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MPPT Techniques for Photovoltaic System: Modeling and Simulation

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A B S T R A C T

The specific aim of this work is to investigate the overall performance of solar power plant on implementing a customized algorithm. Nowadays, PV generation is widely accepted and becoming the most popular energy source due to certain characteristics like, minimal maintenance, no noise and environmental friendliness etc. PV cells being the fundamental component of PV system are connected to form PV array. The variation in load, environmental condition and weather condition influences PV array and ultimately the efficiency of conversion is reduced. Thus, it becomes very essential to find the power (peak) so that energy generation during variation of load can be maximize. This paper states and proposes modelling and simulation of array by engagement of MPPT (Maximum Power Point Tracking) model. The main components for PV system include, PV array, controller (MPPT) and converter those can be impacted and controlled with the help of various conventional and widely accepted methods. In this work three methods/algorithms namely, P&O, incremental conduction and adaptive VS based (voltage-sensor-based) MPPT method are tested individually for given load condition and later the proficiency of most effective method is stated with valid comparison of results gained in simulation.

Keywords:*Maximum. Power Point Tracking. (MPPT), PV Array, Photovoltaic (PV) Cell, SEPIC converters*

1. Introduction

MPPT algorithms are essential to enhance the performance and efficiency of solar plant. Various conventional methods and algorithms have been opted by number of scholars. Few of them are more often utilized due to their ease of installation, shorter time to follow the MPP, and other cost considerations. As MPP fluctuates continually under suddenly changing weather circumstances (irradiance level), the perturbation and observation approach considers it as a just shift in MPP leading to disturbances thus occasionally calculates incorrect MPP [1]. The Incremental Conductance technique, on the other hand, avoids this difficulty since it calculates MPP using two voltage and current samples. However, instead of being more efficient, the algorithm's complexity is much larger than the prior one, increasing the cost of implementation. As a result, we must strike a balance between intricacy and efficiency. It can be observed that the converter has an impact on the system's efficiency. A buck topology is often the most complex, followed by a buck-boost topology, and finally a boost topology. Another analogue technology, TEODI, is also highly successful when many solar modules are linked parallelly [2]. The PV generation is affected when the attributes of PV modules are impacted atmospheric condition, temperature of air and solar insolation [3]. The overall efficacy of PV generating system is estimated with the help of operating point on the characteristics curve of PV module. Several novel approaches have been developed and implemented to enhance the overall efficiency of PV system [4]-[7].PV panel characteristics and PV cell modelling are initially explored for the detailed study. A power conditioning device is used to demonstrate the basics of photovoltaic energy conversion. It concludes by identifying thegoals, addressing its rationale, and describing it briefly. PV generation helps the utilities to predict the future power demands while simultaneously reducing noise, emission of hazardous gases and greenhouse gases [8]. The power electronic devices are implemented in PV system with the aim to maximize the generation of PV power. However, due to changes in various influencing conditions the output of PV cell or PV module is changed w.r.t the operating point [9] – [11]. Furthermore, when a PV system is partially or entirely shaded by trees, passing clouds, high buildings, or

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other circumstances, the entire or a portion of the Partial shading condition occurs. The PV curves for these conditions depicts multiple peaks [11] – [13]. Most of the conventional approaches can successfully monitor the point for MPP for various conditions but fails to give better performance for partial shading. As a outcome a voltage sensor based adaptive approach is preferred in this work. Following are the sequences that are followed for completion of this work.,

a. Develop and test a more efficient photovoltaic system.
b. Design and evaluate three MPPT controllers.
c. To compare their reactions in both stable and changing weather conditions.

2. MAXIMUM POWER POINT TRACKING METHODS AND ALGORITHMS

Out of all the solar radiations received to the solar panel, only 40 % of it is actually converted to get an electrical energy. The overall efficacy of solar panel is boosted with the help of MPPT techniques. According to the concept of Maximum Power Transfer theorem, the gained output seems to be maximum only when the source and load impedance are identical. In PV system, the matching of load and source impedance is done by regulating the converters duty cycle.The point for maximum power can be tracked using variety of methods. The following are a few of the most prevalent techniques.

1. Incremental Conduction
2. Pertub and Observe approach
3. Neural Networks
4. Fuzzy Logic.
5. Short circuit current (Fractional) method.
6. VS based adaptive method
7. Open circuit voltage (Fractional) Method.

The selection of method is done by temporal complexity required to track the MPP, as well as the cost and convenience of implementation. Few of these methods are summarized below.

2.1 Perturbation and Observation Approach

The Perturb and Observe technique is a well-known hill-climbing tactic for a variety of reasons. To begin with, it is the simplest MPPT algorithm, as it just uses one voltage sensor. As a consequence, it's a quick, low-cost, and easy-to-use option. Despite the other MPPT algorithms, the P&O method has a quick computing time and reduced processing complexity since it does not need any mathematical computations. A simple comparison of current and previous voltage and power values is all that is necessary. As a result, P&O can immediately discern which side of the knee point the current level is on and adjust the voltage accordingly. When dealing with a complex system like a PV array, however, this simple method has drawbacks. The first drawback of this method is that the voltage level never remains constant, even when the MPP is close to the power level, due to the way it operates. The algorithm is unable to prevent itself from causing disruption. It decreases the perturb magnitude as it approaches the MPP, but it still loses a lot of power compared to the other methods. Another disadvantage of using P&O is how it responds to ever-changing weather conditions [14]. As the weather changes and the irradiance striking the panel's surface rises, the MPP automatically adjusts to the right, as shown in Figure 1.

