STUDY OF MPPTs UNDER ENVIRONMENTAL FLUCTUATIONS

Project Submitted for the partial fulfilment of the requirement for the award of the degree of

Bachelor of Technology

in

ELECTRICAL & ELECTRONICS ENGINEERING

Dr. A.P.J. Abdul Kalam Technical University, Lucknow

Submitted by

Akash Sharma (2100910210008)
Mohd Asif (2100910210030)
Aditya Kaushik Mishra (2000910210005)

Under the Guidance of

Dr. K.S Sujatha
Professor & Head
Department of Electrical and Electronics Engineering

2024-25

JSS MAHAVIDYAPEETHA
JSS ACADEMY OF TECHNICAL EDUCATION, NOIDA
DEPARTMENT OF ELECTRICAL ENGINEERING
C-20/1, SECTOR – 62, NOIDA- 201301

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material that, to a substantial extent, has been accepted for the award of any other degree or diploma of the university or other institute of higher learning except where due acknowledgement has been made in the text.

Signature of Student-1:
Akash Sharma
Roll No: 2100910210008
Date:

Signature of Student-2:
Mohd Asif
Roll No: 2100910210030
Date:

Signature of Student-3:
Aditya Kaushik Mishra
Roll No: 2000910210005
Date:

ACKNOWLEDGEMENT

We would like to express our gratitude towards all the people who have contributed their precious time and efforts to help us in completing this project, without whom it would not have been impossible for us to understand and analyze the project.

We would like to thank **Dr. K.S. Sujata**, Professor and Head, Department of Electrical Engineering, our Project Supervisor, for his guidance, support, motivation and encouragement throughout the period this work was carried out. His readiness for consultation at all times, his educative comments, his concern and assistance have been invaluable.

We are also grateful to **Dr. Sanjiba Kumar Bisoyi**, Professor, Department of Electrical Engineering, for providing the necessary facilities in the department.

Akash Sharma (2100910210008)
Sign:

Mohd Asif (2100910210030)
Sign:

Aditya Kaushik Mishra (2000910210005)
Sign:

CERTIFICATE

This is to certify that the Project entitled **"Study of MPPT's under Environmental Fluctuations"** submitted by **Akash Sharma, Mohd Asif** & **Aditya Kaushik Mishra** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Electrical and Electronics Engineering at JSSATE NOIDA, is an authentic work carried out by them under my supervision and guidance.

Name & Signature of Supervisor **Name & Signature of HOD**

Name & Signature of External Examiner

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 : INTRODUCTION

1.1.The need for Renewable Energy

Renewable energy is the energy which comes from natural resources such as sunlight ,wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible ,unlike dwindling conventional fossil fuels [1]. The global energy crunch has provided a renewed impetus to the growth and development of Clean and Renewable Energy sources. Clean Development Mechanisms (CDMs) are being adopted by organizations all across the globe.

Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts.

1.2.Different sources of Renewable Energy

1.2.1 Wind power

Wind turbines can be used to harness the energy available in airflows. Current day turbines range from around 600 kW to 5 MW of rated power. Since the power output is a function of the cube of the wind speed, it increases rapidly with an increase in available wind velocity. Recent advancements have led to aerofoil wind turbines, which are more efficient due to a better aerodynamic structure.

1.2.2 Solar power

The tapping of solar energy owes its origins to the British astronomer John Herschel who famously used a solar thermal collector box to cook food during an expedition to Africa. Solar energy can be utilized in two major ways. Firstly, the captured heat can be used as solar thermal energy, with applications in space heating. Another alternative is the conversion of incident solar radiation to electrical energy , which is the most usable form of energy . This can be achieved with the help of solar photovoltaic cells [6] or with concentrating solar power plants.

1.2.3 Small hydropower

Hydropower installations up to 10 MW are considered as small hydropower and counted as renewable energy sources. These involve converting the potential energy of water stored in dams into usable electrical energy through the use of water turbines. Run-of-the-river hydroelectricity aims to utilize the kinetic energy of water without the need of building reservoirs or dams.

1.2.4 Biomass

Plants capture the energy of the sun through the process of photosynthesis. On combustion, these plants release the trapped energy. This way, biomass works as a natural battery to store the sun's energy and yield it on requirement.

1.2.5 Geothermal

Geothermal energy is the thermal energy which is generated and stored within the layers of the Earth. The gradient thus developed gives rise to a continuous conduction of heat from the core to the surface of the earth. This gradient can be utilized to heat water to produce superheated steam and use it to run steam turbines to generate electricity. The main disadvantage of geothermal energy is that it is usually limited to regions near tectonic plate boundaries, though recent advancements have led to the propagation of this technology.

1.3.Renewable Energy Trends Across the Globe: 2025

Recent years have seen a dramatic acceleration in the adoption of renewable energy worldwide. By 2024, clean power—including solar, wind, and other renewables—surpassed 40% of global electricity generation, with solar PV and wind leading this growth. The expansion of renewables is not limited to developed economies; emerging markets such as India, Brazil, and Morocco are also rapidly scaling up their renewable capacity

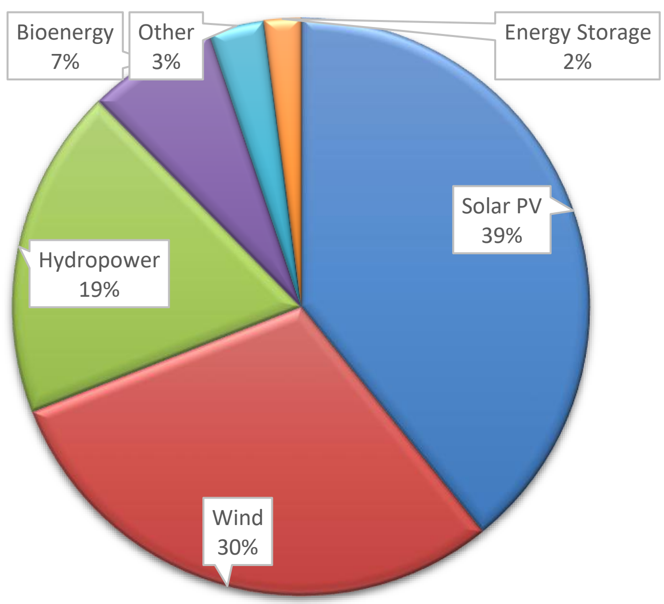

Figure 1.3 : Global energy consumption in the year 2025

1.3.1. Shifts in Technology and Market Dynamics

- **Solar and Wind Dominate**: Solar photovoltaic (PV) and wind energy have become the primary drivers of new renewable capacity, benefiting from significant cost reductions and technological advancements. Between 2013 and 2022, installation costs for solar PV, onshore wind, and offshore wind fell by 69%, 33%, and 45% respectively, making them the most competitive options for new power generation in most regions.

- **Energy Storage and Grid Integration**: The rise of battery energy storage systems (BESS) is transforming the renewable landscape, addressing the intermittency of solar and wind and enabling higher shares of renewables in national grids. Industry experts predict energy storage will be the top growth area over the next five years, with ongoing research into sustainable materials and longer system lifespans.
- **Green Hydrogen**: Green hydrogen is emerging as a key decarbonization tool for heavy industries, with increasing investment and pilot projects worldwide.

1.3.2. Policy Targets and Investment Trends

- By 2025, more than 100 countries have set ambitious renewable energy targets, many aiming for 30–90% of their electricity from renewables by 2030 or 2050. The European Union, for example, is on track to exceed its 2020 target of 20% renewable energy, and India continues to expand its goals, aiming for net zero emissions by 2070 and rapid growth in solar and wind capacity.
- Global investment in renewables reached record highs in 2023, with solar and wind attracting the majority of new capital. Annual investment in clean energy technologies and infrastructure now exceeds $1.9 trillion, but needs to rise further to meet net zero targets

CHAPTER 2 : LITERATURE REVIEW

Photovoltaic (PV) systems have emerged as a pivotal technology in the global transition toward sustainable and renewable energy solutions. As the world shifts away from fossil fuels, the ability to efficiently harness solar energy is more important than ever. However, the practical efficiency of commercial PV panels remains relatively low, with typical energy conversion rates ranging between 30% and 40% under ideal conditions. A significant portion of the incident solar radiation is lost due to reflection, thermalization, and suboptimal material performance. To overcome these limitations and maximize energy output, Maximum Power Point Tracking (MPPT) techniques have become essential components of modern PV systems.

MPPT controllers are designed to dynamically adjust the operating voltage and current of the solar array in response to environmental fluctuations—such as changing irradiance, temperature, and load conditions—to ensure that the system operates at or near its maximum power point (MPP) at all times. This real-time optimization allows the PV system to extract the highest possible power output, improving both system efficiency and economic viability. As global adoption of solar power accelerates, with deployments spanning from residential rooftops to industrial-scale solar farms, the need for reliable, adaptive, and intelligent MPPT algorithms has driven a surge of research and development activity in the field.

Among the numerous MPPT strategies developed over the years, Perturb and Observe (P&O), Incremental Conductance (INC), and Fuzzy Logic-based MPPT (Fuzzy MPPT) have emerged as some of the most widely implemented techniques. Each of these approaches has distinct advantages and trade-offs, and their performance varies significantly depending on environmental conditions, hardware constraints, and system complexity. A comprehensive understanding of these methods is critical for selecting the most appropriate control strategy for specific solar power applications.

- **Perturb and Observe (P&O) Algorithm**

The Perturb and Observe (P&O) method remains the most commonly employed MPPT algorithm in low to mid-scale PV installations. Its widespread popularity is attributed to its algorithmic simplicity, low computational burden, and ease of implementation on microcontrollers or analog circuits. The core principle involves applying a small perturbation to the operating voltage or duty cycle of the converter and observing the resulting change in output power. If the power increases, the perturbation continues in the same direction; otherwise, it is reversed.

Despite its simplicity, P&O has notable shortcomings. One of its key limitations is the steady-state oscillation around the MPP, which leads to minor but continuous energy losses. The oscillation amplitude is closely tied to the perturbation step size—smaller steps reduce oscillations but slow convergence, while larger steps increase tracking speed but also worsen power fluctuation. Furthermore, in rapidly changing irradiance scenarios, such as during cloud transients or partial shading, P&O can become confused, mistaking natural environmental shifts for incorrect power responses. This misinterpretation can lead to deviation from the true MPP, reducing system performance.

- **Incremental Conductance (INC) Method**

To mitigate the limitations of P&O, the Incremental Conductance (INC) technique was developed. INC relies on the mathematical relationship between the derivative of power (P) with respect to voltage (V), i.e., dP/dV. At the maximum power point, this derivative equals zero. By calculating the incremental changes in current (dI) and voltage (dV), the algorithm determines whether the system is operating to the left or right of the MPP and adjusts the operating point accordingly.

INC offers faster and more accurate tracking, especially under dynamic weather conditions where irradiance and temperature fluctuate rapidly. It is less prone to oscillations compared to P&O and has a better capability to distinguish real changes in power from algorithmic perturbations. However, INC is more computationally intensive, requiring additional sensors and more sophisticated processing capabilities. It may also encounter challenges in multi-modal power curves, such as those caused by partial shading, where distinguishing between local and global maxima becomes non-trivial without additional optimization layers or hybrid control strategies.

- **Fuzzy Logic-Based MPPT**

To address the limitations of rule-based and mathematical MPPT approaches, Fuzzy Logic Controllers (FLCs) have gained increasing traction as a robust and intelligent alternative. Fuzzy MPPT leverages a knowledge-based rule set to infer control actions based on inputs like error (difference between current and previous power levels) and change in error. Unlike conventional algorithms, fuzzy logic does not require a precise mathematical model of the PV system, making it inherently flexible and adaptable.

FLCs excel in nonlinear, uncertain, or highly dynamic environments, such as those encountered in off-grid or mobile PV systems. Research has shown that fuzzy logic-based controllers minimize steady-state oscillations, provide rapid convergence to the MPP, and perform exceptionally well under partial shading conditions. Recent developments in Type-2 fuzzy logic and adaptive fuzzy systems have further enhanced their ability to handle noise, parameter drift, and environmental variability.

- **Comparative Insights and Hybrid Approaches**

Comparative studies between P&O, INC, and FLC reveal that while traditional methods like P&O and INC are still valuable due to their simplicity and cost-effectiveness, they fall short under rapidly changing or complex environmental conditions. Fuzzy logic, on the other hand, offers superior tracking efficiency and stability in such conditions but requires more design expertise and computational resources.

To leverage the strengths of both conventional and intelligent approaches, researchers have proposed hybrid MPPT strategies—such as Fuzzy-P&O and Fuzzy-INC—which combine the simplicity of rule-based logic with the adaptability of fuzzy inference. These hybrid systems are capable of switching between strategies depending on operating conditions, thereby enhancing reliability and efficiency.

- **Future Perspectives**

As solar technology continues to evolve, the role of MPPT algorithms becomes even more critical. The integration of machine learning, predictive analytics, and real-time data optimization is poised to redefine MPPT performance benchmarks. Future research is likely to explore deep learning-based adaptive controllers, grid-aware MPPT for smart inverters, and autonomous energy management systems that can self-optimize based on environmental forecasting and usage patterns**.**

In conclusion, while traditional MPPT methods such as P&O and INC remain relevant for many applications, the growing complexity and scale of PV systems demand more intelligent and adaptive solutions. Fuzzy logic-based and hybrid techniques offer promising avenues for achieving high tracking accuracy, faster convergence, and greater resilience to environmental variability. As the solar industry moves toward smarter and more integrated energy systems, the evolution of MPPT strategies will play a central role in maximizing the potential of solar power

CHAPTER 3 : STAND ALONE PHOTOVOLTAIC SYSTEM COMPONENTS

3.1 Photovoltaic Cell

A photovoltaic cell, also known as a photoelectric cell, is a semiconductor device that converts light into electrical energy by means of the photovoltaic effect. When the energy of an incident photon is greater than the band gap of the semiconductor material, an electron is excited and released. The movement of these electrons generates an electric current. It is important to note that a photovoltaic cell is different from a photodiode. In a photodiode, light typically falls on the n-type region of the semiconductor junction and is converted into a current or voltage signal, often under reverse bias. In contrast, a photovoltaic cell is designed to operate under illumination and is generally forward biased to maximize power output.

