MPPT Algorithm for Solar Battery Charging System

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List of Abbreviations

1. PV- Photovoltaic
2. MPPT - Maximum Power Point Tracking
3. P&O - Perturb & Observe
4. INC - Incremental Conductance
5. CV - Constant Voltage
6. HC - Hill Climbing
7. AC-DC - Alternating Current to Direct Current
8. MPP - Maximum Power Point
9. Voc - Open-Circuit Voltage
10. DC-DC - Direct Current to Direct Current

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1. Introduction

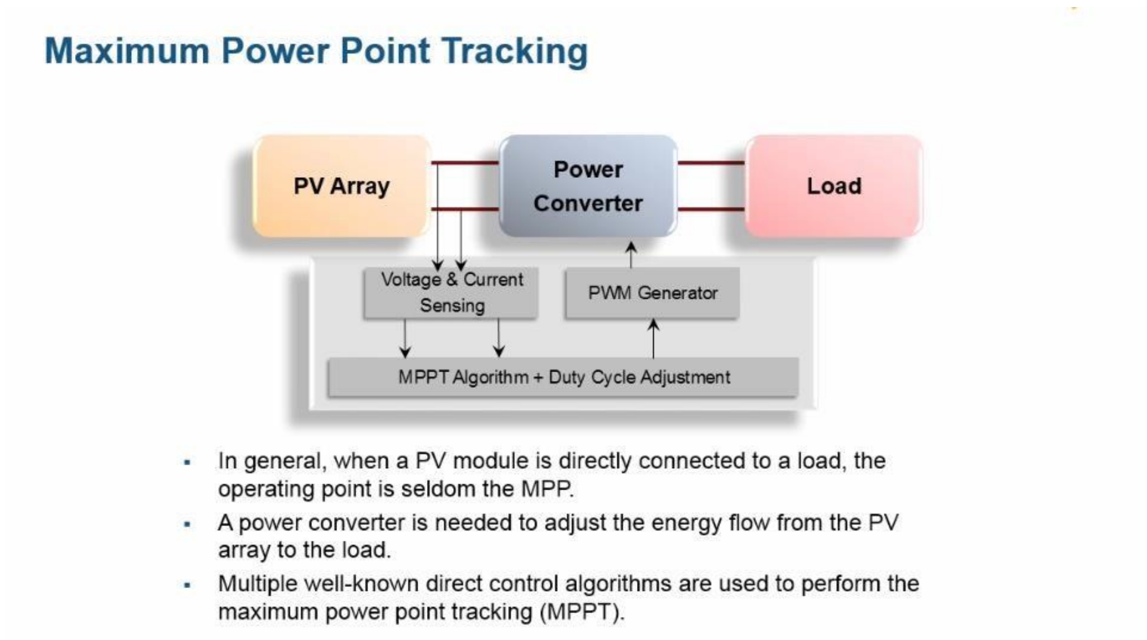
Renewable energy has emerged as a critical area of research for scientists worldwide, driven by the urgent need to address environmental challenges and rising electricity demands. The extensive reliance on non-renewable energy sources, such as fossil fuels and natural gas, has led to a climate crisis that threatens the well-being of populations across the globe. This has heightened the necessity to find sustainable alternatives that ensure the long-term health of the planet.

Among the various renewable energy options explored, solar energy stands out as one of the most promising. As the world shifts away from conventional energy sources, the electrical and electronics industries are increasingly adopting solar power due to its cost-effectiveness and infinite supply. Alongside this transition, the importance of renewable energy storage, particularly through batteries, has grown significantly.

Batteries, as key energy storage components, have a wide range of applications, from telecommunications and electric vehicles to uninterruptible power supplies. The design of a battery charging system plays a crucial role in determining the longevity and performance of the battery, affecting factors such as charging capacity and battery life. However, conventional charging systems, often involving AC-DC converters, can lead to power dissipation and reduced efficiency, necessitating more effective and optimized designs for sustainable energy storage solutions.

