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Research Article

# Performance Enhancement of PV Array Utilizing Perturb & Observe Algorithm

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**Abstract:** Photovoltaic (PV) power generation has received significant attention from scientists over the last few years to help reduce the environmental pollution inherently associated with traditional electric generators. The economic convenience of PV generation is directly connected to the cost of the cells and the amount of energy that the arrays are capable of supplying over their life. This paper presents an investigation study on the modeling and simulation of solar PV systems interfaced with the distribution network (DN) using the Perturb and Observe (P&O) algorithm. The paper investigates the impact of solar radiation variations on the system's performance and proposes an energy storage system to mitigate the power quality issues caused by the intermittency of solar power. The simulation results show that the proposed system enhances the overall performance of the solar PV system by improving energy capture efficiency and reducing power quality issues. The performance of the proposed method was tested and compared with the fixed perturbation MPPT algorithm under different conditions. Experimental results confirm the feasibility and advantages of the proposed method.

**Keywords**: Solar PV; Distribution Network; Perturb and Observe (P&O) Algorithm; Simulation

## 1. Introduction

In light of the dwindling availability of the earth's natural resources and the simultaneous increase in demand for power, the power sector is actively exploring alternative sources of energy. The usage of renewable energy sources holds particular promise, as it offers the potential to mitigate the issue of global warming by reducing the carbon content in the atmosphere [1]. Amongst the various renewable energy options, the solar PV system has emerged as a leading contender due to its simplicity of structure. Extensive discussions have been held regarding the various structures of PV panel systems and their suitability for different locations [2].

Solar PV generation experienced a significant increase in 2021, reaching a record-breaking 179 TWh (22% increase) and surpassing the milestone of 1,000 TWh. This growth in solar PV generation ranked second highest among all renewable technologies, following wind power [3]. Solar PV is rapidly becoming the most cost-effective choice for new electricity generation worldwide, which is expected to drive increased investment in the sector in the coming years. However, to achieve the Net Zero Emissions by 2050 Scenario, it is crucial to maintain an average annual generation growth of 25% during the period 2022-2030 [4]. This ambitious target requires more than a threefold increase in annual capacity deployment by 2030, necessitating stronger policy commitments and collaborative efforts from both public and private stakeholders. Key areas of focus include grid integration and addressing challenges related to policy, regulation, and financing.

The utilization of power electronic devices in conjunction with a maximum power point controller has been established as an effective strategy to increase the efficiency of PV systems. The achievement of maximum power output from a PV module can be obtained through the use of the MPPT controller. The incorporation of MPPT technology has exhibited the capability to considerably enhance the effectiveness of PV systems [5,6]. The closed-loop tracking of sunlight in PV systems can introduce harmonics into the output signal generated by the MPPT controller 4]. These harmonics can be effectively mitigated by implementing filter circuits to refine the output signal. Subsequently, the processed output signal is directed to the DC-DC converter and inverter, which are regulated using various power electronic converter circuits and control techniques that have been extensively explored in prior studies [7].

In the literature, several methods of MPPT control have been presented. In reference [8] focuses on improving the efficiency of MPPT techniques used in PV systems. The conventional fixed step size P&O algorithm often leads to power loss and perturbations around the maximum power point during steady-state operation. To address these issues, the study proposes a self-adaptable step size P&O-based MPPT algorithm with infinitesimal perturbations. The algorithm incorporates four techniques to enhance response speed and reduce power loss: system operation state determination, perturbation direction decision, adaptable step size, and natural oscillation control.

