

Comparative Study of P&O MPPT with Hybrid P&O MPPT for Battery Charging

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Abstract— Extracting maximum power from a solar PV panel requires an effective MPPT algorithm. This work compares two such methods through simulation: a standard Perturb and Observe (P&O) approach implemented in Proteus with an ATmega328P microcontroller, and a hybrid P&O technique combined with Fuzzy Logic Control (FLC) simulated in MATLAB. The hybrid method uses fuzzy logic to adjust the step size of perturbations, allowing it to better track changes when both irradiance and temperature vary. MATLAB also enables detailed analysis of State of Charge (SOC) under these conditions. The voltage observed at the output side of the boost converter is compared for both methods. Results show that the fuzzy-based MPPT reaches the maximum power point faster and operates more smoothly, making it a strong choice for improving PV battery charging systems.

Index Terms— MPPT, Perturb and Observe, Fuzzy logic, MATLABP, roteus.

I. INTRODUCTION

In today's shift toward renewable resources, solar energy is increasingly recognized for its potential and versatility and is widely used in many applications, whether in households, industrial areas, or in grid connections to supply additional power for transmission. A wide range of applications depend on renewable energy sources like solar and wind power. Photovoltaic systems convert sunlight directly into electricity but are inherently affected by variations in irradiance and temperature. This leads to fluctuating output, which poses challenges for consistent battery charging. To overcome this, MPPT algorithms play a vital role by dynamically adjusting the operating point of the PV system to extract maximum available power.

To extract the required amount of power from a PV panel, MPPT (Maximum Power Point Tracking) algorithms play an important role [5] These control methods help in optimizing power extraction from the panel, enabling efficient use of the generated energy across different applications. This process is pollution-free and is known as green energy. As the approach of modifying PO MPPT done in [7], [8] that modified MPPT results in the efficient power from panel

This paper focuses on comparative simulation study of MPPT techniques for photovoltaic (PV) battery charging systems. The classic Perturb and Observe (P&O) algorithm is implemented in Proteus, leveraging its suitability for microcontroller-based environments with the ATmega328P, and is evaluated under varying irradiance at constant temperature. To enhance the performance of P&O, particularly its slower response and steady-state oscillations, a Hybrid P&O approach integrating Fuzzy Logic Control (FLC) is developed and simulated in MATLAB.

In this work, the simulation of the conventional P&O MPPT algorithm was carried out in Proteus using an ATmega328P microcontroller, adapted from a reference study that employed Arduino [1]. This study focuses purely on simulation to analyse and compare the performance of standard and fuzzy-assisted MPPT method under varying irradiance and temperature conditions.

II. METHODOLOGY

This project adopts a dual-simulation approach using both Proteus and MATLAB to evaluate the performance of a battery charging and monitoring system. In Proteus, the Perturb and Observe (PO) MPPT algorithm was implemented using the ATmega32P microcontroller. The simulation was conducted under varying irradiance levels to observe the behaviour of the boost converter. Output voltage readings were recorded to verify the MPPT effectiveness under changing solar input. The single-diode PV cell was modelled using SPICE parameters in Proteus to closely replicate real solar panel characteristics.

The hybrid PO-Fuzzy MPPT algorithm was simulated in MATLAB/Simulink. A lithium-ion battery was integrated, and the system was tested under varying temperature and irradiance conditions. Key battery parameters such as State of Charge (SOC) and voltage were monitored to assess charging performance. This methodology enables a direct comparison of both MPPT approaches to evaluate improvements in tracking efficiency and output voltage of converter.

