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Optimizing Solar Energy Harvesting: A Simulation Study Of Fuzzy Logic And Enhanced Perturb & Observe MPPT Techniques For Standalone PV Systems

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Abstract

Solar photovoltaic technologies provide us the ideal instrument to end our reliance on fossil fuels, which must undoubtedly be curbed. It is necessary to enhance efficiency in order to transition energy production to rely on renewable sources. Solar panels have been around since the 1950s, but they still aren't very efficient. Maximum Power Point Tracking (MPPT) devices are being used to counteract the inefficiency of solar panels by monitoring the maximum working power and voltage. Finding the most effective, stable, and efficient method among three popular techniques to MPPT is the goal of this research. In order to monitor the maximum power, the method uses perturb and observe (P&O), fuzzy logic, and enhanced P&O to change the voltage the battery needs to charge itself. The whole investigation relies on simulations run in MATLAB Simulink with the help of the Simscape module. We assume the panel is in an unmoving, light-filled condition. Being exposed to light at a steady rate with just little variations in ambient light. The primary goal was to determine which algorithm performed the best under controlled conditions using the same inputs. In terms of decreased oscillation in output power, rapid climb to maximum power, level power point tracking, and an efficiency of 96.55%, the enhanced P&O controller performed better when the power and voltage measurements were displayed. The output power of traditional P&O and fuzzy logic algorithms is more harmonic, but they were not far behind with efficiency of 93.91% and 94.39%, respectively. Photovoltaic (PV) techniques can collect water from Chattogram, Bangladesh jerinsultana390@gmail.com [2], [3]. Solar cells are the fundamental building block of the photovoltaic system. These solar cells often make use of semiconductors. In order to facilitate the construction of solar cells, the materials are heavily doped. These cells use a process known as the photoelectric effect to convert sun energy into electrical energy. Solar cells and photovoltaic cells convert light into electricity the second they come into contact with light. Similarly, photovoltaic (PV) modules allow for the rapid conversion of sunlight into power. An array of photovoltaic (PV) modules is formed when many modules are linked in series and parallel to provide an attractive voltage and current distribution. In order to get the most out of a PV module, it's best to use it at or near its maximum power setting. The amount of power generated by the solar PV modules is susceptible to a number of variables. The quantity and pace of energy storage are the most important. Maintaining the output power at the highest possible power from a PV array is how highest Power Point Tracking (MPPT) works [4]. With maximum power point tracking (MPPT), a battery bank may be charged while the PV output voltage is maintained at an optimal level for charging and current regulation. Add as much power as possible to the battery. It continues to operate regardless of cloud cover or reduced sunshine. Therefore, this MPPT may help make better use of renewable solar power.

Keywords—Perturb and observe, Fuzzy Logic, Improved P&O, Efficiency

INTRODUCTION

As a nonrenewable energy source, fossil fuels are continually being produced via the slow but steady degradation of plant and animal life. There is an ongoing scarcity due to the high rate of organic matter conversion to fuel. As far as fossil fuels go, the three most popular ones—oil, coal, and gas—are estimated to run out in around 35, 107, and 37 years, respectively [1]. Since renewable energy sources

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produce very little carbon dioxide, fossil fuels are a dirty way to power our energy needs. Therefore, "green energy" describes renewable sources. Solar power is one of the most common renewable energy sources. Solar energy refers to the power that is extracted from the sun. The solar radiation that reaches Earth is abundant and provides a tremendous amount of energy. It is possible to harness this power The goal of this study is to choose the most effective algorithm from among the most popular ML approaches while keeping the simulation's system and components unchanged. Insight into the efficiency gains made by Perturb and Observe (P&O), Fuzzy Logic, and enhanced P&O will be provided by this.