In reference [9], presents an optimized MPPT control technique for a standalone PV system using a three-level boost (TLB) converter. The proposed method utilizes an intelligent perturb and observe algorithm based on an artificial neural network (ANN-P&O) to reduce oscillations at the maximum power point (MPP). The ANN provides voltage and current values at the MPP for different solar irradiance and cell temperature conditions. The P&O algorithm then uses these values to generate the optimal duty cycle for the TLB converter, enabling precise tracking of the PV generator's MPP. Additionally, a proportional-integral (PI) controller is included to maintain the TLB capacitor voltage balance. The effectiveness of the ANN-P&O approach is demonstrated through Matlab/Simulink simulations and compared to the conventional P&O algorithm under various scenarios, including irradiance, temperature, and load variations. This research paper [10] examines and verifies the effectiveness of the P&O technique in isolating the photovoltaic array (PVA) from the power system. The nonlinear characteristics of PV cells make it crucial to extract the maximum power using a specific voltage setup. Therefore, the MPPT algorithm is employed in the PVA to expand the control range and maximize power output. The MPPT calculations are performed using a DC-DC boost converter, which offers high voltage gain and is suitable for applications with varying sun-oriented irradiances and cell temperatures. The study highlights the significance of MPPT techniques in optimizing the performance of PV systems under different operating conditions.

In reference [11], Solar photovoltaic technology has gained significant adoption in global PV markets, resulting in a cumulative installed PV capacity of 227 GW worldwide in 2015, effectively replacing conventional fossil fuel energy sources. However, improving efficiency remains a substantial challenge for researchers and the PV industry. This study proposes a solution in the form of a solar tracker and a modified P&O algorithm specifically designed for standalone solar photovoltaic systems. Recent research [12] introduces a novel and robust variable-step perturb-and-observe (RVS-P&O) algorithm specifically designed for the machine-side converter (MSC) in a WT system with a permanent-magnet synchronous generator (PMSG). The proposed control strategy addresses the limitations of existing P&O MPPT methods.

The P&O algorithm is a popular technique used in MPPT controllers that aims to achieve optimal power generation by continuously perturbing the operating point and observing the resulting change in power output. The study presents a detailed analysis of the P&O algorithm's performance in a solar PV system connected to a distribution network (DN). The article employs a mathematical model to simulate the PV system's behavior, incorporating the P&O algorithm to track the maximum power point of the solar array. The simulation results demonstrate the effectiveness of the P&O algorithm in extracting the maximum available power and maintaining stable system operation under varying solar irradiance levels. Moreover, the article also investigates the impact of grid-connected inverters on the performance of the PV system. The results reveal the importance of proper control strategies to ensure the safe and stable integration of PV systems into distribution networks. Overall, the modeling and simulation of solar PV systems using the P&O algorithm provide valuable insights into the design and optimization of PV systems for efficient power generation and integration into distribution networks.

The present paper follows a structured outline, starting with **Section 2** which offers an overview of the solar PV power system. **Section 3** elaborates on the Grid-Interfaced PV System, while **Section 4** presents the P&O based on the MPPT algorithm. **Section 5** discusses the simulation parameters, followed by **Section 6** which provides an in-depth analysis of the results. **Sections 7** and **Sections 8** respectively summarize the conclusion and the scope for future research.

## 2. Solar PV Power System

Solar PV power is derived from the conversion of solar energy into electrical energy through the use of photovoltaic materials. The photovoltaic effect is responsible for the generation of an electrical current when these materials are exposed to light, and this effect is achieved through the utilization of photovoltaic cells or solar cells [13]. The construction of solar panels, which are commonly used in this process, involves the assembly of multiple solar cells. These cells are positioned between transparent adhesive film layers and supported by a frame that holds a layer of glass in front. At the rear of the solar panel, a layer of aluminum known as the back sheet acts as a conductor for the electricity produced by the solar cells. The junction, where the electricity generated by the solar cells exits the solar panel, is a crucial component of the system. Thus, a PV power system refers to a type of solid-state semiconductor device that generates electrical energy upon exposure to light. The fundamental unit of a solar panel is the solar cell, and the interconnection of multiple solar cells in a series and parallel configuration yields a photovoltaic module. By connecting PV modules in series, a maximum output voltage can be achieved, whereas parallel connections result in a maximum output current [14]. The long-term benefits and low maintenance requirements of solar PV power systems have resulted in their widespread commercialization in numerous countries. Eq. (1) gives the voltage-current $I_{ph}$characteristic of PV. Eq. (2) points to saturation $I_0$ current module.

$$I_{ph} = \left[\mathrm{Jsc} + k_i\,(T - 298) * \frac{I_r}{1000}\right] \tag{1}$$

$$I_0 = \left[I_{rs}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{(q * E_{g0})}{n\,k}\right]\left(\frac{1}{T} - \frac{1}{T_r}\right) + k_i\,(T - 298) * \frac{I_r}{1000}\right] \tag{2}$$

where: $I_{ph}$ refers to light-generated current. Jsc represents short-circuit current. $I_0$ is well-known as the saturation current of a diode. $E_g$ shows a band gap. $n$ indicates the ideality factor of the diode.

