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Conditional Tracking for Maximizing Power Consumption out of Solar Photovoltaic Array: Temperature and Solar Irradiation with Partial Shading

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***Abstract*— The efficiency of photovoltaic (PV) systems is intricately tied to temperature and solar radiation, impacting the current-voltage (I-V) and power-voltage (P-V) features of photovoltaic arrays. To optimize efficiency, Maximum Power Point Tracking (MPPT) algorithms must ensure PV arrays operate at their Maximum Power Point (MPP). However, variations in solar array attributes can lead to shifts in the MPP. This research employs the Perturb and Observe (P&O) MPPT method for using a solar array to statistically tackle this issue. A novel Simulink-based methodology is employed, accurately estimating peak power outputs of 8.600×10^4 and 10.002×10^4 watts under consistent irradiance and temperature conditions with partial shading. By treating temperature and solar irradiation as distinct factors, along with partial shading—this approach significantly bolsters the model's performance.**

Keywords—partial shading, photovoltaic arrays, boost converter, Perturb and Observe

I. Introduction

Renewable energy sources and photovoltaic (PV) technology have made tremendous progress in recent years [1], owing to growing concern about environmental pollution and the gradual increase of oil prices. Photovoltaic cells have low development costs (no fuel charge) and minimal maintenance requirements. Moreover, they are dependable, noiseless, and simple to install. In accumulation, in several individual applications, photovoltaic cells are suitable in assessment as supplementary energy sources, particularly in certain situations where spaces aren't reachable, making it unbeneficial to set up an established power appearance. But photovoltaic system efficiency is low because the produced power depends on solar irradiation and cell temperature.

Tracking the maximum power point is a complicated operation, usually called MPPT. In this operation, Maximum voltage and maximum current are tracked automatically by the beginning photovoltaic array to find maximum output power at a specified temperature. Along with solar irradiation, this is the major dispute in tracking the highest power point technique. Furthermore, the uniqueness of the photovoltaic array becomes multifaceted when partial shading is introduced. Solar arrays are operated at the highest power point regardless of solar irradiation using the MPPT algorithm and boost converter (DC-DC), and oscillations are also powered by solar power, focusing on a 99% tracking efficiency at the recommended highest power point voltage [2]. Authors in [3] researched the MPPT, a method to get the most out of solar photovoltaic modules and data transfer to load them more efficiently.

Given that solar PV cells include nonlinear characteristics, the DC power amount produced varies with solar irradiation and ambient temperature [4]. In this study, a power generation strategy has been developed that mutually considers output necessities and coordination of efficiency. The method uses a boost converter to oversee the amount produced and observed while the inverter is positioned on transfer side by side to develop the system's efficiency. The system can keep track of the acceptable point of highest efficiency [5]. A photovoltaic (PV) array with partial shading effect occurs when not all the solar panels in the array receive uniform sunlight, resulting in different parts of the array being shaded or exposed to varying light conditions. Partial shading can be caused by a variety of factors, including obstructions such as trees, buildings, nearby structures, cloud cover, or even dust and debris on the solar panels themselves. The authors in [6] optimized the Maximum Power Point Tracking (MPPT) in photovoltaic systems utilizing the Bat Algorithm, specifically under partial shading conditions. This study was primarily concerned with maximizing the power output of the photovoltaic system under varying shading scenarios. The author in [7] developed a predictive model for forecasting photovoltaic power output, which involves a sequential ensemble approach, combining multiple models for improved accuracy. This study was aimed at predicting future power output based on historical data, considering the dynamic nature of solar energy generation.

The main aim of the study is to investigate the troublesome MPPT techniques to discover the optimal current (IMPP) or optimal voltage (VMPP) that a photovoltaic array operates at and is supposed to activate to get optimal power (PMPP) to achieve the maximum power below a specified temperature and light intensity. In this paper, we have used a novel methodology by which we have reduced the cost, increased efficiency, and stabilized the temperature. In this research, we proposed a novel approach for conditional MPPT for optimization during power consumption from a solar photovoltaic (PV) array. Extending beyond traditional MPPT methods, the study integrates the Perturb and Observe (P&O) algorithm with sophisticated conditional tracking mechanisms. The focus is on addressing the influence of temperature variations, fluctuations in solar irradiation, and scenarios involving partial shading on the performance of the PV array. The P&O algorithm dynamically responds to temperature shifts through real-time sensing, adjusting the perturbation step size to accommodate temperature sensitivity. Additionally, an adaptive control mechanism is introduced to manage changing solar irradiation levels, dynamically altering the reference voltage for optimized power output. Moreover, this research aims to offer a comprehensive solution for practical applications in renewable energy systems, enhancing efficiency and ensuring robust performance under diverse and challenging real-world conditions. In the presence of partial shading, the Perturb and Observe (P&O) algorithm employs shading detection techniques, selectively perturbing only the unshaded sections to avoid multiple local maxima in the power-voltage curve. This research study provides a comprehensive solution for practical applications in renewable energy systems, offering improved efficiency and robust performance under challenging real-world conditions.