A. Solar Panel Model and Specification

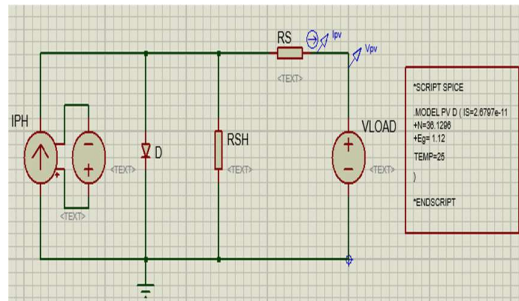


Figure 1. Single-Diode Model of a Solar Cell

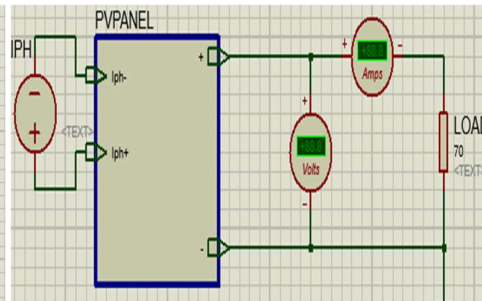


Figure 2. Simulation model of solar panel

This figure 1 and 2 shows a PV cell model using the single-diode circuit, built in Proteus with SPICE parameters. It includes a photocurrent source (IPH) representing light-generated current, a series resistance (RS) accounting for internal losses, and a shunt resistance (RSH) modelling leakage current. A diode (D) simulates the PV cell's p-n junction characteristics. The load voltage (VLOAD) and current (Ipv) are measured across an external load. The SPICE script defines key parameters such as diode saturation current (IS), Ideality factor (N), and bandgap energy (Eg), ensuring realistic behaviour under standard conditions (25°C) and by changing the photon current leads to change in irradiance.[1][2]

TABLE I. SOLAR PANEL SPECIFICATION

Characteristics	Value
Maximum power	20 watts
Voltage at MPP	18.76 volt
Current at MPP	1.07 amps
PV Short Circuit Current	1.17 amps
PV Open circuit voltage	22.7 volt
Temperature Coefficient V_{oc}	-0.35 %/°C
Diode Ideality factor	1.0036
Light generated Current	1.173amps
Number of cells, N_s	36
Temperature Coefficient of I_{sc}	0.043 %/°C
Series Resistance, R_s	0.35ohm

III. MPPT ALGORITHMS

Figure 3 shows the classic Perturb and Observe (P&O) MPPT algorithm. The initial step involves collecting voltage and current data from the solar panel. Power is obtained by $P=V \times I$, and its change (ΔP) is evaluated with

the previous cycle. Based on the direction of ΔP and ΔV , the voltage is increased or decreased to move toward the maximum power point.[3]