The predominant obstacle in the utilization of PV power generation systems is the management of their nonlinear characteristics, which are contingent on the solar irradiance level and temperature. The topology of the DN-connected PV system generation system is depicted in Figure 1. Due to external factors such as passing clouds, nearby buildings, and trees, PV arrays are subjected to diverse irradiance levels.

## 3. Grid-Interfaced PV System

PV systems that are linked to the electricity supply are intended to provide power in parallel with the electrical system. An inverter is employed to turn the DC power created by the PV array into AC power in a request to satisfy the grid's power supply and voltage quality standards. A bidirectional association has been established between the system's AC output applications and the network of utilities in a PV system that has connections to an electric utility network [16]. This interface allows the AC power to either supply or feedback to the network when the PV system output is higher or lower than the load consumer demand. Figure 2, represents a schematic diagram of a PV system that is connected to the distribution network and can operate in either grid-connected or standalone modes. The system utilizes a multilevel inverter and boosts the converter to extract maximum power from the PV panel and transfer it to the utility grid or the standalone system.

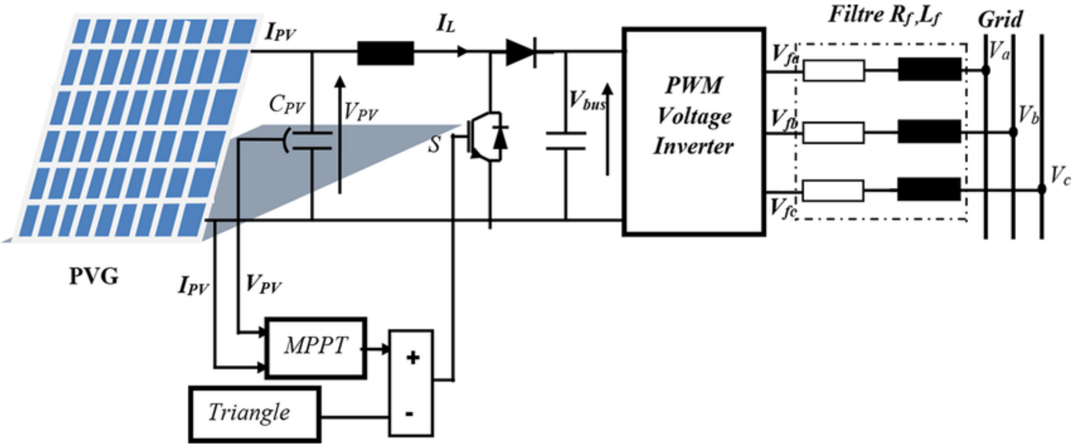

**Figure 1.** Topology of the DN-connected PV system [15]

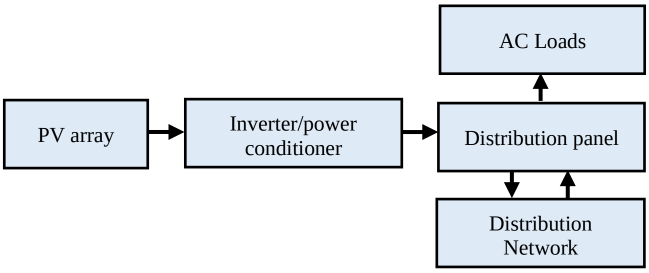

**Figure 2.** Block diagram of PV system connected to the DN.

Standalone PV systems are designed to meet certain DC or AC demand conditions and are designed to function independently of the power grid. The most common type of standalone PV system is a direct-coupled system, which only functions throughout the daytime and doesn't use batteries to store energy. These systems are frequently utilized for things like water pumps, tiny pumps for solar thermal water heating, and ventilation fans. An illustration of a direct-coupled PV system is shown in Figure 3.