II. Proposed Methodology

A block schematic of a photovoltaic system using the MPPT technique has been depicted in Figure 1. The MPPT controller was programmed with these current and voltage parameters. Later, these measurements were processed using the MPPT method to determine the solar array's peak output. The MPPT block's output was the input to the DC-to-DC converter, which was either duty cycle or voltage. The boost converter (DC to DC) assisted in keeping its voltage output as high as possible by adjusting its duty cycle [3].

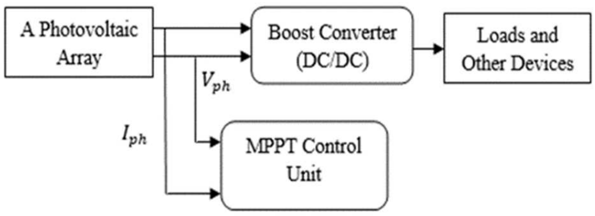

Fig. 1: General block diagram of the MPPT technique

We have taken into consideration the transient behavior of the P&O algorithm, addressing issues such as oscillations around the MPP and slow convergence. By fine-tuning the perturbation step size and incorporating a hysteresis-based control mechanism, we have improved the overall performance of the P&O algorithm in our specific application. Depending on the methodology, the voltage (V) or current (I) of the solar array were both measured [8-10]. The adjustable impedance between both the solar PV cells as well as the given load was provided by a boost converter. To extract the best efficiency from PV, the converter's duty ratio was altered using the MPPT algorithmic approach.

The P&O algorithm operates by perturbing the operating point of the PV array and observing the resulting change in power output. The algorithm continuously adjusts the operating point in the direction that increases power until it reaches the MPP. This iterative process ensures that the PV system operates at its maximum power under varying environmental conditions. Our contribution to this manuscript lies in the integration and optimization of the P&O algorithm for MPPT in the studied PV array. The implementation involves real-time monitoring of the PV array's voltage and current, and subsequent adjustments to the operating point based on the observed changes in power output.

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Modelling of photovoltaic cells according to the concept of electronics, the equivalent of photovoltaic cells can be obtained, as shown in Figure 2. According to the circuit diagram of the photovoltaic cell [8], the total cell's output current (Equation 1),

$$I = I_L - I_D - I_{R_{sh}} \tag{1}$$

That is, the current from output have been shown as equation (2) [8-13],

$$I = I_L - I_0(e^{\frac{q(V+IR_s)}{aKT}-1}) - \frac{V+IR_s}{R_{sh}} \tag{2}$$

where, I = Output current; I_L = Photon current at a given irradiance; I_0 = Reverse saturation current out of the diode; q = electronic charge; K = constant (Boltzmann's); T = given temperature at constant K; a = diode ideality factor; R_{sh} = parallel resistance to the ground; R_s = series resistance whose value depends on diode.

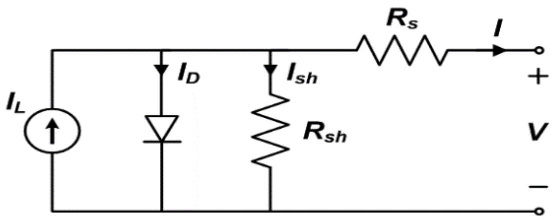


Fig. 2: An equivalent circuit of PV cell [8]

The PV module can be modelled by stacking several solar cells, as given in Figure 3, and the resultant V-I characteristics are shown in Figure 4. In contrast, Figure 5 illustrates the P-V output.

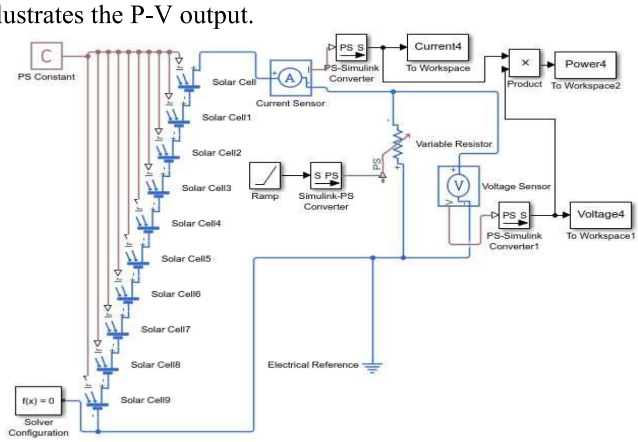


Fig. 3: Modelling of PV module

A. Boost Converter

To "step up" or "boost" a given input voltage to a better or higher level required by a load, the boost converter is utilized, which is depicted schematically in Figure 6 [2]. A boost converter can increase the voltage without the need for a transformer. It is very efficient since it has only one switch. The continuous current is fed into the circuit. The switches can be opened or closed, depending on the output requirement. Variations in the duty ratio in the calculation greatly affect the voltage output. The highest possible current rate is approximately 1–D which is below the total inductor current, therefore the filtered capacitor (energy storage element) would have a much higher current value greater RMS current that flows through it [2, 5-6]. The output voltage will be higher if the boost regulator is set to CC (continuous conduction) mode.

