

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

*Abedul Hadi¹, Gourango Sarkar Mitu², Md. Arif Iqbal³,
Shah Alam⁴, Md. Suhanur Rahman⁵

ABSTRACT: *Solar photovoltaic (PV) systems are scattered energy sources that are an environmentally friendly and renewable source of energy. However, solar PV power fluctuates due to variations in solar irradiance and temperature levels. Besides, when the solar panel is directly connected to the load, the power that is delivered is not optimal. A maximum power point tracker is therefore necessary for maximum efficiency. In this work, we study the design and implementation of Maximum Power Point tracking (MPPT) by using Perturb and Observe (P&O) algorithm which enhanced the efficiency, stability and accuracy of solar photovoltaic cell. The effectiveness of the intended solar regulator system is verified by the simulation by Proteus Design Suite and experimental results under our developed system using conventional Pulse Width Modulation (PWM) algorithms and enhanced P&O algorithm. The proposed MPPT controller is also constructed with Arduino and a mixture of active and passive electrical components. The simulated results of the complete PV system show that the performances of the PV panel using the improved P&O MPPT algorithm provides better steady state and fast transient characteristics when compared with the conventional Pulse Width Modulation Technique. It yields not only a cutback in convergence time to track the maximum power point (MPP), but also a significant reduction in power fluctuations around the MPP when subjected to slow and rapid solar irradiance changes.***Keywords:** *Giardiasis, cryptosporidiosis, S. neurona, Cryptosporidium infection.*

Keywords: *PV System, MPPT, P&O, Renewable energy, Inverter.*

1 Assistant Professor, Department of EEE, UITS

* Corresponding Author: Email: abedul.hadi@uits.edu.bd

2 Research Fellow, Department of EEE, UITS
Email: mitusarkar128@gmail.com

3 Research Fellow, Department of EEE, UITS
Email: arifiqbal222000@gmail.com

4 Research Fellow, Department of EEE, UITS
Email: shahalam56367@gmail.com

5 Research Fellow, Department of EEE, UITS
Email: suhanurrahman2@gmail.com

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

1. INTRODUCTION

In the search for sustainable and renewable energy sources, PV systems have emerged as a potential method for harvesting solar energy. As the world shifts towards renewable energy sources to combat climate change, the MPPT techniques plays an important rule to enhance the efficiency of PV cell. By pushing the boundaries of MPPT algorithm performance, L. Jancale et al [1] unlock the full potential of solar energy, reducing reliance on non-renewable resources, and accelerating the transition to a greener future. The hardware implementation of the designed 2W MPPT charge controller is carried out and the prototype is tested for the PV charging system [2]. The results show that such a type of MPPT controller improves the efficiency of PV panels when compared to conventional charge controllers.

The increasing demand for energy persists despite the depletion of fossil fuel resources, which are not only harmful to the environment but also pose risks to human health. This necessitates the exploration of alternative energy sources. Renewable energy sources, such as wind, tides, solar, and geothermal energy, present viable solutions to these challenges [3]. Solar energy is a powerful and sustainable energy source with the advantages of being virtually limitless, cost-effective, and having a long operational lifespan. However, solar PV modules face two significant challenges: low efficiency, typically below 17%, and performance variability due to changing environmental conditions, especially sunlight intensity and temperature [4]. Solar energy is harnessed in two key processes: a solar charge controller and a MPPT controller. While the solar charge controller safeguards the battery from overcharging, it does not operate the PV module at its maximum power point (MPP), leading to reduced performance and to address this, it's crucial to run the PV module at its peak power to maximize electricity generation and storage. MPPT methods [5] are employed to achieve this, and various DC/DC buck converter topologies are used to efficiently transfer power from PV modules to loads or batteries. Multiple MPPT techniques have been proposed [6], including open-circuit methods; short-circuit methods, fuzzy logic, P&O, and Incremental Conductance (INC). This study focuses on creating an MPPT charge controller based on the Perturb and Observation approach to optimize the performance of stationary PV modules where the hardware implementation in a 25W MPPT charge controller is used. This particular design, using the Perturb and Observation method, is cost-effective and highly efficient.

The outcome of this study demonstrates that such an MPPT controller significantly enhances the performance of PV solar panels compared to traditional solar charge controllers.