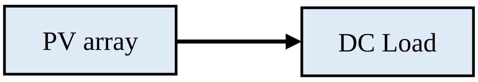

**Figure 3.** Direct-coupled PV system schematic representation.

In the case of the aforementioned direct-coupled PV system, several research investigations have been conducted concerning numerous factors such as fluctuations in solar radiation, optimal load matching, geographic location, climatic variations, utilization levels, and precise sizing specifications to cater to various loads. Another form of standalone PV system that can power both DC and AC loads with a battery storage system is depicted in Figure 4.

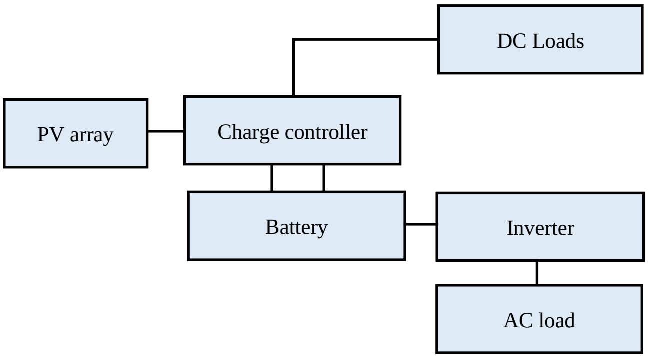

**Figure 4**. PV system with energy storage that powers both DC and AC loads.

## 4. Perturbation and Observation-Based MPPT Algorithm.

The P&O algorithm is a widely used and straightforward technique for MPPT in photovoltaic systems. The algorithm perturbs the PV array in response to solar radiation changes to move the system's operating point towards the MPP, resulting in a corresponding adjustment in the working voltage. However, it oscillates around the MPPT under steady-state conditions, leading to energy wastage. The researcher has proposed modifications to mitigate these oscillations, but they usually reduce the algorithm's response speed to atmospheric changes [17]. This technique involves the measurement of the incremental change in power, represented by $\Delta P$. A positive value of $\Delta P$ leads to an increase in the operating voltage to reach the MPPT. Conversely, a negative $\Delta P$ prompts a reversal in the voltage adjustment direction, with the operating point being adjusted to the nearest possible location close to the MPPT. A flowchart that depicts this algorithm is illustrated in Figure 5.

