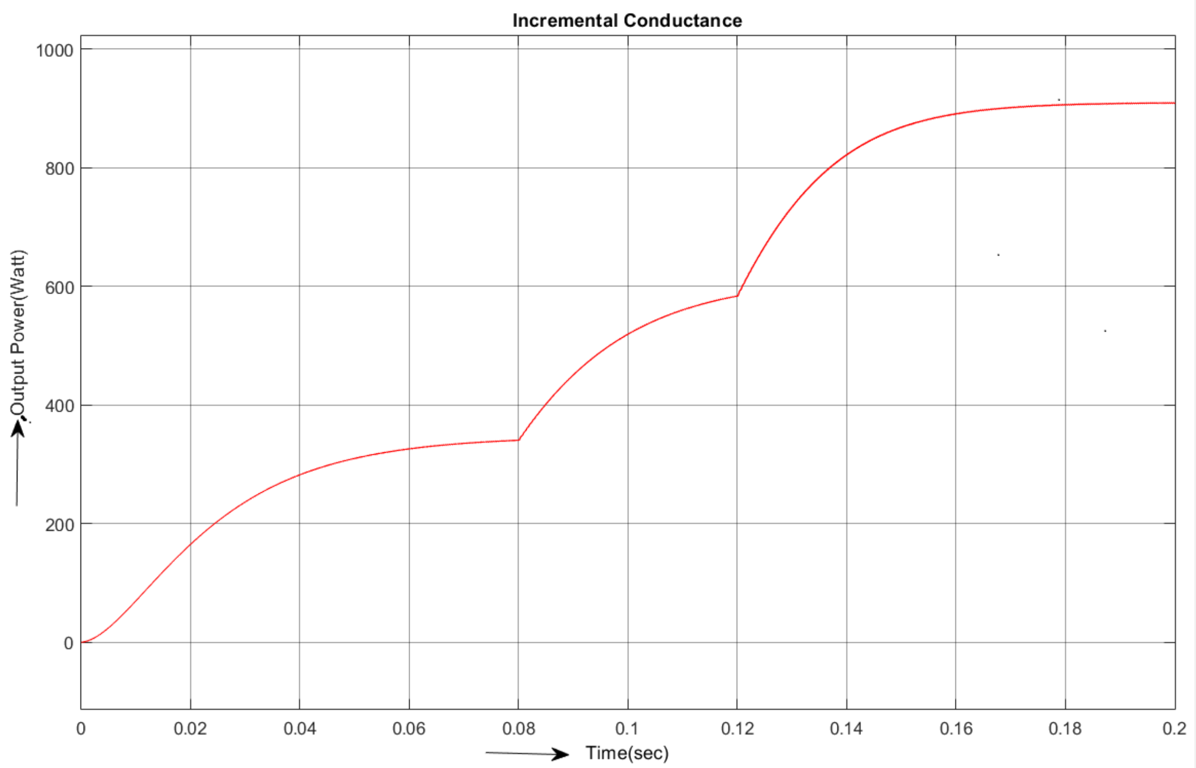

Fig.4.7 Output Power Vs Time for Incremental Conductance Technique

4.2.2.6 Advantages and Disadvantages

Advantages:

- ***Accuracy:*** The incremental conductance method demonstrates remarkable accuracy in tracking the MPP, even amidst swiftly changing environmental conditions. This precision ensures that the system consistently operates at its peak power output.
- ***Efficiency:*** With its swift and efficient convergence to the MPP, the algorithm contributes to high system efficiency. This efficiency is critical for maximizing the energy yield of PV systems, particularly in scenarios where every bit of generated power counts.
- ***Handling Multiple MPPs:*** This method possesses the capability to handle multiple MPPs, which proves invaluable when dealing with modules that encompass partially shaded regions. By effectively managing multiple MPPs, the system can extract maximum power from the PV array despite shading effects.

Dis-advantages:

- ***Complexity:*** Implementing the incremental conductance method requires sophisticated software and hardware, as it involves complex algorithms and calculations. This complexity may necessitate advanced control mechanisms and processing capabilities, which can increase system costs and complexity.
- ***Sensitivity to Noise:*** The method may be sensitive to noise present in the input signals, potentially leading to inaccuracies in tracking the MPP. Noise interference can result in erroneous adjustments to the operating point, affecting system performance and efficiency.
- ***Limitations near Local Extrema:*** In certain scenarios, such as when the PV module operates in the vicinity of local maxima or minima of the voltage-current characteristic, the incremental conductance method may not function optimally. This limitation can hinder its effectiveness in accurately tracking the MPP under specific operating conditions.

4.2.3 Fuzzy Logic Control based MPPT.

4.2.3.1 Introduction

Fuzzy logic is a field of artificial intelligence that deals with reasoning systems. Its major goal is to model human cognitive processes and decision-making skills in computer applications [9]. Fuzzy logic techniques are frequently utilized in circumstances where binary-form process data are not relevant. Fuzzy logic is a type of many-valued logic in which the truth value of variables might be any real integer from 0 to 1 [10]. In contrast, in Boolean logic, the truth values of variables can only be the integers 0 or 1. The functionary's primary responsibility is to establish decision-based rules by assessing system behavior and language input variables inside the context of the system [11]. The inputs supplied to the FLC must go through three fundamental steps of fuzzification, decision-making, and defuzzification before creating the output.

4.2.3.2 Theory

Fuzzy logic control (FLC) is a technology that employs maximum power point tracking (MPPT) to monitor a photovoltaic (PV) panel's maximum power. FLC MPPT handles nonlinearity effectively and can track maximum power faster and more precisely than traditional approaches [20]. It can also enhance MPPT performance in terms of speed, sensitivity to parameter variations, and oscillations around the maximum power point. In FLC for MPPT, the input variables generally include solar irradiance, temperature, and the PV array's voltage-current characteristics [21].

Fuzzy sets are created for each input variable, representing language phrases like "low," "medium," and "high" for solar irradiation. Membership functions explain a given input value's degree of membership in each fuzzy set. The rule base defines control actions using fuzzy logic. Rules are often represented as "if-then" statements that combine input variables and language concepts. For example, a rule may indicate, "If solar irradiance is high and temperature is medium, then increase the duty cycle of the converter [24]."

Fuzzification is the process of transforming crisp (numerical) inputs into fuzzy sets by applying membership functions. Membership functions specify the degree of membership of each input value in a linguistic term. Fuzzy inference determines the subsequent action for each rule depending on the current values of the input variables [29]. The final stage of FLC is defuzzification, which transforms the fuzzy output sets into a crisp (numerical) value. This entails combining the subsequent actions of all activated rules to provide a single output value. FLC's control technique is relatively difficult and costly to execute. The Centroid of Gravity (COG) defuzzification algorithm is widely used because to its simplicity.

4.2.3.3 Algorithm and Rules developed in a block.

Algorithm:

Fig.4.8. shows the algorithm for Fuzzy Logic Control and detailed explanation can be seen through the blocks in an algorithm.