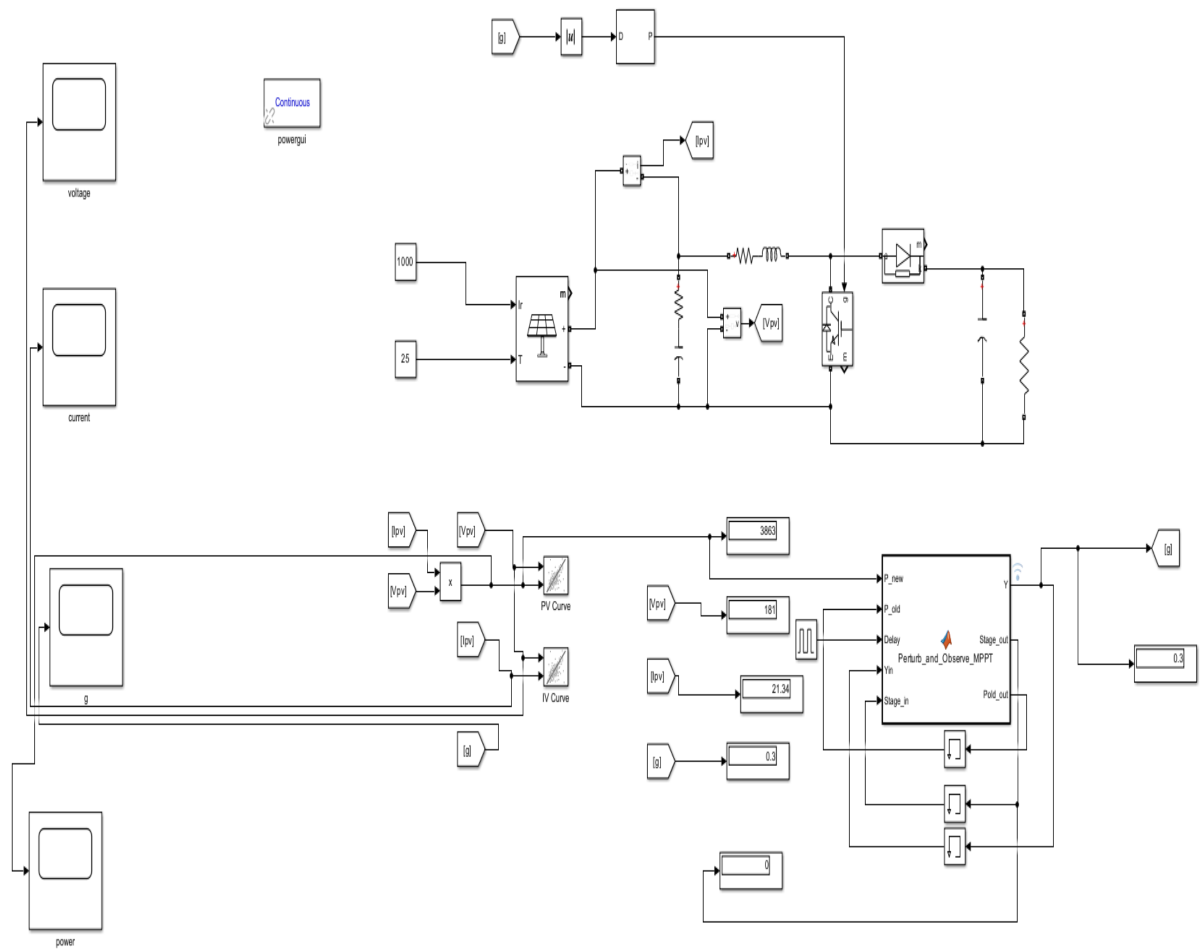
One major problem of the PV system source supply is the instability of the output current or voltage from its system due to various issues such as frequent changes of inner and outer condition. For the PV system to supply electricity voltage, it must absorb light energy from the sun which is also known as irradiance and convert the light energy into electrical energy for the circuit to run. Without using any medium that stabilizes the output voltage or current, the power flow in the system can become easily out of control due to the supply voltage is directly proportional to the irradiance and the surrounding temperature. Thus, any major changes in the irradiance and surrounding temperature, such as weather changes from sunny day to rainy day, will affect the efficiency of the battery charging system. This situation is even worse for a battery load even under fixed temperature and irradiance due to its charging mechanism that makes it an active load that makes its current and voltage inconsistent. Thus, it is strongly recommended to install a mechanism that stabilizes and controls the flow of electricity power in the system, such as using voltage controller and buck converter instead of directly connecting the PV system to the battery load directly.