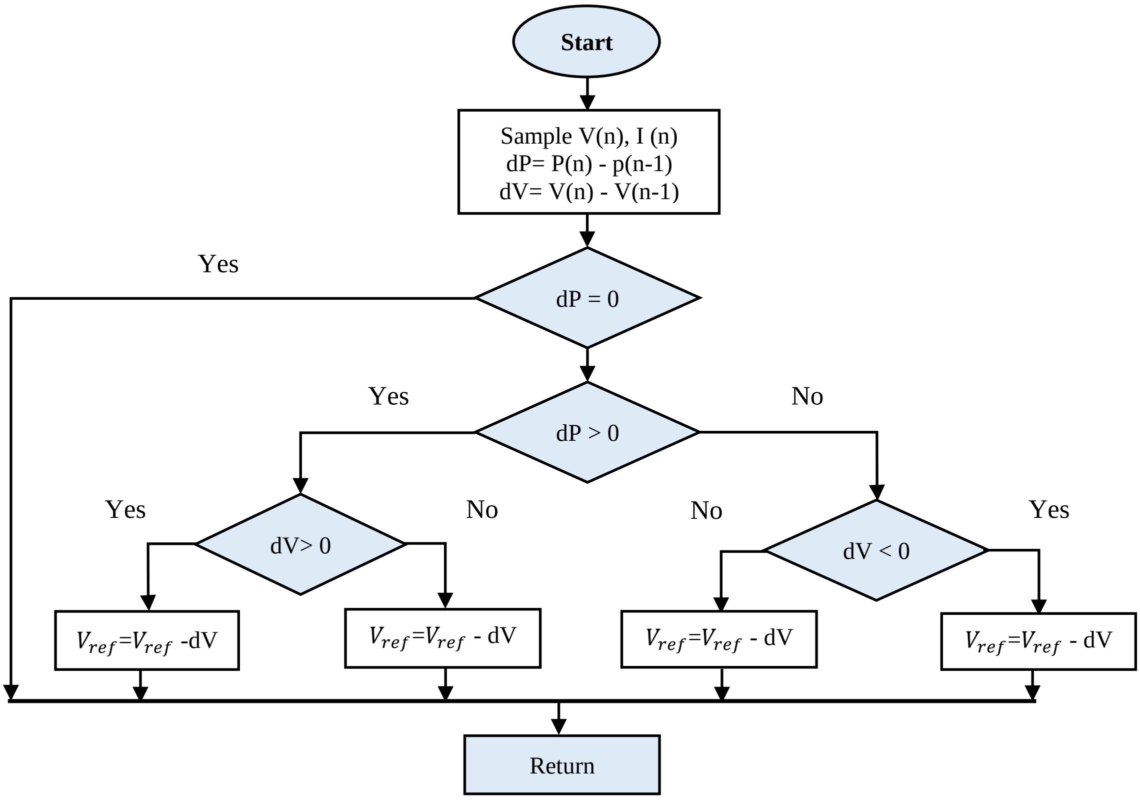

**Figure 5**. Flowchart of incremental conductance algorithms for MPPT.

## 5. Simulation Parameters

The present paper presents an in-depth analysis of the simulation parameters for modeling and simulating the connection of solar PV systems to distribution networks using the P&O algorithm. The parameters used in the simulation are based on measurements obtained from the selected PV-DN site as presented in Table 1. These parameters are integrated into the MATLAB simulation software to accurately simulate the behaviour of the PV system interfaced with the DN.

## 6. Result of Discussion

This simulation endeavours to investigate the performance of a photovoltaic (PV) farm, which is comprised of two PV arrays capable of generating 1.5 MW and 500 kW respectively under conditions of 1000 W/m2 sun irradiance and a cell temperature of 25 degrees Celsius. Both PV arrays are connected to boost converters that are controlled by MPPTs individually. The MPPTs employ the Perturb and Observe methodology to regulate the voltage across the PV array's terminals, ensuring that the maximum amount of power is extracted from the system. The proposal simulation aims to contribute significantly to the knowledge of PV farm performance, particularly in the context of MPPT systems, which have the potential to enhance the efficiency of PV systems. The boost converters' outputs are connected to a shared DC bus with a voltage of 1000 V. Figure 6, presents the O&P algorithm for MPPT. Figure 7, illustrates the PLL& measurement of the system. Figure 8, demonstrates the proposal simulation of 1.5 MW PV interfaced with DN.

A three-level Neutral Point Clamped (NPC) converter is employed to convert the 1000 V DC into approximately 500 V AC. In this direction, A DC voltage regulator controls the NPC converter to maintain the DC link voltage at 1000 V, regardless of the amount of active power generated by the PV arrays. Furthermore, the regulator includes a reactive power regulator that enables the converter to produce or consume up to 1 Mvar. To connect the converter to the grid, a 2.25-MVA 500V/25kV three-phase coupling transformer is employed. Figure 9, illustrates the irradiance of the solar PV system. Figure 10, shows the outcome of the O&P algorithm based on MPPT1 and MPPT2. Figure 11. The outcome of V means PV1 and V mean PV2. Figure 12, depicts the outcome of P mean PV1 and P mean PV2. The grid model comprises typical 25-kV distribution feeders and an equivalent transmission system with a capacity of 120 kV. This research study examines the performance of this system and its ability to integrate renewable energy sources into the grid while maintaining stability and reliability.