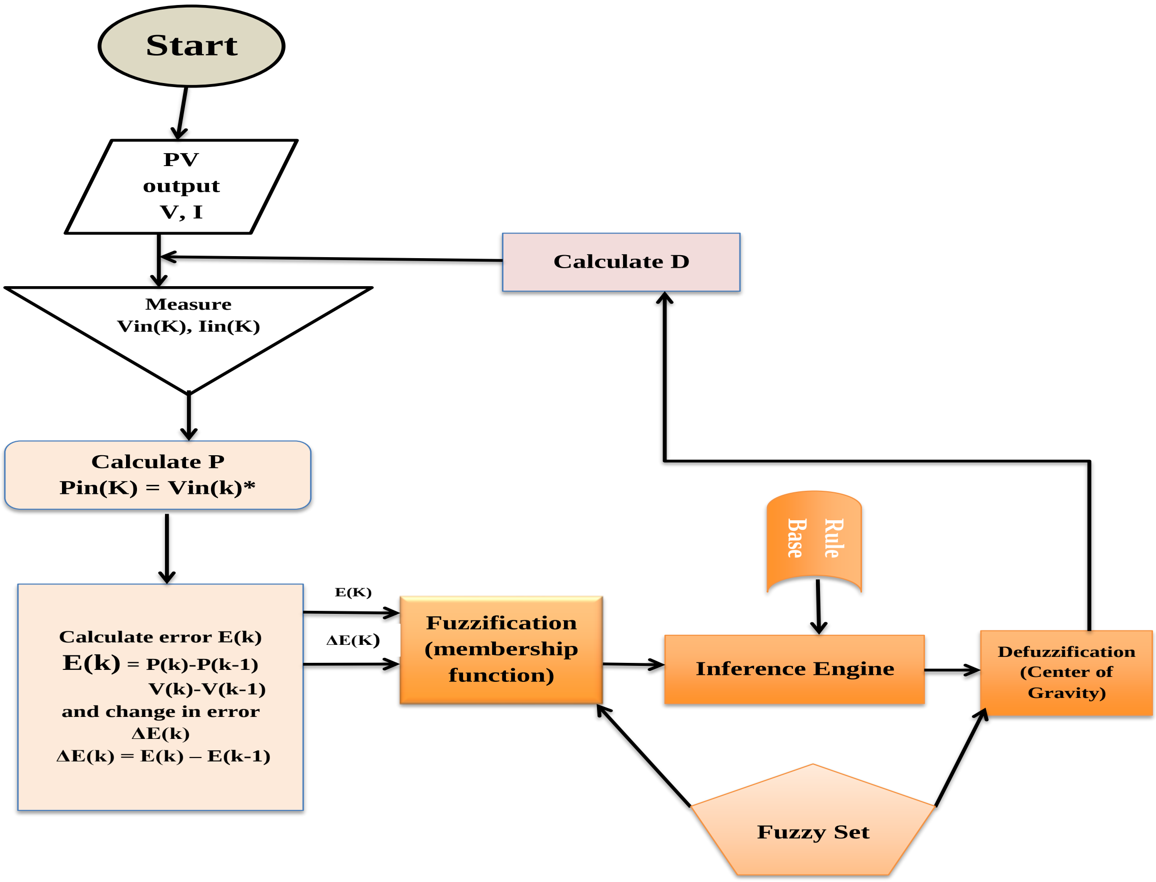

Fig.4.8 Fuzzy Logic Control Algorithm

Rules developed in a Block:

Fig.4.9 shows that the Rules developed in a FLC block. There are 25 rules developed in a block. Also Fig.4.10 shows the membership function plots for two input variables and Fig.4.11 shows the membership function for output variable.

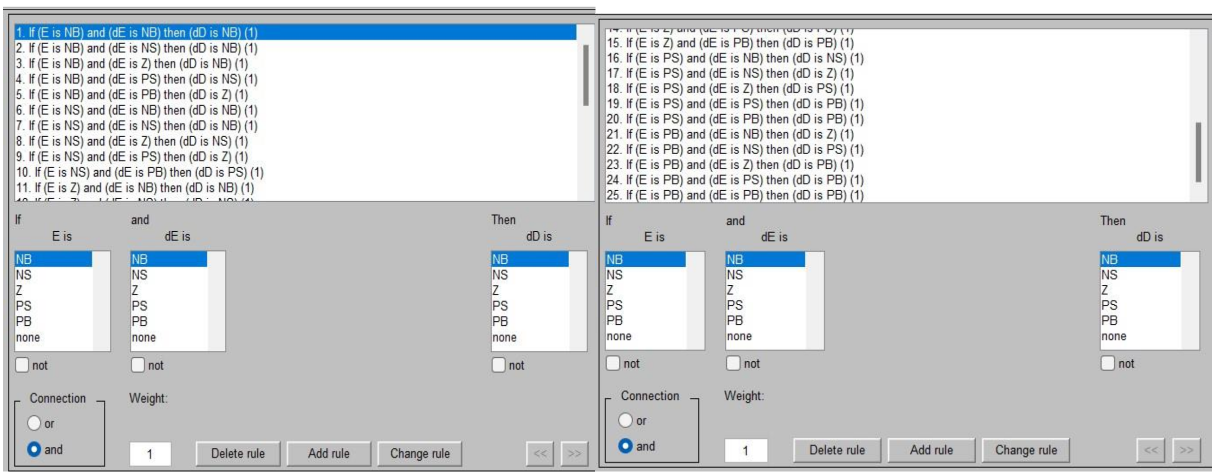

Fig.4.9 Rules developed in a Fuzzy Logic Control Block

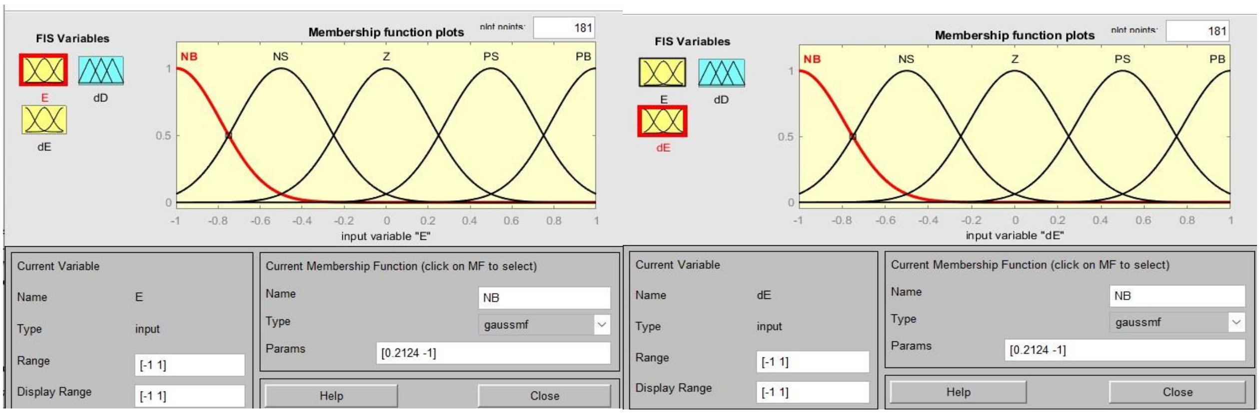

Fig.4.10 Membership function plots for two input variables

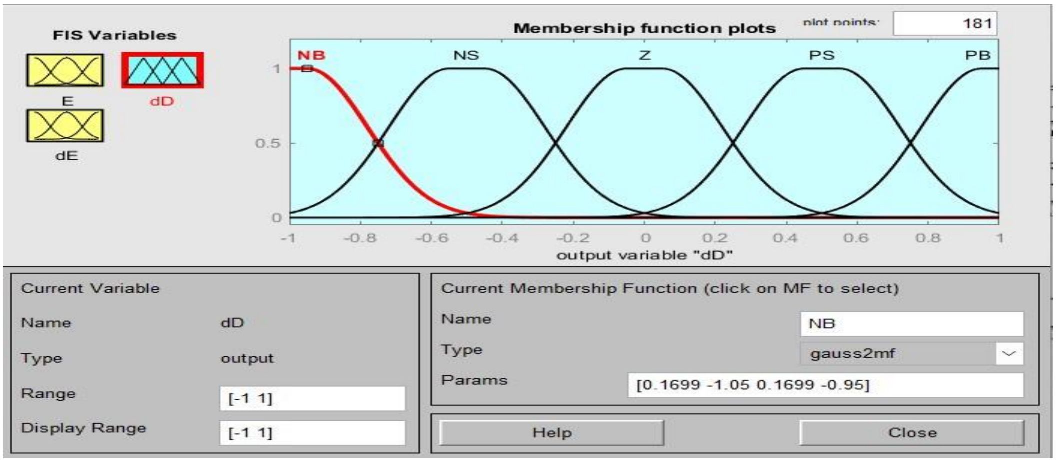

Fig.4.11 Membership function plots for output variables

4.2.3.4 Simulink Model

The Simulink model for MPPT technique using Fuzzy Logic Control with P&O is shown in Fig.4.12.