2. SOLAR TECHNOLOGY

2.1. PV Array Modeling and Characteristics

The photovoltaic effect is the basic principle of how solar panels work. It occurs due to the interaction of light with a semiconductor PN junction. When exposed to light, the junction generates a DC current which varies linearly with the amount of sunlight. To describe the complex physics of a solar panel, we can use an electrical circuit model based on a single diode, as shown in the figure [7].

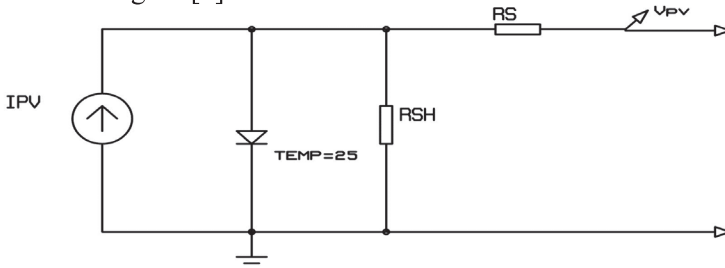


Figure 01: Solar cell single diode Model.

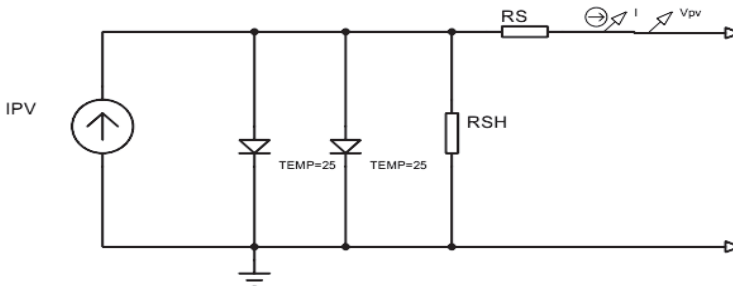


Figure 02: Solar cell double diode Model.

Diodes are frequently used in the widely recognized model for the behavior of polycrystalline silicon power cells. It uses one of the two diodes to symbolize the diffusion current flowing through a PN junction. A parallel connection with a current source linked to it might be thought of as the perfect PV cell. The series and shunt resistances are regarded as zero and infinite, respectively, in the ideal scenario. The semiconductor material used to construct the solar photovoltaic cell has the sun facing negative and the back side as the positive.

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

Electrons are produced in the PV cell's external circuit known as the photocurrent or short-circuit current whenever sunlight strikes the PV materials.

Single-diode solar cell:

When sun rays impact the solar module, photocurrent, also known as short-circuit current, is created and computed using the equation [8],

$$I = I_{sc} - I_d - I_{sh} \quad (1)$$

$$I = I_{sc} - \left(\frac{V + IR_s}{R_{sh}} \right) - I_0 \left(e^{\left(\frac{V + IR_s}{nV_T} \right)} - 1 \right) \quad (2)$$

Thermal voltage, $V_T = \frac{KT}{q}$

Where, $I =$ solar equivalent current, $I_d =$ Diode current and $I_0 =$ saturation current.

The solar cell produced in photocurrent also known as short-circuit generated when the solar rays strike the solar module and is calculated by equation,

$$I_{sc} = \frac{G}{1000} (I_{scr} + K_i(T_c - T_r)) \quad (3)$$

Where, G is solar irradiance, I_{sc} is photocurrent, I_{scr} is reverse saturation current, K_i is temperature coefficient, T_c is the cell temperature and T_r is the reference temperature.

Additionally, the open circuit voltage (V_{oc}) generated by a single diode model of a solar photovoltaic cell can be computed using an equation,

$$V_{oc} = \ln \left(\frac{I_{sc}}{I_0} + 1 \right) \left(\frac{nkT_c}{q} \right) \quad (4)$$

Where V_{oc} open circuit voltage, I_{sc} photocurrent, I_0 saturation current, n ideality factor, k Boltzmann constant, T_c cell temperature, q electric charge.

Gives the relationship between the voltage and current of the solar photovoltaic cell.

$$I = I_s \exp \left(\frac{qV}{KT} - 1 \right) - I_{ph} \quad (5)$$

Where I_s saturation current, V voltage across diode, I_{ph} light to generated current.