LITERATURE REVIEW

highest electricity Point refers to the precise moment when a solar PV panel produces its highest amount of electricity. This study proposes a Maximum Power Point Tracking (MPPT) control system that makes use of Fuzzy logic, the Improved P&O algorithm, and the P&O MPPT algorithm to optimize the power output of photovoltaic (PV) systems under conditions of generally constant temperature and irradiance. According to Kamran, M et al. [5], the algorithm should limit the search region of the power bend to 10% in order to keep the MPP and P&O tracking models inside a limited search space. Through experimental exploration, the recommended procedure's outcome validated the importance of the P&O algorithm in delivering higher-quality, conditioned power to the load. Elbarbary et al. [6] offered a P&O approach that yields an optimistic 94% performance, considering the fast irradiation. When it comes to MPPT accuracy, Tehzeeb-ul et al. [7] shown that using a fuzzy logic controller is more effective than using traditional methods. Remaining unaffected by changes in irradiation levels, the suggested model reduces volatility. In addition, it is able to monitor the constant power, free of variations and background noise, as it approaches the peak power point. When the temperature changed by 99.40% and the amount of radiation changed by 96.64%, Abdullah et al. [8] found that a fuzzy logic controller could achieve standard efficiency based on the simulated results. The Maximum Power Point Tracking approach was used by Remoaldo et al. [9] for a solar system. One part of the two-part model considers the traditional Perturb and Observe (P&O) method. The second step involves implementing the standard P&O with the help of a Fuzzy Logic Controller (FLC), which makes use of fuzzy logic concepts. In an effort to enhance the traditional P&O approach, Tan et al. [10] introduced the support vector regression (SVR) methodology. The model has been trained using SVR, a widely used regression technique. After training the model, it was used to monitor the MPPT voltage, compare it to the operational voltage, and determine an appropriate step size. Through the use of model comparisons, they presented an approach that outperforms the standard P&O technique. We saw a considerable improvement in the timeliness, effectiveness, and precision of the tracking. Once again, in an effort to reduce complexity, Kamran et al. [5] proposed a Perturb and Observe technique that would limit the search space of the original algorithm. This would improve its performance in both uniform and different weather circumstances while simultaneously lowering complexity. The modified P&O MPPT proposed by Pilakkat et al. [11] may be practically used under Partially Shaded Conditions (PSC). The first step involves using the swarm-based meta-heuristic algorithm known as Artificial Bee Colony (ABC). In the second step, the P&O algorithm is further used. In order to provide a concise overview of our literature review, we have read the most relevant publications, examined them, and extracted the main results for application of the fuzzy logic, perturb and observe, and enhanced Perturb and observe MPPT algorithms. This study focuses just on increasing efficiency depending on the algorithm utilized, whereas most of them were adopting several approaches to enhance efficiency and reduce harmonics. Section III.

METHODOLOGY

This section provides a detailed explanation of a simulation research that was conducted on classic P&O, fuzzy logic, and enhanced P&O MPPT approaches in order to traverse the solar peaks. PV System The following is the MATLAB Simscape library's default equation for a PV array:

$$I = I_{ph} - I_s(e^{\frac{(V+I\times R_s)}{(N\times V_t)}} - 1) - I_{s2}(e^{\frac{(V+I\times R_s)}{(N_2\times V_t)}} - 1) - \frac{(V+I\times R_s)}{R_p} \quad (1)$$

Where,

$$I_{ph} = I_{ph0} \times \frac{I_r}{I_{r0}} \quad (2)$$

I_r= Irradiance in W/m^2

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Iph0= Current supplied to Ir, The saturation current of the first diode (Is) and the second diode (Is2), the thermal voltage (Vt), the quality factor (N) of the first diode and the second diode, and the voltage across the solar cell (V) are all variables. In Figures 1 and 2, we can see the V-I and P-V panel characteristics as a function of temperature and irradiance.