Maximum Power Point Tracking (MPPT) algorithms are implemented to extract maximum power from PV panels under varying environmental conditions. MPPT algorithms ensure that the PV modules operate at their optimal power point, thereby maximizing energy extraction and improving the overall efficiency of solar charging systems. This allows solar energy systems to effectively compete with conventional energy sources in terms of performance and cost-efficiency. Different types of MPPT algorithms, such as Perturb and Observe (P&O), Incremental Conductance (INC), Constant Voltage (CV), and Hill Climbing (HC), each offer unique advantages in terms of response time, accuracy, and ease of implementation. The choice of MPPT algorithm can significantly impact the system's performance, stability, and battery lifespan. The implementation of advanced control strategies in solar battery charging systems not only ensures efficient energy utilization but also contributes to extending the life of batteries by maintaining optimal charging profiles.



2. Methodology

The methodology for the solar battery charging system focuses on the integration of a DCDC buck converter to convert the high DC voltage from the PV panel to the lower charging voltage required by the battery. The system aims to optimize power transfer using Maximum Power Point Tracking (MPPT) algorithms that continuously adjust the operating point of the PV module to ensure it delivers maximum power under varying conditions. In the proposed system, the DC-DC buck converter is used to step down the voltage from the solar panel to match the battery charging requirements. The converter is controlled by an MPPT algorithm, which continuously monitors the power output of the PV panel to determine the point at which the panel's power output is maximized. Different types of MPPT algorithms are employed, including Perturb & Observe (P&O), Incremental Conductance (INC), Constant Voltage (CV), and Hill Climbing (HC). Each algorithm provides specific advantages depending on the application, environmental conditions, and desired efficiency.



Circuit design of PV module with current and voltage sensors

Perturb & Observe (P&O):

The Perturb & Observe algorithm is one of the simplest and most widely used MPPT techniques due to its ease of implementation and minimal computational requirements. The algorithm periodically perturbs the PV panel's operating voltage and measures the resulting power change. If the power output increases, it continues to perturb in the same direction; if the power decreases, it reverses the perturbation direction. Despite its simplicity, P&O has some limitations, such as oscillations around the MPP and reduced accuracy under rapidly changing irradiance conditions. To mitigate these issues, adaptive step-size P&O methods can be used, where the perturbation size is dynamically adjusted based on the power change rate to minimize oscillations and improve convergence speed.

Incremental Conductance (INC):

The Incremental Conductance method calculates the change in current and voltage of the PV panel to determine the slope of the power-voltage curve. When this slope is zero, the system has reached the MPP. INC is more accurate than P&O, especially in conditions where irradiance changes quickly, as it directly measures the gradient of power. One of the advantages of INC is its ability to quickly converge to the MPP without significant oscillations. However, its implementation is more complex and requires precise measurements of current and voltage. To enhance its performance, variations of the INC algorithm can be employed, such as fuzzy logic-based INC or adaptive INC, which adjust their parameters to improve the system's dynamic response.

Constant Voltage (CV):

The Constant Voltage method aims to maintain the PV panel voltage at a value close to the estimated MPP voltage. This is typically achieved by using a reference voltage set as a fixed percentage of the panel's open-circuit voltage (Voc). The CV method has the advantage of simplicity and ease of hardware implementation, making it suitable for low-cost systems. However, it is less effective at tracking the actual MPP under varying conditions, as the optimal operating point may change with temperature and irradiance. CV is often used as a backup or secondary control method in systems where precision is not the primary concern or when combined with other MPPT techniques to improve reliability.