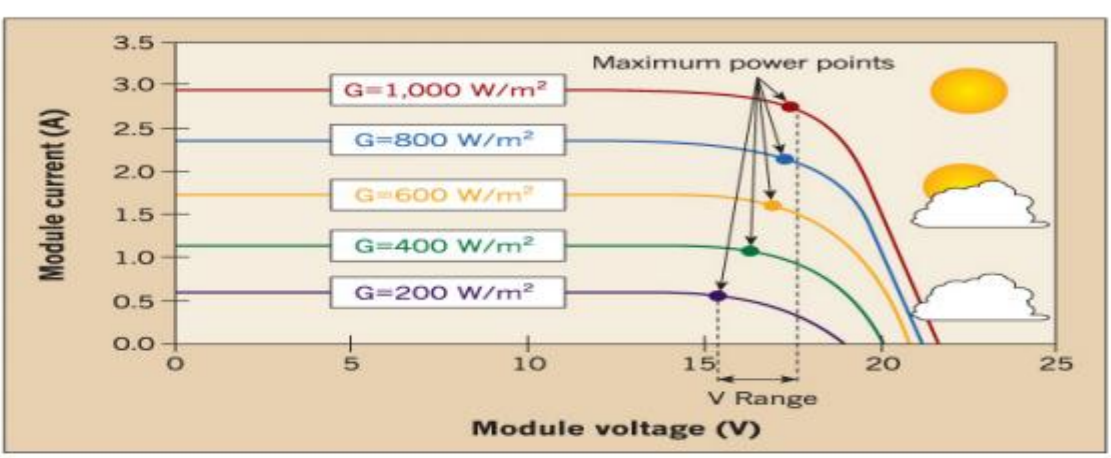


Figure 1: MPP voltage shift after irradiance variation [14]

The difference in voltage between the 200-W per sq meter and 1,000-W per sq meter irradiances isn't large, but it's enough to trick the algorithm. When the MPP shifts to the right or travels farther away from the algorithm's point of view, the algorithm interprets this as a change caused by the perturbation and causes the next cycle to proceed in the incorrect direction, away from the MPP. Small perturbations result in slow tracking speed, but big perturbations cause significant state oscillations.The perturbations must be lead in this operation; as a result of optimization, the system will wobble around the MPP, causing some power loss. Furthermore, while conducting the tracking step, it is difficult to account for both reaction speed and tracking precision. If the step size is too small, the search will take longer, and if the step size is too high, the search will quickly oscillate. It is difficult to follow changes in the external environment, which might lead to the "false positive" phenomenon [14].

2.2 Incremental Conduction Method

The Incremental conductance (IC) approach was the first to overcome the disadvantages of the P&O method. The P&O technique will keep oscillating to come near to and find the MPP throughout changing weather conditions. However, with INC, no oscillations are required, and the algorithm will rapidly increase or decrease the voltage until it reaches the zero slope, which is the MPP, significantly lowering computation time. Another benefit is the enhanced precision with which MPP can be tracked. Unlike P&O, which oscillates about the MPP, INC can pinpoint where the MPP is, making it more efficient. INC's two downsides are its intricacy and the likelihood of inaccuracy. Despite being simpler than Fuzzy logic, INC is more complex to implement than P&O. In addition, while MPPT isn't the best algorithm to use, it outperforms P&O in terms of performance. When it comes to MPPT algorithms, there is always a trade-off between speed and efficiency on one side, and complexity and cost on the other. The voltage fluctuates, the power value will be altered while it is at its peak or lowest value. As a consequence, to increase power, the voltage can be applied in the same direction or in the opposite direction. This technique is more accurate than the P&O because it can track rapidly changing irradiance conditions. Oscillations in this MPP can occur due to noise, resulting in greater calculation time and a lower sampling frequency from the approach [13]. The size of the step determines the tracking speed; when the step size is large and the system responds rapidly, the solar system may not function at its real maximum power point, resulting in fluctuation around the maximum power point [14].

2.3 Adaptive Voltage-Sensor Based Approach

To decrease tracking time and power loss in the steady state, an adaptive voltage sensor based MPPT with variable scaling factor is described. Sensors provide several benefits over traditional measurement methods, including decreased size and weight, increased safety, increased accuracy, non-saturability, and environmental friendliness. In general, voltage sensor based MPPT is done using direct duty cycle control approach since it is developed based on QD characteristics and the step size D is a fixed number. Larger D values improve dynamic performance, while huge steady-state oscillations reduce tracking efficiency.

$$\boldsymbol{dV_{pv} = V_{pv}(k) - V_{pv}(k-1)}$$

$$\boldsymbol{dD = D(k) - D(k-1)}$$

The operational point is found by assessing Q and incrementing or decrementing the duty cycle by D based on the sign of Q, as illustrated in equation. The duty cycle will be raised by D if Q is positive, and it will be lowered by D if Q is negative. D is used directly when changing the duty cycle.

$$\boldsymbol{D(k+1) = D(k) \pm \Delta D}$$

Variations of Q utilizing experimental data for a change in insolation from 0 to 270 W/m2 and a change in insolation from 270 to 480 W/m2 in the start-up example

3. System Development

This section shows how to use MATLAB/ Simulink to simulate a PV array. In addition, the Voltage, Current, and Power properties of the designed PV array are described in this section. The spectral dispersion of solar radiation affects the efficiency of a PV device. As a load, the variable resistances are linked. The Voltage, Current, and Power characteristics curve is plotted by adjusting the resistance from open circuit voltage to short circuit voltage and recording the related current and power. Figure 2 indicates the model developed and simulation results gained without implementation of any of the MPPT algorithm or method.

The PV module receives the irradiance data as a step input. The MPPT algorithm block receives the values of solar panel characteristics such as voltage, current, and power as input. The control algorithms make up the MPPT algorithm block. These algorithms are used for direct duty ratio control, which adjusts the duty ratio to run at maximum power at all times for varied irradiance levels. The duty ratio is used as an input for the boost converter, which keeps the solar cells' peak output. The boost converter will then be linked to the load at At [1000 800 400 700 1000], Voc – 22.25, Isc- 8.66.

