MPPT For Microgrid Connected PV System Using ANN, Incond And P&O Techniques

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Abstract

The paper examines MPPT algorithms based on P&O, InCond, and ANN with a boost converter that supplies constant output to the load in a PV stand-alone system operating under varying irradiance conditions. To generate the duty cycle of a converter, the Perturb and Observe (P&O), Incremental Conductance (InCond), and Artificial Neural Network (ANN) algorithms are utilised. MATLAB and Simulink are used to conduct simulation research on the PV system. As the world approaches an alarming energy crisis, the demand for renewable energy sources increases daily. India is aiming to develop 20 GW of solar power by the year 2022. In a tropical nation like ours, solar energy is an essential source of energy. The principal issue with solar PV systems is their low efficiency and high initial investment. In this research paper, we discuss the various varieties of MPPT techniques in order to devise a method for obtaining the utmost possible output from a PV module and supplying it to the grid in order to increase the overall efficacy.

Keywords: Perturb and Observe, Incremental Conductance, Photovoltaic System, Artificial Neural Network,MATLAB Simulink, Maximum Power Point Tracking etc.

1. Introduction

Fossil fuels negatively impact the climate, rendering them unsustainable. Therefore, there is an immediate need to investigate this issue so that we can move towards sustainable development. The concept of utilising solar energy has existed for a very long time [1, 2]. Solar collectors are the fundamental devices used to concentrate the sun's beams on their surfaces and convert them into energy. Solar energy is an excellent and efficient method to power rural areas without expensive power lines. Solar energy, which is a renewable, emission-free source of energy, has a high energy capacity that can be utilised in a variety of applications [3]. Increasing technological advancements have made solar energy systems widely available for residential and industrial use with minimal maintenance costs.A standalone PV (photovoltaic) system, also known as an off-grid solar system, is a solar power system that operates independently from the electrical grid. It consists of solar panels, a charge controller, batteries for energy storage, and an inverter to convert DC (direct current) power from the panels into AC (alternating current) power for use in household appliances and devices [4, 5].Analyzing a standalone PV system involves assessing several key aspects:

1.1. Solar Panels: The efficiency and capacity of the solar panels determine the amount of electricity generated. Higher efficiency panels convert more sunlight into electricity. The capacity should be chosen based on the energy demand and available sunlight in the location.

1.2. Battery Bank: The battery bank stores excess solar energy generated during the day for use during periods of low or no sunlight. The battery capacity should be sufficient to meet the energy requirements during nights or cloudy days. Factors to consider include the depth of discharge, battery chemistry (lead-acid, lithium-ion, etc.), and maintenance requirements.

1.3. Charge Controller: The charge controller regulates the flow of electricity between the solar panels and the batteries, preventing overcharging or deep discharging. It ensures optimal charging and protects the batteries from damage. The charge controller type (PWM or MPPT) should be selected based on system size and solar panel configuration.

1.4. Inverter: The inverter converts DC power from the batteries into AC power for household appliances. The inverter capacity should be chosen to handle the maximum power demand. Additionally, the inverter may have features like surge protection and grid-forming capabilities for certain applications.

1.5. Load Assessment: It is essential to evaluate the energy requirements of the loads or appliances that will be powered by the system. This analysis helps determine the system size, battery capacity, and inverter requirements. Energy-efficient appliances can reduce the overall energy demand.

1.6. Solar Resource Assessment: Understanding the solar irradiation and weather patterns in the installation area is crucial for estimating the system's energy generation potential. Factors such as shading, orientation, and tilt angle of the panels affect the overall system performance.

1.7. System Sizing: Properly sizing the PV system involves calculating the total energy demand, estimating the solar energy generation capacity, and determining the battery capacity needed to meet the load requirements during periods of low sunlight. Oversizing the system can help account for inefficiencies and provide a buffer during cloudy days.

1.8. Economic Analysis: Assessing the economic viability of a standalone PV system involves considering the initial investment costs, including equipment and installation, as well as ongoing maintenance and operational expenses. Additionally, factoring in the potential savings from reduced or eliminated electricity bills can determine the payback period and return on investment.

1.9. System Monitoring and Maintenance: Implementing a monitoring system allows for real-time performance tracking, early fault detection, and maintenance optimization. Regular maintenance, including cleaning panels, checking connections, and battery maintenance, ensures the system operates at peak efficiency.

1.10. Environmental Impact: Analyzing the environmental benefits of a standalone PV system involves considering the reduction in greenhouse gas emissions, dependence on fossil fuels, and the system's contribution to sustainability and renewable energy goals.

These factors collectively contribute to the analysis of a standalone PV system, helping assess its feasibility, performance, and economic viability for a specific location and energy demand [6-10].Maximum Power Point Tracking (MPPT) is a critical technique used in autonomous photovoltaic (PV) systems to optimise the power output from the solar panels. MPPT guarantees that the PV system operates at the maximum power point (MPP) of the current-voltage (I-V) characteristic curve of the solar panel, regardless of atmospheric conditions and capacity requirements. There are numerous MPPT techniques, each with their own advantages and disadvantages [6]. In this article, Authorsanalysed some of the most prevalent MPPT techniques used in standalone PV systems.

1.11. Perturb and Observe: P&O is one of the most frequently employed MPPT techniques. It operates by perturbing the PV system's operating point and observing the resulting variation in power output. On the basis of this observation, the algorithm modifies the operating point to enhance power. Implementing P&O is straightforward and requires few computational resources. Nevertheless, it is susceptible to oscillations around the MPP, particularly under rapidly changing irradiation conditions.

1.12. Incremental conductance (IncCond):It is a method of MPPT that considers both the power and conductance (slope) of the I-V curve. The direction of the MPP is determined by comparing the conductance of the PV system with the instantaneous change in conductance. IncCond provides quicker tracking than P&O without oscillations around the MPP. However, it is computationally more difficult and may require additional hardware.

1.13. Fractional Open Circuit Voltage (FOCV): The FOCV is a straightforward and inexpensive MPPT technique that uses the open circuit voltage (Voc) of the PV panel. The MPP voltage is estimated by multiplying the Voc by a fractional value. FOCV is straightforward to implement and appropriate for low-power PV systems. However, it may not be as precise as other MPPT methods and is susceptible to temperature fluctuations.

1.14. Constant Voltage (CV): The CV MPPT technique maintains a constant voltage across the PV system and optimises power transmission by modifying the duty cycle of a DC-DC converter. It is commonly used in battery-powered systems. CV offers reliable operation and efficient charging, but it requires a precisely defined battery voltage and may not react well to varying irradiation conditions.

1.15. Model Predictive Control (MPC): MPC is a more advanced MPPT technique that utilises a mathematical model of the PV system to predict the optimal operating point. Optimising power output involves considering multiple factors, including solar irradiance, temperature, and demand conditions. MPC provides accurate monitoring and can effectively manage dynamic changes. However, it requires intricate modelling and computational resources, which makes it more appropriate for larger-scale PV systems [11-13].Considerations such as system size, cost, complexity, desired efficacy, and environmental conditions influence the selection of the MPPT technique. Due to their simplicity of implementation, basic techniques such as P&O and FOCV are commonly used in small-scale PV systems. However, more sophisticated techniques such as IncCond and MPC are suitable for larger installations where efficiency and precise tracking are essential. To determine the most appropriate MPPT technique, it is crucial to evaluate the specific requirements and constraints of a standalone PV system[14, 15].