**Table 1.** Simulation parameters of 1.5 MW PV interfaced with DN [18].

| System Quantities | Unit | Ratings |
|---|---|---|
| Distribution Network | kV | 120.0 |
| PV Array | MW | 1.5 |
| Parallel Strings | - | 282.0 |
| Maximum Power | W | 355.0 |
| Cell per module | Ncell | 83.0 |
| Open circuit voltage | V | 51.9 |
| Short-circuit current | A | 8.86 |
| Sun irradiance and cell | W/m2 | 1000.0 |
| Temperature | °C | 25.0 |
| load | MW | 2.0 |
| Nominal phase-to-phase voltage | Vrms | 25.0K |
| Nominal frequency | Hz | 60.0 |
| Active power | MW | 6.0 |

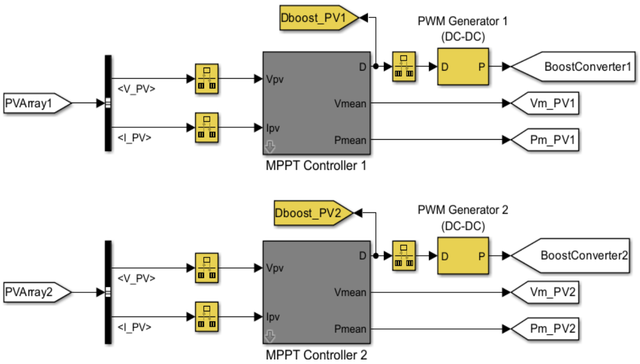

**Figure 6**. The O&P algorithm based on MPPT

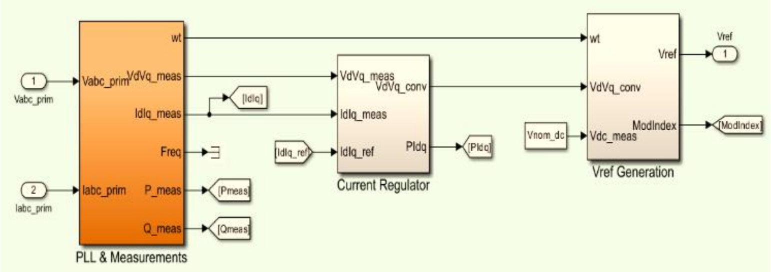

Figure 7. The PLL& measurement of the system

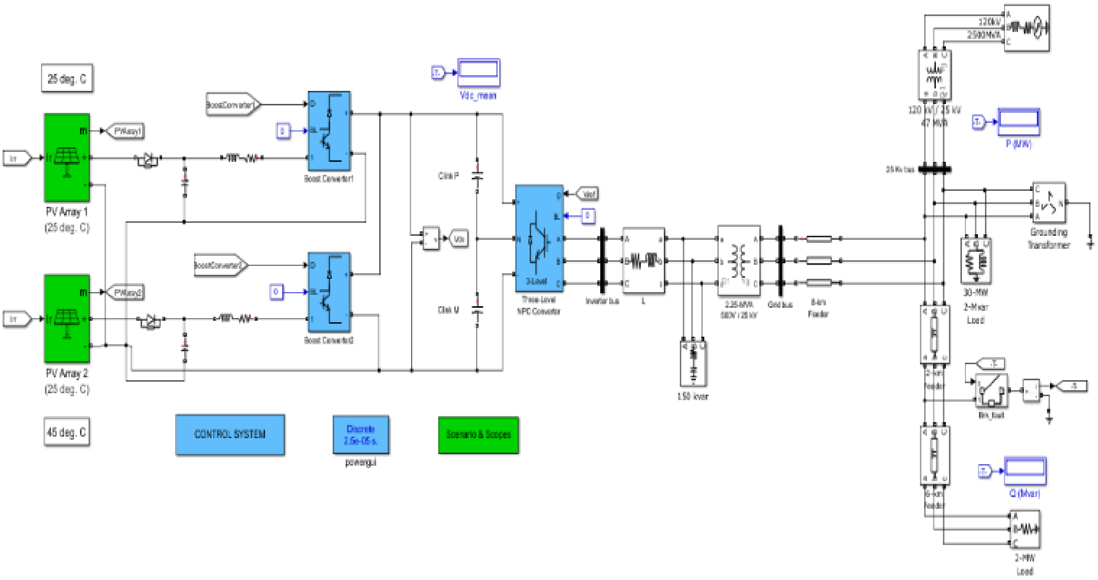

Figure 8. The proposal simulation of 1.5 MW PV interfaced with DN

Figure 9. The irradiance of solar PV system

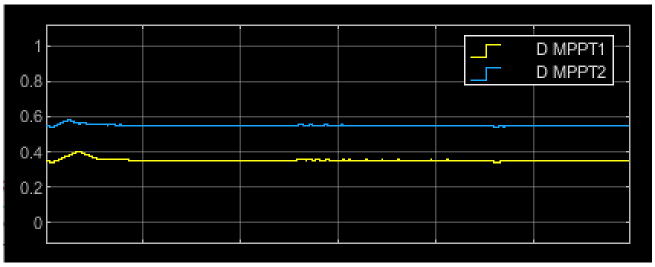

Figure 10. The outcome of the O&P algorithm based on MPPT1 and MPPT2

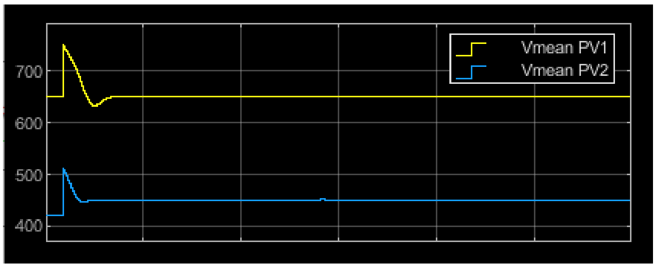

**Figure 11**. The outcome of V mean PV1 and V mean PV2

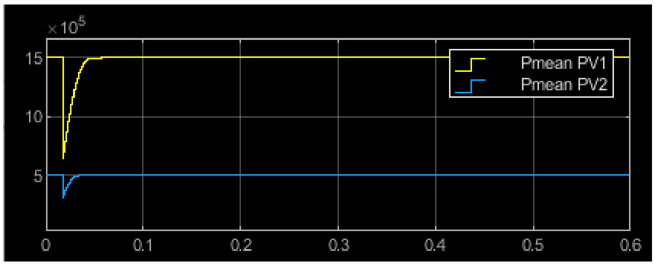

**Figure 12**. The outcome of P means PV1 and P mean PV2

## 7. Conclusion

This article aims to contribute to the development of modelling and simulation techniques for PV systems interfaced with distribution networks, focusing on the use of the P&O algorithm for MPPT. The P&O algorithm is a well-established technique for extracting the maximum available power from a PV array by perturbing the operating voltage or current and observing the corresponding changes in power output. The P&O algorithm is implemented in a simulation environment that includes a model of a distribution network, allowing for the analysis of the PV system's impact on the network's voltage and power profiles. The simulation results are validated