3.2 PV Module

To meet practical energy requirements, multiple PV cells are connected in series and parallel to form a PV module. PV modules are **commercially** available in various sizes, typically ranging from 60 W to 170 W. For instance, a small-scale desalination plant may require several thousand watts of power, necessitating the use of multiple PV modules.

3.3 PV Modelling

A PV array comprises several photovoltaic cells connected in series and parallel. Series connections increase the overall voltage of the module, while parallel connections increase the available current.

A solar cell can typically be modelled electrically by a current source in parallel with a diode (representing the p-n junction), along with series and parallel (shunt) resistances. The series resistance arises from the resistance to the flow of electrons through the cell material and contacts, while the parallel (shunt) resistance accounts for leakage currents across the junction.

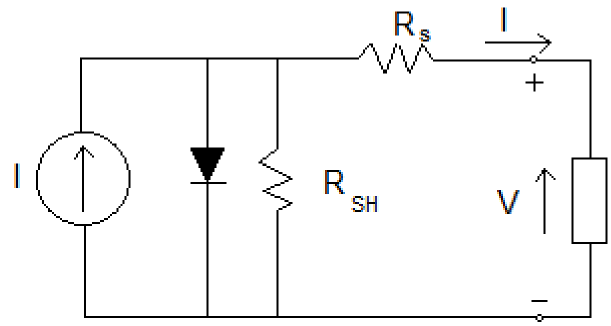

Figure 3.3(a) : Single diode model of a PV cell

In this model we consider a current source (I) along with a diode and series resistance (R_s). The shunt resistance (R_{SH}) in parallel is very high, has a negligible effect and can be neglected.

The output current from the photovoltaic array is

$$I = I_{sc} - I_d \quad (3.1)$$

$$I_d = I_o(e^{qV_d/kT} - 1) \quad (3.2)$$

where I_o is the reverse saturation current of the diode, q is the electron charge, V_d is the voltage across the diode, k is Boltzmann constant ($1.38 * 10^{-19}$ J/K) and T is the junction temperature in Kelvin (K)

From eq.3.1and 3.2

$$I = I_{sc} - I_o(e^{qV_d/kT} - 1)$$

Using suitable approximations,

$$I = I_{sc} - I_o(e^{q((V+IRs)/nkT)} - 1) \tag{3.4}$$

where, I is the PV cell current , V is the PV cell voltage , T is the temperature (Kelvin) and n is the diode ideality factor.

In order to model the solar panel accurately we can use two diode model but in our project our scope of study is limited to the single diode model. Also, the shunt resistance is very high and can be neglected during the course of our study.

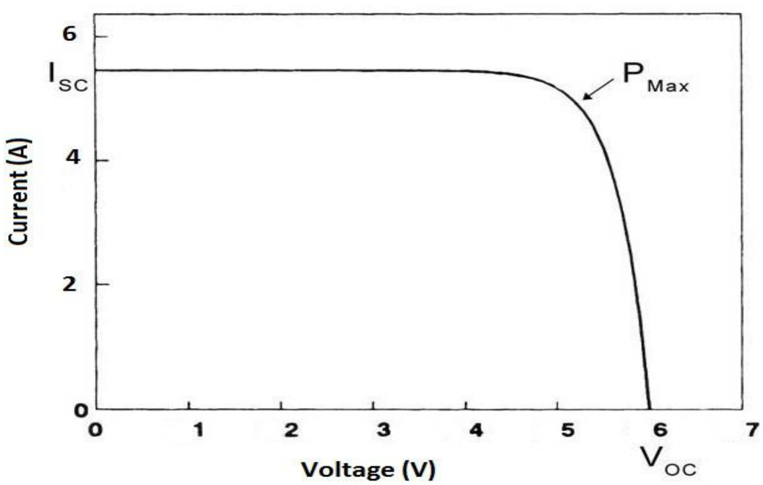

Figure 3.3(b) : I-V characteristic of solar panel

When the voltage and the current characteristics are multiplied we get the P-V characteristics as shown in Figure 3.3. The point indicated as MPP is the point at which the panel power output is maximum.

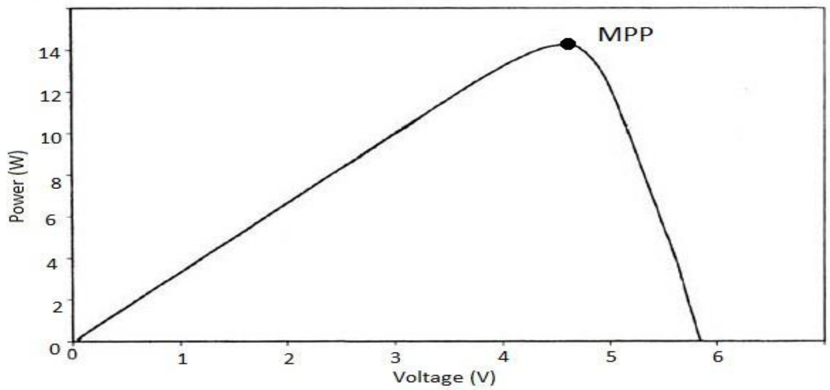

Figure 3.3 (c) : P-V characteristics curve of photovoltaic cell

CHAPTER 4 : BUCK CONVERTER

As stated in the introduction, the maximum power point tracking is basically a load matching problem. In order to change the input resistance of the panel to match the load resistance (by varying the duty cycle), a DC to DC converter is required.

It has been studied that the efficiency of the DC to DC converter is maximum for a buck converter, then for a buck-boost converter and minimum for a boost converter but as we intend to use our system to charge a battery system which requires 48V the output end, so we use a buck converter.

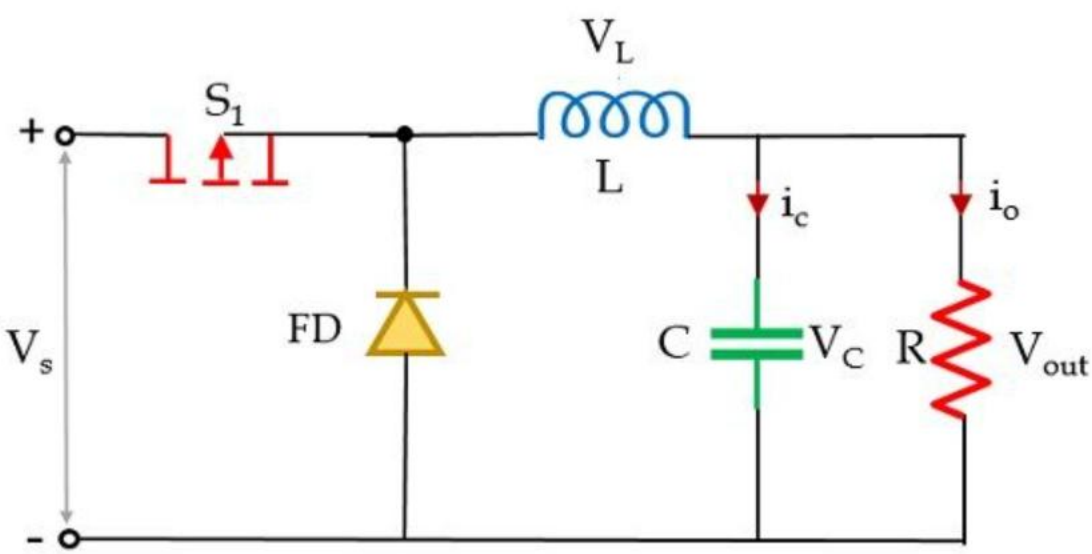

Figure 4.0 : Circuit Diagram of a Buck Converter

4.1 Mode 1 operation- S_1 is in closed condition

When the switch is closed the inductor in the path stores energy in the form of a magnetic field. Also, there is a capacitor in the circuit and current flows through it also, therefore, it will store the charge and the voltage across it will appear across the load.

However, due to Lenz's law, the energy stored within the inductor will oppose the cause which has produced it and so an induced current will get generated and the polarity across the inductor will get reversed.

Here the total time period is a combination of T_{on} and T_{off} time.

$$T = T_{on} + T_{off}$$

Duty Cycle (D)-

$$D = \frac{T_{on}}{T}$$

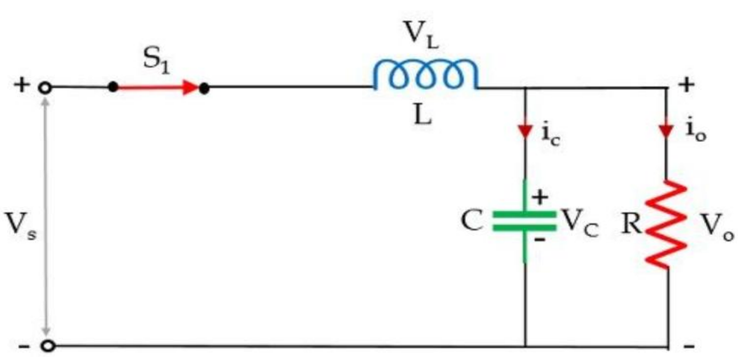

Figure 4.1 : Mode 1 operation of Buck Converter

On applying KVL, in the above-given circuit,

$$V_s = V_L + V_{out}$$

$$V_L = V_s - V_{out}$$

$$V_L = L\frac{di_L}{dt} = V_s - V_{out}$$

$$\frac{di_L}{dt} = \frac{V_s - V_{out}}{L}$$

When S1 is in closed condition then T_{on} = DT , thus Δt = DT.

Therefore, we can write,

$$\frac{\Delta i_L}{\Delta t} = \frac{V_s - V_{out}}{L}$$

$$\frac{\Delta i_L}{DT} = \frac{V_s - V_{out}}{L}$$

Hence,

$$\Delta i_t = (\frac{V_s - V_{out}}{L})DT$$

4.2 Mode 2 operation- S_2 is in closed & S_1 open condition

In this mode, the inductor releases the energy which is stored in the previous mode of operation Due to this, the flow of current takes place in a way as shown below:

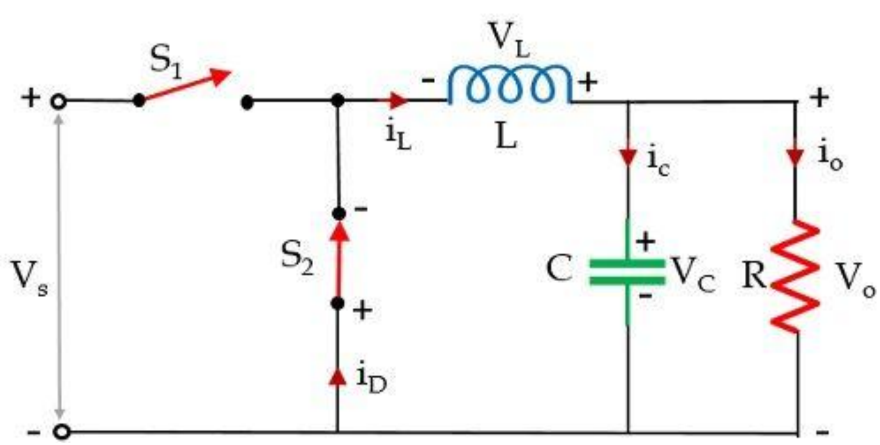

Figure 4.2 : Mode 2 operation of Buck Converter

This flow of current will take place till the time the stored energy within the inductor gets completely collapsed. As once the inductor gets completely discharged, the diode comes in reverse biased condition leading to cause opening of switch S_2, and instantly switch S_1 will get closed and the cycle continues.