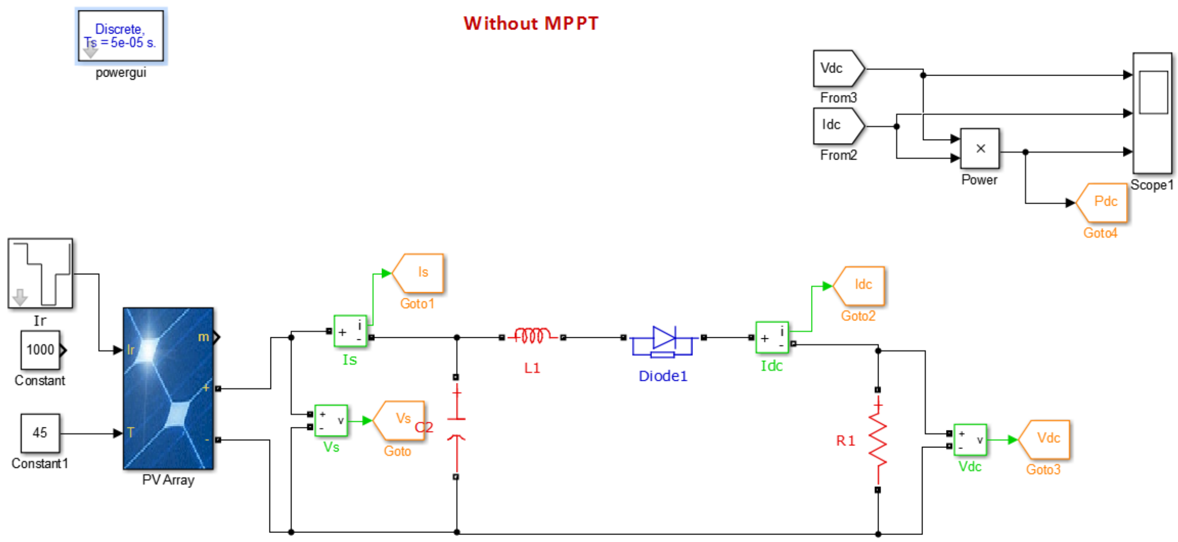


Figure 2: Simulation without MPPT

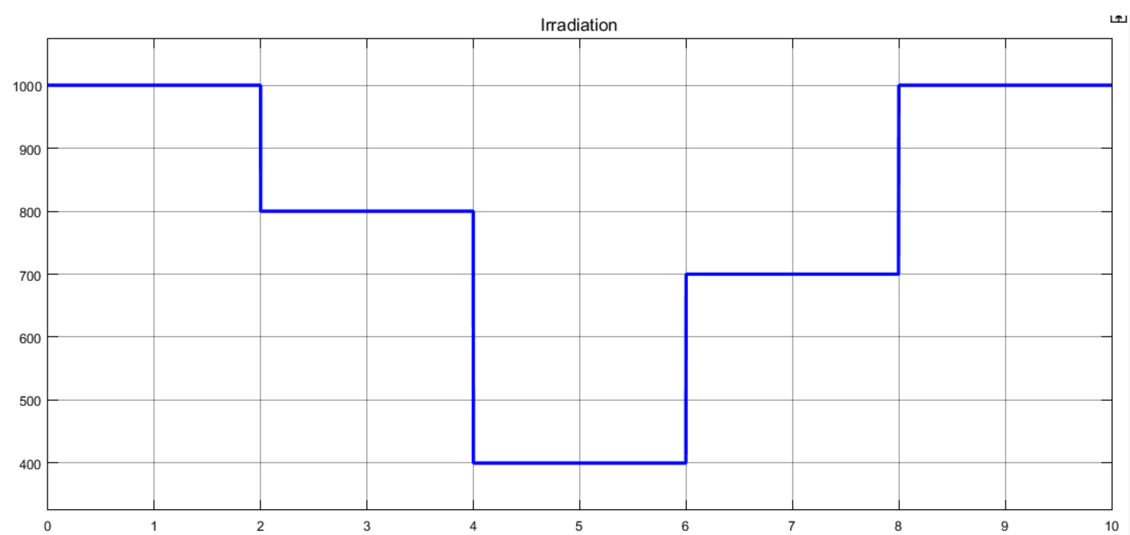


Figure 3: Irradiation

To achieve the necessary voltage and current, the PV modules can be linked in series and/or parallel. The duty ratio waveforms are seen while the simulation model is evaluated for various irradiance values. The duty ratio's optimal response is a three-step waveform, since it oscillates around two points as it approaches the maximum power point. The method is designed in such a way that the duty ratio value adjusts automatically whenever the irradiance values change. Figure 4 shows the results gained for voltage, current and power for the developed system without implementing MPPT algorithm.

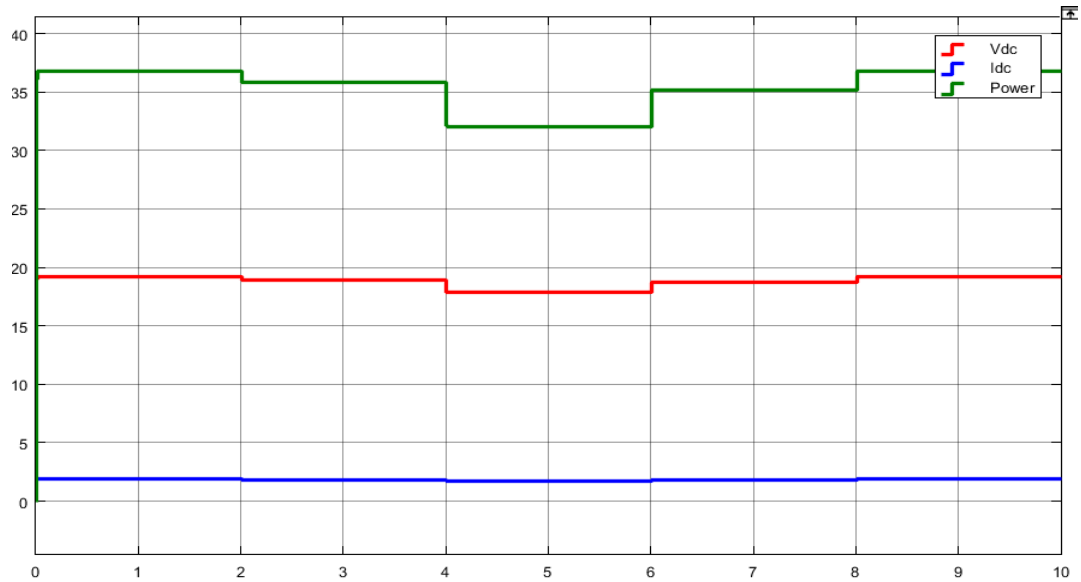


Figure 4.: Result-Voltage, Current & Power

4. Performance Analysis

A. Implementing Incremental Conduction Algorithm

Figure 5 shows a Simulink model of a PV array with a dc-dc boost converter and the Inc MPPT algorithm, which is simulated under the identical conditions as the P & O method. The INC MPPT method's step size is usually fixed.