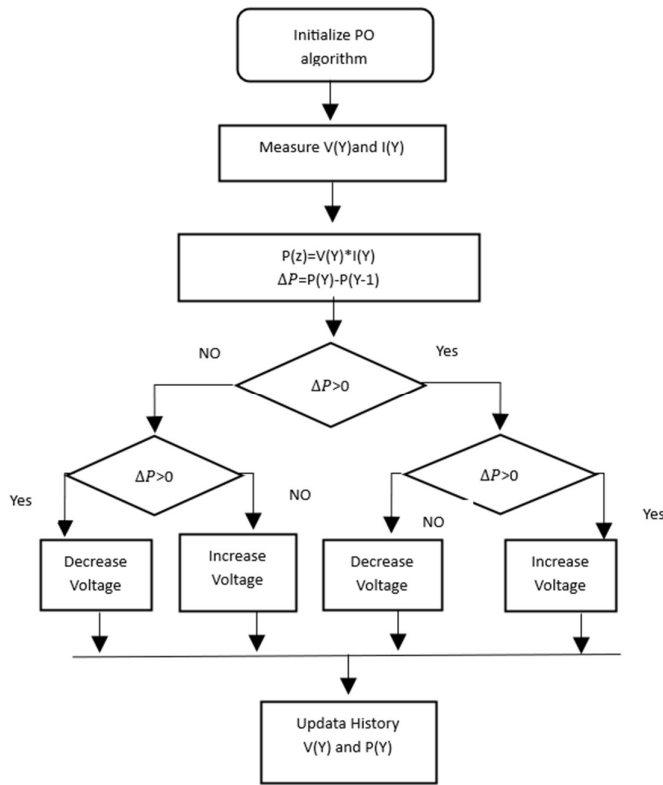


Figure 3. P&O flowchart

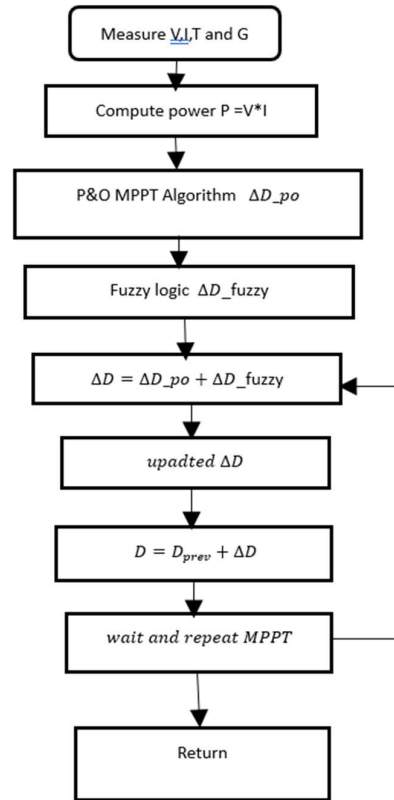


Figure 4. Hybrid P&O flowchart

Figure 4 shows the hybrid MPPT method, which combines P&O with fuzzy logic. It takes voltage, current, temperature, and irradiance as inputs. Both the P&O output (ΔD_{po}) and fuzzy logic output (ΔD_{fuzzy}) are added to form an updated duty cycle change. This improved method helps reduce oscillations and gives faster tracking. The system keeps adjusting until the maximum power is reached. The fuzzy logic-based MPPT model presented in [4] was used as a reference for designing the fuzzy controller in this work, using ΔV and ΔP as inputs to minimize power oscillation, this hybrid approach helps minimize oscillations around MPP and improves convergence speed under changing environmental conditions. Compared to the traditional method, the hybrid system shows better dynamic response during irradiance and temperature variation. The hybrid control is implemented in MATLAB/Simulink and tested with a PV-battery charging setup. Based on the simulation, the system's performance is better under varying conditions. It has been observed in recent studies that advanced control methods like fuzzy logic and neural networks can make MPPT more reliable and efficient in PV systems [4][6].

IV. SIMULATION AND RESULTS

A. PO Simulation in Proteus and Results

Proteus software is used to simulate the complete circuit. Figure 5 shows the complete system design implemented in Proteus and results in figure 5 is at photon generated current at 1.13. To monitor the system, a solar panel model is used as the input source, and its output is tracked using appropriate sensors [1]. These sensor values are fed into the microcontroller, which executes the classic P&O algorithm. The system applies the MPPT algorithm to estimate the duty cycle required for the MOSFET switching in the boost converter to extract maximum power. At the output side of the boost converter, a current-consuming circuit is connected that mimics the behaviour of a battery under charging conditions. The output of the converter is measured using a voltage

sensor and is used for SOC (State of Charge) estimation. The SOC estimation is based on the Open Circuit Voltage (OCV) method. Since there is no actual battery connected in the simulation, the SOC is shown as 0%, indicating no real charge accumulation. The SOH (State of Health) is displayed as 100% as a placeholder value, assuming the battery to be in ideal condition. The voltage observed at the boost converter's output (Figure 7) is around 34V, and the output current (Figure 6) is approximately 0.48A. These values result from a 20W solar panel model under test conditions. However, consequence to the variation in irradiance and constant temperature conditions, the expected output power is not fully achieved.