Under shows the $P_{pv} - V_{pv}$ and $I_{pv} - V_{pv}$ curves

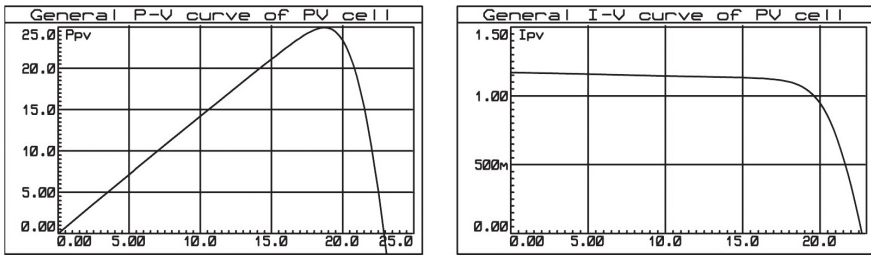


Figure 03: P-V Curve of PV Cell.

Depicts that solar irradiation and temperature are two critical factors that significantly impact the performance of solar modules. To achieve the maximum power output in real-time, it is essential to constantly track the maximum power point (MPP) of the solar generation system.

2.2. Analysis of DC-DC converter

DC-DC converter analysis is the study of electronic circuits that transform one DC voltage level into another. This analysis focuses on key parameters, including efficiency, voltage regulation, and power transfer capacity. DC-DC converters have broad applications in power electronics, with their analysis being pivotal in designing efficient and dependable power systems. In photovoltaic systems, DC-DC converters play a crucial role as intermediaries between solar panels and loads, ensuring the system operate at its (MPP). This analysis is essential for optimizing energy conversion and overall system efficiency. In this part two different models of converters are introduced in Buck and Boost converter.

Buck converter: Buck converter is one type of DC-DC converter. This converter is used in the upper voltage to lower voltage conversions with varies D (Duty cycle) of MOSFET. In voltage input and output ratio $M = V_{out}/V_{in}$ [8].

Boost Converter: Boost converter is opposite of Buck converter, here Input voltage to converter in higher output voltage. This converter also known step-up converter.

Since, as was previously said MPPT algorithms are necessary in PV applications because the MPPT of a solar panel varies with the irradiance and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar panel.

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

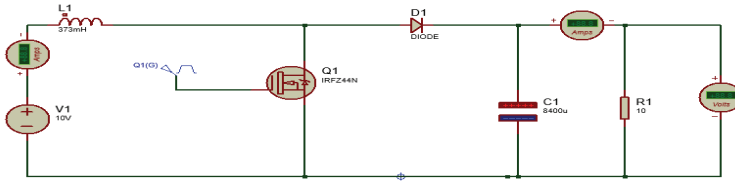


Figure 04: Buck Converter.

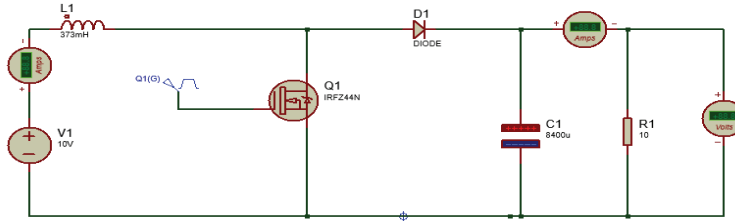


Figure 05: Boost Converter.

MPPT solar panel of DC-DC converter analysis is the study of electronic circuits that transform one DC voltage level into another. This analysis focuses on key parameters, including efficiency, voltage regulation, and power transfer capacity. DC-DC converters have broad applications in power electronics, with their analysis being pivotal in designing efficient and dependable power systems. In photovoltaic systems, DC-DC converters play a crucial role as intermediaries between solar panels and loads, ensuring the system operate at its MPP. This analysis is essential for optimizing energy conversion and overall system efficiency. In this part two different models of converters are introduced in Buck and Boost converter.

2.3. Charge Controller

This study presents a charge controller that has MPPT capabilities to extract the maximum power from a PV panel. There are two primary categories of MPPT approaches: direct and indirect. Direct methods include artificial neural networks (ANN) [9], fuzzy logic, incremental conductance, suggested Perturb and observation approaches, and fuzzy logic. On the other hand, indirect methods include open-circuit voltage and short-circuit current techniques. To monitor the system, simple measures are used to establish sample assumptions and periodic MPPT calculations. Photovoltaic systems optimize energy output by continuously adjusting load or voltage, operating at the point of maximum power production from solar panels or other renewable resources.