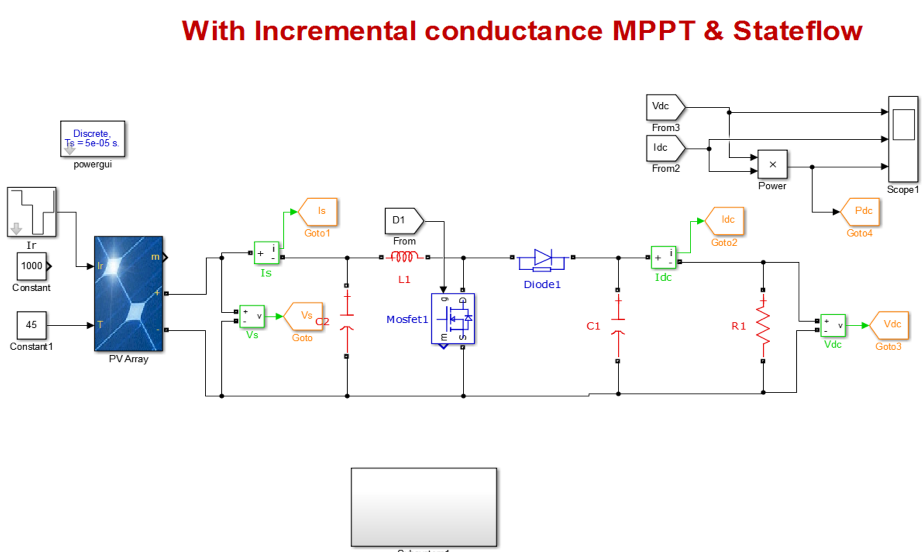


Figure 5: With Incremental conductance MPPT

The increased power taken from the PV array with a larger step size results in quicker dynamics but more steady state oscillations, leading in a lower efficiency. When the MPPT is running with a reduced step size, the situation is reversed. As a result, the MPPT with fixed step size should provide a good balance of dynamics and oscillations. Variable step size iteration can be used to tackle such a design challenge. The modified variable step size algorithm for the INCMPPT technique is utilized in this study to identify a simple and effective solution to increase tracking accuracy and tracking dynamics.If there is a fluctuation in the voltage while it is at its highest or lowest value, the power value will be influenced. As a result, the voltage can be applied in the same direction, or in the other way, to enhance power. Because it can follow quickly increasing and falling irradiance conditions, this approach is more accurate than the P&O. Due to noise and mistakes, oscillations can arise in this MPP, resulting in increased calculation time and a decreased sampling frequency from the method

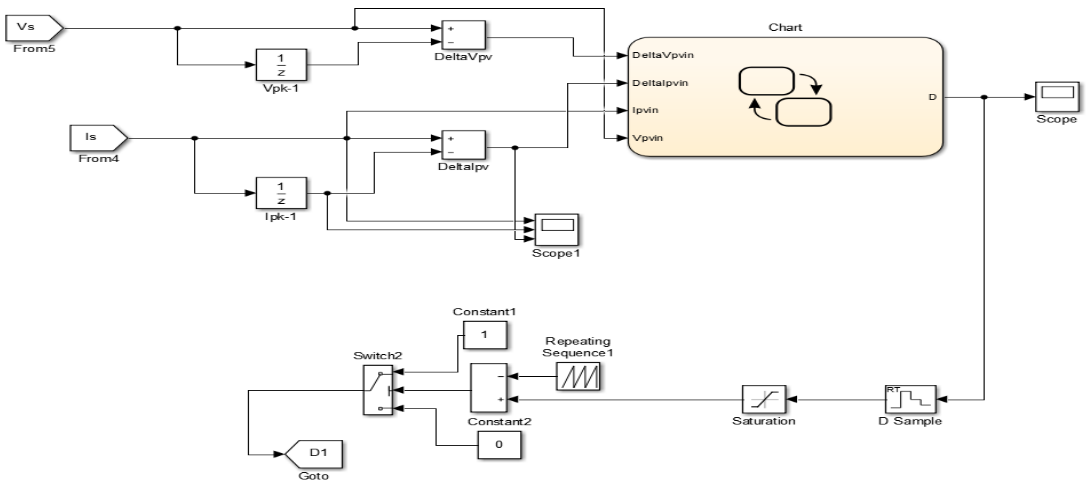


Figure 6: Controller of Incremental conductance MPPT

Figure 6 explains the incremental conductance algorithm's principle. The MPPT approach is done using a state flow diagram in MATLAB/Simulink. The state flow chart is a useful tool for visualizing logical event-based controllers and state machines. Figure depicts the state flow diagram for the incremental conductance MPPT approach. We'll be measuring both voltage and current at the same time. As a result, the inaccuracy caused by changes in insolation is no longer an issue. Because it does not induce steady state oscillations and enables accurate control under quickly changing air conditions, the incremental conductance approach is the optimum method. It can track the sun's maximum power.