Hill Climbing (HC):

Hill Climbing is similar to P&O in that it adjusts the converter duty cycle to track the MPP by moving along the power curve of the PV panel. The main difference is that HC works by adjusting the duty cycle directly rather than perturbing the panel voltage. The algorithm continuously climbs the power hill to find the peak. Hill Climbing is effective but can lead to steady-state oscillations around the MPP, which reduces system efficiency. To address these issues, advanced versions of the algorithm, such as adaptive Hill Climbing or hybrid approaches that combine HC with other MPPT techniques, can be employed to reduce oscillations and improve tracking speed. These enhancements make HC more suitable for systems with rapidly changing environmental conditions, as it can quickly adjust to new MPP locations. The choice of MPPT algorithm depends on various factors, including the desired accuracy, complexity, cost, and environmental conditions.

For instance, in environments where sunlight intensity changes rapidly, INC may be preferred due to its faster response time, whereas P&O or CV might be more suitable for stable conditions due to their simplicity. The entire system, including the PV panel, buck converter, MPPT controller, and battery, is modeled and simulated in MATLAB/Simulink to analyze its performance. Simulation allows for the testing of different algorithms under a variety of conditions, providing insights into their efficiency, stability, and responsiveness. The simulation results help in determining the best algorithm and system configuration for a specific application, ensuring that the solar battery charging system operates at its peak efficiency.

3. Literary Survey

Various MPPT algorithms have been developed and tested in academic and industrial research to enhance solar energy harvesting efficiency. Here are a few notable techniques:

1. Perturb & Observe (P&O):

This simple, widely adopted MPPT method periodically perturbs the voltage of the PV panel and observes the corresponding power change. If the power increases, the perturbation continues in the same direction; otherwise, it reverses. However, this method is prone to oscillations around the maximum power point.

2. Incremental Conductance (INC):

The INC method is more efficient in dynamic environments. It calculates the instantaneous conductance and the incremental conductance to determine the maximum power point. The INC algorithm can adjust rapidly to changes in sunlight, making it suitable for conditions with fluctuating irradiance.

3. Constant Voltage (CV):

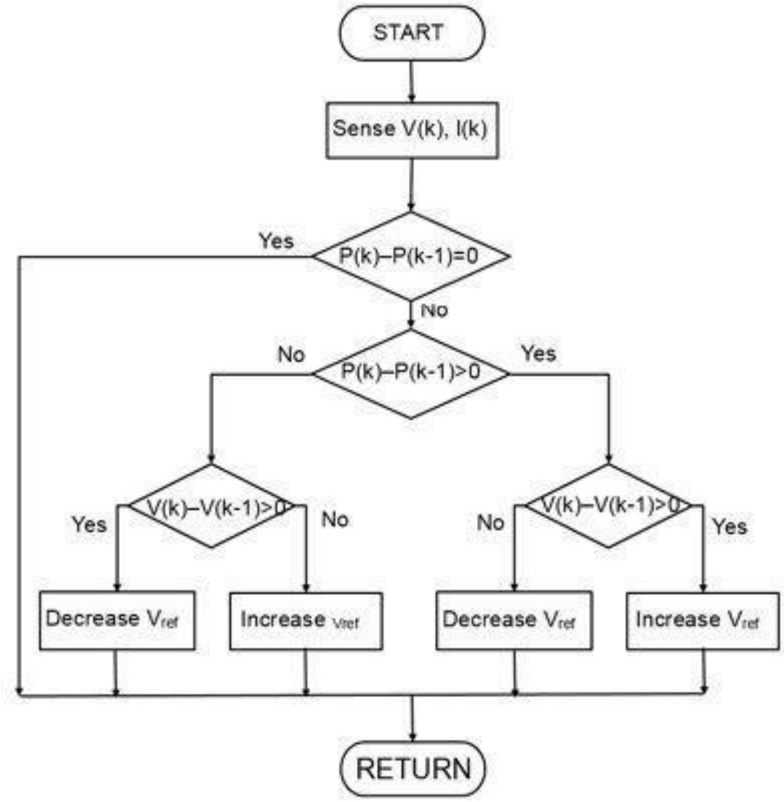
The CV method is relatively simple. It maintains the PV panel's output voltage at a predetermined constant level, which is generally near the maximum power point. While easy to implement, CV is not as efficient as other MPPT techniques, as it does not track the actual maximum power point dynamically.