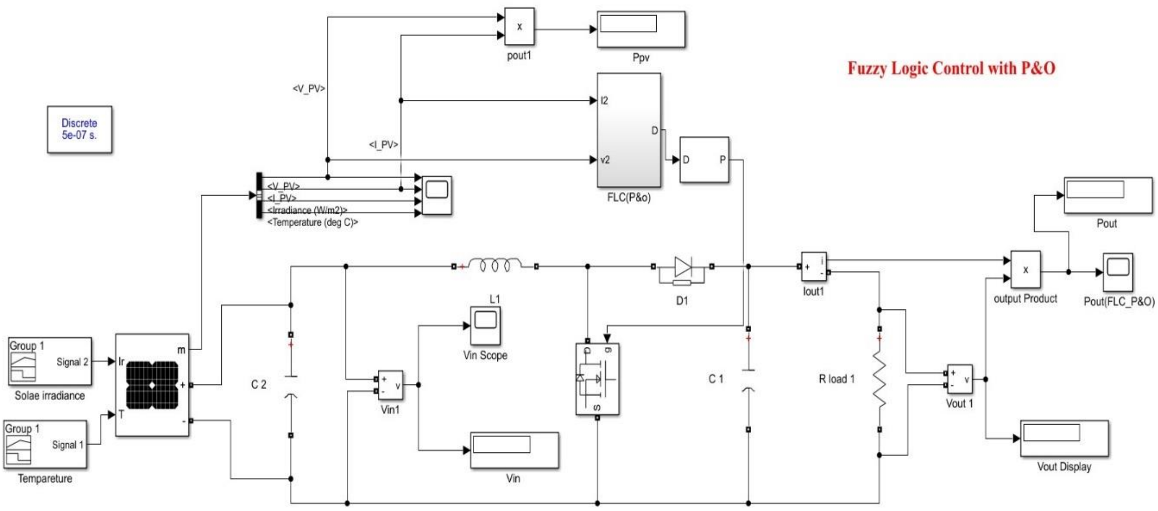

Fig.4.12 Simulink Model of Fuzzy Logic Control with P&O method

The Simulink model for MPPT technique using Fuzzy Logic Control with Inc Cond is shown in Fig.4.13.

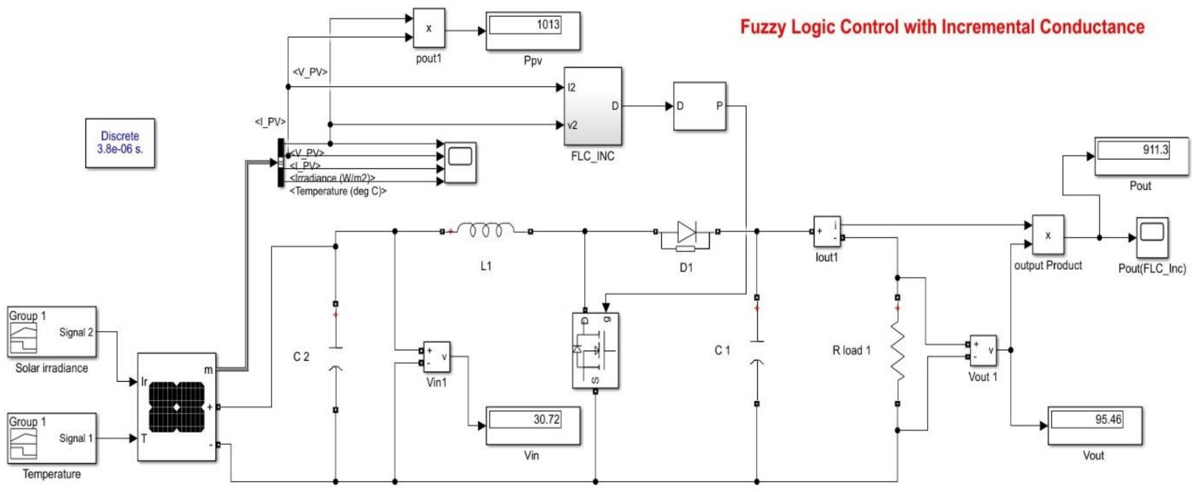

Fig.4.13 Simulink Model of Fuzzy Logic Control with Incremental conductance method

4.2.3.5 Results

Fig.4.14 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for FLC with P&O. The maximum power obtained for FLC with P&O is 910.6W, the settling time is 0.188sec, rise time is 59.607ms, steady state error is1.132% and efficiency is 90.516%

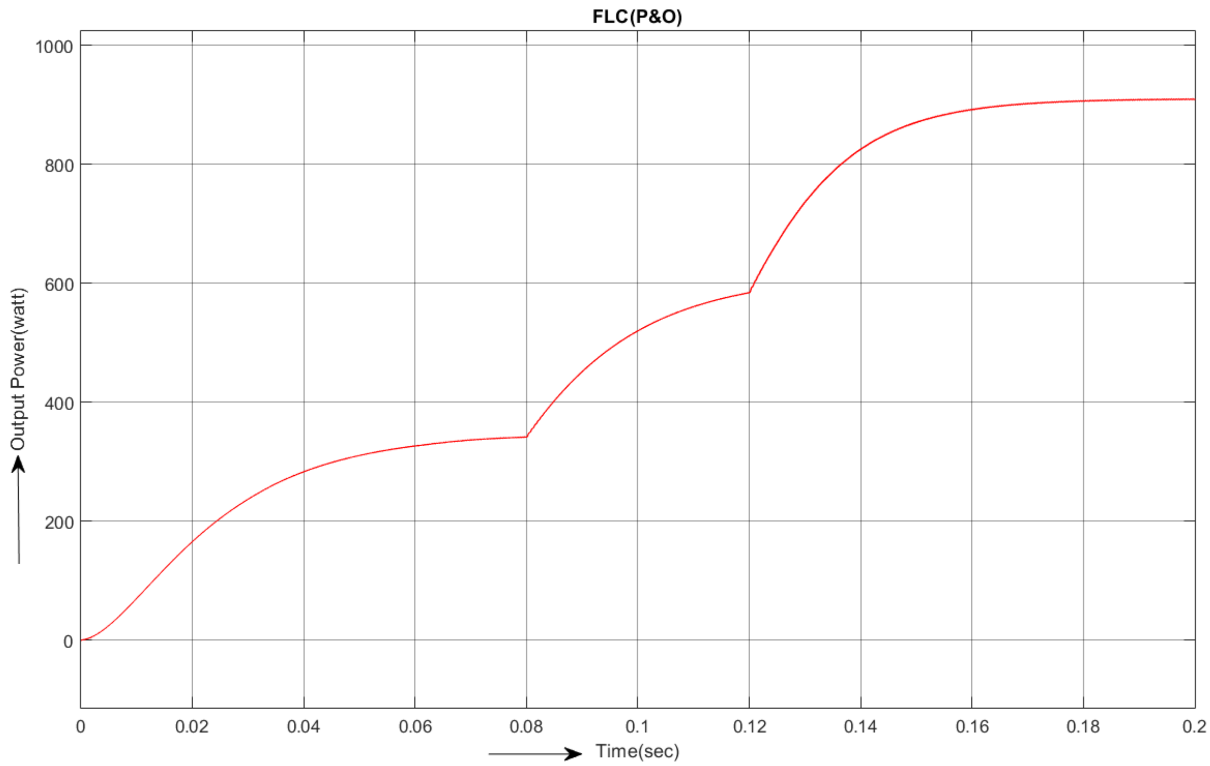

Fig.4.14 Output Power Vs Time for Fuzzy Logic Control with P&O method

Fig.4.15 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for FLC with Inc Cond. The maximum power obtained for FLC with Inc Cond is 911.3W, the settling time is 0.17sec, rise time is 54.428ms, steady state error is 0.646% and efficiency is 89.96%.