2. Literature Review

Chapman was one of the first papers considered for my project's foundation [16, 17]. Different MPPT techniques are discussed in this paper. There are only evaluations of MPPT techniques presented. The authors were well-versed in a variety of topics and utilised P&O, InCond, and ANN techniques for additional research. "Comprehensive approach to modelling and simulation of photovoltaic arrays" by Marcelo GradellaVillavla, Jones Rafael Gazoli, and Ernesto Ruppert Filho was the second paper cited by the authors. This allowed the authors to compare simulation outcomes for further improvement. In this P&O, InCond is clarified more thoroughly [18-20]. Taking the paper 'Comparison of ANN and ANFIS-based MPPT controllers for grid-connected PV systems" by Ankita Arora and Prerna Gaur into consideration, we went ahead with the artificial neural network-based MPPT algorithm. Sabir Mesalti's article "A New Neural Network MPPT Controller for PV Systems" served as the premise for this study [21, 22]. This paper uses training data from a system employing the P&O technique to train a neural network and then analyses the network's output. Similarly, for our project, neural network training data was derived from data obtained from a system employing the P&O technique [23, 25]. In regions without utility connections, photovoltaic (PV) systems are frequently used to produce electricity. To ensure the efficacy and efficiency of these systems, it is necessary to optimise the power output of the PV modules [26, 27].

A standalone PV system, also known as an off-grid solar system, is a solar power system that operates independently of the electrical utility. It consists of solar panels, a charge controller, batteries for energy storage, and an inverter to convert DC (direct current) power from the solar panels into AC (alternating current) power for household appliances and devices [28-30].Analysing a stand-alone PV system requires evaluating several crucial factors like choosing the correct solar panels [31]. The quantity of electricity generated is determined by the efficiency and capacity of the solar panels. Solar panels with greater efficacy convert more sunlight into electricity [32]. The capacity should be determined by the energy demand and the amount of available sunlight in the area.The battery bank retains excess solar energy generated during the day for use during low- or no-sunlight periods. The battery capacity should be adequate to meet energy demands during cloudy or night-time conditions. Consider the extent of discharge, battery chemistry (lead-acid, lithium-ion, etc.), and maintenance requirements when selecting a battery.The charge controller regulates the passage of electricity between the solar panels and the batteries, prohibiting overcharging and deep depletion. It ensures optimal charging and prevents damage to the batteries. The type of charge controller (PWM or MPPT) should be selected based on the size and configuration of the solar panel array [33, 34]. The inverter converts DC power from the batteries to AC power for use with household appliances. The capacity of the inverter should be chosen to accommodate the highest power demand. In addition, the inverter may include surge protection and grid-forming capabilities for particular applications.The energy requirements of the devices or appliances that will be powered by the system must be determined. This analysis aids in determining the necessary system size, battery capacity, and inverter specifications. Appliances that are energy-efficient can reduce the overall energy demand.Understanding the solar irradiation and weather patterns in the installation location is essential for calculating the system's energy production potential. The overall system efficacy is affected by factors such as shading, orientation, and tilt angle.Sizing the System Appropriately sizing the PV system requires calculating the total energy demand, estimating the solar energy generation capacity, and determining the battery capacity necessary to meet load requirements during periods of low sunlight. The system's oversizing can help account for inefficiencies and provide a cushion for cloudy days. Assessing the economic viability of a stand-alone PV system requires taking into account the initial investment costs, which include equipment and installation, as well as ongoing maintenance and operational expenses. In addition, the repayment period and return on investment can be calculated by calculating the potential savings from reduced or eliminated electricity expenditures.The implementation of a monitoring system permits real-time performance tracking, early defect detection, and maintenance optimisation. Regular maintenance, such as cleansing the panels, inspecting the connections, and maintaining the batteries, guarantees that the system operates at optimal efficiency.Analysing the environmental benefits of a stand-alone PV system requires taking into account the reduction in greenhouse gas emissions, the reliance on fossil fuels, and the system's contribution to sustainability and renewable energy objectives.Collectively, these factors contribute to the analysis of a stand-alone PV system, assessing its practicability, performance, and economic viability for a particular location and energy demand. Maximum Power Point Tracking (MPPT) is one of the main techniques used to maximise power output.Photovoltaic (PV) systems are frequently used to generate electricity in remote locations or regions without utility connectivity. Tracking the maximum power point (MPP) of the PV array is one of the main challenges in maximising the efficacy of a standalone PV system. Several techniques, including artificial neural networks (ANN), incremental conductance, and perturb and observe (P&O) algorithms, can be used to accomplish this. To optimise the power output of a standalone PV system, MPPT techniques such as artificial neural networks (ANN), incremental conductance (InCond), and perturb and observe (P&O) can be utilised. Let's analyse each technique in more detail [35-38]:

2.1 Artificial Neural Networks (ANN) are computational models that are inspired by the neural structure of the human brain. Using input variables such as solar irradiance, temperature, and voltage and current measurements, an ANN can be trained to predict the optimal operating point of the PV system in the context of MPPT. The ANN is trained using a dataset consisting of multiple input-output pairs that represent varying operating conditions. Once trained, the ANN can estimate the maximal power point and make the necessary adjustments to the system. ANN-based MPPT algorithms use neural networks' ability to learn and determine the optimal operational conditions for optimum power output. In this method, the ANN is trained using a dataset containing various environmental and operating parameters, including solar irradiance, temperature, and PV array voltage and current. Based on real-time measurements, the ANN learns the relationship between these inputs and the corresponding MPP and then predicts the optimal operating point. Even in rapidly changing environmental conditions, MPPT algorithms based on ANN can provide accurate monitoring.Advantages: ANN can manage complex and nonlinear input-output relationships. It can adapt to shifting environmental and system conditions. MPPT based on ANN can provide precise monitoring and rapid convergence. MPPT algorithms based on ANN can adapt to varying environmental conditions and effectively monitor the MPP in nonlinear and dynamic systems. They can be trained to optimise system performance under particular operating conditions, resulting in increased productivity. ANN algorithms have the ability to manage intricate relationships between input parameters, allowing for an accurate prediction of the MPP. Training an ANN requires a substantial quantity of data and computational resources. An ANN's efficacy is contingent on the quality and representativeness of its training dataset. ANN-based MPPT may have scalability and generalisation limitations for various PV system configurations. ANN-based MPPT algorithms require a large quantity of training data to accurately understand the system's behaviour, which can be time-consuming and resource-intensive.Designing and training a neural network can be difficult and may necessitate machine learning expertise.The computational complexity of the ANN algorithm may be greater than that of other MPPT techniques, necessitating an increase in processing capacity.