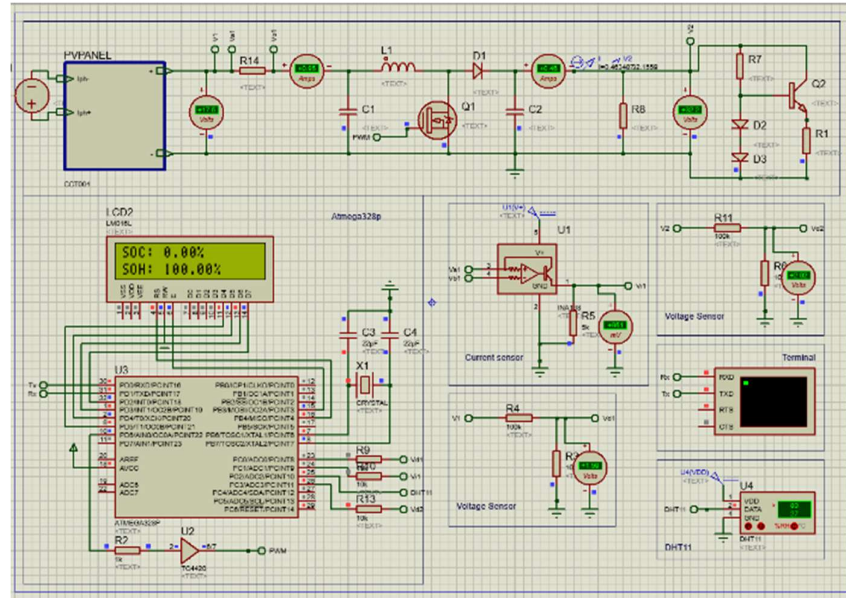


Figure 5.P&O Simulation in proteus

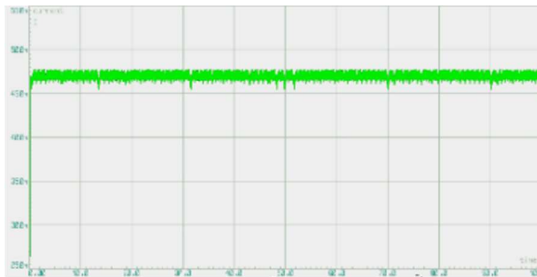


Figure 6. Output current

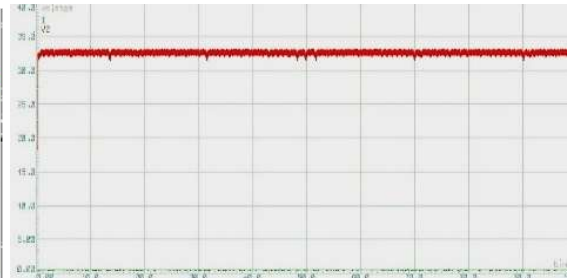


Figure 7. Output voltage

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TABLE II. SIMULATION RESULTS FOR VARIOUS IRRADIANCE

Sl. no	Photon generated current	Solar voltage(volts)	Solar current (amps)	Boost voltage(volts)	SOC and SOH at ideal condition	Temperature
1	1.17	18.3	1.04	34	SOC-0 SOH-100	25
2	1.15	17.8	1.02	33	SOC-0 SOH-100	25
3	1.13	17.5	0.95	32.3	SOC-0 SOH-100	25

The Simulation data is presented in Table 2 for varying irradiance levels, illustrating the impact of photon-generated current variations on solar voltage, solar current, and output voltage. A decrease in photon-generated current results in a slight reduction in both solar voltage and solar current, highlighting the influence of irradiance fluctuations on system performance. Despite these variations, the output voltage remains relatively stable, demonstrating the effectiveness of the MPPT algorithm in maintaining power regulation.

B. Hybrid PO Simulation in Matlab and Results

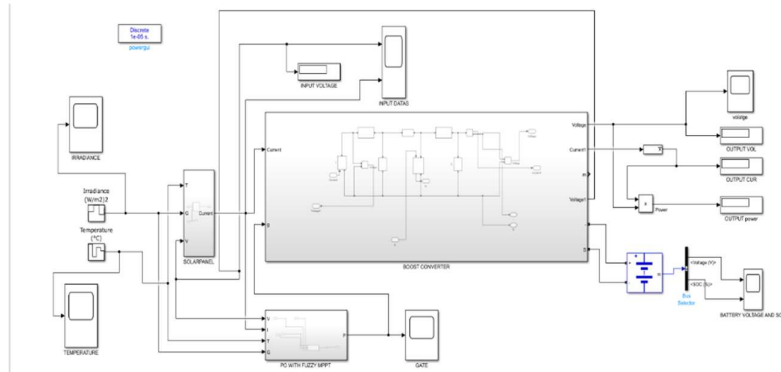


Figure 8. Hybrid P&O simulation in matlab

Figure 8 shows the simulation of the hybrid PO MPPT algorithm implemented in MATLAB. In this setup, a solar panel is connected to temperature and irradiance sources that apply step changes to simulate changing environmental conditions. The output of the solar panel under these variable conditions is fed into a hybrid MPPT block that combines both fuzzy logic and the P&O method. This block generates an optimized duty cycle or gate pulse, shown in Figure 10, and this signal is used to drive the MOSFET switch in the DC-DC boost converter. The boost converter steps up the voltage from the panel to a level suitable for battery charging, ensuring power continuity even under low irradiance. The converter is designed with an inductance value of 29 mH, an input capacitor (C_1) of 213 μ F, and an output capacitor (C_2) of 357 μ F. These values are computed by employing standard boost converter design equations referenced from [1], ensuring appropriate sizing based on voltage, current, and switching frequency. The identical component values are also used in the Proteus simulation for consistency and accurate comparison between the two platforms. The resulting boosted voltage, as seen in Figure 9, is supplied to a Li-ion battery. Figure 11 also illustrates the State of Charge (SOC) and battery voltage, reflecting consistent and effective charging under variable input conditions.