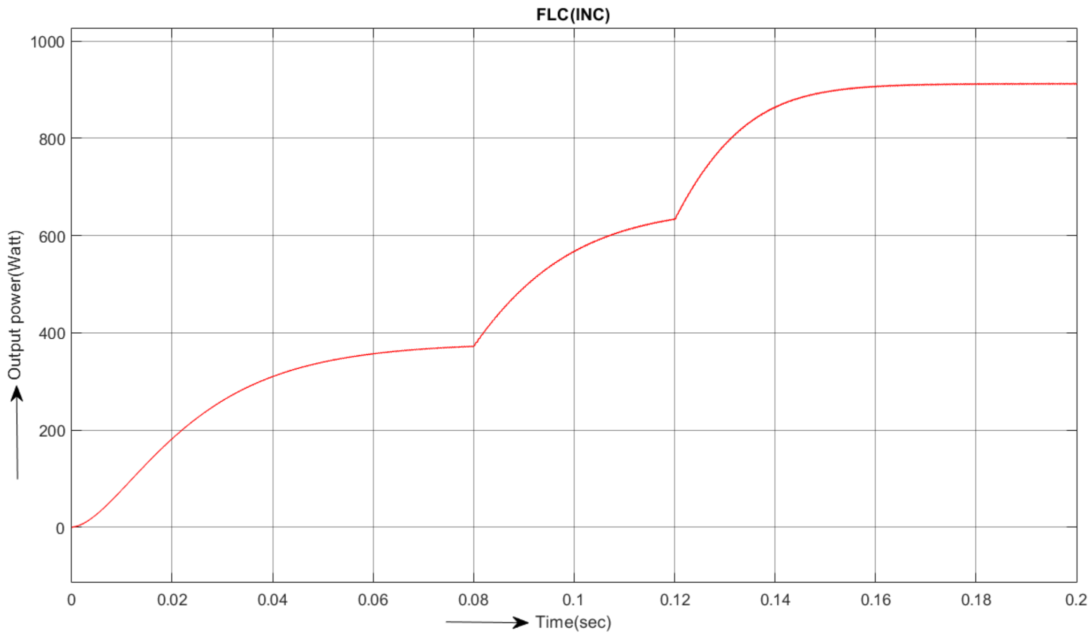

Fig.4.15 Output Power Vs Time for Fuzzy Logic Control with Incremental conductance method

4.2.3.6 Advantages and Disadvantages

Advantages:

- FLC can perform in any weather condition, including changes in temperature or irradiance level.
- FLC can handle nonlinearity conditions, which can help you obtain the maximum power from PV modules.
- Rules can be easily modified to improve performance over time.
- FLC can handle nonlinearity conditions, which can help you obtain the maximum power from PV modules.
- FLC can improve the efficiency of the PV system by allowing you to charge batteries during low solar radiation.
- FLC is fast, flexible, and robust, which is important in situations with spontaneous environmental changes.

Dis-advantages:

- Sometimes fuzzy logic implementation becomes difficult because no systematic approach to solving through fuzzy logic is possible.
- Setting up fuzzy logic itself is sometimes very difficult.
- Setting accurate, fuzzy guidelines and enrollment capacities can be a tough task.
- Fuzzy logic systems can be slow to generate outputs.
- Fuzzy control systems depend on human knowledge and expertise.

4.2.5 Particle Swarm Optimization based MPPT.

4.2.5.1 Introduction

Particle swarm optimization (PSO) is a computer approach for solving problems by iteratively enhancing a potential solution. This is a population-based algorithm. Particle Swarm Optimization is a strong metaheuristic optimization approach based on the social behavior of birds flocking or fish schooling [12]. In PSO, a system is given a set of random solutions. The algorithm then assesses the objective function for each particle. The program then determines the updated velocity of each particle. The particles move, and the program reevaluates. Particles in PSO may adjust their locations and velocities as the environment changes. In PSO, the swarm moves freely and continually searches for the best solution in the available solution space.

4.2.5.2 Theory

PSO is an iterative process in which the particle strives for the highest fitness value in each iteration. After multiple rounds, the velocity decreases or equals zero, indicating the maximum power point. In one way, the variable step size of PSO reduces steady-state oscillations, which can have an influence on PV system efficiency when partially shaded. Another approach for optimizing the power output of solar panels is to employ a DC-DC boost converter [13].

PSO operates by initializing a population of particles. These particles iteratively travel around the search space, changing their locations based on their individual best-known position (local best) as well as the swarm's global best-known position. The fitness function examines the solar panel's power production depending on the duty cycle setting.

During each iteration, the PSO algorithm directs the particles to the ideal duty cycle, which maximizes the solar panel's power production under changing external circumstances such as sun irradiance and temperature. By using the swarm's collective intelligence and the exploration-exploitation balance inherent in PSO, the algorithm efficiently converges to the MPPT point, even in scenarios with partial shadowing or fast changes in solar conditions [14].

4.2.5.3 Algorithm

Fig.4.16 shows the algorithm for Particle Swarm Optimization technique.

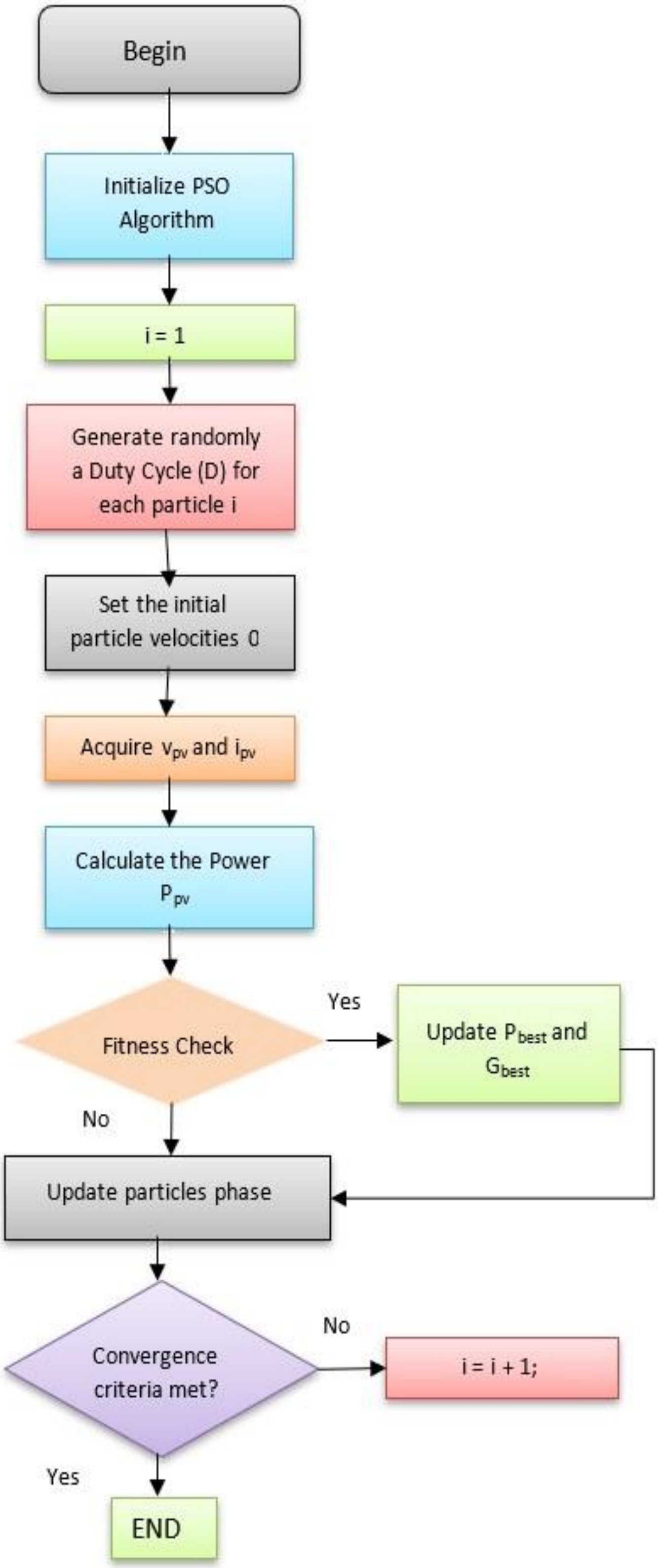

Fig.4.16 PSO Algorithm

4.2.5.4 Simulink Model

The Simulink model for MPPT technique using PSO is shown in Fig.4.17. It consists of PSO code in a MATLAB function block.