4. Hill Climbing (HC):

Similar to P&O, this technique adjusts the voltage to climb the power hill. It’s useful for systems with more noticeable oscillations. Although HC is simple to implement, it can be unstable under rapid irradiance changes, leading to suboptimal tracking.

4. Algorithms with Code

This section provides code snippets and flowcharts for implementing various MPPT algorithms. These algorithms control the duty cycle in a simulated environment like MATLAB/Simulink.



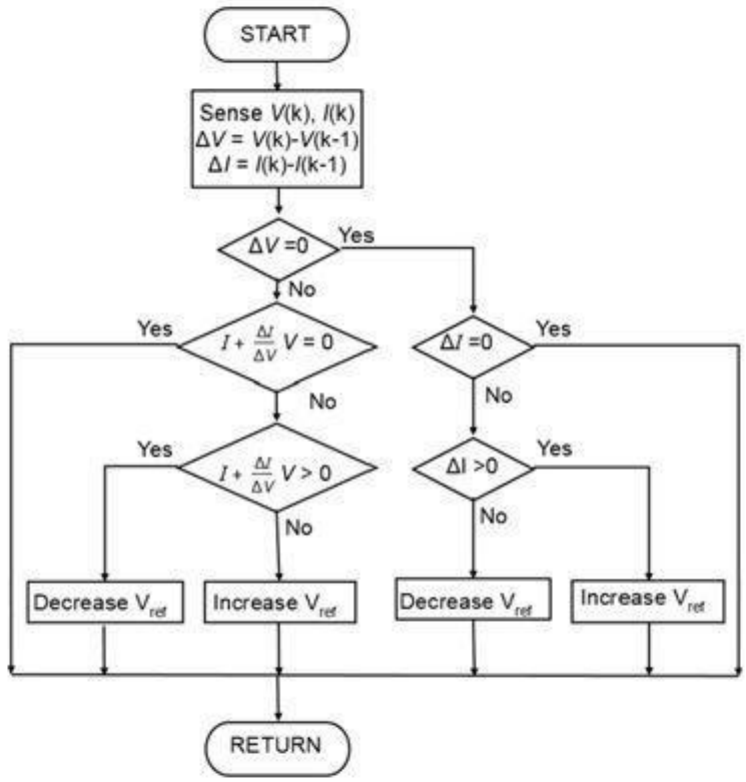
Flowchart of Perturb & Observe Algorithm

1. Perturb & Observe Algorithm:

```
deltaV = 0.01; if (powerNew >
powerOld)     if (voltageNew >
voltageOld)        voltage =
voltage + deltaV;     else
voltage = voltage - deltaV;
end else     if (voltageNew >
voltageOld)        voltage =
voltage - deltaV;
   else
      voltage = voltage + deltaV;
   end end powerOld =
powerNew; voltageOld =
voltageNew;
```

2. Incremental Conductance Algorithm:

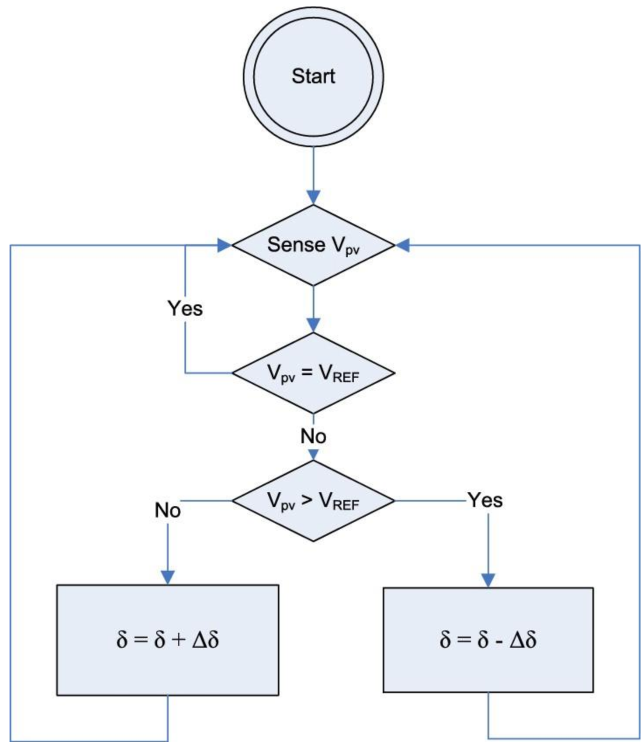
if (dI/dV == -I/V) % MPPT
reached elseif (dI/dV > -I/V)
voltage = voltage + deltaV;
else voltage = voltage -
deltaV; end