PWM Solar Charge Controller: A PWM-based solar charge controller is a device that regulates the power output of solar panels to charge a battery using PWM [10]. It is commonly used in small off-grid solar systems due to their affordability and simplicity. The controller switches on and off the connection between the solar panels and the battery, determining the power delivered to the battery. The duty cycle depends on the battery state of charge (SoC) and the voltage difference between the solar panels and the battery. A high duty cycle allows the battery to receive maximum power from the solar panels, while a low duty cycle reduces power delivery to prevent overcharging. PWM controllers typically have three charging stages: bulk, absorption, and float. Bulk mode charges the battery at a constant current until it reaches a certain voltage level, absorption mode gradually reduces current while maintaining a constant voltage level, and float mode maintains a low current and voltage level to keep the battery fully charged [11].

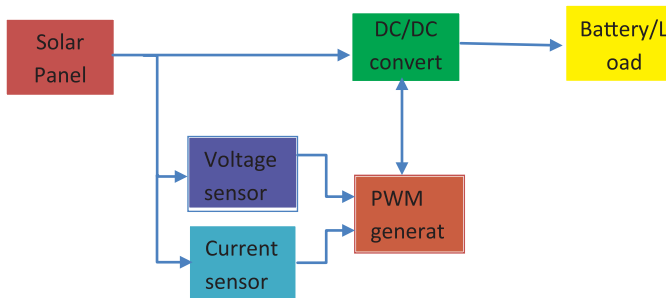


Figure 06: Block diagram of PWM based solar charge controller.

In a PWM based solar charge controller, the solar panel converts sunlight into direct current (DC) electricity, while the PWM controller regulates the power output to charge the battery using PWM. The battery, a storage device, stores the electrical energy produced by the solar panel and consumes the DC energy stored in the battery. The load, an appliance, consumes the DC energy stored in the battery. The main connections of the PWM based solar charge controller are the solar panel to the PWM controller, the PWM controller to the battery, and the battery to the load. The controller monitors the voltage and current to determine the battery's state of charge and applies the appropriate charging algorithm. It also controls the power delivered to the battery and protects it from overcharging and over-discharging. The PWM controller also allows or blocks the connection based on user preferences or timer settings. In summary, a PWM based solar charge controller is a cost-effective and user-friendly solution for regulating the power output and charging the battery.

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

MPPT Charge Controller:

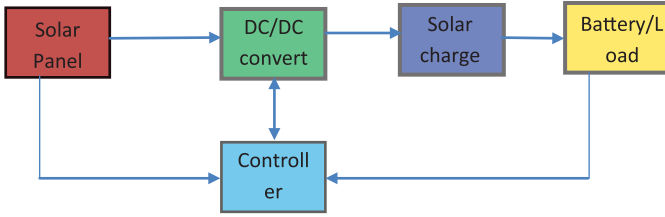
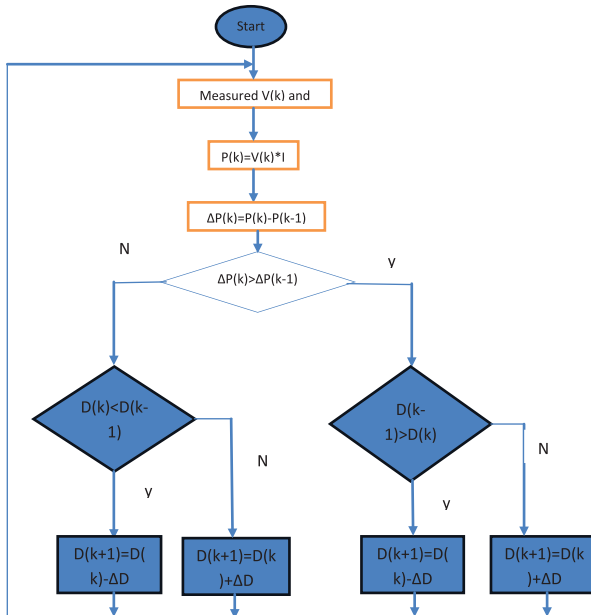


Figure 07: Block diagram of MPPT Charge Controller.

Solar panels have a specific point, known as the MPP at which they generated the most power. Controller to select the maximum power of solar panels, after selecting that based MPP on the supply in power in Batteries/Load. The MPP changed based on the temperature, shading and panel age. MPPT controller works to ensure that solar panel always operate as closely as possible to at any point, maximizing energy production. MPPT controller improves the system efficiency and its controller has been introduced as shown in figure. The MPPT controller is connected between the PV module and Battery/Load to extract maximum power from PV module and delivered to the batteries/Load. It is communicated with solar panel and batteries, after which decided how to maximize the power supply in solar panel to load/batteries [12].