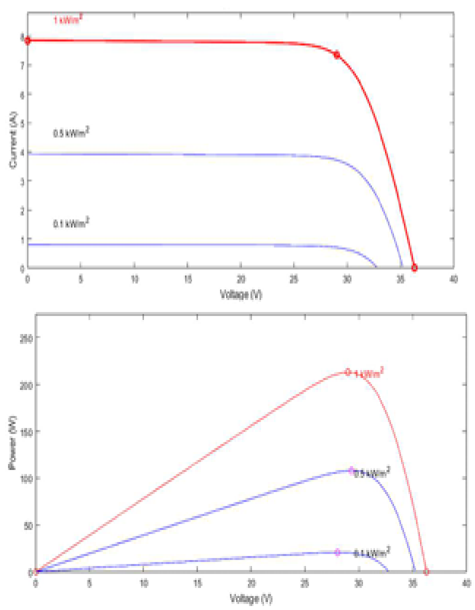

Fig. 1. V-I and P-V characters in variable Irradiance level

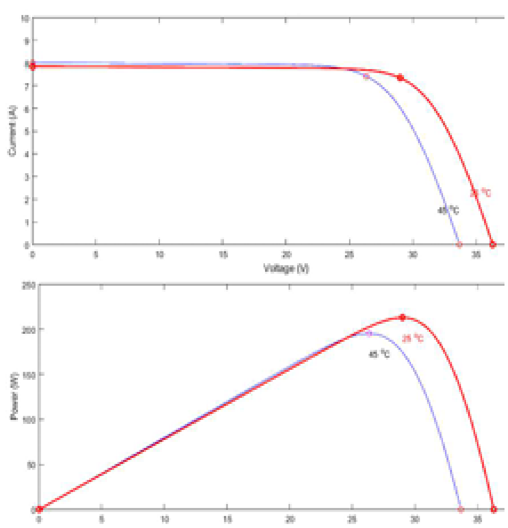

Fig. 2. V-I and P-V characters in variable Temperature

When the amount of sunlight reaching the solar panel varies, the current it generates increases, leading to a higher output voltage. While changes in temperature cause the potential difference to grow, current remains unaffected by temperature variations. Power also stays the same in this graph. To avoid any potential introduction of new variables caused by these variations, the suggested model operates at a constant temperature of 25°C and an identical irradiance of 1kW/m2. Figure 3 shows the layout of the solar PV system that was taken into account in this study. It clearly shows how the MPPT system works. While the DC-DC buck converter receives the real power, the PV panel communicates V-I data with the MPPT controller. After that, the MPPT controller interprets the data and sends it to the buck converter so that the battery may receive maximum power while the potential difference remains steady.

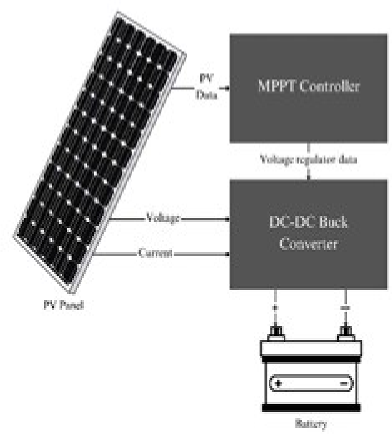

Fig. 3. Scheme of the solar PV system

Machine learning In this research, we take a look at three of the most popular MPPT techniques. The system calculates the optimal voltage to charge the battery effectively by taking current and voltage readings from the PV array and feeding them into an electronic MPPT controller. The system has chosen Perturb and Observation (P&O), Fuzzy Logic, and

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Improved P&O as its MPPT approaches. The buck controller receives signals from each of these algorithms after they compare to a reference point; this is a commonality throughout their operations. The efficiency and harmonic properties of each algorithm are then examined by plotting the output power and voltage data. B.1. Eliminate and Monitor The perturb-and-observation (P&O) method is among the most popular and easy-to-understand MPPT approaches [12]. Considering the potential precision and efficiency it offers, its cheap cost makes it a more appealing alternative. To use it, you merely need to tweak a single variable and, depending on what you see, modify the other settings. In stable environments, it performs well as an MPPT controller algorithm, but it may struggle when faced with sudden changes. Its time-tested efficacy, low power usage, simplicity, resilience, and cost-effectiveness have set it apart from all other methods. Figure 4 shows the working concept of the traditional P&O that was used.

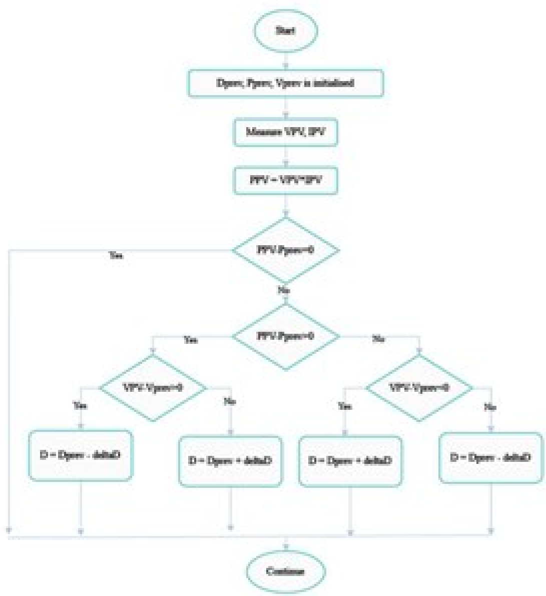

Fig. 4. Block Diagram of P&O algorithm

Fuzzy reasoning Uncertainty is handled by a fuzzy logic system using linguistic classification [7], [8]. Complex models that make use of binary logic operations may benefit greatly from it. This is the key that unlocks the door to Fuzzy Logic algorithms' great potential in MPPT. Use it to make your solar PV array more precise and efficient. Not only that, it optimizes the power output to a load or battery and helps in adapting to different environmental situations [8]. Compared to other algorithms, such as P&O, fuzzy logic models may be more resource intensive and taxing on the system, despite their relatively basic model architecture.