Now, let us apply KVL, in the above circuit,

$$0 = V_L + V_{out}$$

$$V_L = L\frac{di_L}{dt} = -V_{out}$$

Since, we know,

$$T = T_{on} + T_{off}$$

$$T = DT + T_{off}$$

$$T_{off} = T - DT$$

$$T_{off} = (1 - D)T$$

$$V_L = L\frac{\Delta i_L}{\Delta t} = -V_{out}$$

$$T_{off} = \Delta t = (1 - D)T$$

$$L\frac{\Delta i_L}{(1-D)T} = -V_{out}$$

Hence,

$$\Delta i_L = -\frac{V_{out}}{L}(1-D)T$$

4.3 WAVEFORM REPRESENTATION OF BUCK CONVERTER

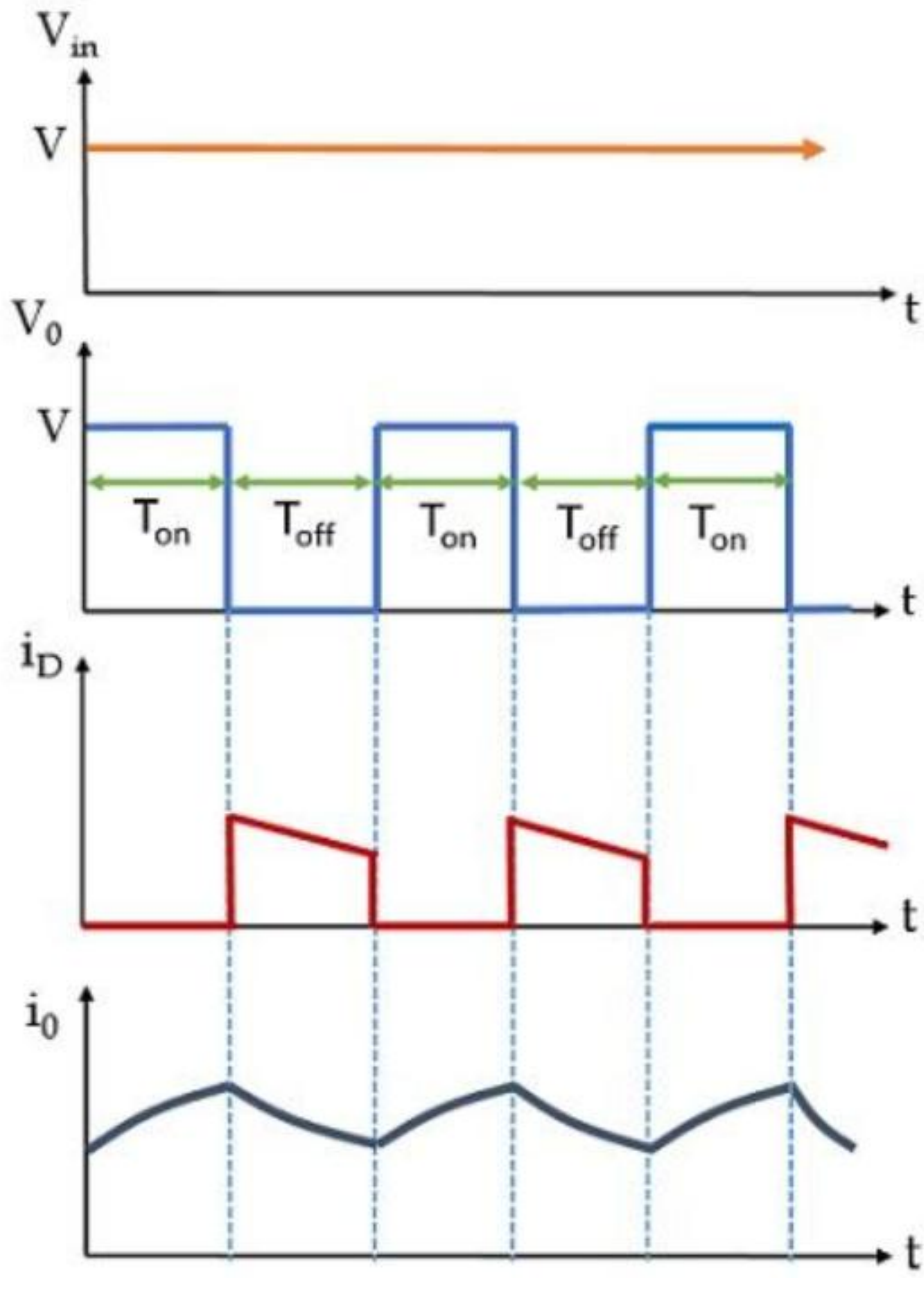

Figure 4.3 Output Waveform of Buck Converter

CHAPTER 5 : BATTERIES IN SOLAR PANEL SYSTEMS

5.1 Introduction to Solar Energy Storage

In solar energy systems, batteries are essential for storing energy produced by solar panels for later use, such as during night-time or cloudy conditions. Since solar power is intermittent, batteries provide a reliable energy buffer, enabling both off-grid and grid-tied systems to maintain stable power delivery. Energy storage is crucial for enhancing self-consumption, offering backup during outages, and supporting load balancing in hybrid solar configurations.

5.2 Role of Batteries in Solar Systems

Batteries store the direct current (DC) electricity generated by photovoltaic (PV) panels. This stored energy can be used when the solar system is not actively generating power. Key roles include:

- **Backup Power Supply:** Ensuring electricity availability during blackouts.
- **Load Shifting:** Using stored energy during peak demand hours to reduce electricity bills.
- **Off-grid Operation:** Powering systems in remote areas with no grid access.
- **Grid Support:** Enhancing energy resilience in hybrid solar systems.

By integrating batteries, solar systems become more flexible, autonomous, and efficient.

5.3 Characteristics of Solar Batteries

Effective solar batteries must meet specific performance requirements to handle the unique demands of solar systems:

a. Deep Cycle Capability

They must withstand frequent deep discharge and recharge cycles.

b. Long Cycle Life

Durability over thousands of charge-discharge cycles ensures better return on investment.

c. High Depth of Discharge (DoD)

A high DoD indicates more usable capacity from the battery without damaging it.

d. Low Self-Discharge

Efficient batteries lose very little charge when not in use, which is crucial for intermittent usage.

e. Temperature Stability

Stable performance across different environmental conditions is vital for outdoor solar setups.

f. Low Maintenance

Modern batteries aim to minimize upkeep, especially for residential and remote systems.

5.4 Types of Batteries Used in Solar Panel Systems

Different battery technologies are used depending on budget, application, performance expectations, and location. The most common types include:

A. Lead-Acid Batteries

i. Flooded Lead-Acid (FLA)

- **Description:** Oldest and most traditional type.
- **Pros:** Cost-effective, widely available.
- **Cons:** Requires frequent maintenance and ventilation.

ii. Sealed Lead-Acid (SLA) / Valve-Regulated Lead-Acid (VRLA)

- **Types:** AGM (Absorbent Glass Mat) and Gel
- **Pros:** Maintenance-free, spill-proof
- **Cons:** Higher cost than FLA, limited lifespan

B. Lithium-Ion Batteries

- **Types:** Lithium Iron Phosphate ($LiFePO_4$) is the most used for solar systems.
- **Pros:** High energy density, deep discharge capacity, long lifespan, fast charging.
- **Cons:** Higher upfront cost, but longer service life reduces lifecycle cost.

C. Flow Batteries

- **Description:** Store energy in externally circulated electrolytes.
- **Pros:** 100% DoD, long cycle life, scalable capacity
- **Cons:** High cost, bulky, better suited for commercial-scale systems

D. Nickel-Based Batteries

i. Nickel-Cadmium (Ni-Cd)

- **Pros:** Rugged, temperature-resistant
- **Cons:** Toxicity, memory effect, regulatory limitations

ii. Nickel-Metal Hydride (NiMH)

- **Pros:** Safer alternative to Ni-Cd
- **Cons:** Less commonly used due to the dominance of lithium technologies

5.5 Comparison of Battery Types

Table 5.1 : Comparison of Batteries

Feature	Lead-Acid	Lithium-Ion	Flow Battery	Ni-Cd
Cost	Low	High	Very High	High
Cycle Life	500–1500	2000–10000+	5000+	1000–2000
Depth of Discharge	50%–70%	90%–95%	~100%	70%–80%
Maintenance	Medium-High	Low	Medium	Medium
Energy Density	Low-Medium	High	Low	Medium

5.6 Trends and Advancements in Battery Technology for Solar Systems

With growing demand for renewable energy storage, battery technology is advancing rapidly. Key trends and innovations include:

a. Solid-State Batteries

Solid-state batteries use solid electrolytes instead of liquid. They promise:

- Higher energy density
- Enhanced safety (non-flammable)
- Longer life spans

Although still in development, they could revolutionize solar energy storage in the near future.

b. Lithium Iron Phosphate ($LiFePO_4$) Dominance

This lithium-ion variant is becoming the standard for solar storage due to:

- Superior thermal stability
- Safety

- Long cycle life

  It’s widely adopted in home energy storage solutions like Tesla Powerwall and other modular systems.

c. Second-Life EV Batteries

Repurposing used electric vehicle (EV) batteries for solar storage offers:

- Cost-effective energy storage
- Sustainability by extending battery life

  This approach is gaining popularity in commercial and residential solar systems.

d. Smart Battery Management Systems (BMS)

Modern BMS enhance:

- Battery safety
- Efficiency and charge optimization
- Real-time monitoring and predictive maintenance

  Integration with IoT and AI is enabling smarter, self-regulating solar storage systems.

e. Hybrid Energy Storage Systems

Combining batteries with supercapacitors or multiple battery chemistries (e.g., lithium-ion + flow) can improve performance, offering:

- Fast response times
- Better power density and longevity

  This is especially useful in microgrid and industrial solar applications.

f. Eco-Friendly and Recyclable Materials

There is a rising focus on developing batteries with:

- Non-toxic, recyclable materials
- Reduced environmental footprint

  This aligns with the sustainability goals of renewable energy deployment.

CHAPTER 6 : Battery Management System (BMS) in MPPT-Based Solar Panel Systems

A Battery Management System (BMS) is a critical component in solar photovoltaic (PV) systems, especially those integrated with Maximum Power Point Tracking (MPPT) technology and battery storage. In such systems, the BMS ensures safe, reliable, and efficient operation of the battery bank while the MPPT controller optimizes the energy harvested from the solar panels.

In an MPPT solar charging system, the MPPT controller continuously tracks the optimal operating point of the solar panel to extract the maximum possible power, adapting to changes in irradiance and temperature. The energy extracted is then used to charge the battery. However, to prevent battery damage and ensure longevity, a BMS is essential.

6.1 Functions of BMS in MPPT Solar Systems-

1. State of Charge (SOC) Monitoring: The BMS continuously monitors the battery's SOC to ensure it operates within a safe range. It prevents overcharging by disconnecting or signalling the MPPT controller to reduce charging current when the battery is full.
2. Overvoltage and Undervoltage Protection: The BMS ensures each battery cell remains within its safe voltage limits. Overvoltage can degrade the battery, while undervoltage can cause permanent damage, especially in lithium-based chemistries.
3. Current Control and Overcurrent Protection: The BMS limits the current drawn during charging and discharging. It protects the system from faults like short circuits or excessive loads that could overheat or damage the battery.
4. Temperature Management: Temperature sensors integrated in the BMS help monitor battery temperature. If temperatures exceed safe thresholds, the BMS can throttle or stop charging to prevent thermal runaway or degradation.

5. Cell Balancing: In multi-cell battery packs, the BMS balances individual cells to ensure uniform charging and discharging. Balanced cells improve battery efficiency and extend life.
6. Communication with MPPT Controller: Advanced BMS units can communicate with the MPPT controller via protocols like CAN or UART. This enables dynamic charging current control based on battery status, enhancing system efficiency and safety.

6.2 Integration in Simulink Models-

In simulation models like Simulink, the BMS block is implemented alongside the MPPT controller to model real-time decision-making. It interacts with the MPPT to regulate the energy flow, reflecting realistic scenarios like load variation, solar fluctuation, and battery degradation. This integration allows detailed analysis of system behaviour and performance under varying conditions.

CHAPTER 7 : Maximum Power Point Tracking Algorithms

A typical solar panel converts only about 15 to 22 percent of the incident solar irradiation into electrical energy, although advanced laboratory cells can reach efficiencies of up to 30 to 40 percent. To maximize the usable output from a solar panel, a technique called Maximum Power Point Tracking (MPPT) is employed to improve the overall efficiency.

According to the Maximum Power Transfer Theorem, the power output of a circuit is maximized when the source (Thevenin) impedance matches the load impedance. Therefore, the challenge of tracking the maximum power point in a photovoltaic system can be viewed as an impedance matching problem.

In this topology, we use a buck converter connected to the solar panel to step down the output voltage, making it suitable for various applications such as charging batteries or supplying DC loads. By appropriately adjusting the duty cycle of the buck converter, we can match the source impedance with the load impedance, thereby ensuring operation at or near the maximum power point.

7.1 Different MPPT techniques

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

1) Perturb and Observe (hill climbing method)
2) Incremental Conductance method
3) Fuzzy logic Control

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

7.1.1 Perturb & Observe

It is the simplest and most widely used MPPT method. It requires only one sensor—a voltage sensor—to measure the PV array voltage, which reduces implementation cost and complexity.

The algorithm has low time complexity and is easy to implement.

However, as the algorithm approaches the Maximum Power Point (MPP), it does not settle exactly at the MPP but continues to perturb in both directions, causing oscillations around the maximum power point. To mitigate this, an appropriate error tolerance can be set, or a wait function can be introduced to stop perturbations when close enough to the MPP. These modifications, however, increase the algorithm's time complexity.

Another limitation of P&O is its inability to distinguish between changes in power caused by perturbation and those caused by rapid changes in irradiance. When irradiance changes suddenly, P&O may incorrectly interpret this as a perturbation effect and converge to the wrong MPP. To overcome this issue, the **Incremental Conductance (INC)** method is often used, as it better handles rapidly changing environmental conditions.

Method:

1) Perturbation: The P&O method starts by introducing a small, incremental change (perturbation) to the operating voltage of the PV array.

2) Observation: The change in power output is then observed.

3) Direction Tracking: If the power output increases, the perturbation is continued in the same direction (e.g., increasing the voltage). If the power output decreases, the perturbation is reversed (e.g., decreasing the voltage).

4) Hill Climbing: This process of perturbing and observing continues until the maximum power point (MPP) is reached or the change in power output becomes very small, indicating that the system is near the MPP.

5) Oscillation: The P&O method tends to oscillate around the MPP due to the incremental nature of the perturbations, but it can be a simple and cost-effective approach for MPPT.

Key Concepts:

1) Maximum Power Point (MPP): The point on the PV array's power-voltage curve where the maximum power is generated.

2) Photovoltaic (PV) System: A system that converts sunlight into electricity using photovoltaic cells.

3) Hill Climbing: A search algorithm that iteratively moves towards a solution by exploring neighboring points and selecting the one that leads to a higher value.

Benefits of P&O:

1) Simple Implementation: It's relatively easy to implement compared to more complex MPPT algorithms.

2) Low Cost: The algorithm requires minimal computational resources.

3) Wide Applicability: It's widely used in commercial PV systems.

Limitations of P&O:

1) Oscillation: The P&O method can oscillate around the MPP, leading to some power loss.

2) Slow Tracking: It may take a relatively long time to find the MPP, especially under rapidly changing environmental conditions.

3) Less Accurate: It may not be as accurate as other MPPT algorithms, especially under partial shading conditions.

Advantages of P&O:

1) Simplicity: The algorithm is straightforward to understand and implement, requiring minimal computational resources.