2.4. Perturb and Observation Method



In this journal, the P&O method has been used for MPPT solar charge controllers, which are typically, implemented using various methods. The primary benefit of the method is its high efficiency at a low cost. The P&O method is a widely used technique in photovoltaic systems to track the maximum power point. It involves introducing a small perturbation to the operating voltage of the PV system and observing the resulting change in output power. The perturbation is then continued in the same or reversed direction until the maximum power point is reached. However, this method has limitations, such as causing oscillations around the MPP, failing to track in rapidly changing environmental conditions, and getting stuck in a local maximum when multiple peaks in the power-voltage curve are present. To address these limitations, various variations and improvements have been proposed, including adaptive perturbation step size, fuzzy logic control, neural network control, and hybrid methods that combine P&O with other MPPT techniques. And P&O work in very simple mechanism.

3. ANALYSIS OF CHARGE CONTROLLER

3.1. Comparison of MPPT solar charge and PWM solar charge controller

MPPT and PWM are two types of solar charge controllers. They both regulate the power output of the solar panels to charge the battery, but they use different technique to do so. MPPT controller and PWM solar charge controller are using different algorithms [14].

Table 01: Comparison between MPPT and PWM Charge controller.

MPPT solar charge controller	PWM solar charge controller
1. MPPT solar controller algorithm uses maximum power point tracking to control solar panel power output, harvest maximum power, and protect battery from overcharging and over-discharging.	1. PWM solar charge controller algorithms regulate solar panel power output to charge batteries using PWM. They switch on/off connections at high frequency, regulating voltage and current, and protecting batteries from overcharging and over-discharging.
2. The MPPT solar charge controller based photovoltaic system efficiency is more than 90%.	2. The PWM solar charge controller based photovoltaic system efficiency is less than 75%.
3. This controller is one of the most common MPPT algorithms is three stage charging algorithms, which is consist of bulk, absorption, and float modes.	3. This PWM based solar charge controller algorithms is also common three stage charging algorithms, which is consist of bulk, absorption, and float modes.

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

<p>4. An MPPT controller’s main job is to maximize the power output of solar panels by altering the voltage and current to determine the panels’ MPP under various circumstances (like changes in temperature, shading, or sunlight intensity).</p>	<p>4. PWM controllers regulate the amount of power supplied to the battery by use of a switching mechanism. They quickly turn the electricity on and off. The controller keeps the voltage constant while adjusting the PWM.</p>
<p>5. An MPPT controllers are regulates in the charging of batteries and solar panels by maintaining a regulated voltage in the battery. They prevent overcharging by solar panel gradually reducing the charge current as the battery approach in maximum capacity.</p>	<p>5. To charge the batteries, the PWM charge controller controls the voltage and current flowing from the solar panels. It ensures the battery is charged at the ideal voltage without overcharging.</p>

PV systemin proteus software:

Proteus software was used to design the PV system. The system can be divided into nine blocks as shown:

- a. Sub circuit of the PV panel model.
- b. Boost converter.
- c. Embedded board (Arduino Uno).
- d. LCD screen for displaying values of PV voltage, current, and power.
- e. Driver (TC4420) for controlling the MOSFET transistor of the Buck converter.
- f. Presents the current sensor (INA169), which measures the PV current. The sensor model is based on INA168, which is available in Proteus. To model the sensor, follow these steps:
 - Launch the proteus tool application.
 - Open the pick devices.
 - Select the INA 168 component (current sensor)
 - Add two resistances R5 (0.1Ω) and R6 (50Ω). Where RS is a shunt resistor placed in series between the output of the PV module and buck converter, and RL load is connected to a load resistor connected between the pin 1 of INA169 and the ground.
 - Set the power supply voltage to 6V to adapt it with that of INA169. Then, the PV panel output current can be divided by the equation.

$$I_s = \frac{V_{out1} \times 1K\Omega}{R_5 R_6} \quad \#(6)$$

- g. Presents the B25 voltage sensor module used for measuring PV voltage. It is essentially a voltage divider that uses two series resistances. The output of the PV panel is defined by the following equation:

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

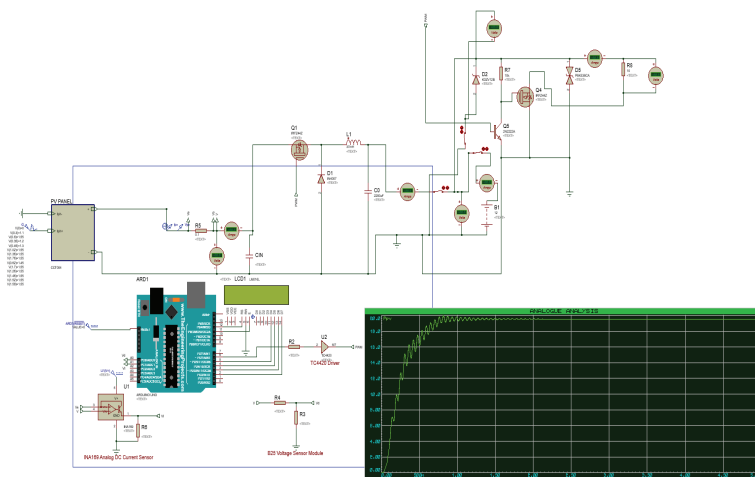


Figure 08: Schematic Diagram of PWM Solar Charge Controller

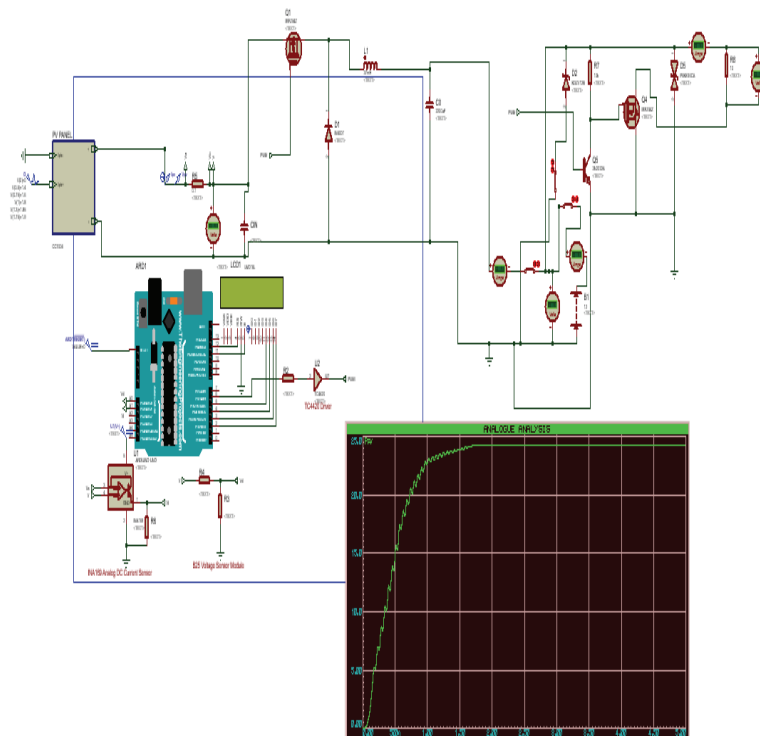


Figure 09: Schematic Diagram of MPPT Based Solar Charge Controller.

$$V_{out2} = \frac{R3}{R3 + R4} \times V_{in} \quad \#(7)$$

Where (R3=25KΩ) and (R4=100kΩ)

- h. Represents by protection circuit. Its circuit protects in batteries and load and reverse polarities in input and output terminal in solar and batteries. Protection circuits are crucial in MPPT charge controllers to prevent component damage and ensure system safety and reliability.
- Overvoltage protection: The MPPT controller rated limits are used to prevent input or output voltage from exceeding them, preventing damage or fire hazards, and can be achieved using fuses, breakers, surge arresters, or clamping diodes.
 - Overcurrent protection: The MPPT controller rated limits are used to prevent overcurrent, which can lead to overheating, short circuits, or fire hazards, and can be achieved using fuses, breakers, current limiters, or shunt regulators.
 - Reverse polarities protection: This prevents the input or output terminals from being connected in the wrong direction, which could damage the MPPT controller or the battery. Reverse polarity protection can be achieved by using diodes, relays, or MOSFETs.
 - Temperature protection: This prevents the MPPT controller from operating at extreme temperatures, which could affect its performance or lifespan. Temperature protection can be achieved by using thermistors, thermostats, or fans.
- i. Represents the graph analysis in PV system:

A PV system is a renewable energy source that converts sunlight into electricity. It consists of several components, including solar panels, an inverter, a mounting structure, and cabling and electrical accessories. The panels capture sunlight and can be mounted on rooftops, ground, or other structures. The inverter converts the DC electricity produced by the panels into AC electricity, which can be used by appliances or fed into the grid. The mounting structure supports and positions the solar panels, optimizing their performance. Cabling and electrical accessories link the solar panels, inverter, and the grid or load, including safety devices like fuses, circuit breakers, and switches. Battery and charge controllers are optional components that store excess electricity and provide backup power when the sun is not shining, or the grid is down. PV systems can be grid-connected or off-grid, depending on the grid's availability and stability. Grid-connected systems can reduce user electricity bills by offsetting consumption or selling excess electricity to the grid. Off-grid systems operate independently and can provide electricity to remote areas or places with unreliable or expensive grids.