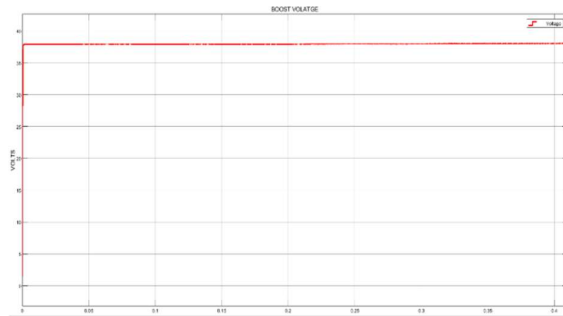


Figure 9. Boost voltage

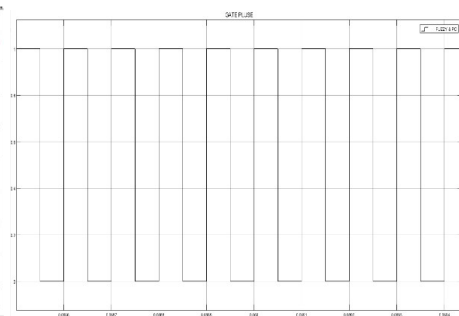


Figure 10. Generated gate pulse

Figure 11 illustrates the output performance of the system under variable temperature and irradiance conditions using a hybrid P&O MPPT algorithm. The top plot shows the battery voltage, which is maintained steadily around 36.9 V, indicating that the boost converter is effectively regulating the voltage despite environmental changes. The bottom plot displays the State of Charge (SOC) of the Li-ion battery. A gradual increase in SOC can be observed, which confirms that the battery is being charged efficiently and consistently. The ability to maintain stable voltage and steadily charge the battery under fluctuating input conditions demonstrates the robustness and adaptability of the hybrid MPPT control strategy. The table 3 shows the comparison of the two MPPT methods.

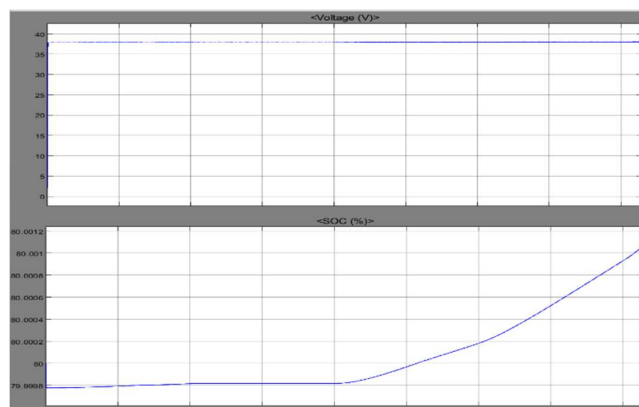


Figure 11. SOC and battery Voltage

TABLE III. COMPARISON TABLE

SI no.	Aspect	P&O MPPT	Hybrid P&O MPPT
1	Accuracy	Less accurate	More accurate
2	Dynamic response	slower	Faster
3	Power efficiency	Less efficient (under variable irradiance)	Efficient (under variable temperature and irradiance)
4	Simulation Output	34volts(variable irradiance)	37volts(variable temperature& irradiance)

V. CONCLUSIONS

A simulation-based comparison is carried out between the traditional P&O MPPT technique and a hybrid approach combining P&O with fuzzy logic. The P&O algorithm was implemented in Proteus with an ATmega328P microcontroller and tested under varying irradiance and constant temperature conditions. The hybrid MPPT, designed in MATLAB using fuzzy logic to dynamically adjust perturbation steps, was evaluated under both variable irradiance and temperature conditions. Simulation results show that the hybrid approach offers faster dynamic response, improved voltage regulation, and more stable battery charging behaviour. The SOC of the battery increases steadily over time, and the system maintains a consistent output voltage, confirming show well the hybrid MPPT controller works. Overall, the hybrid P&O MPPT algorithm demonstrates superior tracking performance and system stability, making it a promising solution for real-time PV battery charging applications under fluctuating environmental conditions.

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