2) Low Cost: Due to its simplicity, it can be implemented using inexpensive hardware, making it cost-effective for many applications.

3) Robustness: P&O is relatively robust against noise and can be implemented in both analog and digital systems.

Perturb & Observe Algorithm

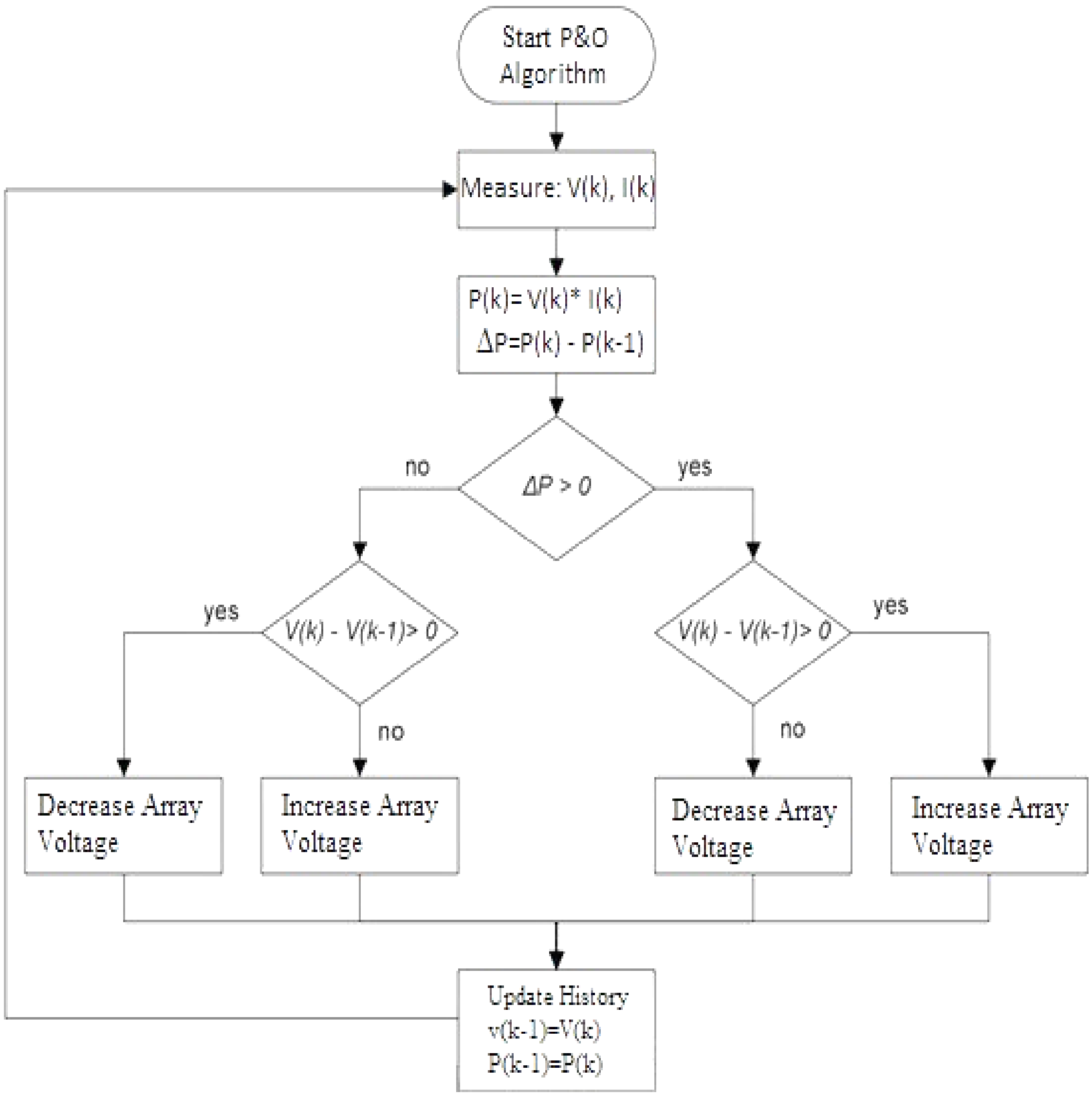

Figure 7.1.1 : Flow Chart of Perturb & Observance MPPT

It operates by periodically perturbing (i.e., slightly changing) the operating voltage of the PV array and observing the resulting change in power output. The goal is to continuously adjust the operating point to maximize power extraction despite changing environmental conditions like irradiance and temperature.

Step 1: Measure Initial Voltage and Current

- Measure the current voltage $V(k)$ and current $I(k)$ from the PV array at the current time step k
- Calculate the power output:

$$P(k) = V(k) \times I(k)P(k) = V(k) \times I(k)$$

Step 2: Perturb the Operating Voltage

- Introduce a small incremental change (perturbation) to the PV array voltage, either increasing or decreasing it by a small step ΔV.

Step 3: Measure New Voltage and Current

- After the perturbation, measure the new voltage $V(k+1)$ and current $I(k+1)$.
- Calculate the new power output:

$$P(k+1) = V(k+1) \times I(k+1)P(k+1) = V(k+1) \times I(k+1)$$

Step 4: Compare Power Outputs

- Calculate the change in power:

$$\varDelta P = P(k+1) - P(k)$$

- Calculate the change in voltage:

$$\varDelta V = V(k+1) - V(k)$$

Step 5: Decide Perturbation Direction

- If $\Delta P>0$, the power has increased due to the last perturbation:
- Continue perturbing in the same direction (increase or decrease voltage as before).
- If $\Delta P<0$, the power has decreased:
    - Reverse the direction of perturbation for the next step.

Step 6: Repeat the Process

- Repeat steps 2 through 5 continuously to track the Maximum Power Point (MPP) as environmental conditions change.

Step 7: Handle Oscillations Near MPP

- As the operating point approaches the MPP, the algorithm tends to oscillate around it due to the incremental perturbations.
- To minimize this oscillation and improve stability, reduce the perturbation step size or implement an error threshold to stop perturbing when changes become negligible.

7.1.2 Incremental Conductance

The Incremental Conductance (INC) method uses two sensors—one for voltage and one for current—to simultaneously measure the output voltage and current of the PV array. This allows the algorithm to calculate both the instantaneous conductance (change in current over change in voltage) and the instantaneous conductance (current over voltage) of the solar panel.

According to the INC method, the Maximum Power Point (MPP) is reached when the instantaneous conductance equals the incremental conductance. By sensing both voltage and current simultaneously, the INC algorithm can effectively eliminate errors caused by rapid changes in irradiance, improving tracking accuracy compared to simpler methods.

However, this improved accuracy comes at the cost of increased complexity and higher implementation costs due to the need for additional sensors and more sophisticated calculations. As the complexity of MPPT algorithms increases, so do their costs and computational requirements, making them more suitable for complex or large-scale PV systems.

Method:

1) Instantaneous Conductance (I/V):This refers to the ratio of the current to the voltage at a specific operating point of the PV array.

2) Incremental Conductance ($\Delta I/\Delta V$):This represents the change in current divided by the change in voltage between two successive operating points, effectively describing the slope of the PV array's current-voltage characteristic curve at that point.

3) Finding the Maximum Power Point (MPP):The MPPT algorithm continuously adjusts the operating voltage and current of the PV array to minimize the difference between the instantaneous conductance and the incremental conductance. When these two values are equal, the algorithm determines that the system is operating at the MPP.

4) MPP Condition:At the Maximum Power Point, the slope of the power-voltage curve is zero, indicating that the power output is at its maximum for the given environmental conditions.

Advantages of INC MPPT:

1) Simplicity and Low Implementation Complexity: The algorithm is relatively straightforward to implement, making it suitable for various applications.

2) Fast Tracking Time: It can effectively track the MPP under changing conditions, such as varying solar irradiance or temperature.

3) Good Steady State Accuracy: The algorithm can maintain the operating point near the MPP with good accuracy.

4) Robustness: It can handle changes in solar irradiance and temperature, ensuring

optimal power extraction.

In essence, the INC algorithm uses the relationship between instantaneous and incremental conductance to intelligently adjust the PV array's operating point, ensuring that it operates at the MPP and maximizes power generation.

Limitations of Incremental Conductance MPPT

1. Complexity: Requires more complex calculations and precise measurements of current and voltage.
2. Implementation Cost: May necessitate more sophisticated hardware and control systems.
3. Sensitivity to Noise: Accurate derivative calculations can be affected by measurement noise.

Incremental Conductance Algorithm

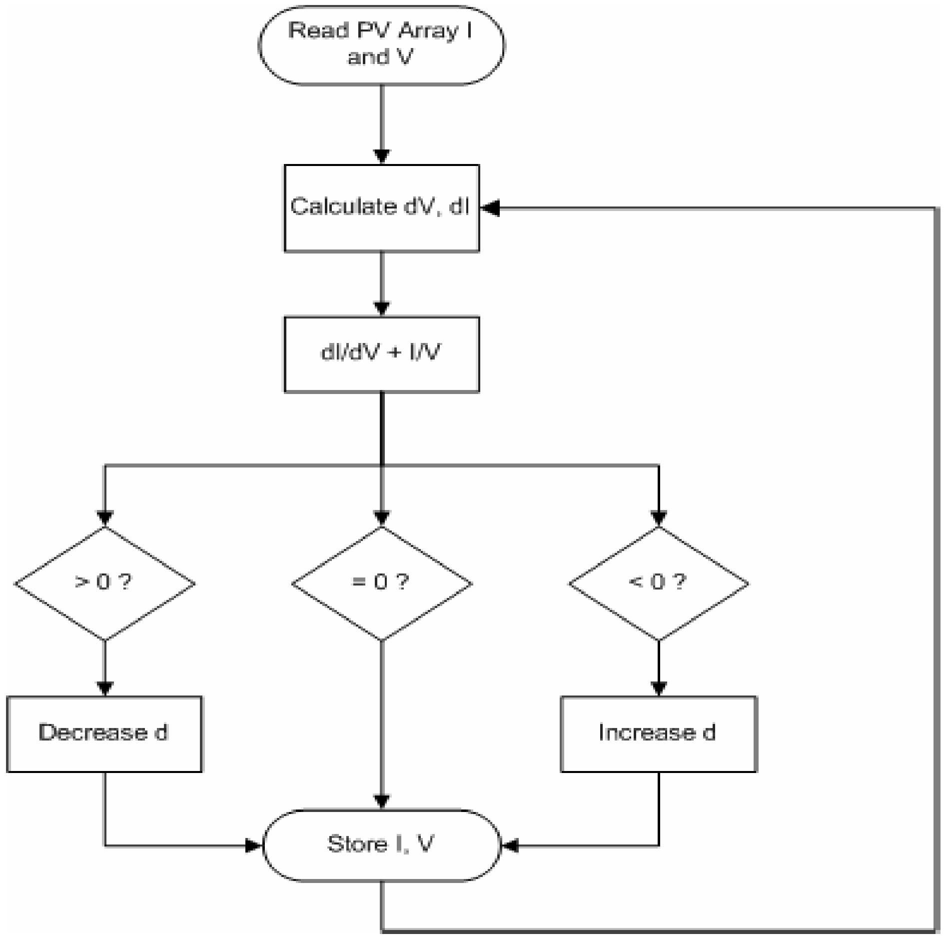

Figure 7.1.2 : Flow Chart of Incremented Conductance MPPT

Step1: Measure PV voltage (V) and current (I).

Step2: Calculate:

- Change in voltage: $\Delta V = V(t) - V(t-1)$
- Change in current: $\Delta I = I(t) - I(t-1)$

Step3: Determine the slope of the power curve:

- At MPP: $dP/dV = 0 \rightarrow dI/dV = -I/V$
- Left of MPP: $dP/dV > 0 \rightarrow dI/dV > -I/V$
- Right of MPP: $dP/dV < 0 \rightarrow dI/dV < -I/V$

Step4: Check conditions:

- If $\Delta V = 0$:
  - If $\Delta I = 0$ → At MPP → Do not adjust
  - If $\Delta I > 0$ → Left of MPP → Decrease voltage
  - If $\Delta I < 0$ → Right of MPP → Increase voltage
- If $\Delta V \neq 0$:
  - Calculate: $\Delta I/\Delta V$
  - Compare with $-I/V$:
    - If $\Delta I/\Delta V = -I/V$ → At MPP → Do not adjust
    - If $\Delta I/\Delta V > -I/V$ → Left of MPP → Decrease voltage
    - If $\Delta I/\Delta V < -I/V$ → Right of MPP → Increase voltage

Step5: Adjust the duty cycle of the DC-DC converter accordingly:

- Increase or decrease the voltage to track MPP.

Step6: Repeat steps periodically.

7.1.3 Fuzzy Logic Control

The Fuzzy Logic Control (FLC) method employs a rule-based approach to track the Maximum Power Point (MPP) of a photovoltaic (PV) system. Unlike traditional methods that rely on explicit mathematical models or exact measurements, FLC uses qualitative reasoning based on linguistic rules to make decisions. This makes it especially effective in handling system nonlinearities and uncertain or rapidly changing environmental conditions such as irradiance and temperature.

Fuzzy Logic MPPT typically requires two inputs—the change in power (ΔP) and the change in voltage (ΔV)—which are derived from real-time voltage and current measurements of the PV array. These inputs are then processed by a fuzzy inference system that applies a set of predefined if-then rules to determine the appropriate change in duty cycle or voltage adjustment needed to move toward the MPP.

The fuzzy controller uses membership functions to convert numerical input values into fuzzy variables (e.g., "small," "medium," "large") and applies fuzzy rules to decide the control action. The output of the fuzzy system is then defuzzified to generate a crisp control signal, such as a specific adjustment to the duty cycle of the DC-DC converter.