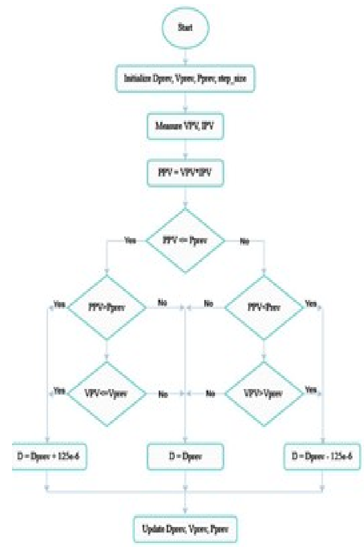

Fig. 5. Block Diagram of Fuzzy Logic algorithm

As shown in Figure 5, the applied Fuzzy Logic algorithm operates according to this premise. Two, enhanced P&O When it comes to locating and retaining maximum power, the perturb and observe model sticks to the basics. It

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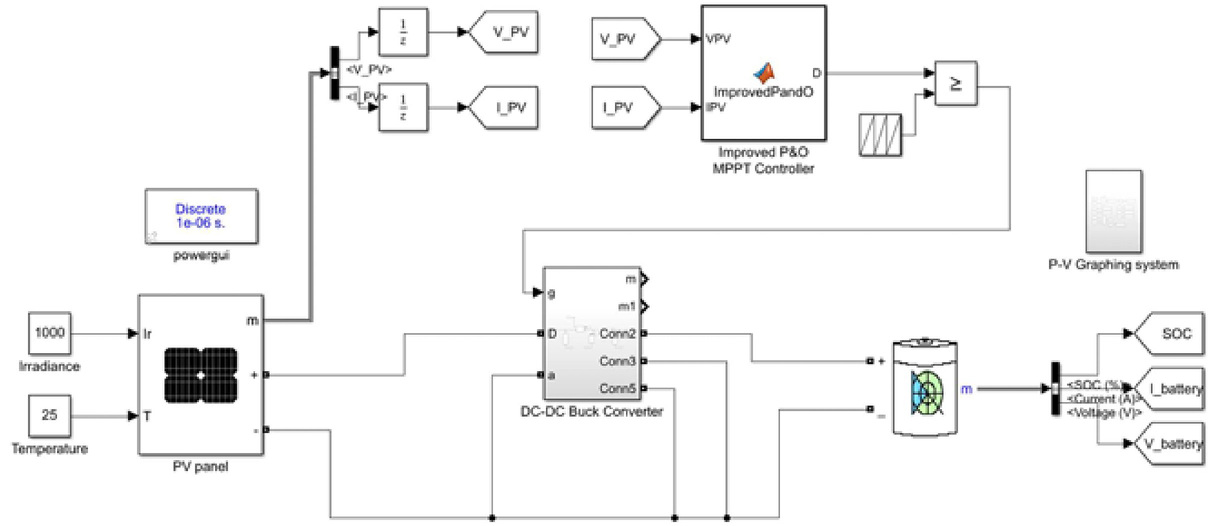

Fig. 7. Proposed Circuit Diagram of PV array with Improved P&O MPPT controller

In order to monitor the Maximum Power and ensure that the battery receives the maximum current while maintaining the ideal voltage for the battery to accept it, algorithms such as P&O, Fuzzy Logic, and Improved P&O are used. sometimes causes oscillations in the output power since it takes a set delta value and travels through current and voltage levels comparing with the previous maximum point. Incorporating a variable delta into this criteria improves it as it searches for the maximum power point (MPP) within a short margin and only does so when the power changes [10], [13]. Modified or Improved P&O approach may also refer to other elements, such as limiting the search area [13]. Reducing the likelihood of oscillations is the first objective of a better P&O approach. A variable delta was taken into account for this specific model. Figure 6 shows the working concept of the modified P&O algorithm that was used.