2.2 Incremental Conductance (InCond): The Incremental Conductance technique is a popular MPPT technique that measures the rate of change of PV module conductance. It compares the instantaneous conductance to the preceding conductance to ascertain the operating point's adjustment direction. Incremental conductance is a widely employed MPPT algorithm that utilises the PV array power derivative with regard to voltage to monitor the MPP. It evaluates the variation in power in relation to the voltage and adjusts the operating point accordingly. The algorithm implies the MPP has been attained when the power change becomes negative. The algorithm is founded on the premise that the incremental conductance (dP/dV) is zero at the MPP.InCond is a straightforward and widely used technique.It has high tracking efficacy in environments that undergo rapid change. Effectively manages partial shading conditions. Incremental Conductance MPPT is a basic and effective technique that can rapidly monitor the MPP, making it suitable for environments that undergo rapid change.This algorithm is extensively used and can be found in numerous commercial MPPT controllers. The computational complexity of the incremental conductance algorithm is modest, necessitating less processing capacity.InCond may oscillate around the maximal power point under certain conditions, particularly when the system operates near the knee point of the power-voltage curve. It requires accurate measurements of voltage and current, which may result in measurement errors. Incremental Conductance When a PV array operates in close proximity to local extremes or under partial shading, the MPPT may have difficulty accurately monitoring the MPP.Due to noise or measurement errors, the algorithm may experience oscillations around the MPP, necessitating additional filtering or damping techniques.It relies on the precision of the system's measurements, such as voltage and current sensors, to calculate the derivative and make the necessary adjustments.

2.3 Perturb and Observe (P&O): P&O is a prevalent MPPT technique that modifies the operating point by perturbing the voltage or current and observing the resulting power change. The algorithm continues in the same direction if the power increases; otherwise, it reverses the perturbation. The algorithm attempts to identify the optimal voltage or current to maximise power output.This popular MPPT technique modifies the operating point by perturbing the duty cycle of a DC-DC converter and observing the resulting change in power. It compares the output power at each perturbation stage to determine the adjustment direction. P&O is comparatively simple to implement and requires fewer computational resources, which are both advantages. It is capable of achieving a high level of monitoring efficacy under steady-state conditions.P&O is appropriate for inexpensive and low-power PV systems.P&O may exhibit oscillations around the maximal power point, particularly when irradiance levels change abruptly.It may not perform optimally under partially shaded conditions or when the power-voltage curve has multiple local maxima. P&O MPPT is relatively straightforward to implement and requires minimal computational resources. It can effectively monitor the MPP under constant-state and uniform environmental conditions. P&O algorithms have been extensively studied and implemented, and their behaviour is well understood. P&O MPPT can experience steady-state oscillations around the MPP under swiftly varying or non-uniform input conditions. In conclusion, each MPPT technique has its own advantages and disadvantages. ANN-based MPPT has the benefits of adaptability and precision, but it requires substantial computational resources and training data. InCond is resistant to varying environmental conditions and shading, but it may oscillate near the maximal power limit. P&O is simple and appropriate for low-cost systems, but it is susceptible to oscillations and suboptimal performance in certain circumstances. The choice of MPPT technique is determined by the specific requirements, system characteristics, and tradeoffs between complexity, precision, and cost [39, 40].