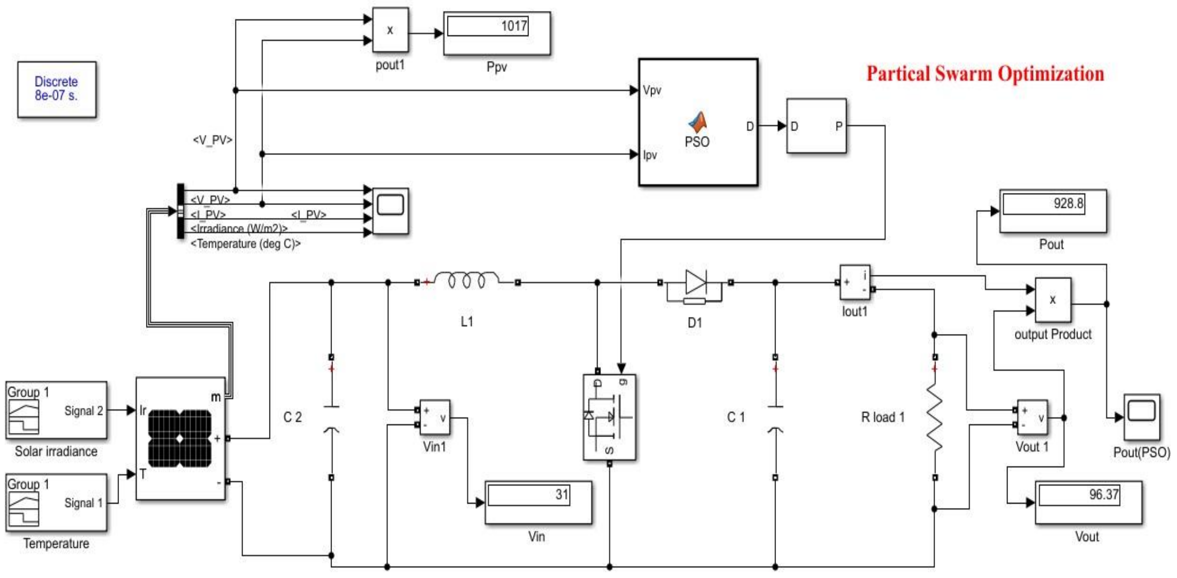

Fig.4.17 Simulink Model with Particle Swarm Optimization Technique

4.2.5.5 Results

Fig.4.18 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for PSO. The maximum power obtained for PSO is 928.8W, the settling time is 0.172sec, rise time is 53.157ms, steady state error is 0.254% and efficiency is 91.327%.

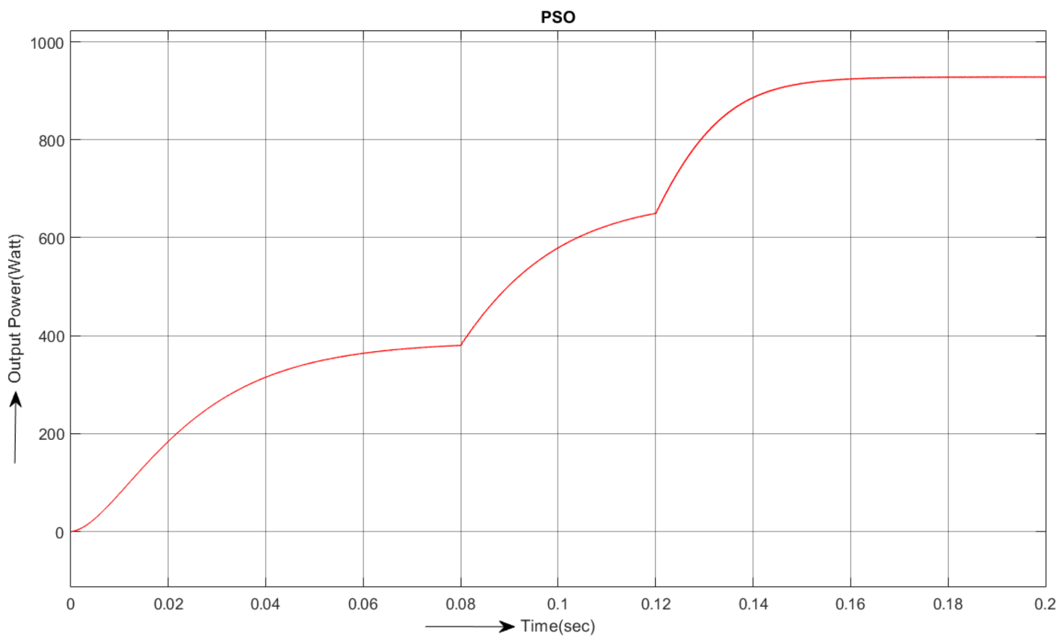

Fig.4.18 Output Power Vs Time for Particle Swarm Optimization Technique

4.2.5.6 Advantages and Disadvantages

Advantages:

- PSO has very high tracking efficiency.
- PSO is easy to implement.
- PSO has a simple structure.
- PSO-MPPT gives a better response than IC-MPPT.
- PSO adjusts quickly to changes in solar irradiance and temperature.
- PSO is suitable for non-linear characteristics of solar panels.
- PSO is capable of real-time tracking and optimization.
- PSO minimizes energy losses and improves overall system efficiency.

Dis-advantages:

- PSO may converge slowly, especially in complex and high-dimensional optimization spaces, leading to longer computational times.
- PSO can get stuck in local optima, limiting its ability to find the global maximum power point under certain conditions.
- PSO performance can be sensitive to its parameters (such as inertia weight, acceleration coefficients), requiring careful tuning for different applications.
- In some cases, PSO may struggle to explore diverse regions of the search space effectively, potentially missing out on alternative optimal solutions.
- PSO's robustness can be impacted by noise, uncertainties, or disturbances in the system, affecting its ability to maintain optimal MPPT performance in real-world scenarios.

4.2.6 Adaptive Neuro-Fuzzy Inference System based MPPT.

4.2.6.1 Introduction

The Adaptive Neuro-Fuzzy Inference System (ANFIS) is a sophisticated artificial intelligence approach that combines neural network learning with fuzzy logic interpretability. In essence, ANFIS combines fuzzy logic's language principles with neural network adaptive learning to create a hybrid intelligent system [15]. It has a structure like a fuzzy inference system, in which input variables are mapped using fuzzy membership functions and then processed by adaptive nodes that learn from training data using techniques such as backpropagation or least squares.

One of ANFIS's fundamental characteristics is its capacity to manage nonlinearities and uncertainties in data, which makes it suited for modeling and control jobs in a variety of fields including engineering, finance, and healthcare. Overall, ANFIS functions as a bridge between neural network-based learning and fuzzy logic-based reasoning, providing a versatile and successful strategy for solving complicated issues that incorporate both numerical data and human-like reasoning [17].

4.2.6.2 Theory

ANFIS provides a framework that blends neural network learning capabilities with fuzzy logic's language representation and reasoning, making it ideal for dynamic and nonlinear systems such as solar panels. In the context of MPPT, ANFIS adjusts its fuzzy logic rules and membership functions depending on training data, which may include solar irradiance levels, temperature, and voltage/current characteristics. This adaptation allows ANFIS to properly estimate the intricate interactions between these factors and the best operating point for maximum power production from the solar panels [18].

During operation, the ANFIS-based MPPT system uses its learned model to anticipate optimal operating parameters in real time. ANFIS-based MPPT algorithms can efficiently monitor the maximum power point in a variety of scenarios, including partial shade and fast variations in solar intensity, by continually analyzing and modifying depending on current environmental conditions and system parameters. The combination of ANFIS adaptive learning capabilities and fuzzy logic reasoning with MPPT's goal-oriented optimization job results in increased efficiency, performance, and robustness of solar energy harvesting devices [23]. This incorporation of sophisticated AI approaches helps to drive the continual growth of renewable energy technology toward higher sustainability and efficiency in energy conversion.