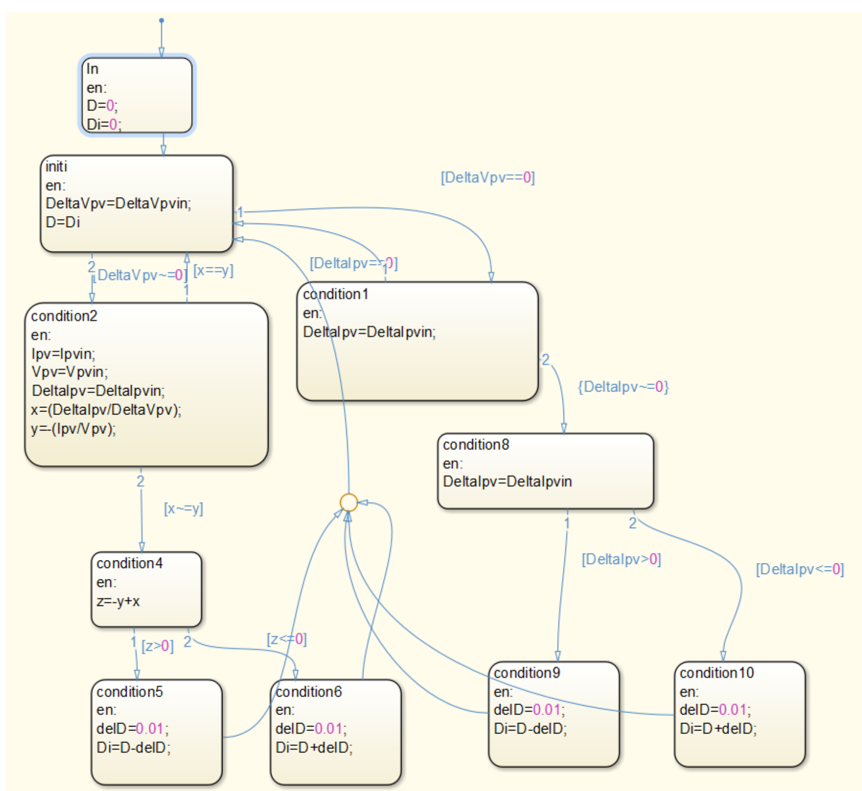


Figure 7: Controller Logic – With Incremental conductance

A simulation model of the PV system is created in MATLAB-SIMULINK to validate the feasibility and performance of the proposed enhanced variable step-size INR MPPT algorithm. The simulation configurations are same to compare the performance of the proposed approach with the fixed step-size INR MPPT method.

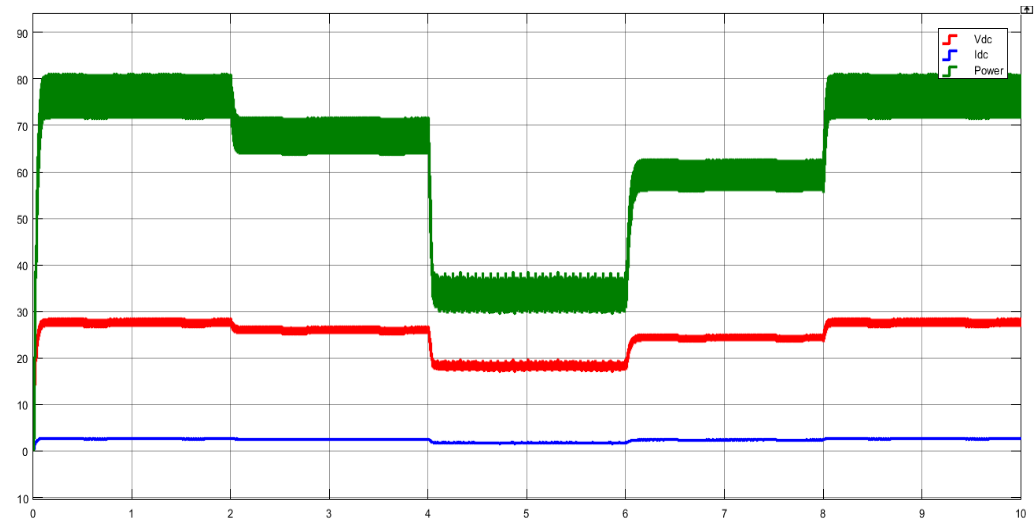


Figure 8: Result – Voltage, Current & Power

B. With Perturbation and Observation (P&O) MPPT

The 70W PV array is included in the MATLAB subsystem, as are the equations needed to represent it. The MATLAB subsystem combined with PV array replaces the DC voltage source of the dc-dc boost converter. The duty ratio of a dc-dc boost converter is changed, which changes the PV array current and, as a result, the PV array voltage. The MPPT subsystem is used to compute the power at various duty cycles and compare it to the power at the present operating point. The duty cycle either rises, falls, or remains constant. The Simulink model of a PV array with dc-dc boost converter and P&O MPPT is shown in Figure 9.