Flow chart of Incremental Conductance Algorithm

3. Constant Voltage Method:

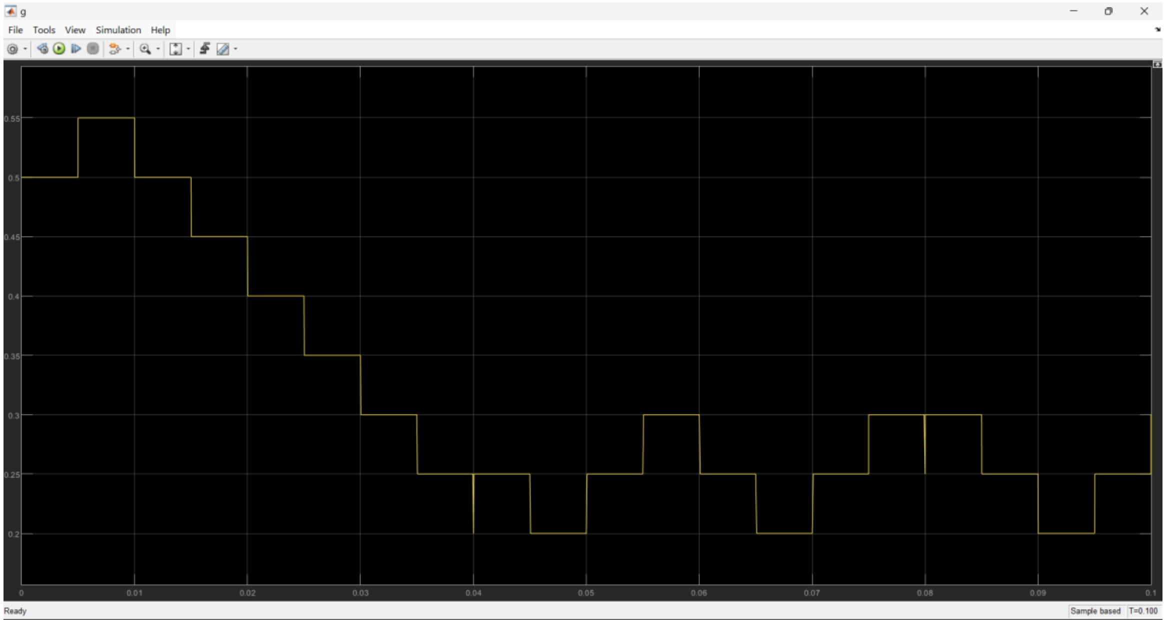
referenceVoltage = Vref; if
(voltage < referenceVoltage)
voltage = voltage + deltaV;
else voltage = voltage -
deltaV; end