$$L_{min} = \frac{Dr\,(1-Dr)^2\ R}{2f} \tag{3}$$

Because, from Figure 6, when the switch is on, we get,

$$V_s = \Lambda \frac{\triangle I_L}{\delta T}$$

$$\text{or} \quad \triangle I_L = \frac{V_s\,\delta T}{L}$$

$$\text{or} \quad \triangle I_L = \frac{V_0\,(1-Dr)\,\delta T}{L}$$

$$\text{or} \quad \Lambda = \frac{Dr\,(1-Dr)^2\ R}{2f}$$

On the other hand, the expression $V_{RR} = \frac{\triangle V_0}{V_0}$ gives the lowest amount of filtering capacitance that causes ripple voltage.

$$\text{Because} \quad V_{RR} = \frac{\triangle V_0}{V_0} = \frac{Dr}{RCf}$$

$$\text{Therefore,} \quad C_{min} = \frac{Dr}{V_{RR}\,R\,f} \tag{4}$$

The boost converter uses a dc source voltage, a capacitive filter, a diode, a switch (IGBT), an inductor, and a load. On the other hand, the value of Dr can tune the output voltage [1].

B. Proposed Simulink Model

Every simulink necessitates the creation of a comprehen sive model configuration. The system is designed to give electricity to the load since the major goal is to produce a working PV model for the Simulink environment. The MPPT control unit and the DC-DC Boost converter are the two main parts of this model. Figure 7 and Figure 8 depict the whole SIMULINK model for the proposed work, which shows the modes for fixed temperature and irradiation, respectively. The core of this effort is the MPPT block, which determines the maximum operating point and provides the gate signal to the Boost converter. The PV module chosen for this model is the 1Soltech 1STH-215-P, which provides 213.15W of nominal maximum power and has 47 parallel rows. It implements a PV array consisting of parallel strings of PV modules. Each string is made up of modules that are linked in sequence. Table I shows the parameter specifications for the 1Soltech 1STH-215-P PV module. The circuit's parameters are as follows: C1 = 1000e-6F, C2 = 3227e-6F, L = 1.45e-3H, R1 = 0.0001Ω, R2 =2.8Ω, duty cycle = 50%, and frequency = 60Hz.

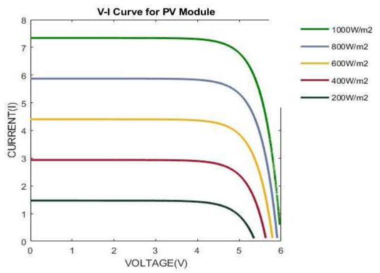


Fig. 4: V-I Curve for PV Module

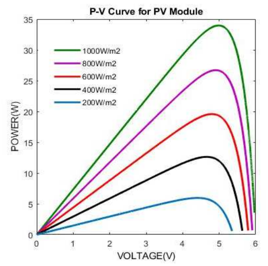


Fig. 5: P-V characteristics out of PV Module

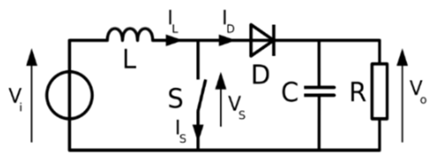


Fig. 6: Typical boost converter circuit [2].