against experimental data obtained from a real PV system. The main contribution of this study is the development of a comprehensive simulation framework that allows for the evaluation of the performance and grid integration of a PV system using the P&O algorithm. This framework can be used to assess the impact of various factors such as system sizing, shading, and network topology on the performance of the PV system and DN. The results of this study can help in the design and optimization of PV systems for grid-tied applications, contributing to the development of sustainable and efficient energy systems.

## 8. Future Scope

The future scope of the modelling and simulation of solar PV interfaced with the distribution network using the P&O algorithm can be extended by integrating a hybrid energy storage system to improve the system's performance. The hybrid energy storage system can consist of different energy storage technologies such as batteries, and flywheels, which can be used to store the excess solar energy generated during the day for use during periods of low solar irradiance. This will enhance the reliability and stability of the system by reducing the dependency on the grid and mitigating the impact of intermittent solar energy generation. Furthermore, the P&O algorithm can be improved to mitigate power quality issues such as harmonics, flicker, and voltage fluctuations in the system. This can be achieved by incorporating a control strategy that can regulate the power quality parameters within the acceptable limits set by the grid codes. Moreover, the P&O algorithm can be combined with other advanced control strategies such as fuzzy logic, neural networks, and genetic algorithms to enhance the performance of the system and optimize power generation and consumption in real-time.

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