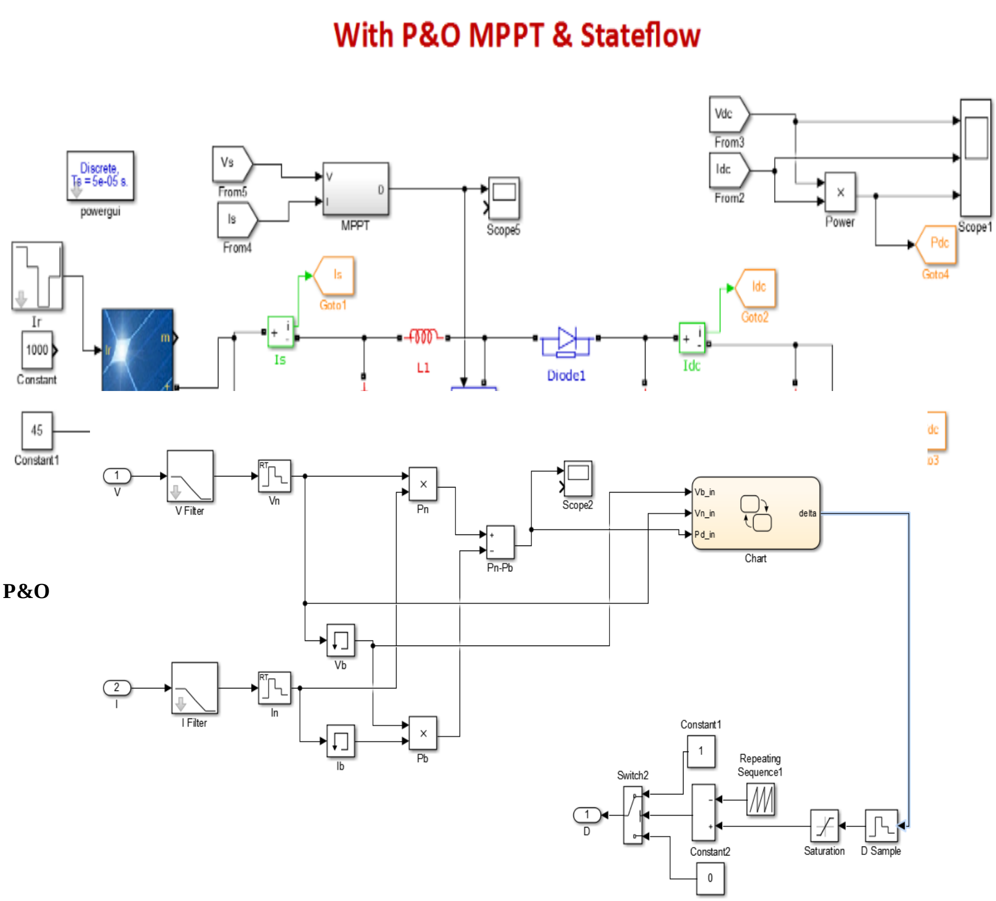


Figure 9: With P&O MPPT

Figure 10: Controller of P&O MPPT

The numerous graphs depict the changes in voltage, current, and power over time. Temperature and irradiance are altered, and voltage, current, and power characteristics curves are displayed against time. The plots show that when the irradiance increases, the voltage increases, and the output waveform changes. As a result, there is a direct relationship between the output voltage and the irradiance and temperature. When the temperature is raised, the PVG produces more electricity.