As a result, FLC-based MPPT offers a good balance between adaptability and performance, making it particularly attractive for medium to large-scale PV systems or applications requiring high reliability under dynamic environmental conditions.

Method:

1. Input Selection

- The most common inputs are:
    - Change in power (ΔP) = P(t) - P(t-1)
    - Change in voltage (ΔV) = V(t) - V(t-1)

2. Fuzzification

- The numeric input values (ΔP and ΔV) are converted into fuzzy variables using membership functions (e.g., "Negative Large", "Zero", "Positive Small").
- Example fuzzy sets:
    - For ΔP: {Negative, Zero, Positive}
    - For ΔV: {Negative, Zero, Positive}

3. Rule Base

- A set of if-then rules is defined by an expert or derived from system behavior.
- Example rules:
    - If ΔP is Positive and ΔV is Positive → Decrease voltage
    - If ΔP is Negative and ΔV is Negative → Increase voltage
    - If ΔP is Zero → Maintain current voltage

These rules are designed to move the operating point toward the MPP.

4. Inference Engine

- The fuzzy logic controller evaluates all applicable rules using fuzzy logic operations (AND, OR).
- It combines the results of all matching rules to produce fuzzy outputs.

5. Defuzzification

- The fuzzy output is converted back to a crisp numerical value.
- This output is typically used to adjust the duty cycle of the DC-DC converter to control the PV array voltage.

6. Duty Cycle Adjustment

- The output from the defuzzifier is used to update the PWM duty cycle.
- This controls the converter to bring the PV operating point closer to the MPP.

7. Repeat

- The process is repeated periodically to ensure continuous tracking of the MPP under changing conditions.

Advantages of Fuzzy Logic MPPT

1) Model-Free Operation: Does not necessitate an accurate mathematical model of the PV system, making it versatile across different setups.

2) Robustness: Effectively handles the nonlinear and time-varying characteristics of PV systems, maintaining performance under rapid changes in irradiance and temperature.

3) Reduced Oscillations: Minimizes power oscillations around the MPP compared to traditional methods like Perturb and Observe (P&O).

4) Fast Response: Exhibits quick convergence to the MPP, enhancing the overall efficiency of the PV system .

Limitations of Fuzzy Logic MPPT

1) Design Complexity: Developing an effective rule base and selecting appropriate membership functions require expert knowledge and can be time-consuming.

2) Computational Demand: May require more computational resources than simpler algorithms, potentially increasing the cost and complexity of the control system.

3) Performance Dependence: The effectiveness of the FLC is highly dependent on the quality of the designed rules and membership functions .

CHAPTER 8 : Modelling and Simulation of PV System with MPPT Algorithms

8.1 Solar panel

The entire system has been modeled on MATLAB Simulink™. The block diagram of the solar PV panel is shown in Figure 5.1 and Figure 5.2. The inputs to the solar PV panel are temperature, solar irradiation, number of solar cells in series and number of rows of solar cells in parallel.

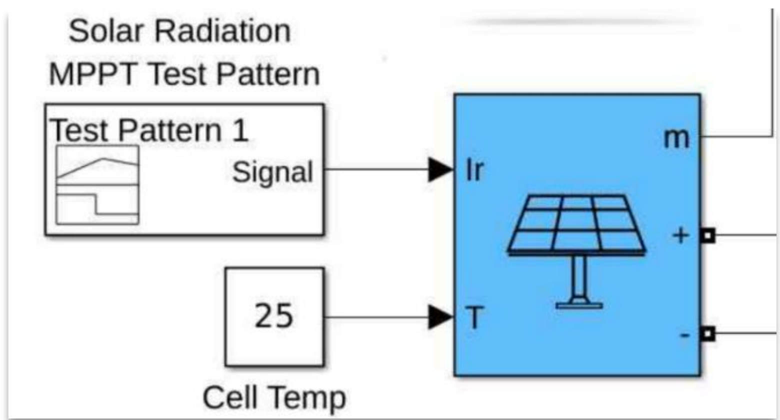

Figure 8.1(a) : Masked block diagram of the modeled Solar PV Panel

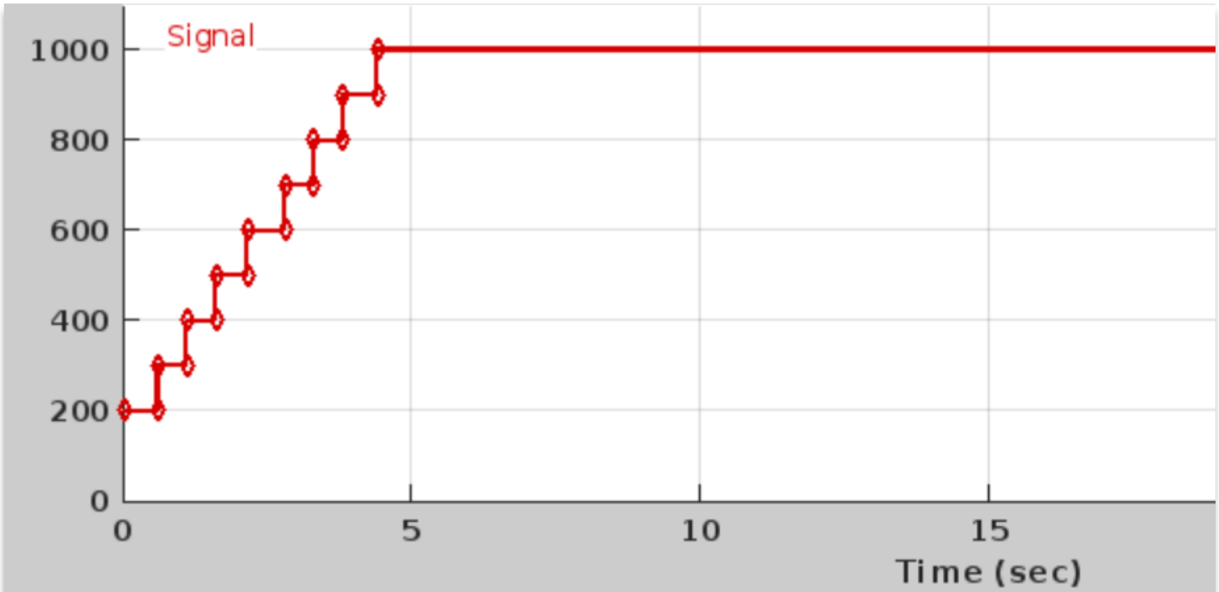

Figure 8.1((b) : Radiation Pattern fed to PV panel from 0 to 15sec

The simulation is carried out for a cell surface temperature of 25°C, using 279 W solar panels configured with 4 panels in series and 2 parallel strings. This configuration is selected to achieve the desired voltage and current ratings suitable for the standalone system. The irradiation (shown in Figure 5.2) is taken to be varying, to reflect real-life conditions and effectively demonstrate the use of an MPPT algorithm during field operation. The irradiation values vary from 200 W/m² to 1000 W/m², which closely approximates the typical daily range of solar radiation received on the Earth's surface.

The simulation is run for a total duration of 5 seconds, with the irradiation updated every 0.5 seconds. During each 0.5-second interval, the irradiation remains constant to allow the MPPT algorithm sufficient time to track and adjust the operating point of the PV array effectively. This stepwise variation simulates transient environmental conditions such as passing clouds or shading, providing a realistic scenario for evaluating the MPPT controller's dynamic response and efficiency.

8.2 Buck Converter

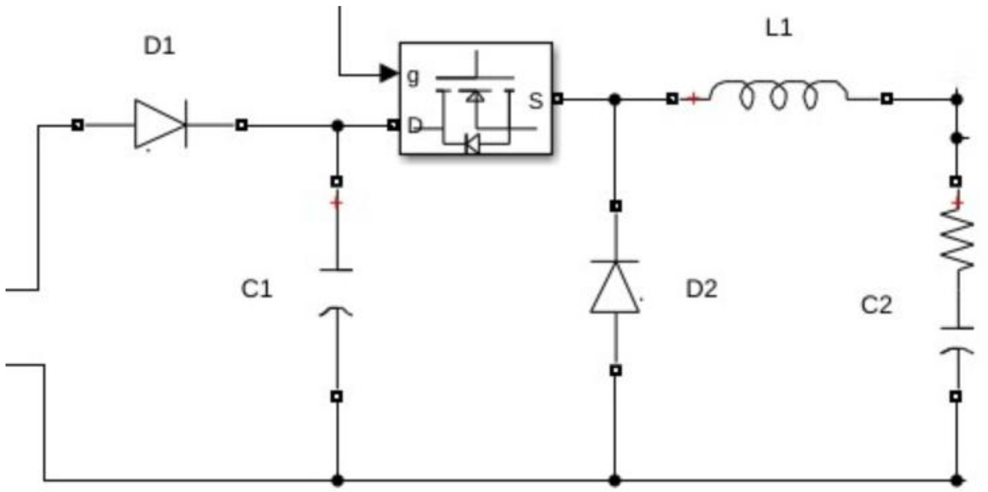

Figure 8.2 : Buck Convertor

In our Simulink model of the buck converter, we have used specific component values to achieve stable voltage regulation and smooth current flow, particularly for high-current, low-voltage applications.

- **C1 = 1000 µF** and **C2 = 1000 µF** are used as input and output filter capacitors. These large capacitance values help suppress voltage ripples caused by the high-frequency switching of the converter. C1 filters any noise or fluctuations from the input supply, while C2 maintains a steady output voltage, ensuring smooth DC delivery to the load.
- **L1 = 10 mH** is selected to provide continuous conduction and reduce output current ripple. In our model, the inductor ensures gradual energy transfer from input to output, stabilizing the converter’s response and improving overall efficiency. The high inductance also helps maintain current flow when the switch is turned off, which is critical for maintaining output voltage stability.
- **R1 = 0.1 Ω** represents the load in our simulation. This low resistance value simulates a high-current load scenario, helping us analyze the converter’s ability to deliver substantial current with minimal voltage drop. It also allows us to study losses and the dynamic performance under realistic load conditions.

8.3 Battery/Power Source-

In our Simulink model, we have used a **48V, 200Ah Nickel-Cadmium (NiCd) battery** to simulate a practical energy storage system suitable for solar and power backup applications. This battery setup reflects real-world characteristics, allowing us to analyze charging/discharging behavior and overall system performance under different load and generation conditions.

- **48V Nominal Voltage**: This voltage level is commonly used in solar and industrial energy systems. It provides a good balance between power delivery and safety, making it ideal for integration with DC-DC converters and inverters in renewable energy setups.
- **200Ah Capacity**: The high ampere-hour rating indicates that the battery can deliver 200 amps of current for one hour, or proportionally less over a longer duration. In the model, this large capacity helps simulate long-duration energy storage, supporting both high-power loads and extended backup times during low solar generation.
- **Nickel-Cadmium (NiCd) Chemistry**: NiCd batteries are known for their ruggedness, tolerance to deep discharge, and wide operating temperature range. In the Simulink model, using a NiCd type allows us to represent applications where durability and reliability are critical. These batteries also handle high charge/discharge rates well, which is essential when used with power converters like a buck converter.