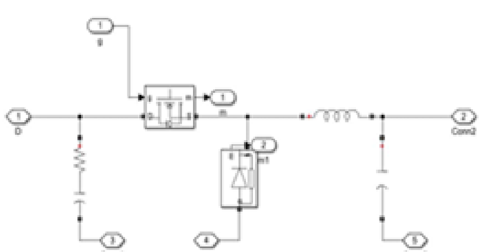

Fig. 8. DC-DC Buck Converter

The voltage curve is favorably affected by a battery's State of Charge (SOC), which means that the Buck Controller (Fig. 8) must always provide the battery with the appropriate voltage. This keeps the power at its maximum by adjusting the voltage and current. The suggested model assumed a starting state of charge (SOC) of 0% and made use of a 0.75 Amp-Hours Li-ion battery. In order to have a better grasp of the algorithms' efficacy and efficiency, the overall charging time was monitored.

THE OUTCOME

The findings are shown as graphs that indicate the P-V input and output. All systems have the identical P-V input from the solar array (Fig. 1 and Fig. 2), with the MPPT controller being the sole changeable factor. All three models use the same P-V input curve, but their P-V output graphs are quite different. Figure 9, which depicts the P&O MPPT, demonstrates that the graph hits maximum power rapidly but exhibits greater oscillation as a result of the current's fast fluctuations. Compared to the P&O approach, the curve in Fig. 10, which represents the MPPT using the Fuzzy Logic method, achieves maximum power considerably later. Figure 11. The curve, however, is far more stable and exhibits hardly any fluctuation.

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P&O Technique The simulation results are encouraging for the Perturb and Observe method, even if it takes a simple and rudimentary approach to monitoring and sustaining MPP. A power of more than 200 Watts was maintained over the voltage range, despite the fact that the power variable showed minor oscillations. Starting at 13.56 volts—just above our battery's voltage rating—the output increased to 198.1 watts. From 0% to 100% State of Charge (SOC), the voltage needed to charge the battery gradually rose. Power was 211.9 watts, with a maximum output voltage of 27.27 volts, and 7.77 amps of current going into the battery. P&O algorithms' great efficiency and lightweight calculative methodology cause the curve to quickly increase to maximum power. In only 241 seconds, this unit fully charged a 0.75 Amp-Hours battery.

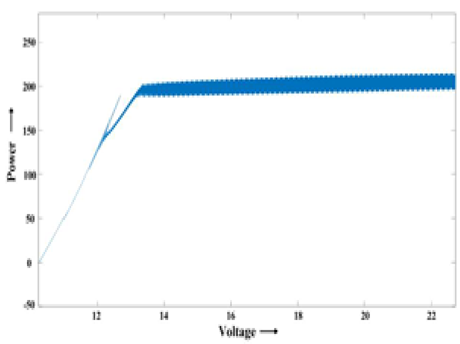

Fig. 9. P-V output of the P&O model

While the P&O approach is quite simplistic, the Fuzzy Logic algorithm mimics the way the human brain works. The power readout was 157.7 Watts at startup, and the voltage was a meager 13.4 Volts. The gradual but consistent rise in power, as seen in Fig. 10, continues until it reaches around 19.5 Volts. After reaching its peak, the power stays rather constant until the very end. With a voltage of 25.18 volts and an output current of 8.35 amps to the battery, the final power measurement was 210.2 watts. The maximum power has not been established yet since the curve stays sloping in the first phases up to 19.5 V. Which is a regression toward the old, inefficient P&O methods.

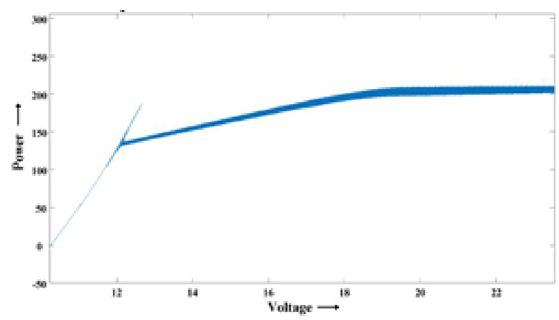

Fig. 10. P-V output of Fuzzy Logic model

The Fuzzy Logic algorithm's P-V out curve is far more stable than the P&O algorithm's. The 0.75 Amp Hour battery took around 254 seconds to get from empty to full. C. The P&O Method Got Better A more consistent P-V curve with less oscillations is produced by the Improved P&O as a result of its more limited searching and tracking. The power surged to its utmost and began charging the battery in no time. There was an initial power of 197.7 watts and a voltage of 25.28 volts. As it supplied 205.8 watts of power to the battery pack, the voltage was almost constant across the curve, reaching a final reading of 25.2 volts.