Figure 1: Simulink model of P & O based MPP Tracker with PV Panel

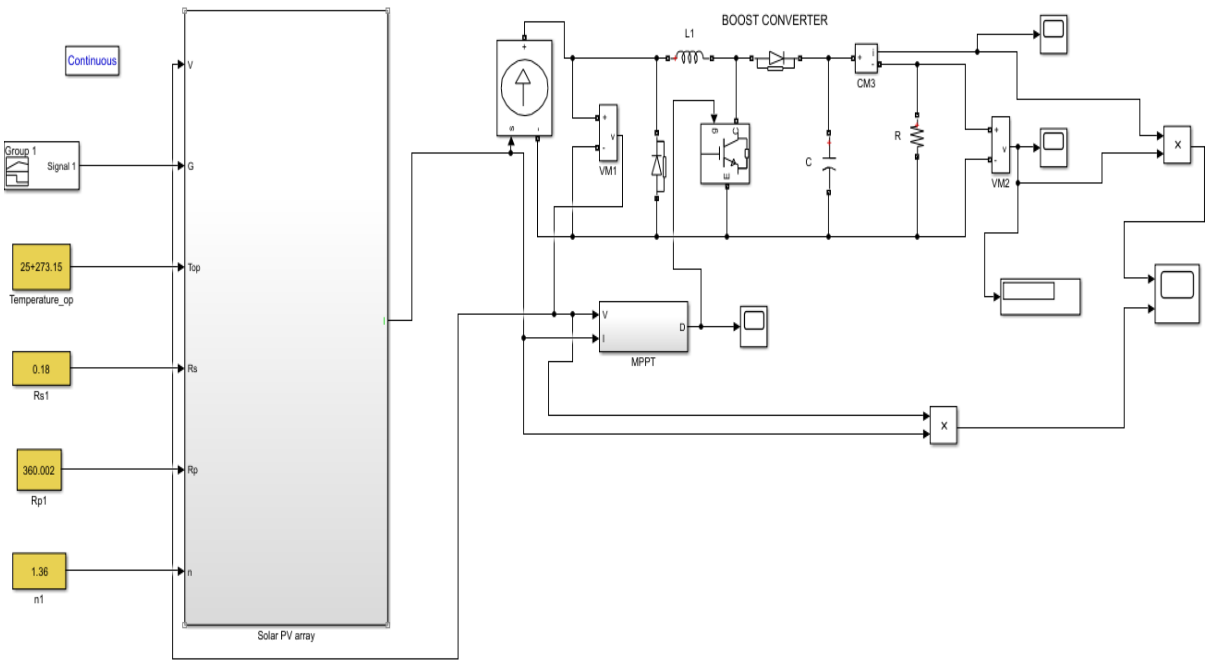


Figure 2: Simulink of InCond based MPP Tracker with PV Panel

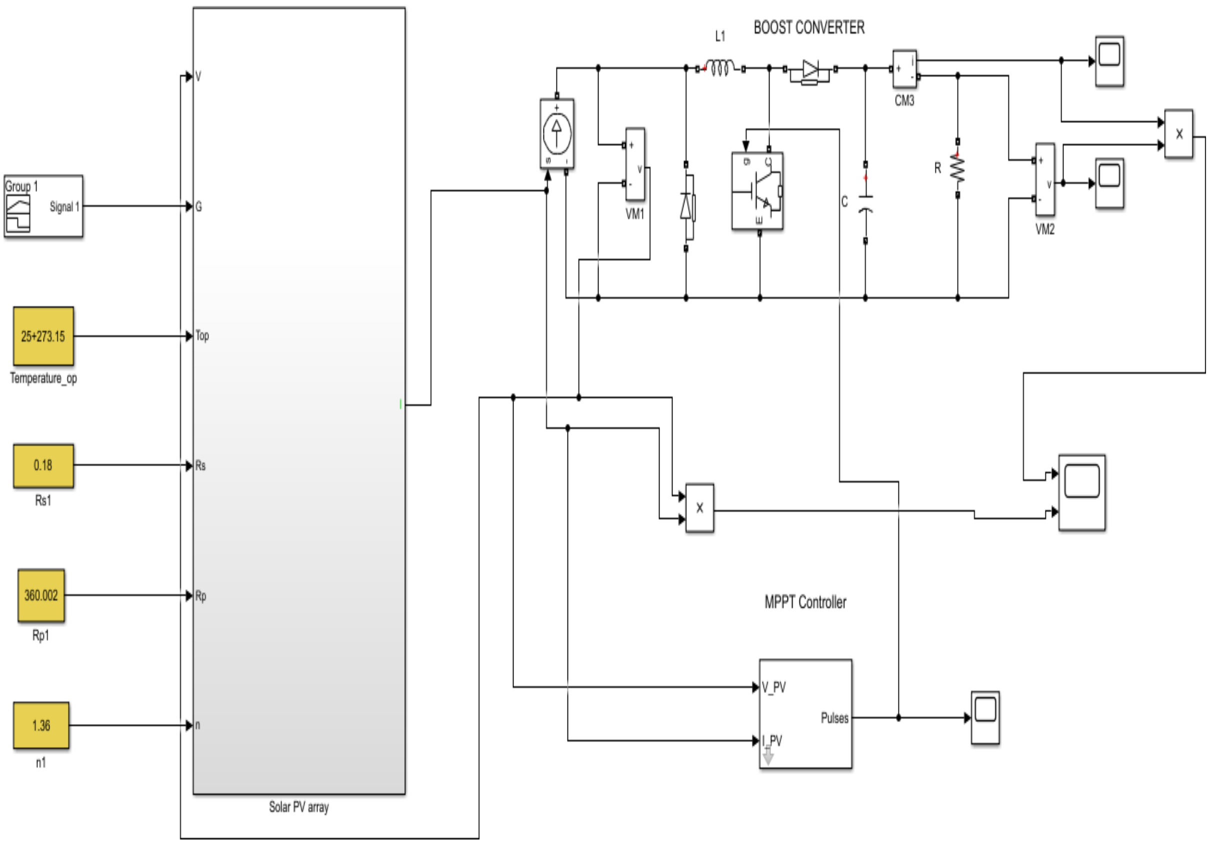
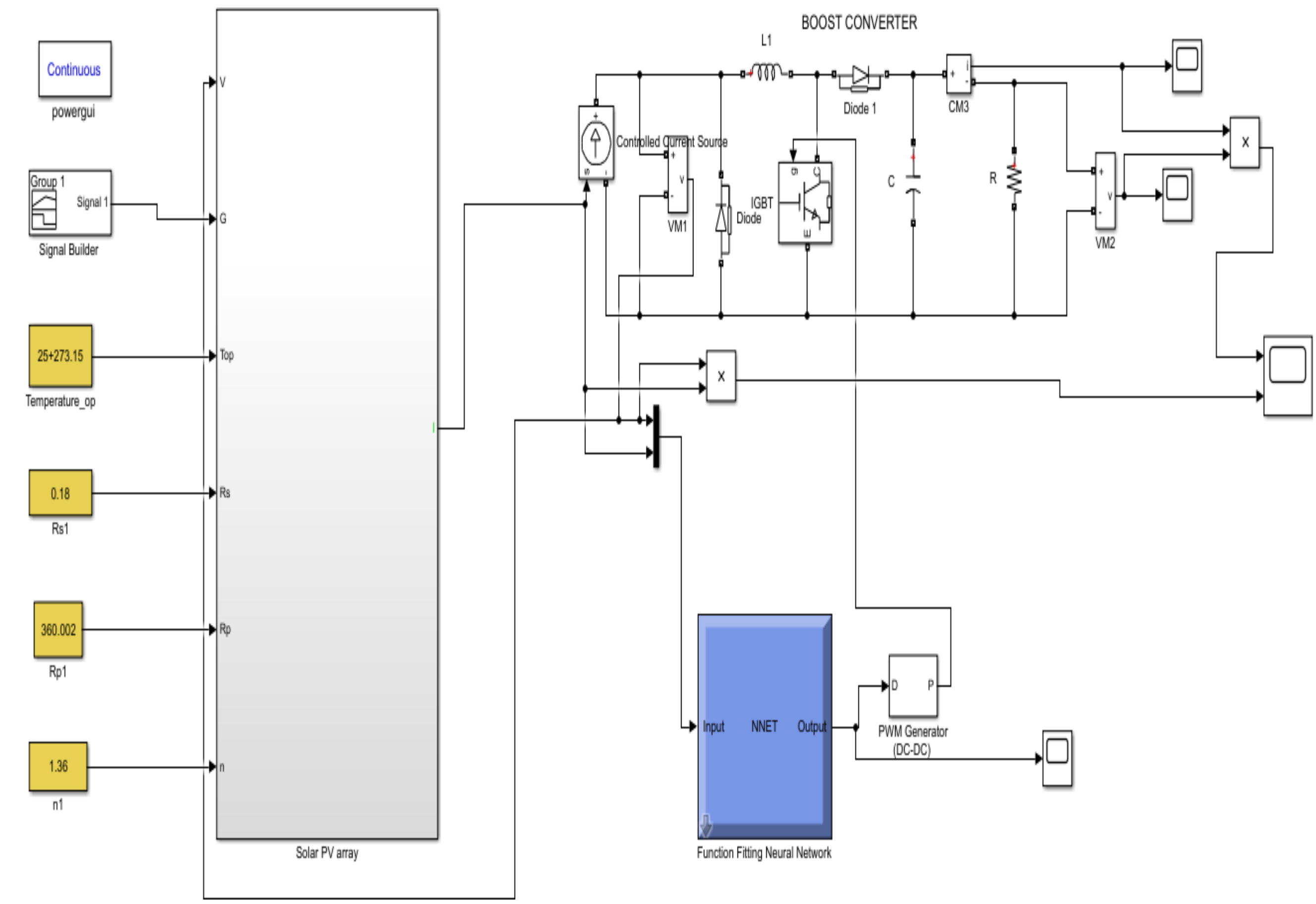


Figure 3: Simulink model of ANN based MPP Tracker with PV Panel



The solar panel considered for the project is for houses in villages. Hence, the parameters considered for modelling of PV Panel on Simulink are as follows-

Table 1: Electrical Data

S. No.	Parameters	Values
1.	Peak Power Pmax (Wp)	250
2.	Maximum Voltage Vmpp (V)	30.7
3.	Maximum Current Impp (A)	8.19
4.	Open Circuit Voltage Voc (V)	36.5
5.	Short Circuit Current Isc (A)	8.6

All data refers to STC [1000 W/m2, 25 degrees Celsius].

3. Results

3.1 Output Characteristics of PV Cells

As depicted in Fig. 9.1.1, the output characteristics of PV arrays are nonlinearly affected by changes in meteorological conditions such as varying irradiance level and temperature, and thus the maximal output power point also varies.