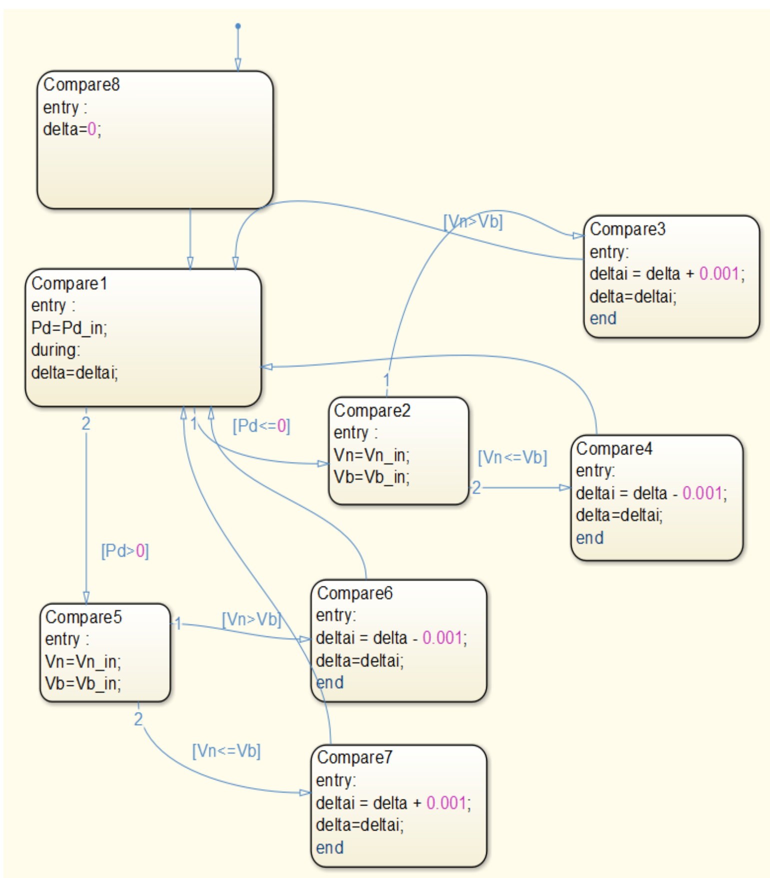


Figure 11: Logic P & O Controller

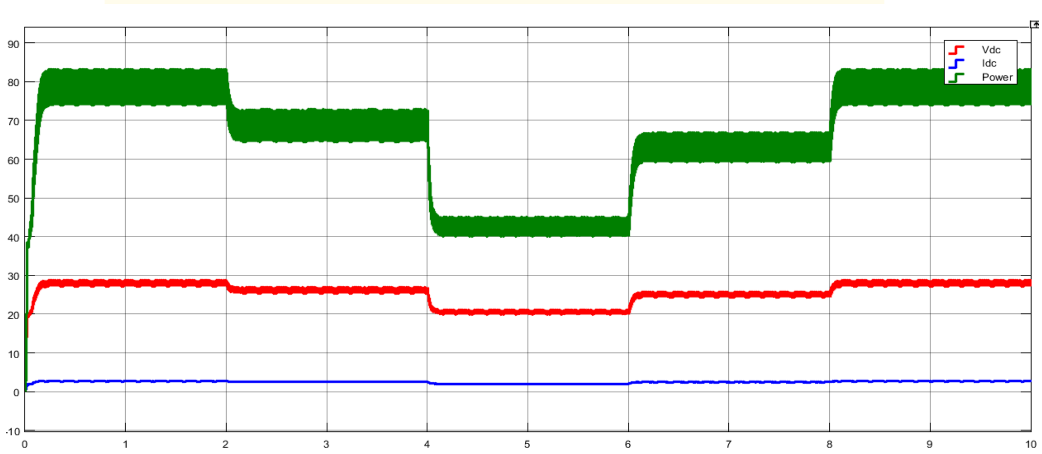


Figure 12: Result – Voltage, Current & Power

C. Adaptive Voltage-Sensor-Based MPPT & simulation

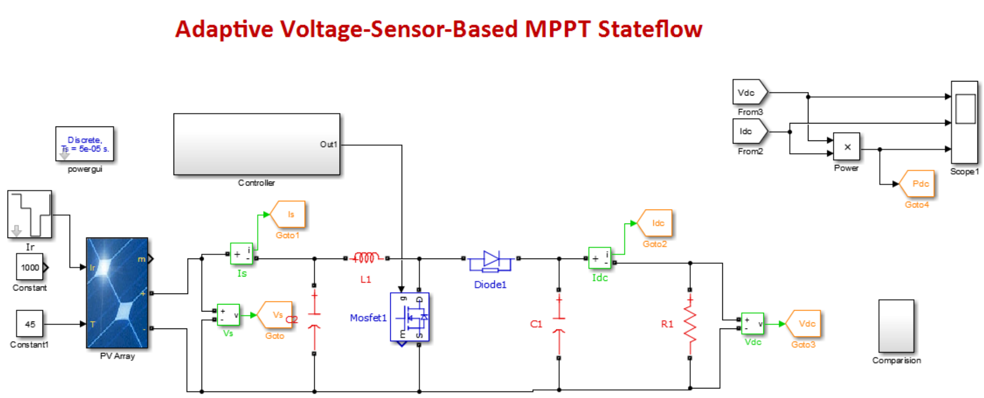
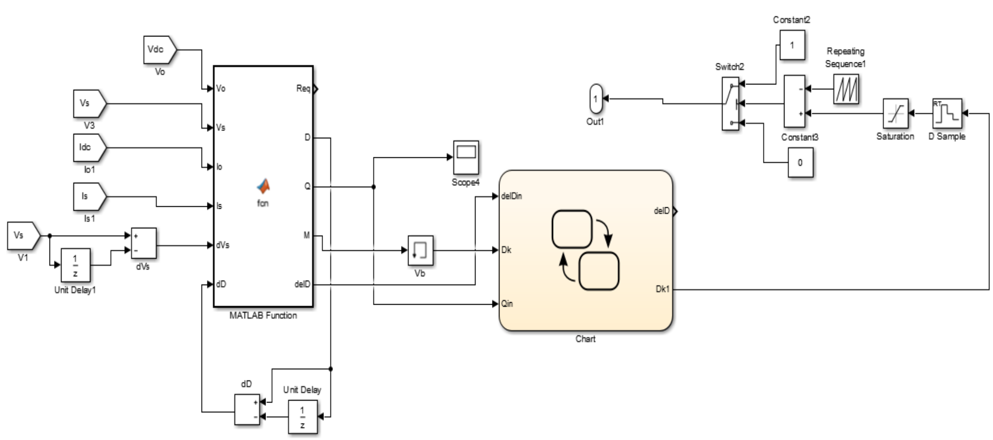