TABLE 1: COMPARATIVE RESULTS BETWEEN P&O, FUZZY LOGIC AND PROPOSED IMPROVED P&O

MPPT Method	Variations						
	Initial V	*Average Maximum V*	*Initial P*	*Average Maximum P*	*Time to 100% SOC (s)*	*Oscillations*	*Efficiency*
P&O	13.56	27.27	158.1	200.17	241	More	93.91%
Fuzzy Logic	13.4	25.18	157.7	201.2	254	Less	94.39%
Improved P&O	25.28	25.2	197.9	205.8	248	Least	96.55%

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TABLE 2: RESULTS IN PREVIOUS STUDIES

Reference	MPPT Method	Efficiency	Remarks
[5]	Improved P&O	-	Reduced oscillation
[6]	P&O	94%	Better time response
[10]	Improved P&O	96.14%	Reduced oscillation
[11]	Improved P&O	84.42%	Reduced oscillation

Within 248 seconds, the 0.75 Amp-Hours battery could be fully charged using the modified/improved P&O model. Because it produces electricity with many fewer harmonic qualities, this model is far superior to the old P&O model. response [10] Higher P&O by 96.14 percent the eleventh P&O is now 84.42% better. Decreased tremor Decreased tremor Table 1 displays the results in a way that allows for comparison. Look no farther than the table to see that this method outperforms its Fuzzy Logic equivalent in almost every single category. Additionally, the efficiency achieved in related tasks is shown in Table 2.

a noticeable improvement in the suggested model's efficiency V. COMMENTARY Each algorithm employed the same circuit and components in order to exclude the possibility of a second variable interfering with the outcome. Our results show that the Modified/Improved P&O MPPT method outperforms the conventional P&O and Fuzzy Logic approaches in this particular case. It charges the battery much faster and provides it more power than the Fuzzy Logic controller. Figures 9, 10, and 11 further demonstrate that, in comparison to the conventional P&O and Fuzzy Logic approaches, the Improved P&O technique detects and retains the maximum power at a somewhat earlier stage. Additional conditioned power is supplied to the battery pack via the enhanced P&O technique. Therefore, with respect to a stationary location and constant illumination, Improved P&O stands out as the most effective method. When compared to the classic P&O model's 93.91% efficiency, the Fuzzy Logic model's 94.39% efficiency, and the Improved P&O model's 96.55% efficiency, this becomes more compelling. In both P&O and Fuzzy Logic approaches, oscillations are seen. These oscillations may increase operational temperature and power loss, as well as decrease the lifespan of capacitive loads and inverters. To address this, different safety bounds can be included [14], [15]. However, the system's setup price can go higher as a result. Improved P&O, on the other hand, provides more consistent power, which does double duty by lowering setup costs and guaranteeing the security and longevity of the DC components used.

CONCLUSION

Enhanced P&O offers superior efficiency and harmonic control, which is a key component in the pursuit of the most effective, reliable, and economical MPPT algorithms. In order to monitor the maximum power, the upgraded P&O approach feeds the battery more power and charges it in a much shorter time than the Fuzzy Logic controller. Compared to the Fuzzy Logic Method and conventional P&O in the same circuit, the enhanced P&O approach clearly outperforms both when it comes to maximum power tracking. An efficiency of 96.55% is achieved using the enhanced P&O approach. However, efficiency of 93.91% and 94.39%, respectively, are achieved by the conventional P&O technique and Fuzzy. A more consistent P-V curve is produced by the enhanced P&O, which has low harmonic characteristics. Thus, under constant location, irradiance, and temperature, P&O is a more organized maximum power point tracking (MPPT) approach than Fuzzy logic and conventional P&O. Even though they use the same parts and connections, enhanced P&O provides more consistent and efficient power to charge the battery. This information may be used in real-world applications by choosing an appropriate ML approach to monitor the Maximum Power Point. The potential of the P&O approach will continue to grow as new efficiency-enhancing methods emerge, such as solar tracking. To build a flexible and efficient PV array system, a solar tracker equipped with efficient motors that allow for two-degree movement may use irradiance data, GPS data, or a mix of the two to follow the sun's position and generate more power. Even in the most inaccessible areas, such a device has the ability to provide optimal outcomes because to its portability.

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