Figure 4: SolarCell I-V characteristics

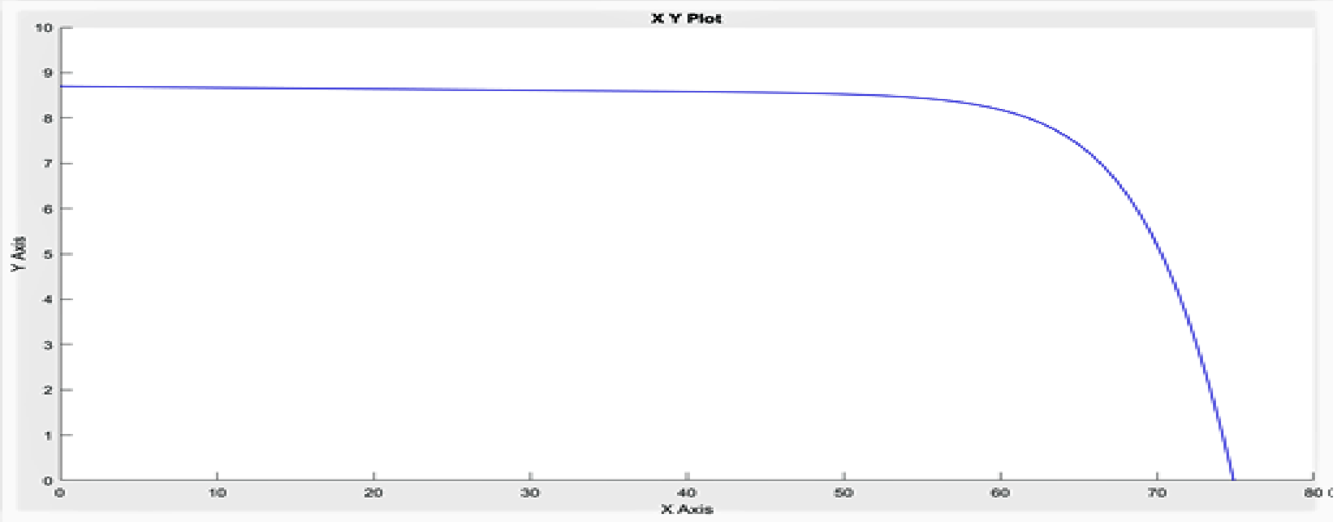
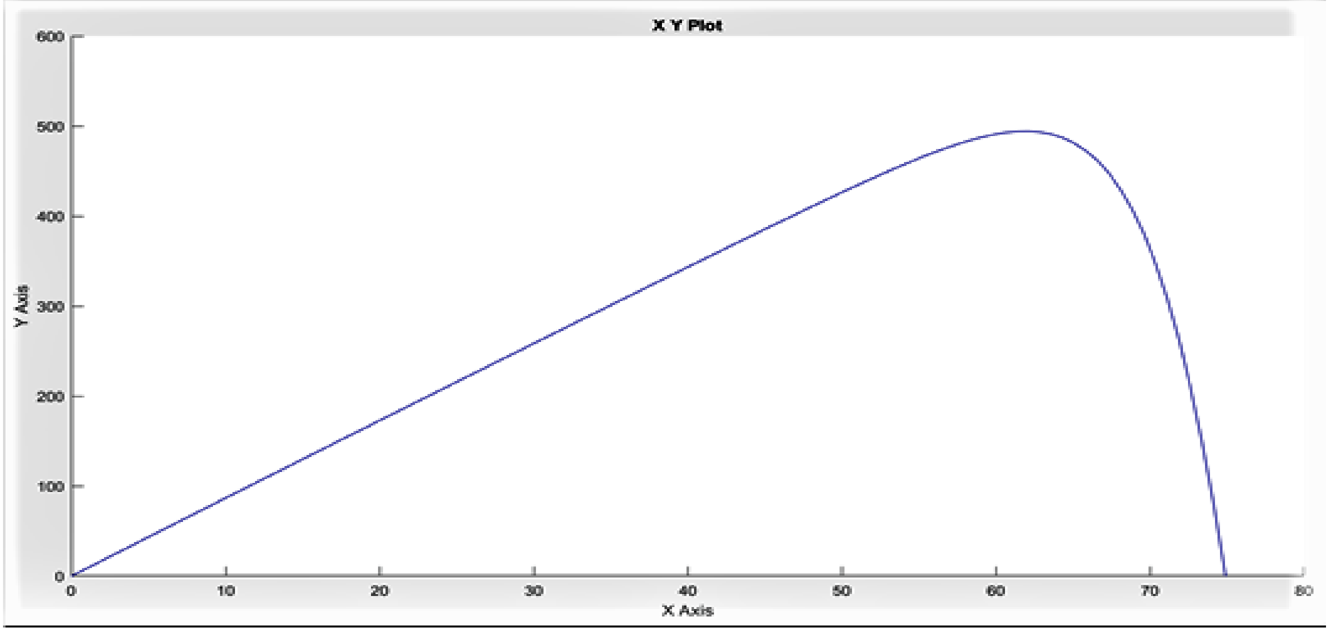