4.2.6.3 Algorithm and Training block
Fig.4.19 shows the algorithm for Adaptive Neuro Fuzzy Interface System.

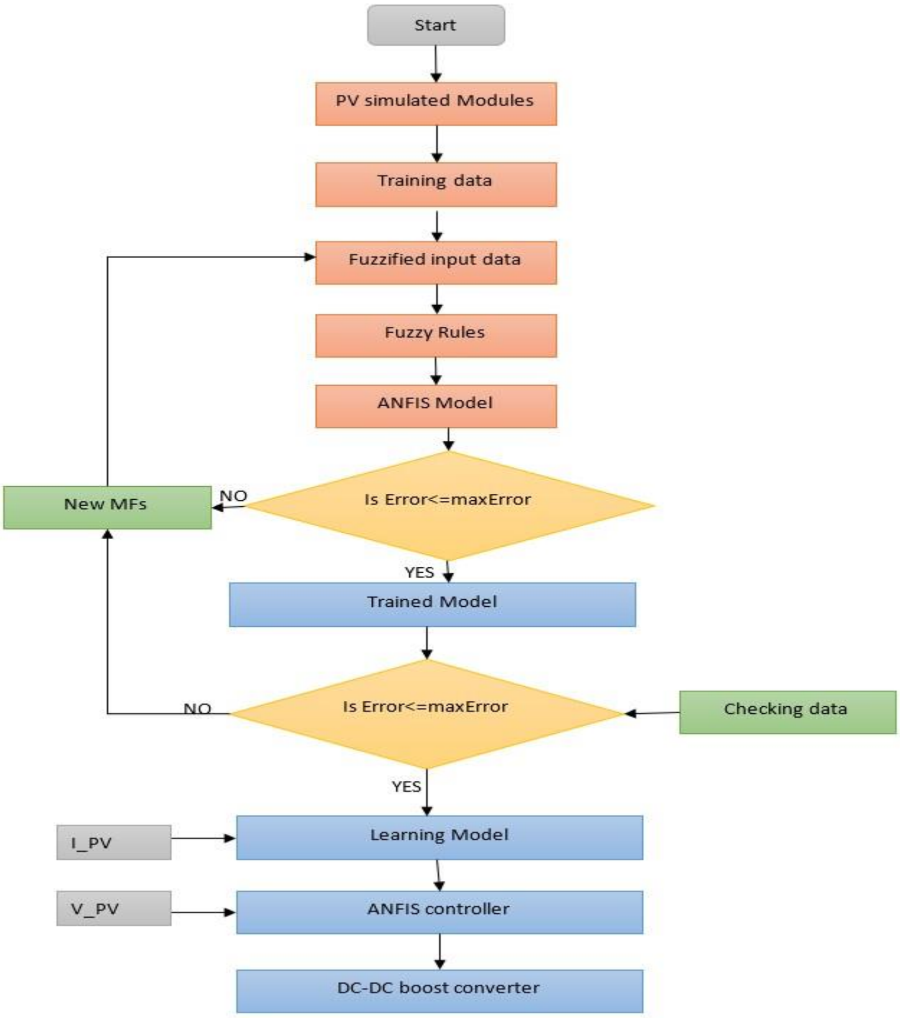

Fig.4.19 ANFIS Algorithm

Training blocks:
Fig.4.20 shows how the data is being trained and tested. And it shows the structure of the block, which was implemented for Simulink model.

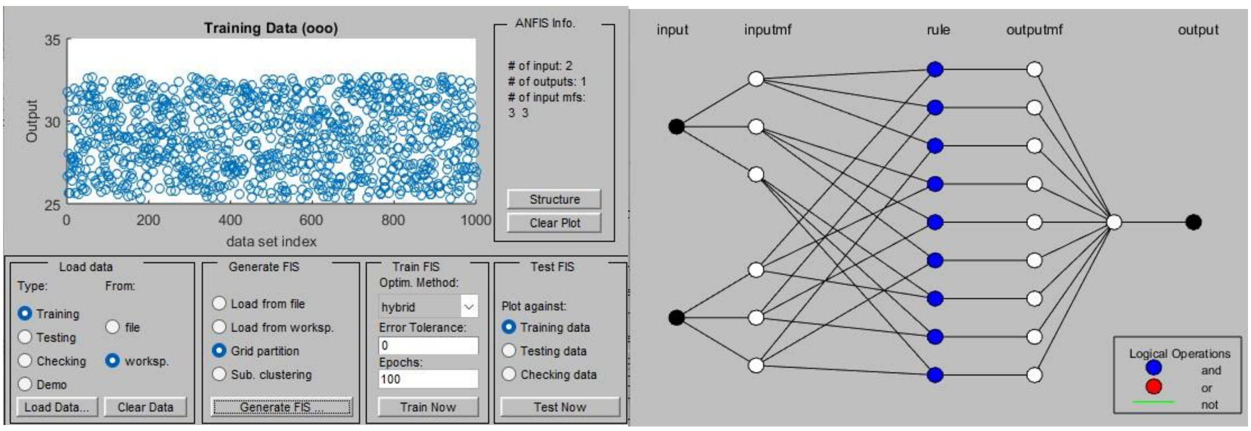

Fig.4.20 Data training and Structure block

4.2.6.4 Simulink Model

The Simulink model for MPPT technique using ANFIS is shown in Fig.4.21. It consists of ANFIS code as well as Fis file in it.

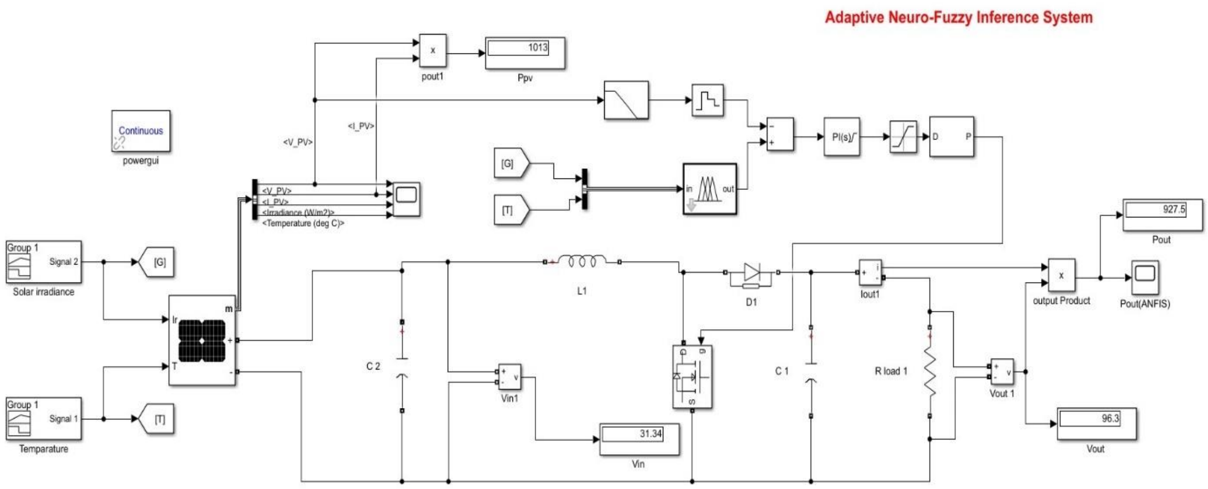

Fig.4.21 Simulink Model with ANFIS Technique

4.2.6.5 Results

Fig.4.22 shows the Simulink model graph drawn between Output power in watts versus Time in seconds for ANFIS. The maximum power obtained for ANFIS is 927.4W, the settling time is 0.170sec, rise time is 52.006ms, steady state error is 0.646% and efficiency is 91.549%.