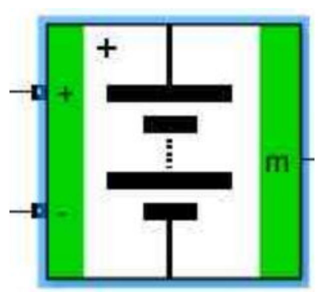

Figure 8.3 : Battery

8.4 MATLAB Simulink Model of P&O –

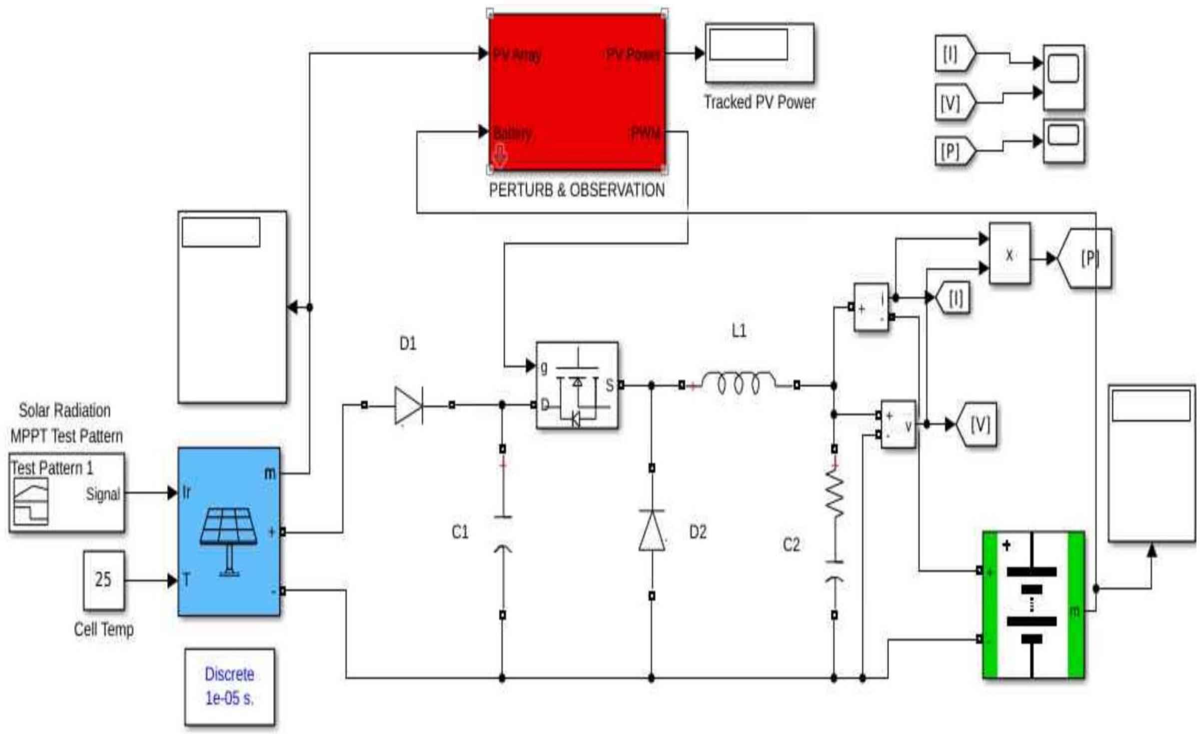

Figure 8.4(a) : MATLAB Simulink of P&0 Model

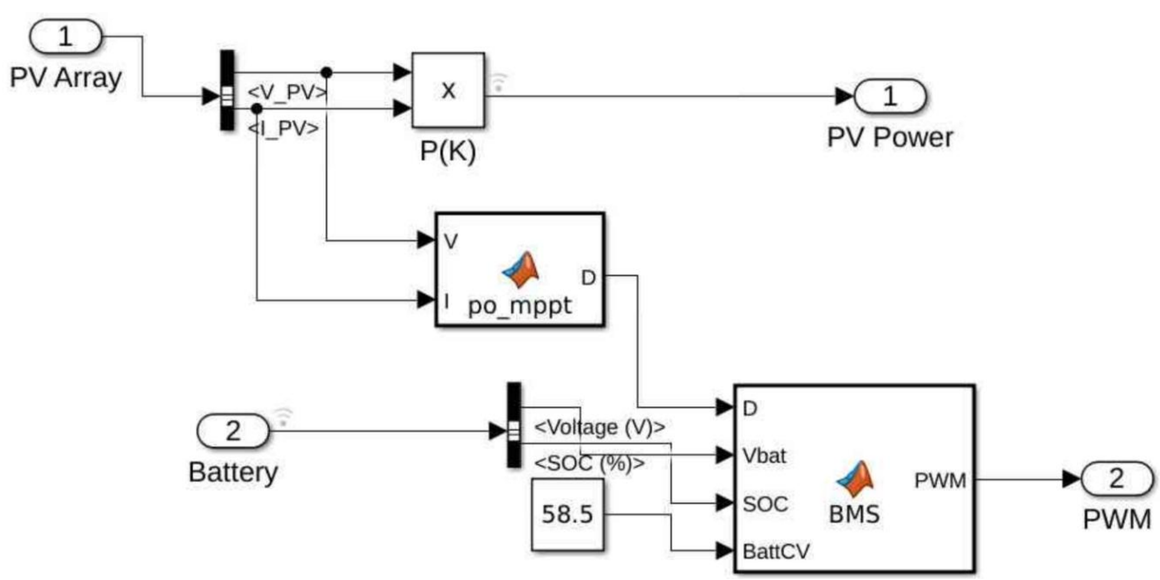

Figure 8.4(b) : MATLAB Simulink of P&0 MPPT & BMS

P&0 MPPT Code-

```
function  D=po_mppt(V,I)

persistent V_prev P_prev D_prev
if isempty(V_prev)
    V_prev=0;
    P_prev=0;
    D_prev=0.5;
end

deltaD=0.01;
D_min=0.0;
D_max=1.0;

P=V*I;

dP=P-P_prev;
dV=V-V_prev;

if dV~=0
    if dP>0
        if dV>0
        D=D_prev + deltaD;
    else
        D=D_prev-deltaD;
    end
else
    if dV>0
        D=D_prev-deltaD;
    else
        D=D_prev+deltaD;
```

```
    end
    end
else
    D=D_prev;
end

D=min(max(D,D_min),D_max);

V_prev=V;
P_prev=P;
D_prev=D;
```

BMS Code-

```
function PWM=BMS(D,Vbat,SOC,BattCV)
floatEnable= SOC<90;
cvEnable=Vbat<=BattCV;
chargingEnable=floatEnable*cvEnable;
PWM=D*chargingEnable;
```

8.5 MATLAB Simulink Model of INC –

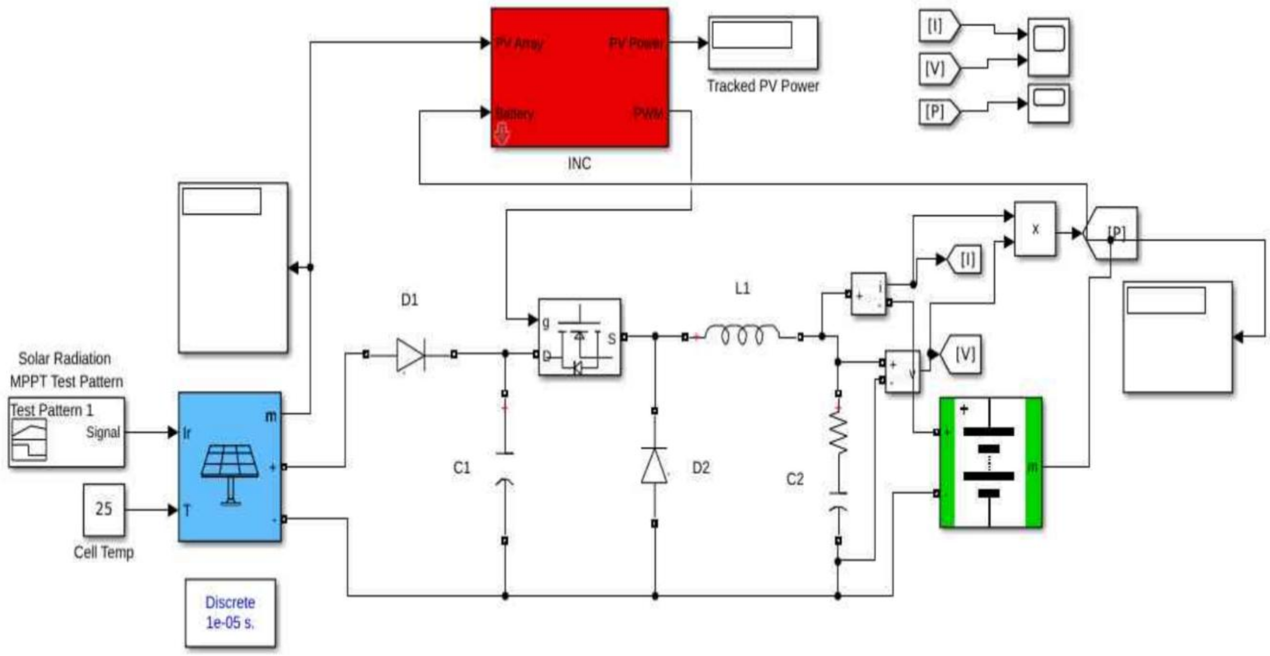

Figure 8.5(a) : MATLAB Simulink of INC Model

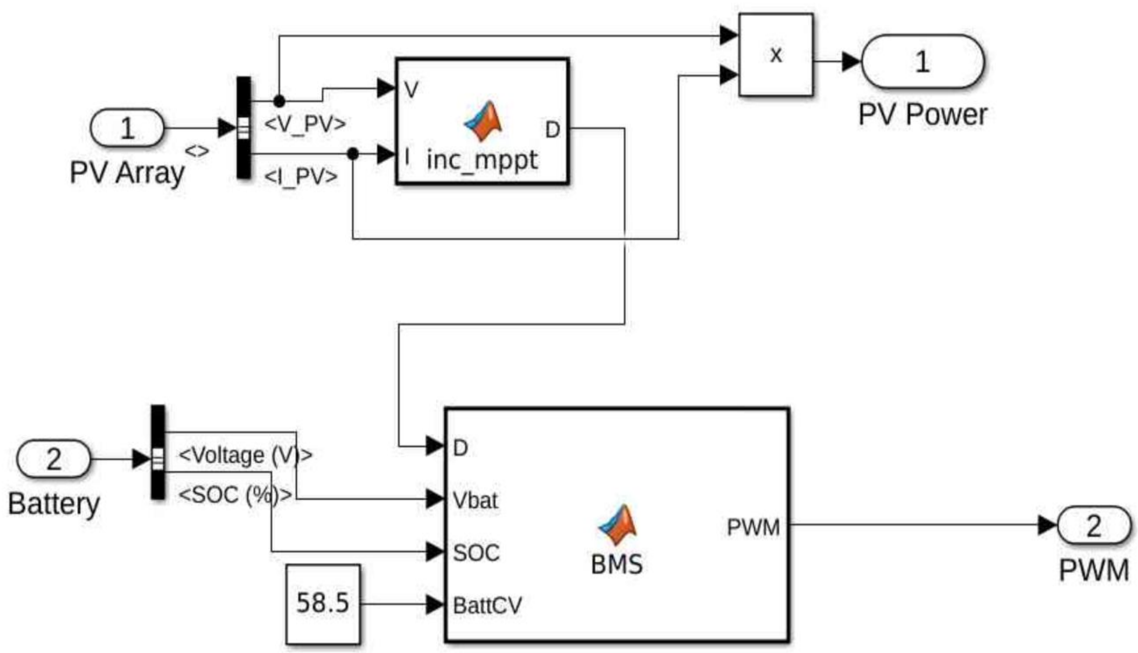

Figure 8.5(b) : MATLAB Simulink of INC MPPT & BMS

INC MPPT Code-

```
function D= inc_mppt(V,I)

persistent V_prev I_prev D_prev
if isempty(V_prev)
    V_prev=0.1;
    I_prev=0.01;
    D_prev=0.5;
end

deltaD=0.01;
D_min=0.0;
D_max=1.0;
epsilon=1e-6;


dV=V-V_prev;
dI=I-I_prev;

if abs(dV)<epsilon
    if dI~=0
        if dI>0
            D=D_prev-deltaD;
        else
            D=D_prev+deltaD;
        end
    else
        D=D_prev;
    end
else
    incCond=dI/dV;
```

```
    instCond=I/V;

    error=incCond+instCond;
    if error>0
        D=D_prev-deltaD;
    elseif error< 0
        D=D_prev+deltaD;
    else
        D=D_prev;
    end
end
D=min(max(D,D_min),D_max);
V_prev=V;
I_prev=I;
D_prev=D;
```

BMS Code-

```
function PWM=BMS(D,Vbat,SOC,BattCV)
floatEnable= SOC<90;
cvEnable=Vbat<=BattCV;
chargingEnable=floatEnable*cvEnable;
PWM=D*chargingEnable;
```

8.6 MATLAB Simulink Model of Fuzzy Logic Control –

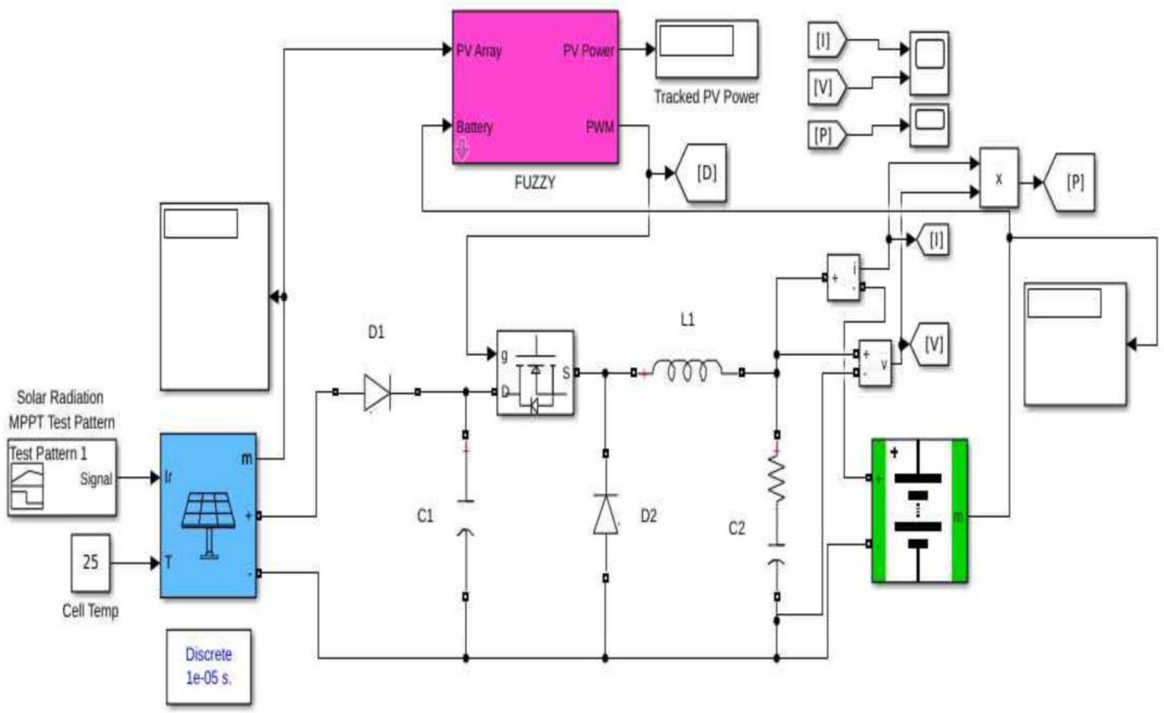

Figure 8.6(a) : MATLAB Simulink of Fuzzy Model

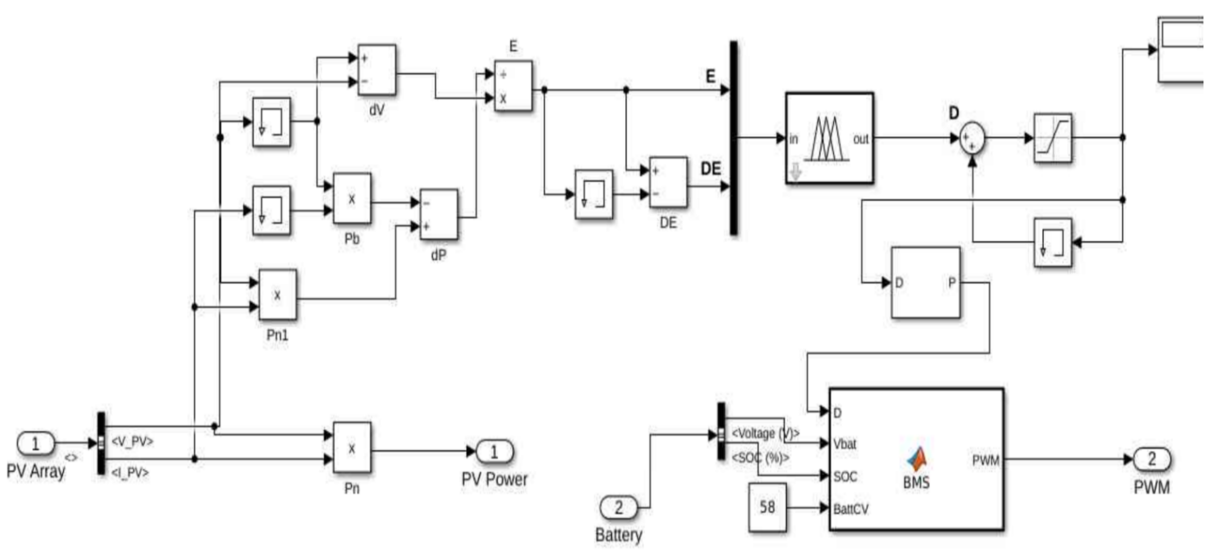

Figure 8.6(b) : MATLAB Simulink of INC Algorithm

8.6.1 **Step-by-Step Explanation of the Fuzzy MPPT Algorithm with BMS Integration**

1. PV Array Inputs:

- The system begins with a PV array, providing two outputs:
    - V_PV (Voltage)
    - I_PV (Current)

    These are fed into the MPPT controller.