Figure 5: Solarcell P-V characteristics



3.2 System output voltage utilizing P&O, InCnd, and ANN techniques

Figure 6: P&O Output Voltage

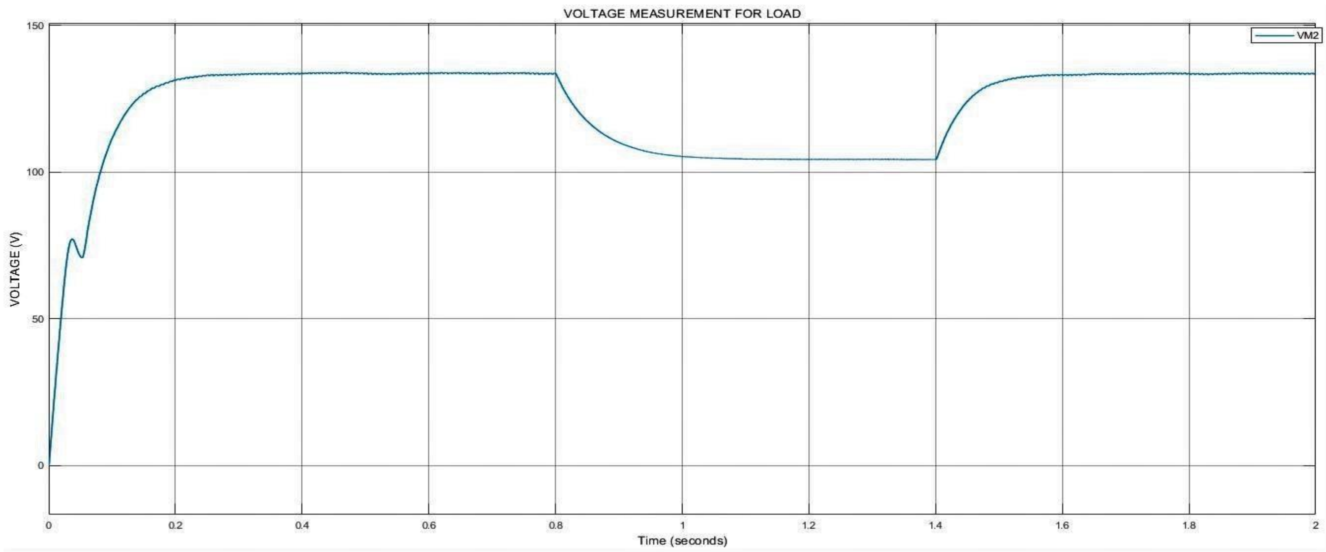


Figure 7: InCond Output Voltage

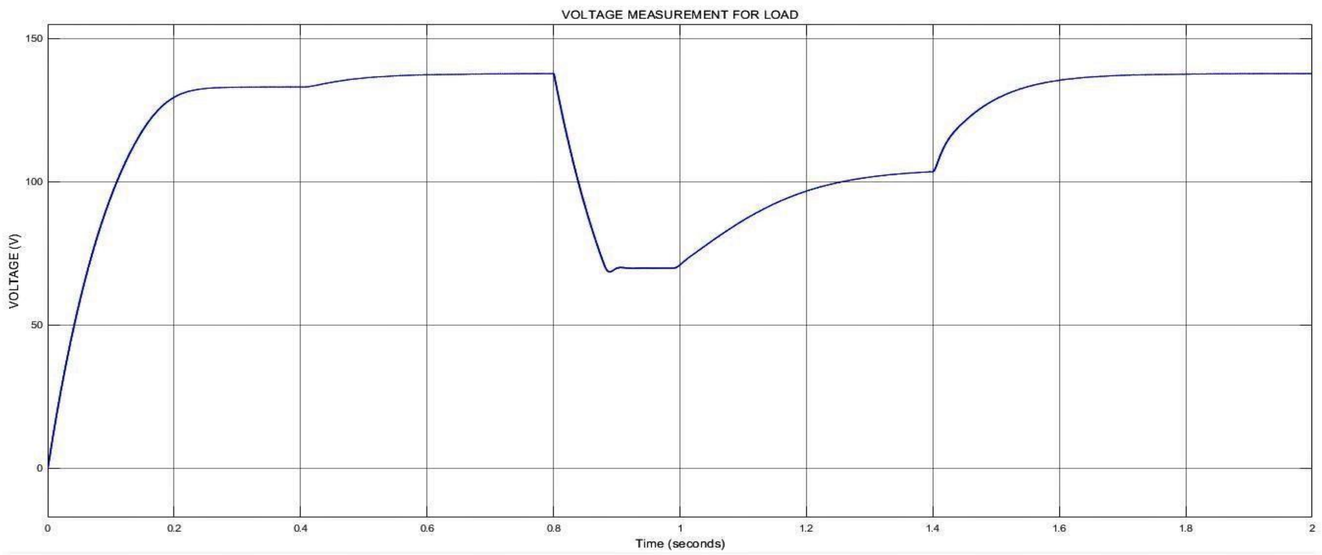
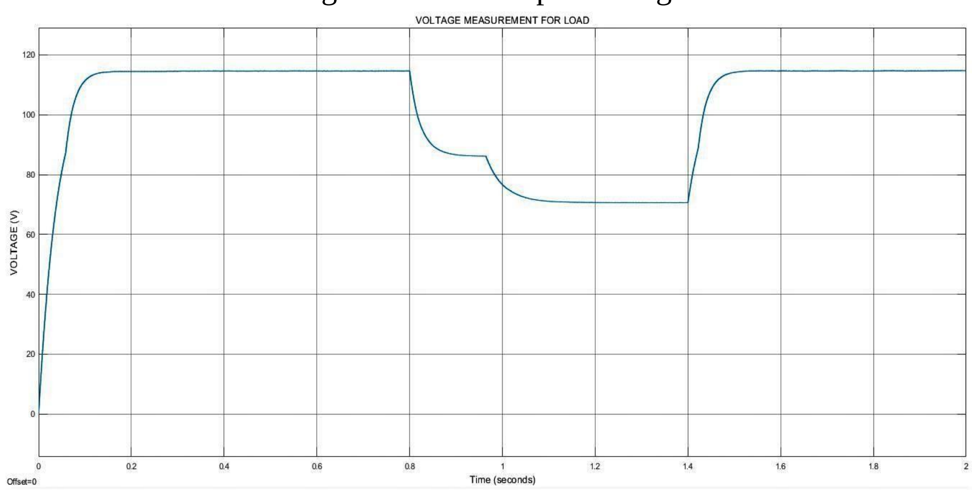