PV systems can range in size and capacity, from small portable devices to large utility-scale systems. They can also be integrated into buildings or structures to enhance their aesthetic and environmental performance.

PWM Solar Charge Controller:

4. RESULTS

4.1. Simulation Results

To authenticate the implementation of the recommended algorithm, we developed a Proteus model as shown. The PV module in this study was simulated based on the solar panel equation characteristics explained earlier. The MPPT algorithm was implemented using a flowchart-based coding that made it easy to understand and implement in the Perturb and Observe method. The power MOSFET (IRF544N) based DC-DC Buck converter was controlled the gate signal which proposed P&O algorithms. The switching frequency was set at 30 kHz and the boost converter consisted of a 37 μ F inductor and a 2200 μ F capacitor. Another PWM-based solar charge controller generates only PWM signals, but it does not check the condition of the solar panel or batteries. A PWM-based solar charge controller is a device that regulates the charging of a battery from a solar panel using PWM technique. PWM is a method of reducing the average power delivered by an electrical signal by switching it on and off at a high frequency. PWM can improve the efficiency and lifespan of the battery by preventing overcharging, undercharging, or deep discharging.

Table 02: Specification of PV syste ms.

Parameters	Value
Solar panel capacity	25W
Open circuit voltage	23.4V
Short-circuit voltage	1.98A
Maximum Power at MPP	23.90
Maximum Voltage at MPP	13.83

Table 03: PWM Based solar charge controller.

Parameters	Value
1. Input Voltage	12.8
2. Output Voltage	12.05
3. Input Power	23.89
4. Output Power	18.12

Table 04: MPPT charge controller.

Parameters	Value
1. Input Voltage	12.85
2. Output Voltage	12.1
3. Input Power	23.89
4. Output Power	22.86

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

PWM based solar charge efficiency= $18.12/23.89 \times 100\% = 75.81\%$.

MPPT based solar charge efficiency= $22.86/23.89 \times 100\% = 95\%$.

4.2 Input and Output Voltage and Power Graph

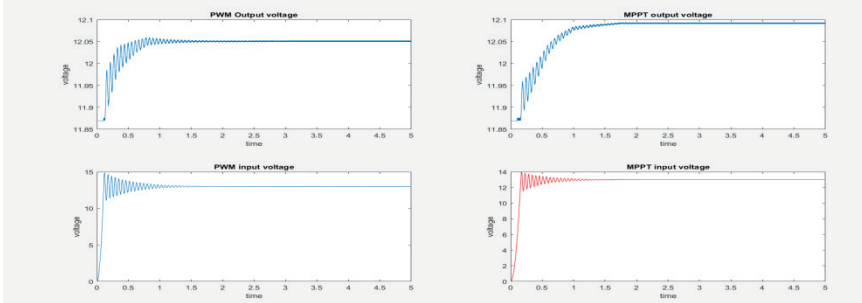


Figure 10: Input and Output Voltage of PWM and MPPT Controller.

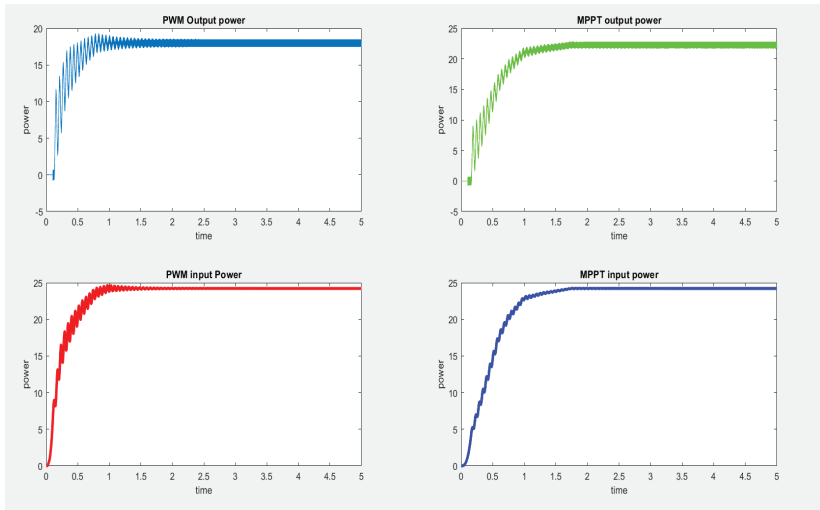


Figure 11: Input and Output Power of PWM and MPPT Controller.