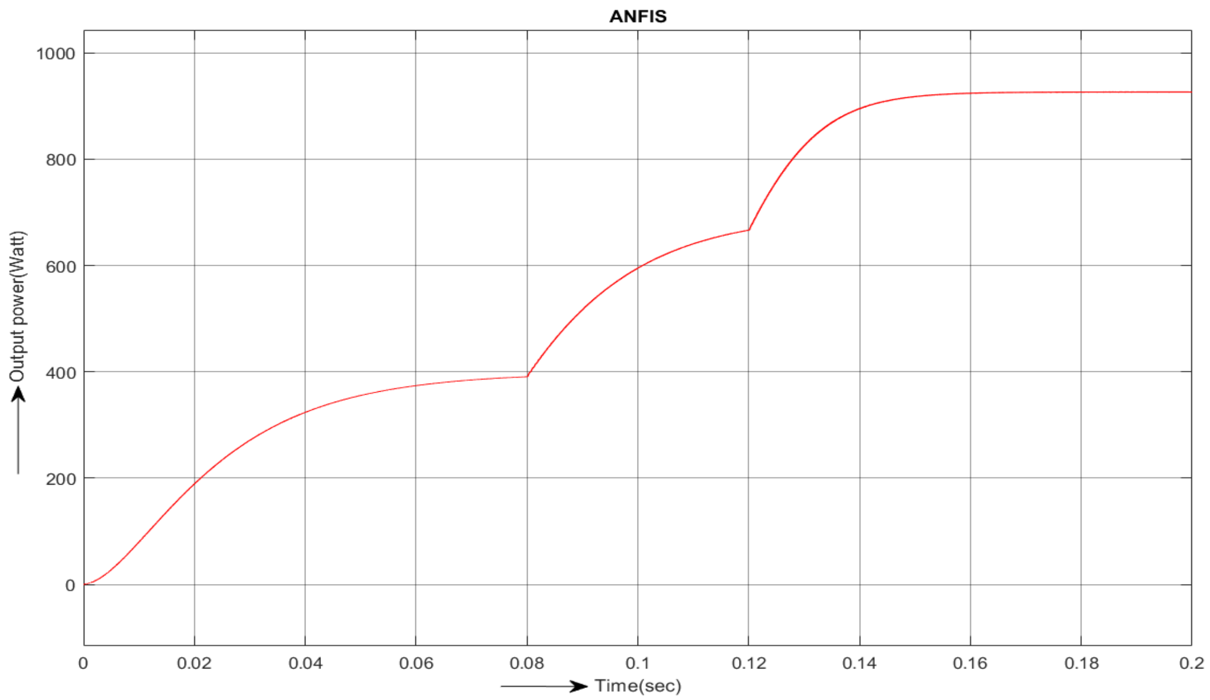

Fig.4.22 Output Power Vs Time for ANFIS Technique

4.2.6.6 Advantages and Disadvantages

Advantages:

- ANFIS-based MPPT dynamically adjusts to changing solar conditions, maximizing power output in real-time.
- ANFIS captures complex nonlinear relationships in solar panel behavior for accurate MPPT.
- ANFIS handles uncertainties like partial shading, ensuring consistent energy generation.
- ANFIS's hybrid approach combines neural network learning with fuzzy logic reasoning, leading to smart and efficient MPPT.
- By optimizing the operating point continuously, ANFIS-based MPPT boosts overall system efficiency and energy yield.

Dis-advantages:

- ANFIS-based MPPT systems can be complex to design and implement, requiring expertise in both fuzzy logic and neural networks.
- Training ANFIS models for MPPT may require significant computational resources and time due to the need for extensive data and parameter tuning.
- ANFIS models may struggle to generalize well to unseen or extreme environmental conditions, affecting their adaptability in real-world scenarios.
- ANFIS-based MPPT systems may require ongoing maintenance and updates to ensure optimal performance and accuracy, adding to operational costs.
- Integrating ANFIS with existing MPPT hardware or software infrastructure can pose integration challenges and compatibility issues, requiring careful planning and testing.

Chapter-5
COMPARISON AND DISCUSSION OF VARIOUS MPPT TECHNIQUES

COMPARISON:

The below Table.5.1 show the Comparison between various types of MPPT techniques for different parameters. In such parameters, it includes the maximum power, settling time, rise time, steady state error, and efficiency for various techniques.

Table.5.1 Comparison of Maximum power, settling time, rise time, steady state error, and efficiency for various techniques.

Parameter / Method	Ppv (w)	Pout (W)	Settling Time (sec)	Rise Time (ms)	Steady State Error (%)	Efficiency (%)
PI	1008	894.3	0.198	60.855	1.136	88.720
P&O	1006	906.6	0.196	60.754	1.332	90.119
Inc Cond	1006	909.8	0.189	60.681	1.332	90.437
FLC (P&O)	1006	910.6	0.188	59.607	1.332	90.516
FLC (Inc Cond)	1013	911.3	0.170	54.428	0.646	89.96
ANFIS	1013	927.4	0.170	52.006	0.646	91.549
PSO	1017	928.8	0.172	53.157	0.254	91.327

Fig.4.23 shows the Output Power Vs Time for PI, P&O, Inc, Fuzzy(P&O), Fuzzy (Inc), ANFIS and PSO whereas color curve line indicates the output power range of different methods.

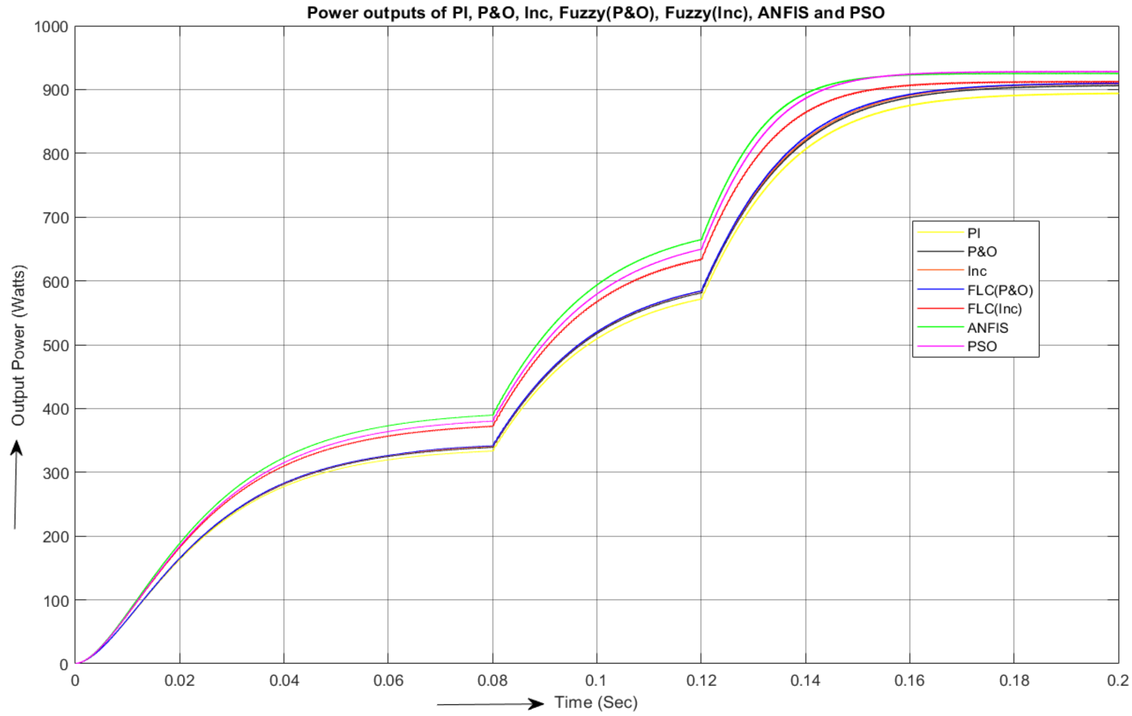

Fig.4.23 Output Power Vs Time for PI, P&O, Inc, Fuzzy(P&O), Fuzzy (Inc), ANFIS and PSO.

DISCUSSIONS:

Based on the comparative study on Solar PV System MPPT Techniques for Boost Converter, the conclusion highlights the performance metrics including Maximum Power Extraction, Settling Time, Rise Time, Steady State Error, and Efficiency for various MPPT methods compared to the closed-loop PI controller.