2. Power Calculation:

- The PV power (Pn) is calculated using:

$$Pn = V \times I$$

This gives the real-time output power of the PV system.

3. Change Detection (ΔP and ΔV):

- The model computes:
    - dV: Change in voltage from the previous step
    - dP: Change in power from the previous step

This is done using a unit delay block (for past values) and a subtraction block.

4. Normalization:

- The algorithm then calculates Pb = Pn1 / dV or similar terms to normalize the power change relative to the voltage change.
- These values (ΔP and ΔV) are important inputs for the fuzzy logic controller, as they define the slope of the P-V curve to determine whether the operating point is left or right of the MPP.

5. Fuzzy Logic Controller:

- The two inputs to the fuzzy logic controller are:
  - ΔP (change in power)
  - ΔV (change in voltage)
- The fuzzy controller uses membership functions and rules (typically "If-Then" statements) to determine the control action (ΔD):
  - For example:
    "If ΔP is positive and ΔV is positive, then decrease duty cycle"
    "If ΔP is negative and ΔV is negative, then increase duty cycle"

This helps track the MPP by adjusting the duty cycle intelligently based on the power curve's slope.

6. Duty Cycle Adjustment:

- The output of the fuzzy logic controller (ΔD) is added to the previous duty cycle to compute the new D (duty cycle).
- This value is then passed through a PWM block, which generates a pulse-width modulated signal for the converter switch.

7. Battery Management System (BMS):

- The BMS receives inputs from the battery:
  - Vbat (Battery Voltage)
  - SOC (State of Charge)
  - BattCV (possibly battery control voltage)
- Based on these, the BMS ensures:
  - No overcharging
  - Safe discharge limits
  - Charging cut-off at full SOC
- The BMS adjusts or overrides the PWM signal from the fuzzy controller if battery safety thresholds are breached.
- Output from BMS: Final PWM control signal that governs charging.

Table 8.1 : Rule for Fuzzy based MPPT

ΔE \ E	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

This table shows the 25 fuzzy logic rules for a controller using two inputs: error (E) and change in error (ΔE). Each cell gives the output action based on combinations of these inputs.
The abbreviations are:

- NB: Negative Big
- NS: Negative Small
- ZE: Zero
- PS: Positive Small
- PB: Positive Big

BMS Code-

```
function PWM=BMS(D,Vbat,SOC,BattCV)
floatEnable= SOC<90;
cvEnable=Vbat<=BattCV;
chargingEnable=floatEnable*cvEnable;
PWM=D*chargingEnable;
```

CHAPTER 9 : SIMULATION INSIGHTS AND RESULT DISCUSSION

All simulations and results for the converter have been documented to ensure an accurate comparison of the circuit. The main factors for comparison include input and output voltage, current, and power. The circuit's complexity and simplicity have been assessed based on existing literature. The initial temperature is set to 25°C.