5. CONCLUSIONS

P&O can be swiftly introduced since it is easy to implement. The power obtained by the P&O method oscillates around the MPP in steady state operation, it can track incorrectly under rapidly varying irradiance levels and load levels, and the step size (the magnitude of the change in the operating voltage) determines both the speed of convergence to the MPP and the range of oscillation around the MPP at steady state operation. The experimental results show that the proposed system is more efficient than the conventional design.

Design and Implementation of Improved MPPT Solar System using P&O Algorithm

- [8] Ahmed G et al. (2014) Design and implementation of MPPT solar system based on the enhanced P-&O algorithm using Lab view, International Renewable and Sustainable Energy Conference (IRSEC), pp. 203-208.
- [9] Villalva M G and Filho E.R (2008) Dynamic Analysis of the input-controlled buck converter fed by a photovoltaic array, Revista Control & Automatic, 19 (4), pp. 463-474.
- [10] Villalva M G et al. (2010) Voltage regulation of photovoltaic arrays: small-signal analysis and control design, Power Electronics, IET, 3 (6), pp. 869-880.
- [11] Bryant B and Kazimierczuk M K (2006) Voltage Loop of Boost PWM DC-DC Converters, IEEE Trans on circuits and systems, 53 (1), pp. 99-105.
- [12] Hua C et al. (1998) Implementation of a DSP-controlled photovoltaic system with peak power tracking, IEEE Trans. Ind. Electron, 45 (1), pp. 99-107.
- [13] Middlebrook R.D (1988) Small-signal modeling of pulse-width modulated switched-mode power converters, Proc. IEEE, 76 (4), pp-343-354.
- [14] Koizumi H.K et al. (2006) A novel microcontroller for grid-connected photovoltaic systems, IEEE Trans. Ind. Electron, 53 (6), pp. 1889-1897.

This research has a very significant natural influence on the ecosystem. A faster transition to sustainable energy, less impact on the environment, and less reliance on non-renewable resources are all directly correlated with improved PV system efficiency. At the end of the day, maximizing power point tracking helps to minimize the problems caused by climate change, optimize energy production and consumption, and promote a more sustainable future [14]. As the world strives for greener, more sustainable energy solutions, this study serves as a foundational step, emphasizing the potential for further advancements in MPPT techniques and their significant impact on the transition to a more environmentally conscious and energy-efficient future.

REFERENCES

- [1] Jancale L et al. (2005) A Maximum Power Point Tracker for PV Systems Using a High Performance Boost Converter, *Solar Energy*, 80 (7), pp. 772-778.
- [2] Yu T C and Chien T S (2009) Analysis and Simulation of Characteristics and Maximum Power Point Tracking for Photovoltaic Systems, *Proceedings of Power Electronics and Drive Systems Conference*, pp. 1339 – 1344.
- [3] Maka A.O. M and Alabid J. M (2022) Solar Energy Technology and Its Roles in Sustainable Development, *Clean Energy*, 6(3), pp. 476-483.
- [4] Salman S et al. (2018) Design of a P-&O algorithm based MPPT charge controller for a stand-alone 200W PV system, *Protection and Control of Modern Power Systems*, 3:25.
- [5] Soufi Y et al. (2014) Maximum Power Point Tracking using Fuzzy Logic Control for Photovoltaic System, *Renewable Energy Research and Application (ICRERA)*, 2014 International Conference, pp. 902-906.
- [6] Hussein K H et al. (1995) Maximum photovoltaic power tracking: An algorithm for rapidly changing atmospheric conditions, *Proc. Inst. Elect. Eng.*, 142 (1), pp. 59–64.
- [7] Xiong Y et al. (2012) Single-Phase Grid-Connected Photovoltaic System Based on Boost Inverter, *Power and Energy Engineering Conference (APPEEC)*, Asia-Pacific, pp 1-3.