- ***Maximum Power Extraction:***
  - Among the MPPT methods investigated, Particle Swarm Optimization (PSO) and Adaptive Neuro Fuzzy Interface System (ANFIS) demonstrated the highest maximum power extraction, with PSO achieving 928.8W and ANFIS achieving 927.4W.
  - Closed-loop PI controller achieved a maximum power output of 894.3W, lower compared to advanced MPPT methods.

- ***Settling Time:***
  - Fuzzy Logic Control with Incremental Conductance and Adaptive Neuro Fuzzy Interface System exhibited the fastest settling times at 0.170sec, closely followed by Particle Swarm Optimization at 0.172sec.
  - Closed-loop PI controller had a settling time of 0.198sec, comparatively slower than some of the MPPT methods.

- ***Rise Time:***
  - Adaptive Neuro Fuzzy Interface System (ANFIS) demonstrated the fastest rise time at 52.006ms, followed by Fuzzy Logic Control with Incremental Conductance at 54.428ms.
  - Closed-loop PI controller had a rise time of 60.855ms, slower compared to most of the MPPT methods.

- ***Steady State Error (%):***
  - Particle Swarm Optimization exhibited the lowest steady-state error at 0.254%, followed by Fuzzy Logic Control with Incremental Conductance at 0.646%.
  - Closed-loop PI controller had a steady-state error of 1.136%, higher than most of the advanced MPPT methods.

- ***Efficiency (%):***
  - Adaptive Neuro Fuzzy Interface System (ANFIS) demonstrated the highest efficiency at 91.549%, followed closely by Particle Swarm Optimization at 91.327%.
  - Closed-loop PI controller had an efficiency of 88.720%, lower compared to several MPPT methods.

Chapter-6

CONCLUSIONS AND FUTURE ENHANCEMENT

CONCLUSIONS

In this project, the comparative study of various Maximum Power Point Tracking techniques with boost converter in solar PV system has provided valuable insights into the performance of different methods. In conclusion, the analysis focused on key parameters such as maximum power extraction, settling time, rise time, steady state error and efficiency, while comparing closed-loop PI controllers with different MPPT algorithms including Perturb and Observe (P&O), Incremental Conductance (Inc Cond), Fuzzy Logic Control (FLC) with P&O and Incremental conductance, Particle Swarm Optimization (PSO), Adaptive Neuro Fuzzy Interface System (ANFIS) approaches.

After a comprehensive comparative study, it's evident that intelligent techniques like Particle Swarm Optimization (PSO), Adaptive Neuro Fuzzy Interface System (ANFIS), and Fuzzy Logic Control with Incremental Conductance outperform the traditional closed-loop PI controller across all performance metrics. These intelligent methods consistently demonstrate superior maximum power extraction, faster settling and rise times, lower steady-state errors, and higher efficiency levels. Among them, ANFIS stands out as the top performer, followed closely by PSO and Fuzzy Logic Control with Incremental Conductance. This highlights the effectiveness of adaptive and intelligent control strategies in optimizing solar PV system performance.

FUTURE ENHANCEMENT

Future research could further explore hybrid approaches and real-world implementation to validate these findings and facilitate broader adoption of efficient MPPT technologies in renewable energy systems. It also involves investigating hybrid MPPT techniques that combine the strengths of multiple methods. For instance, integrating machine learning and deep learning algorithms with traditional controllers like PI or FLC could leverage the adaptive learning capabilities of ML and DL to enhance the robustness and accuracy of MPPT systems.

PUBLICATION DETAILS

[1] M. S. Sujatha, K. Madhusudhan, K. G. Yamunappa, S. Prameela, P. Sai Chandana, S. Mahesh Kalyan, ***"A Review Across Diversified Applications of Solar Energy"*** has been submitted at the *"2024 IEEE International Conference on Recent Innovation in Smart and Sustainable Technology (ICRISST 2024)",* held at Presidency University, Bengaluru, Karnataka, India, on March 15-16, 2024.

[2] M. S. Sujatha, K. Madhusudhan, K. G. Yamunappa, S. Prameela, P. Sai Chandana, S. Mahesh Kalyan, **"*Implementation of Perturb & Observe MPPT Strategy with Buck and Boost Converters in Photovoltaic System*"** has been submitted at the *"5th International Conference on Energy, Control, Computing, and Electronic Systems (ICECCES 2024)" held at Mohan Babu University (Erst While Sree Vidyanikethan Engineering College), Tirupati, Andhra Pradesh, India,* on March 22-24, 2024. ISBN Number : 978-93-340-1488-4

FINANCE AND PROJECT MANAGEMENT

The software used for this project is MATLAB Software with 2023b versions with additional toolboxes. The total cost for this software is shown in Table 6.1.

Table 6.1 Software configuration and price

Module type	**Price (Rs.)**
MATLAB /SIMULINK Software with 2023b version (Purchased by the college including toolboxes)	11,09,558/-
Total	11,09,558/-

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PATTEM SAI CHANDANA	20121A02B6

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POs Attained:

Project title	**Program Outcomes**												**Program Specific Outcomes**			
	PO 1	**PO 2**	**PO 3**	**PO 4**	**PO 5**	**PO 6**	**PO 7**	**PO 8**	**PO 9**	**PO10**	**PO11**	**PO12**	**PSO 1**	**PSO 2**	**PSO 3**	**PSO 4**
Comparative Study on Solar PV System with various MPPT Techniques for Boost Converter	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Signature of the Guide

SREE VIDYANIKETHAN ENGINEERING COLLEGE

(AUTONOMOUS)

SreeSainath Nagar, A.Rangampet - 517 102

Department of Electrical and Electronics Engineering

PROJECT TITLE: Exploring Performance Enhancement of MPPT Techniques for Boost Converter in Solar PV System.

ABSTRACT:

The efficiency of photovoltaic (PV) systems will continue to heavily rely on meteorological conditions and load features, making maximum power point tracking (MPPT) methods even more essential for optimizing power delivery. Implementing MPPT will still require a DC-DC converter, and choosing the right MPPT technique will remain crucial for overall system efficiency. This project goes with comprehensive study on the analysis and performance of a step-up DC-DC converter topology paired with closed loop PI controller and with different MPPT techniques: Perturb and Observe, Incremental Conductance, Fuzzy Logic Controller with P&O and Incremental conductance method, Particle Swarm Optimization, and Adaptive Neuro Fuzzy Inference System.

Unlike existing literature, this project includes comparing and analyzing the performance of each MPPT method in terms of maximum power, settling time, rise time, steady state error and efficiency for power converter. The main contribution of this project will lie not only in identifying the optimal combination of converter and MPPT strategy for typical PV systems but also in presenting a methodology to support solar PV system design. Simulation results are to be achieved with Simulink/MATLAB environment for different methods.

The novelty of this project will lie in its focus on comparing the key characteristics and simulated results of all mentioned MPPT techniques, offering insights into their relative performances.

PROJECT BATCH:

KURUVA GUDISE YAMUNAPPA	20121A0283
SAMINENI MAHESH KALYAN	20121A02D9
KURUBA MADHUSUDHAN	20121A0282
SAKE PRAMEELA	20121A02D8
PATTEM SAI CHANDANA	20121A02B6

GUIDE: Dr. M.S. Sujatha, M. Tech, Ph.D., Professor & Head, Dept. of EEE.

CO - POs Mapping table:

Course Outcomes	Program Outcomes											
	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1. knowledge on the project topic.	√											
CO2. analytical ability exercised in the project work.		√										
CO3. design skills applied on the project topic.			√									
CO4. ability to investigate and solve complex engineering problems faced during the project work.				√								
CO5. ability to apply tools and techniques to complex engineering activities with an understanding of limitations in the project work.					√							
CO6. ability to provide solutions as per societal needs with consideration to health, safety, legal and cultural issues considered in the project work.						√						
CO7.understanding of the impact of the professional engineering solutions in environmental context and need for sustainable development. experienced during the project work.							√					
CO8. ability to apply ethics and norms of the engineering practice as applied in the project work.								√				

CO9. ability to function effectively as an individual as experienced during the project works.									√			
CO10. ability to present views cogently and precisely on the project work.										√		
CO11. project management skills, as applied in the project work.											√	
CO12. ability to engage in life-long learning as experience during the project work												√

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