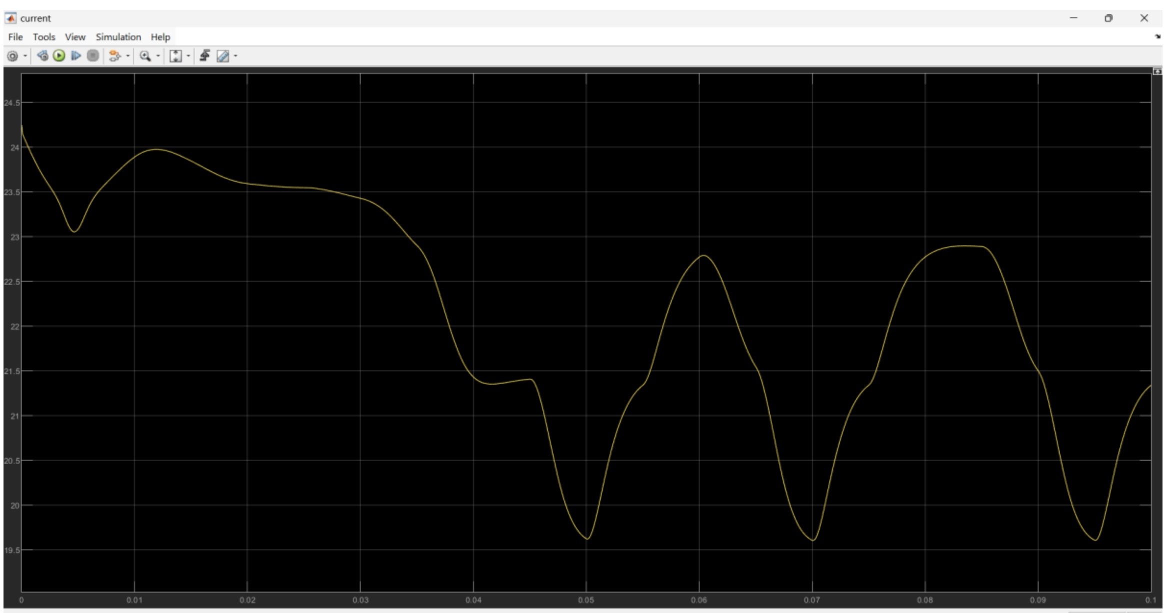
Flow chart of Constant Voltage Method

5. Simulation Results using P&O Algorithm

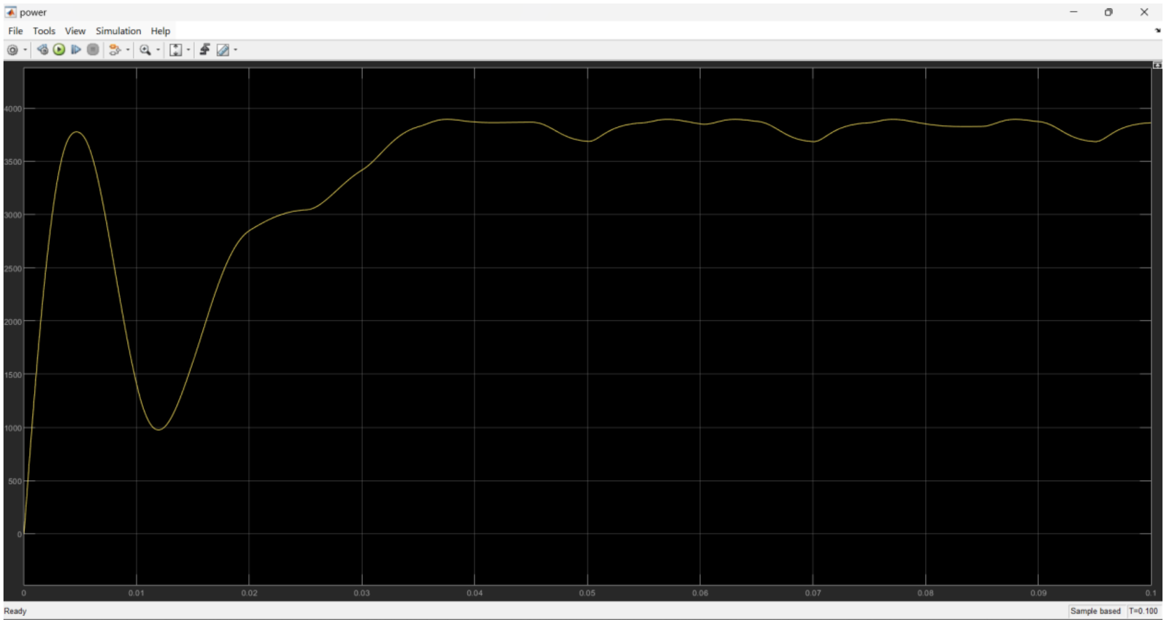
Duty Cycle



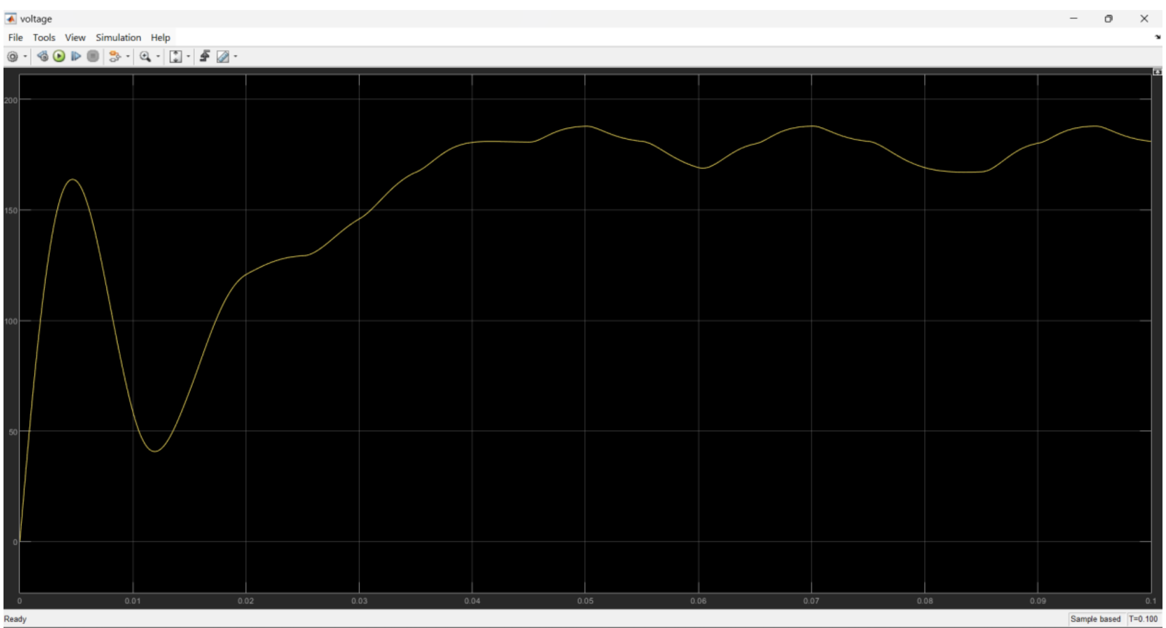
Output Current



Output Power



Output Voltage



Power Curve Observation:

The power vs. voltage (P-V) curve of the PV system typically shows the following:

- The algorithm finds a point close to the peak power.
- Oscillations can be observed around this point.

6. Conclusion

In conclusion, MPPT algorithms are essential for optimizing solar battery charging systems, allowing PV modules to operate at their maximum power points even under varying environmental conditions. The Incremental Conductance (INC) method is considered the most effective due to its ability to track rapidly changing irradiance and provide stable, highefficiency output. Comparatively, P&O and HC offer simpler implementations but may suffer from increased oscillations. CV provides stability but lacks dynamic optimization. The study evaluates the effectiveness of various MPPT algorithms in solar battery charging systems, comparing their efficiency, stability, and responsiveness under different environmental conditions. The key takeaway is that MPPT algorithms significantly enhance the performance of solar battery chargers by ensuring that the photovoltaic system operates at or near the maximum power point, improving both energy harvesting and battery longevity. Ultimately, the choice of MPPT algorithm depends on the specific application and environmental conditions. Incremental Conductance stands out as the best overall performer, while P&O and Hill Climbing offer simpler alternatives that may be beneficial in certain cases. Constant Voltage remains a viable option for applications where stability is prioritized over dynamic power optimization. Future work could explore hybrid MPPT solutions that combine the strengths of these algorithms to further optimize solar energy systems