Figure 13: Adaptive Voltage-Sensor-Based MPPT



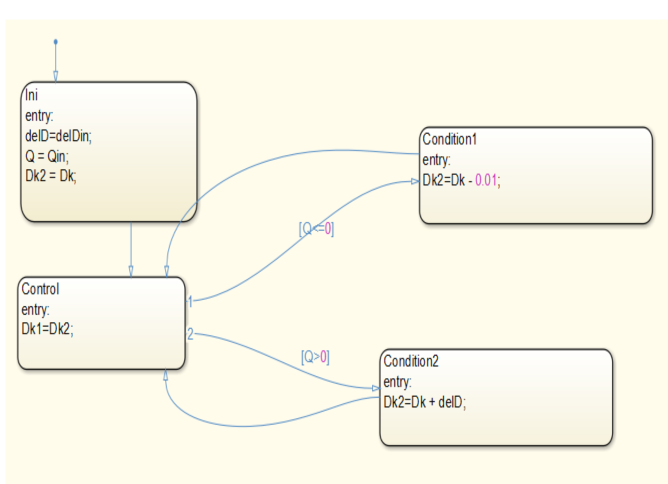


Figure 14: Controller of Adaptive Voltage-Sensor-Based MPPT

Figure 15:Controller Logic- Adaptive Voltage-Sensor-Based

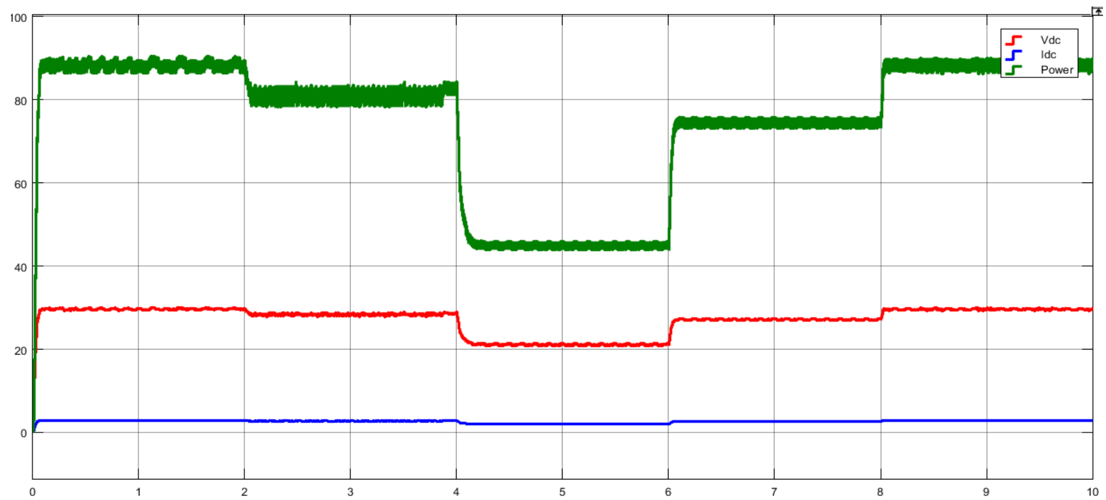


Figure 16: Result of Controller Logic

D. A Comparative Analysis

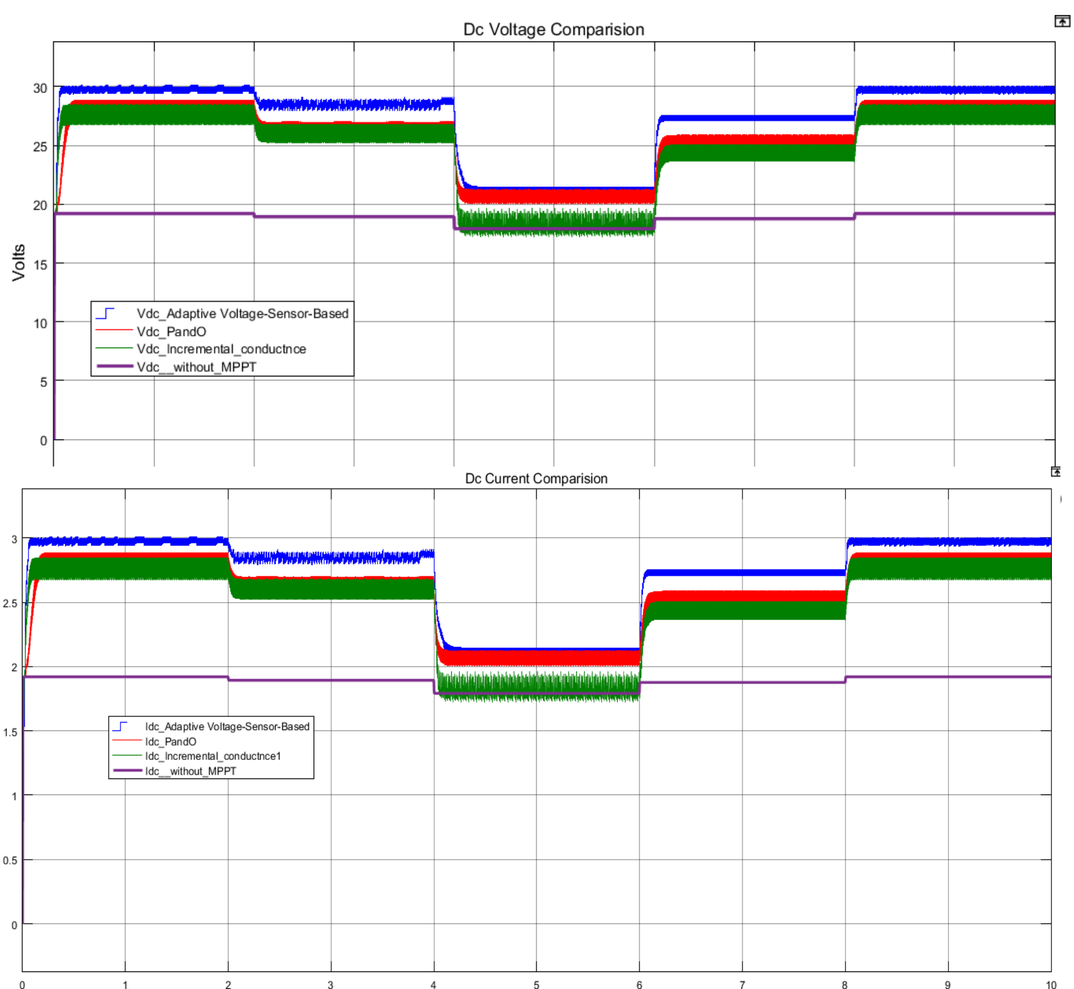


Figure 17: Voltage waveform

Figure 18: Current waveform

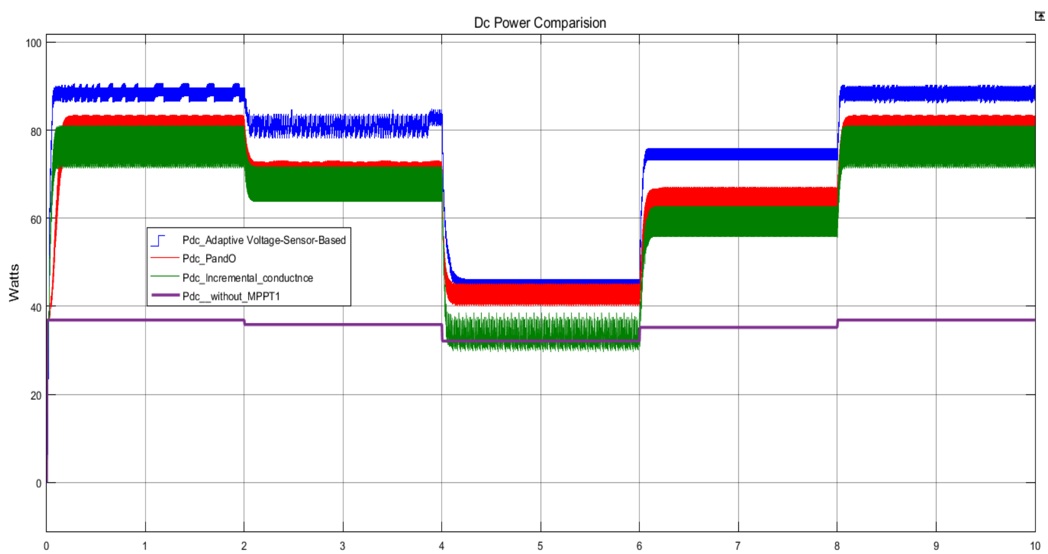


Figure 19: Power waveform

5. Conclusion

This thesis implements an adaptive voltage-sensor-based MPPT algorithm for SEPIC converters with variable scaling factor and direct duty cycle control technique. The suggested system has been constructed, and the MPPT control's functioning has been shown. The modelling and experimental findings show that the suggested system can track the maximum power from the PV module; moreover, this tracking algorithm's benefits include steady-state two-level operation and drift-free phenomena. As a result, this technology enhances PV system efficiency and lowers power loss in steady state.

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