Figure 8 ANN Output Voltage



3.3 System output current utilizing P&O, InCnd, and ANN techniques

Figure 9: Output using P & O

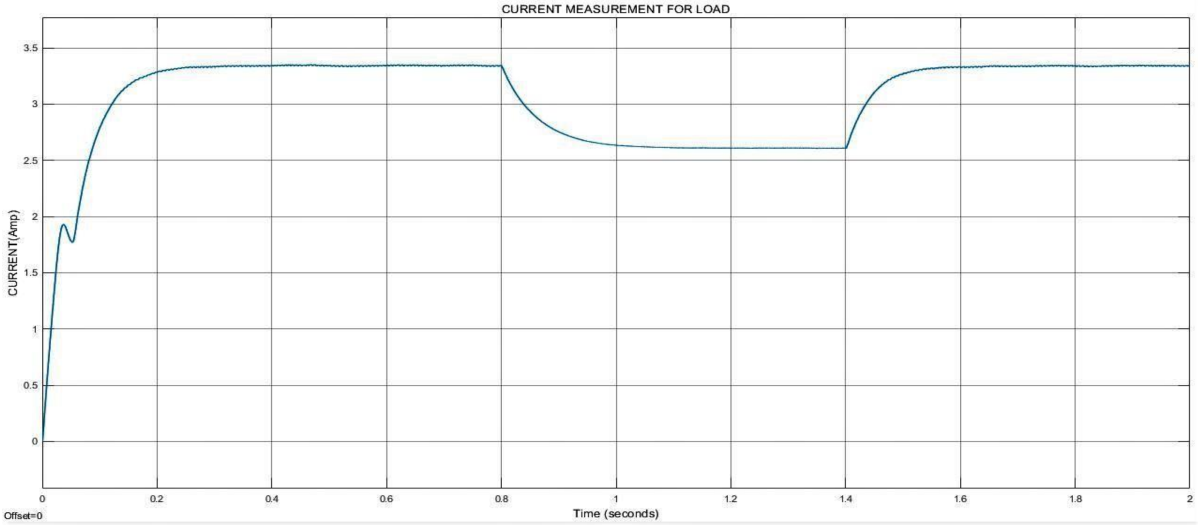


Figure 10: Output using InCond

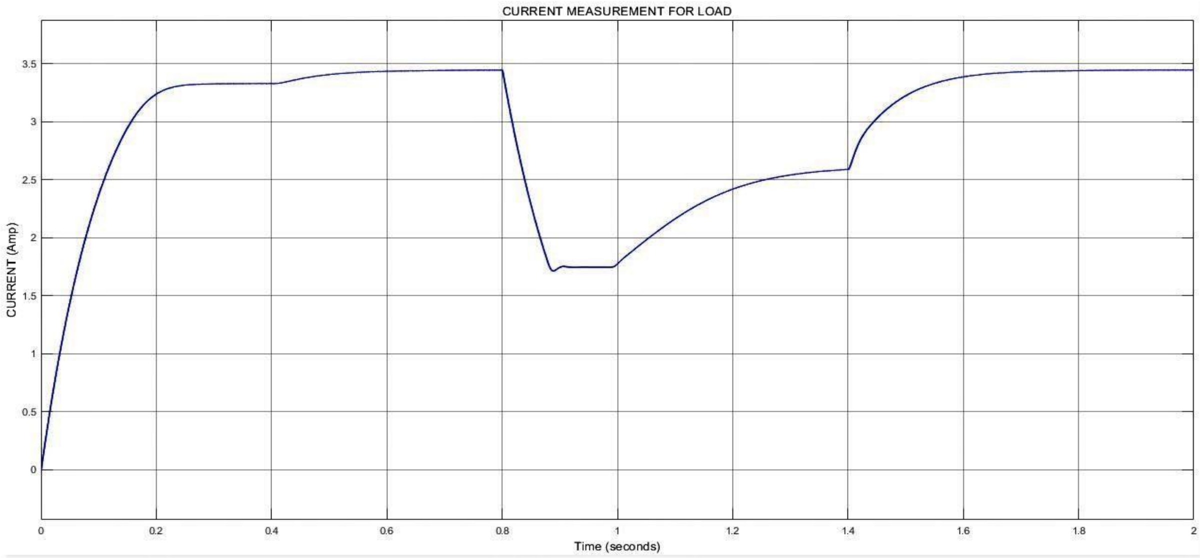


Figure 11: Output using ANN

4.4 System output power utilizing P&O, InCnd, and ANN techniques

Figure 12: Output using P & O

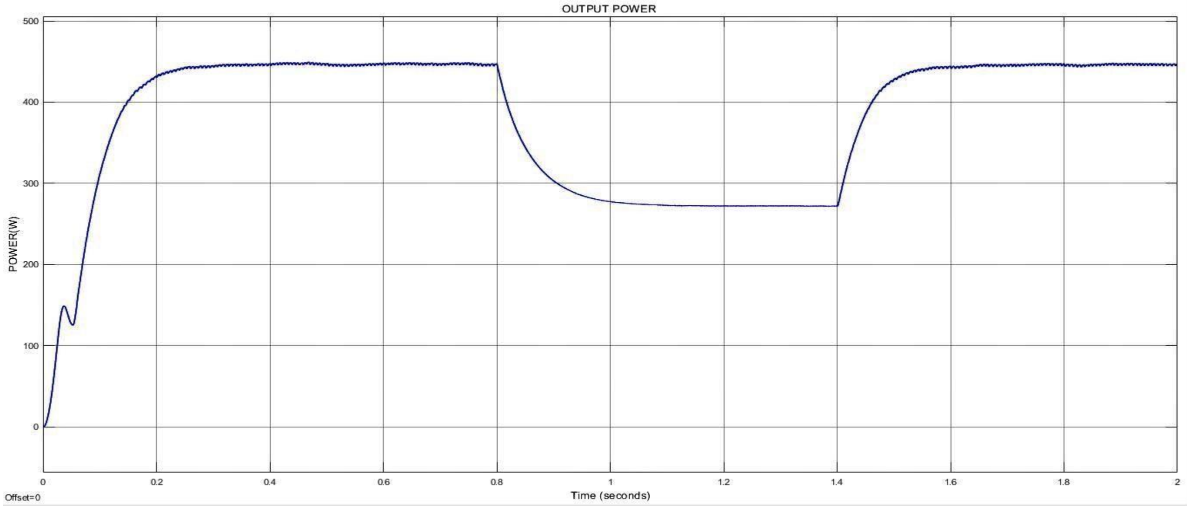


Figure 13: Output using InCond

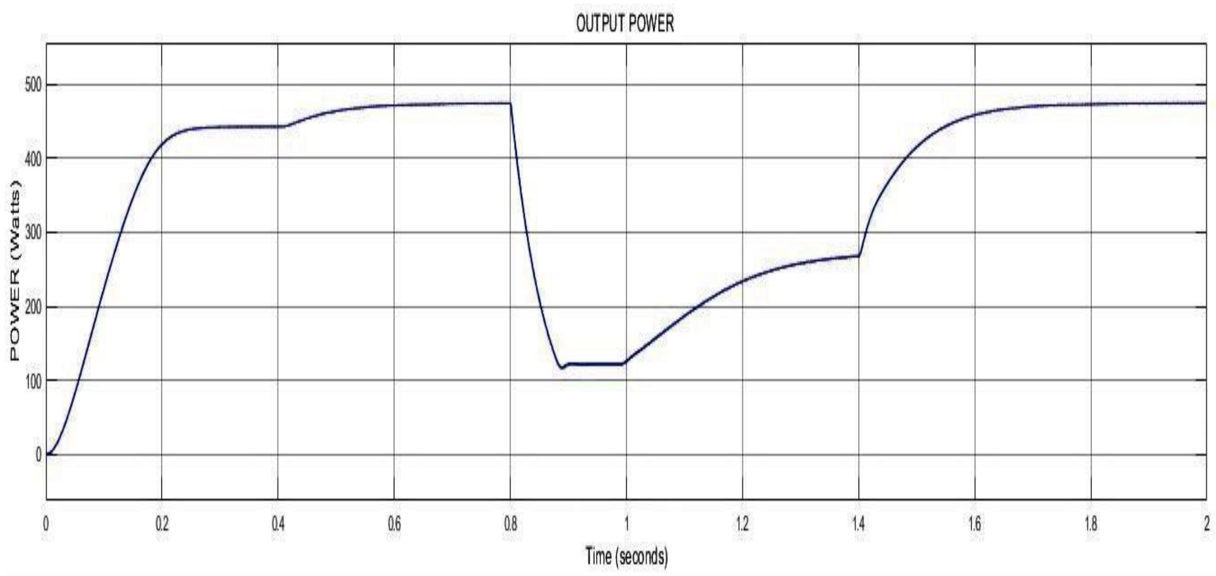
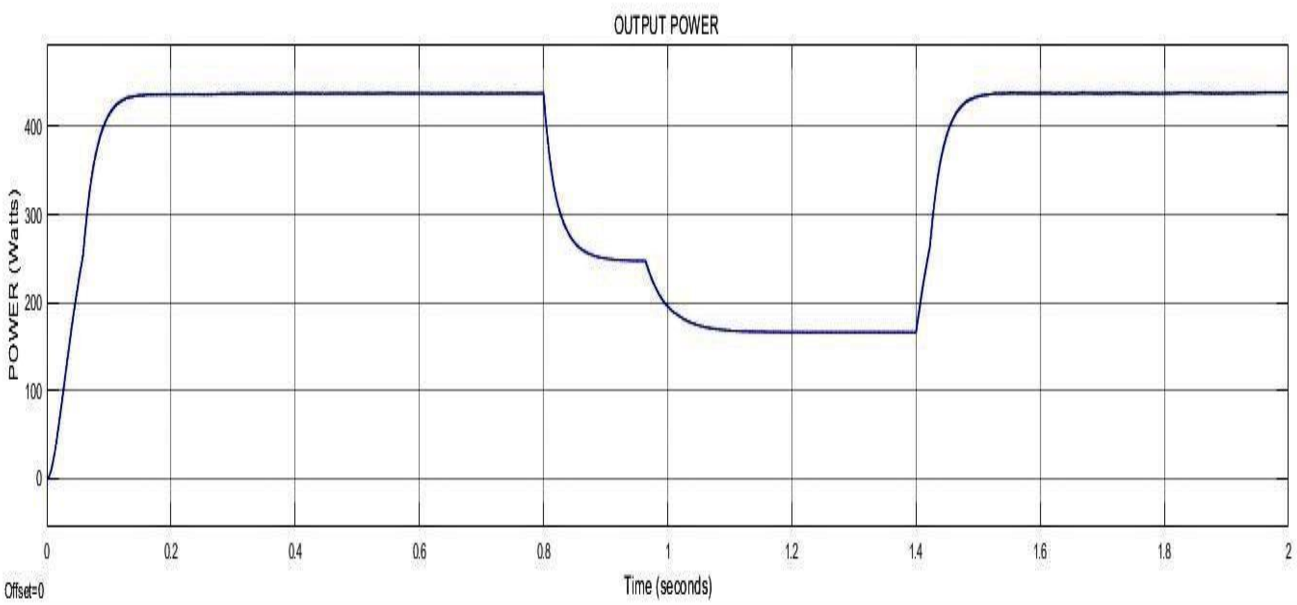