9.1 COMPARISON OF P&0, INC & FUZZY MPPT

9.1.1 P&O System

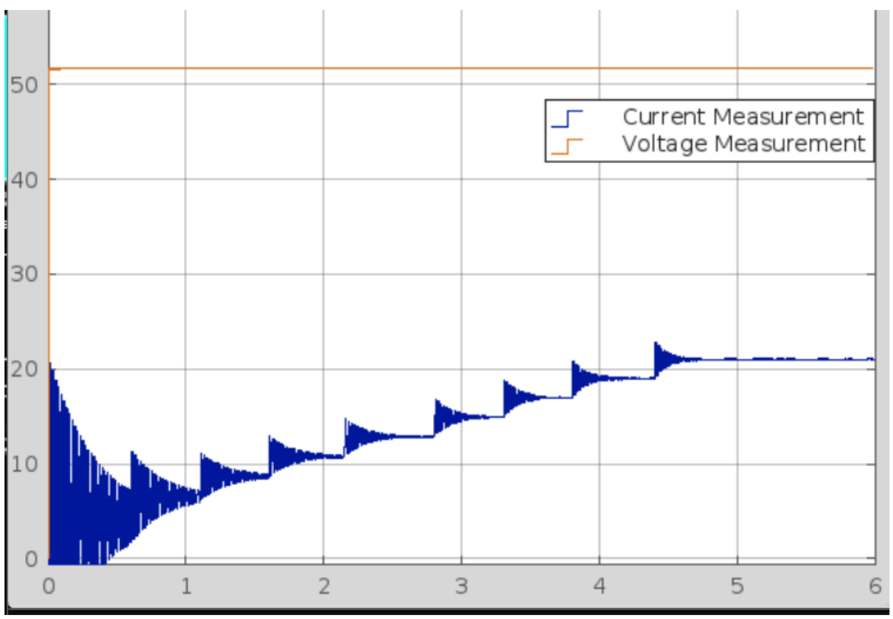

Fig.9.1.1 (a) Output IV Profile under P&O

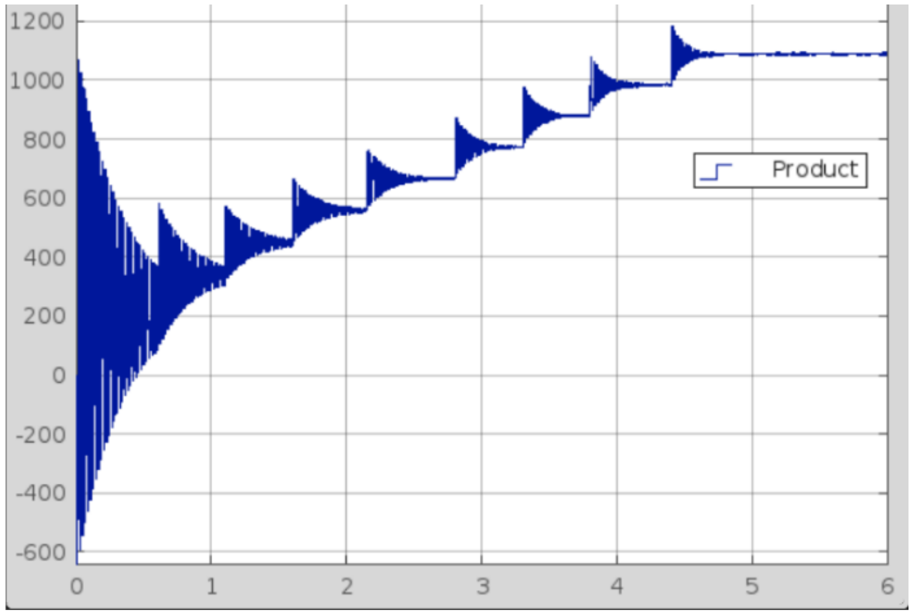

Fig.9.1.1 (b) Output P Profile under P&O

9.1.2 IC System

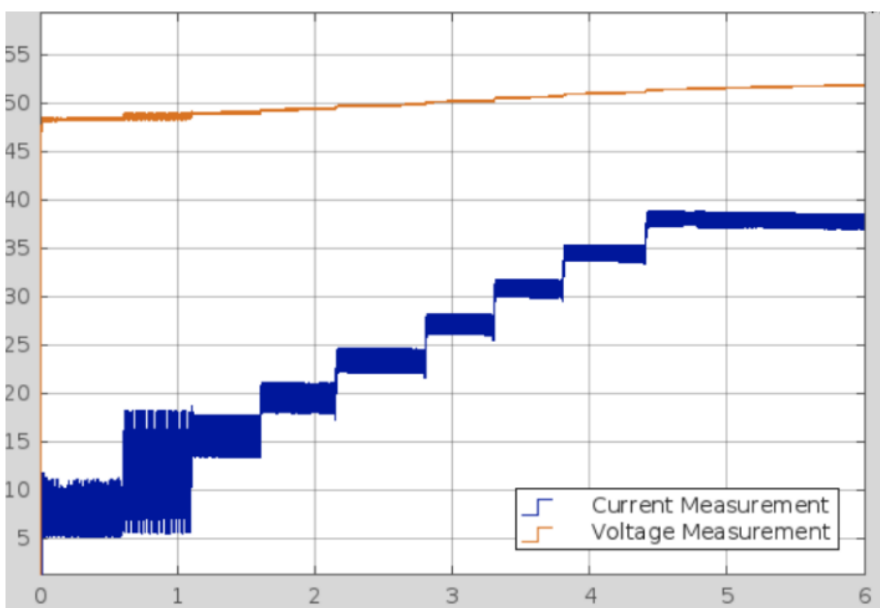

Fig.9.1.2 (a) Output IV Profile under IC

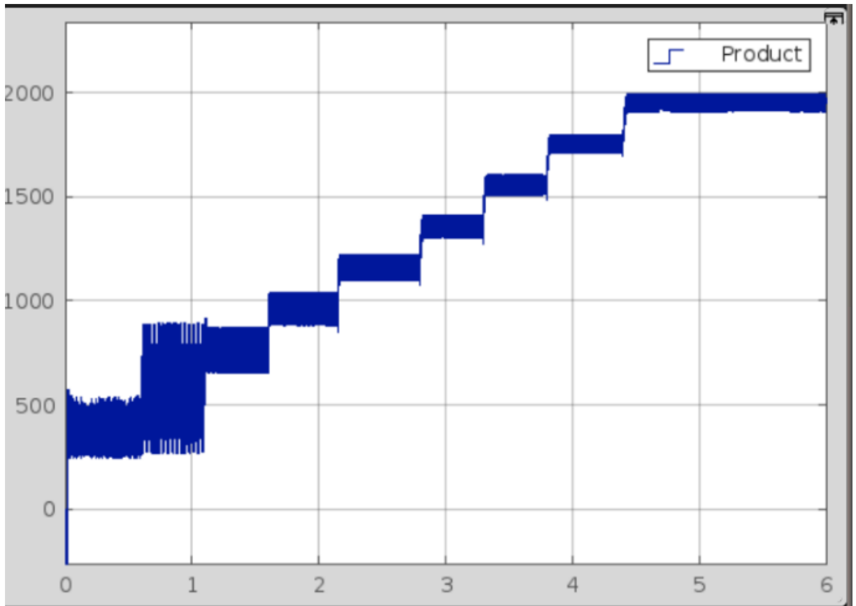

Fig.9.1.2 (b) Output P Profile under IC

9.1.3 Fuzzy System

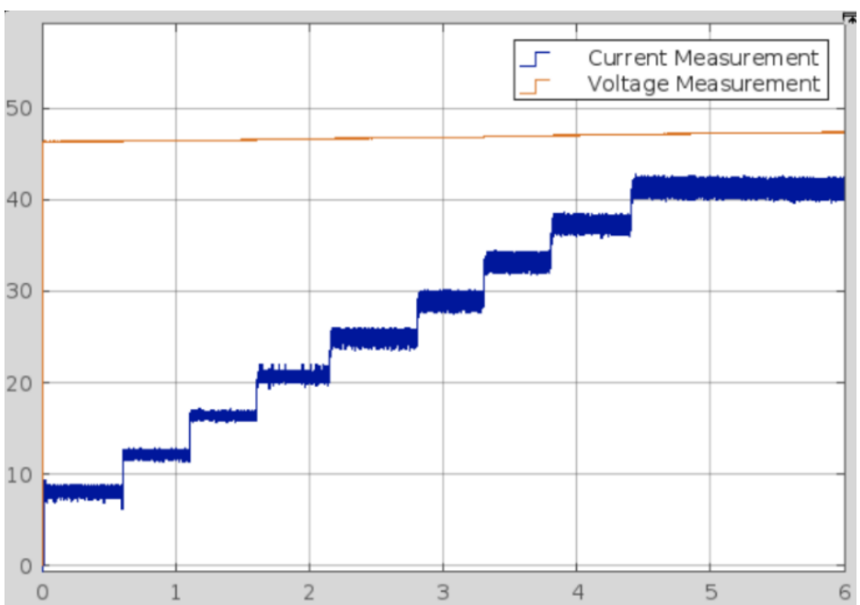

Fig.9.1.3 (a) Output IV Profile under Fuzzy

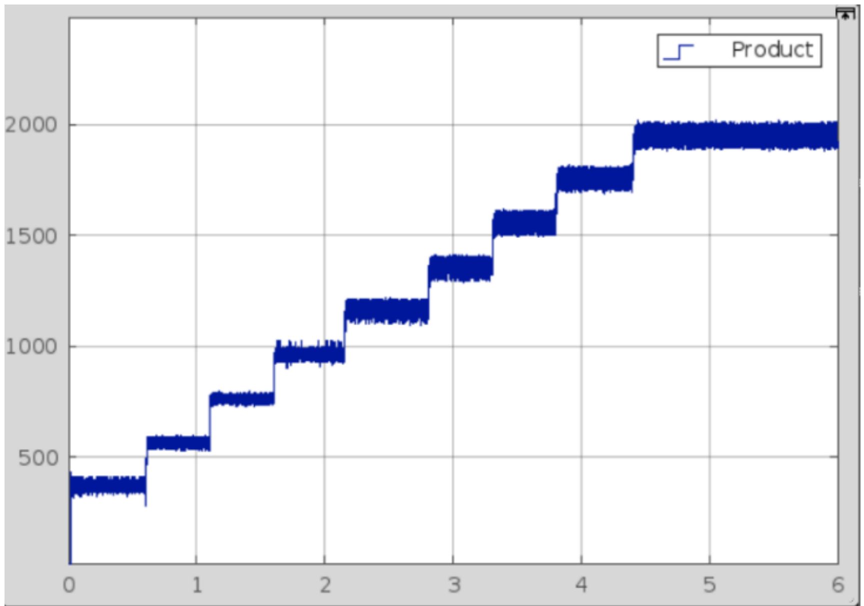

Fig.9.1.3 (b) Output P Profile under Fuzzy

TABLE 9.1 COMPARISON TABLE

S.No	**Radiation**	**MPPT**	**Vo, Io**	**Po**	**%P Increased in Fuzzy w.r.t P&O**	**%P Increased in IC w.r.t P&O**	
1	1000 rad/s	P&O	48.5v 21.5a	1042.75w	48.27	49. 33	
		IC	49v 42a	2058w			
		Fuzzy	48v 42a	2016w			
2	700 rad/s	P&O	48.5v 17a	824.5	50.92	49.01	

		IC	49v 33a	1617w			
		Fuzzy	48v 35a	1680w			
3	300 rad/s	P&O	48.59	436.5w	50.4	48.5	
		IC	49v 17.3a	847.7w			
		Fuzzy	48v 18a	864w			

CHAPTER 10 : CONCLUSION

This study presents a comparative analysis of three broadly used MPPT techniques: P&O, IC, and fuzzy logic-based MPPT controllers. The evaluation is conducted using a low voltage output converter under standard solar insolation and temperature conditions. Simulation results show that although the IC method performs better than the conventional P&O technique in terms of tracking accuracy and steady-state behavior, the fuzzy logic-based MPPT controller delivers the best overall performance. It provides faster convergence to the peak power point, minimal swings, and improved dynamic response. The low voltage output converter setup consistently demonstrated optimal behavior when paired with the fuzzy MPPT controller.

REFERENCES

[1]. R. S.Lewis, "Antartic Research and Relevant of Science," in Bulletin of the Atomic Scientists, vol. 26, 1970, pp. 2.

[2]. Y.-H. Chang and C.-Y. Chang, "A Maximum Power Point Tracking of PV System by Scaling Fuzzy Control," presented at International Multi Conference of Engineers and Computer Scientists, Hong Kong, 2010.

[3]. S.Mekhilef, "Performance of grid connected inverter with maximumpower point tracker and power factor control,"International Journal of Power Electronics, vol. 1, pp. 49-62, 2008.

[4]. M.E.Ahmad and S.Mekhilef, "Design and Implementation of a Multi Level Three-Phase Inverter with Less Switches and Low Output Voltage Distortation," Journal of Power Electronics, vol. 9,pp. 594-604, 2009.

[5]. S. Chin, J. Gadson, and K. Nordstrom, "Maximum Power Point Tracker," Tufts University Department of Electrical Engineering and Computer Science,2003, pp.1-66.

[6]. R. Faranda and S. Leva, "Energy Comparison of MPPT techniques for PV Systems," WSES Transaction on Power Systems, vol. 3, pp. 446-455, 2008.

[7]. Vikrant.A.Chaudhari, "Automatic Peak Power Traker for Solar PV Modules Using dSpacer Software.," in Maulana Azad National Institute Of Technologyvol. Degree of Master of Technology In Energy. Bhopal: Deemed University, 2005, pp. 98.

[8]. T. P. Nguyen, "Solar Panel Maximum Power Point Tracker," in Department of Computer Science & Electrical Engineering: University of Queensland, 2001, pp. 64.

[9]. B. S, Thansoe, N. A, R. G, K. A.S., and L. C. J., "The Study and Evaluation of Maximum Power Point Tracking Systems," International Conference on Energy and Environment 2006 (ICEE 2006), pp. 17-22, 2006.

[10]. C. S. Lee, " A Residential DC Distribution System with Photovoltaic Array Integration.," vol. Degree of Honors Baccalaureate of Science in Electrical and Electronics Engineering, 2008, pp. 38.

[11]. T. Esram and P. L.Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," in 9. Urbana.

[12]. E. I and O. Rivera, "Maximum Power Point Tracking using the Optimal Duty Ratio for DC-DC

Converters and Load Matching in Photovoltaic Applications," IEEE, pp. 987-991, 2008.

[13]. G. Adamidis, P. Bakas, and A. Balouktsis, "Photovoltaic System MPPTracker Implementation using DSP engine and buck – boost DCDC converter."

[14]. M. Azab, "A New Maximum Power Point Tracking for Photovoltaic Systems," in WASET.ORG, vol. 34, 2008, pp. 571-574.

[15]. H. Knopf, "Analysis, Simulation, And Evaluation of Maximum Power Point Tracking (MPPT) Methods for a solar power vehicle," in Electrical and Computer Engineering, vol. Master of Science in Electrical and Computer Engineering: Portland State University 1999, pp. 177.

[16]. T.S.USTUN and S. Mekhilef, "Effects of a Static Synchronous Series Compensator (SSSC) Based on Soft Switching 48 Pulse PWM Inverter on the Power Demand from the Grid," Journal of Power Electronics, vol. 10, pp. 85-90, 2010.

[17]. Oi,"Design and Simulation of Photovoltaic Water Pumping System," in Electrical Engineering, vol. Master of Science in Electrical Engineering. San Luis Obispo: California Polytechnic State University, 2005, pp. 113.

[18]. S.Mekhilef and M. N. A. Kadir, "Voltage Control of Three-Stage Hybrid Multilevel Inverter Using Vector Transformation," IEEE Transactions on Power Electronics, vol. 25, pp. 2599-2606, 2010.

[19]. S. Azadeh and S. Mekhilef, "Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter," IEEE Transaction on Industrial Electronics,vol. DOI:10.1109/ TIE . 2010 . 2048834 , 2010.

[20]. P. Sanchis, J. Lopez, A. Ursua, E. Gubia, and L. Marroyo, "On the Testing, Characterization, and Evaluation of PV Inverters and Dynamic MPPT Performance Under Real Varying Operating Conditions," 2007.

[21]. B. S. Energy, "What is Maximum Power Point Tracking (MPPT)," vol. 2009.

[22]. J. H. Lee, H. S. Bae, and B. H. Cho, "Advanced Incremental Conductance MPPT Algorithm with a Variable Step Size," 2006

[23]. Ahmad El Khateb, Nasrudin Abdul Rahim,Jeyraj Selvaraj, “Fuzzy Logic Controller for MPPT SEPIC Converter and PV Single-Phase Inverter”, IEEE Symposium on Industrial Electronics and Applications (ISIEA2011), pp. 182 - 187, 2011.

[24]. N. Ravikumar, J. Kohila, “Tracking Maximum Power Point from Photovoltaic System Using

Fuzzy Logic Technique”, IEEE Conference on Information and Communication Technologies, pp. 93 – 97, 2013.

[25]. S. P. Singh, A. K. Gautam, S. P. Tripathi, Bhavnesh Kumar. "Performance comparison of MPPT techniques using Cuk converter for photovoltaic energy conversion system", 2017 3rd International Conference on Computational Intelligence & Communication Technology (CICT), 2017]

[26]. Abd El-Shafy AN, Fahmy FH, Abou El-Zahab EM. Maximum-power operation of a stand-alone PV system using fuzzy logic control . Int J Numer Model, 2002;15:385-98.

[27]. Mamdani EH, Assilian S. An experiment in linguistic synthesis with a fuzzy logic controller. Int.J Man-Machine Studies,1975; 7(1):1-13. [18] Salameh ZM, Casacca MA, Lynch WA. A mathematical model for lead-acid batteries. IEEE T Energy Conver, 1992;7(1):93-98

APPENDIX A


16th INTERNATIONAL CONFERENCE ON RECENT ENGINEERING & TECHNOLOGY 2025

ORGANIZED BY

EAST WEST COLLEGE OF ENGINEERING, INDIA

IN ASSOCIATION WITH

ORGANIZATION OF SCIENCE & INNOVATIVE ENGINEERING TECHNOLOGY

IN COLLABORATION WITH

SAMARKAND STATE UNIVERSITY, UZBEKISTAN

EAST WEST

1968

Certificate of Participation

This is to certify that Dr. / Mr. / Ms. .... Aditya Kaushik .... from .... JSS Academy of Technical Education, Noida .... has presented a paper titled .... STUDY OF MPPT's UNDER ENVIRONMENTAL FLUCTUATION .... in the "16th International Conference on Recent Engineering & Technology" held on 16th & 17th May 2025 at East West College of Engineering, Bangalore, India.

Dr. Akhatov Akmal Rustamovich	Dr. Christo Ananth	Dr. Santhosh Kumar G	Dr. K. Sivakumar	K.Janani, M.Tech.,
Vice Rector of International Affairs, Samarkand State University, Uzbekistan	Professor, Dept of IT Samarkand State University, Uzbekistan	Principal / Director, East West College of Engineering, India	Advisor, OSIET	CEO, OSIET


16th INTERNATIONAL CONFERENCE ON RECENT ENGINEERING & TECHNOLOGY 2025

ORGANIZED BY

EAST WEST COLLEGE OF ENGINEERING, INDIA

IN ASSOCIATION WITH

ORGANIZATION OF SCIENCE & INNOVATIVE ENGINEERING TECHNOLOGY

IN COLLABORATION WITH

SAMARKAND STATE UNIVERSITY, UZBEKISTAN

EAST WEST

1968

Certificate of Participation

This is to certify that Dr. / Mr. / Ms. .... Akash Sharma .... from .... JSS Academy of Technical Education, Noida .... has presented a paper titled .... STUDY OF MPPT's UNDER ENVIRONMENTAL FLUCTUATION .... in the "16th International Conference on Recent Engineering & Technology" held on 16th & 17th May 2025 at East West College of Engineering, Bangalore, India.

Dr. Akhatov Akmal Rustamovich	Dr. Christo Ananth	Dr. Santhosh Kumar G	Dr. K. Sivakumar	K.Janani, M.Tech.,
Vice Rector of International Affairs, Samarkand State University, Uzbekistan	Professor, Dept of IT Samarkand State University, Uzbekistan	Principal / Director, East West College of Engineering, India	Advisor, OSIET	CEO, OSIET

16th INTERNATIONAL CONFERENCE ON RECENT ENGINEERING & TECHNOLOGY 2025

ORGANIZED BY

EAST WEST COLLEGE OF ENGINEERING, INDIA

IN ASSOCIATION WITH

ORGANIZATION OF SCIENCE & INNOVATIVE ENGINEERING TECHNOLOGY

IN COLLABORATION WITH

SAMARKAND STATE UNIVERSITY, UZBEKISTAN

Certificate of Participation

This is to certify that Dr. / Mr. / Ms. Dr. K.S. Sujatha from JSS Academy of Technical Education, Noida has presented a paper titled STUDY OF MPPT's UNDER ENVIRONMENTAL FLUCTUATION

in the "16th International Conference on Recent Engineering & Technology" held on 16th & 17th May 2025 at East West College of Engineering, Bangalore, India.

Dr. Akhatov Akmal Rustamovich	Dr. Christo Ananth	Dr. Santhosh Kumar G	Dr. K. Sivakumar	K.Janani, M.Tech.,
Vice Rector of International Affairs, Samarkand State University, Uzbekistan	Professor, Dept of IT Samarkand State University, Uzbekistan	Principal / Director, East West College of Engineering, India	Advisor, OSIET	CEO, OSIET

16th INTERNATIONAL CONFERENCE ON RECENT ENGINEERING & TECHNOLOGY 2025

ORGANIZED BY

EAST WEST COLLEGE OF ENGINEERING, INDIA

IN ASSOCIATION WITH

ORGANIZATION OF SCIENCE & INNOVATIVE ENGINEERING TECHNOLOGY

IN COLLABORATION WITH

SAMARKAND STATE UNIVERSITY, UZBEKISTAN

Certificate of Participation

This is to certify that Dr. / Mr. / Ms. Mohd. Asif from JSS Academy of Technical Education, Noida has presented a paper titled STUDY OF MPPT's UNDER ENVIRONMENTAL FLUCTUATION

in the "16th International Conference on Recent Engineering & Technology" held on 16th & 17th May 2025 at East West College of Engineering, Bangalore, India.

Dr. Akhatov Akmal Rustamovich	Dr. Christo Ananth	Dr. Santhosh Kumar G	Dr. K. Sivakumar	K.Janani, M.Tech.,
Vice Rector of International Affairs, Samarkand State University, Uzbekistan	Professor, Dept of IT Samarkand State University, Uzbekistan	Principal / Director, East West College of Engineering, India	Advisor, OSIET	CEO, OSIET