Figure 14: Output using ANN



4. Discussion

On the basis of various control system parameters, such as control system efficiency, disturbances, stability, and settling time, a comparison of the efficacy of MPPT controllers in tracking power and voltages was conducted.

Table 4.2: Power comparison between different algorithms

MPP TECHNIQUE	MAXIMUM POWER	EFFICIENCY (%)
P & O	449.6 W	89.9
InCond	439.7 W	87.9
ANN	474.7 W	94.94

Table 4.3: Current comparison between different algorithms

MPP TECHNIQUE	MAXIMUM CURRENT
P & O	3.35 A
InCond	3.82 A
ANN	3.44 A

Table 4.4: Voltage comparison between different algorithms

MPPT ALGORITHM	MAXIMUM VOLTAGE	STATUS
P & O	134.1 V	STABLE
InCond	114.9 V	STABLE
ANN	137.8 V	STABLE

Compared to P&O MPPT's 89.9% and ANN MPPT's 87.9%, the InCond MPPT model's efficacy is 94.94%, which is higher than P&O MPPT's 89.9% and the ANN MPPT technique's 87.9%. The ANN model produces significantly fewer voltage and current fluctuations than the P&O and InCond models. On the basis of the provided parameters, it is straightforward to conclude that InCond provides superior efficacy to the stand-alone PV system.

5. Conclusion

Using energy efficiently and transitioning to renewable energy sources not only conserves fossil fuels and energy but is also an economical and environmentally friendly solution to problems caused by traditional fuels. The demand for eco-friendly energy solutions is increasing day by day. PV energy is a solution to the energy crisis and an essential instrument for addressing environmental issues. This project compares the P&O, InCond, and ANN techniques used to track optimum power under varying irradiance conditions for a PV system with a Boost DC-DC Converter. Using a neural network, the optimum power point can be readily and precisely traced when atmospheric conditions change. PV maximum power point monitoring using a neural network yields superior dynamic performance compared to other methods. Changing the duty cycle is a fundamental method for varying the electricity. The presence of non-uniform shading exacerbates the difficulty of modifying the duty cycle. Due to its prior knowledge and training regarding probable MPP in response to a specific input, the ANN model can monitor the changes in MPP more accurately than the perturb and observe method and the incremental conductance method. The aforementioned Simplot curves plainly illustrate the utmost power tracked by both P&O and ANN. The maximum power tracked by ANN is 439.7 watts, whereas the maximum power tracked by P&O and InCond is 449.6 watts and 474.7 watts, respectively, indicating that the model using InCond provides more power than those using ANN and P&O.Our model utilisingInCond yields an efficiency of 94.94%, while P&O yields an efficiency of 89.9% and ANN yields an efficiency of 87.9%. Voltage and current fluctuations derived from the ANN model are considerably smaller than those derived from the P&O and InCond models. Thus, InCond responds more smoothly than P&O and ANN. The project's results are consistent with those of the theoretical approach.

6. Conflict of Interest

There is no conflict of interest.

7. Authors' Biography

Mukul Singh is a PhD. research scholar in electrical engineering department of Gautam Buddha University. He received the Integrated dual-degree (B.Tech and M.Tech) in electrical engineering from the Gautam Buddha University, Uttar Pradesh, India, in 2019. His area of expertise is in power systems. He has industry experience of work as an engineer at R.S. Infratech Pvt. Ltd. in 2019 before starting his research work at Gautam Buddha University. Mukul Singh is UGC-NET qualified and is receiving fellowship equivalent to junior research fellow from the govt. of India since February, 2022 for conducting his research work. He is working as researcher in the Electrical Engineering Department, School of Engineering, Gautam Buddha University, U.P. India. He has published several conference research papers, book chapters, and journal research papers in IEEE, Springer Nature (Singapore), Taylor and Francis, Nova Publishers (USA), SSRN (Elsevier), IGI Global, etc. He is an active reviewer of the Journal of Electrical Engineering and Technology (Springer). He is currently conducting his research on the development and analysis of an intelligent protection scheme for AC micro-grid. His sub-areas of research also include smart microgrid, microgrid protection, fault analysis, renewable energy generation using distributed energy sources. He is the corresponding author of this research paper.

Dr. Omveer Singh has 16 years of experience in teaching as well as research and development. He achieved his Ph.D. (Power Systems) from Faculty of Engineering and Technology, Jamia Millia Islamia (NAAC A++ Grade, A Central University), New Delhi, India. Currently, he is working as an Assistant Professor (Senior Scale) in Deptt. of Electrical Engineering, School of Engineering, Gautam Buddha University (Established by Government of Uttar Pradesh), Greater Noida, Uttar Pradesh, India. He is also serving as an Additional Director (Electrical) in Gautam Buddha University, Greater Noida. He is an active Senior Member of IEEE and Power & Energy Society of Asia Pacific Region. He is Editor and Co-editor of several Journals like Journal of World’s Electrical Engineering and Technology (Iran), International Journal of Emerging Advancements in Electronics and Electrical Engineering (USA), Progress of Electrical and Electronic Engineering Journal, WHIOCE Publishing Pvt. Ltd., and Advance Innovation and Technology with Sustainability Engineering, International Journal of Social Ecology and Sustainable Development (IGI Global, USA), etc.. He is also providing voluntary service to several National/International publishing houses as a Reviewer. He has published more than 120 research articles in the peer refereed journals, reputed conferences and book chapters. Presently, he has guided 01 research scholar, 36 M. Tech. and 54 B. Tech. students. Also, guiding 04 research scholars, 07 M.Tech.

and 08 B. Tech. students. He has diversified research interests and teaching experience of the subjects of Power Systems, Renewable Energy Sources, Electric Vehicles and Artificial Intelligence, etc.

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