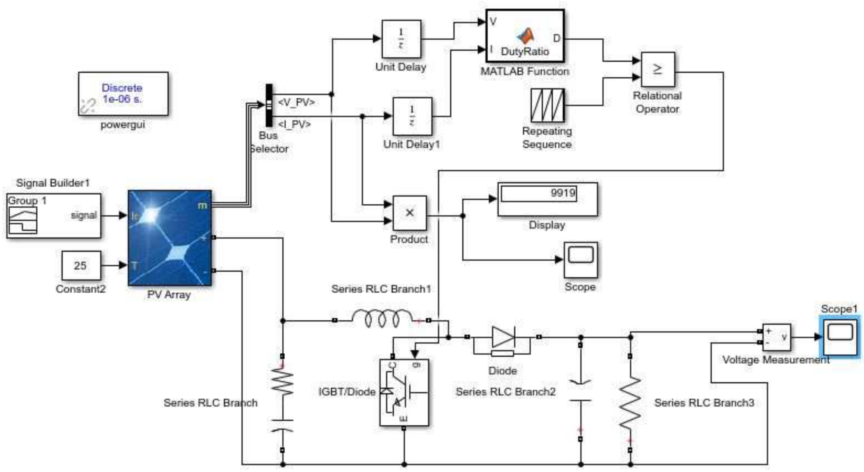


Fig. 7: Simulink model for MPPT in fixed temperature

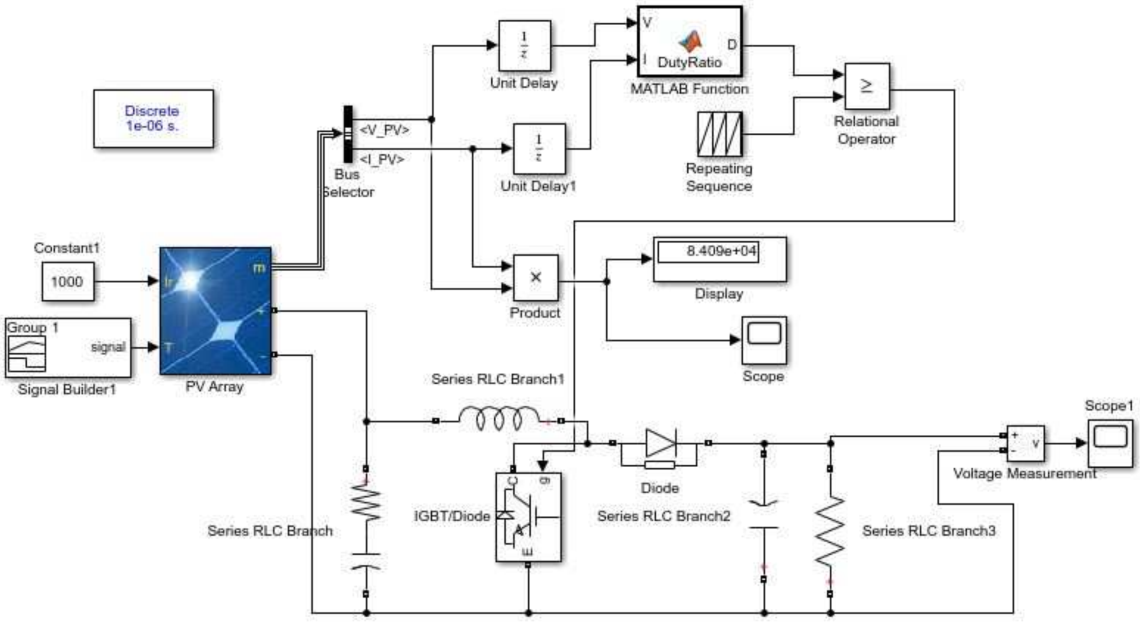


Fig. 8: Simulink model for MPPT in fixed irradiation

III. Results

The experimental results shown in this section illustrate some important voltage, current, and power values, which help develop an output curve with two different conditions, as explained below. Given that the photovoltaic cell can function at a variety of currents and voltages by raising the load resistor gradually on irradiation, the optimized or peak power, the threshold that increases current and voltage, which was determined.

A. Condition 1: Fixed Temperature

The output from the Simulink model for MPPT in fixed temperature with different irradiation has been illustrated in Figure 9.

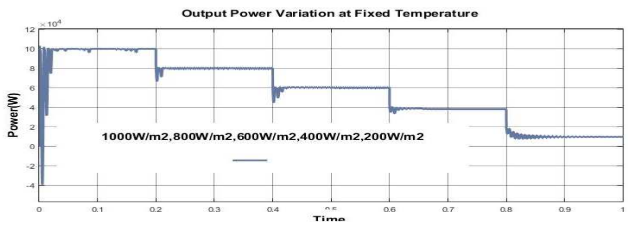


Fig. 9: Output for MPPT with fixed temperature with different irradiation

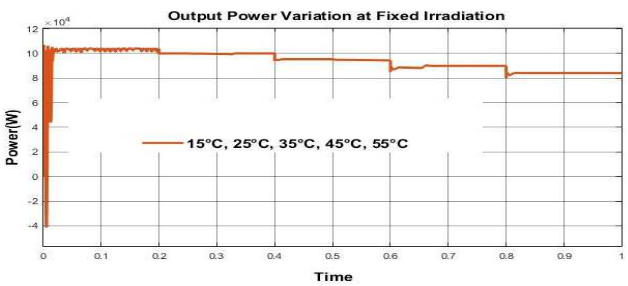


Fig. 10: Output for MPPT with fixed irradiation with different temperature

From Table I, when applying different irradiations, the output power decreased significantly due to change in irradiation.

TABLE I. EFFECTS OF DIFFERENT IRRADIATION LEVELS AT 25°C

Temperature (℃)	Power (Watt)
55	8.6×10^4
45	9.1×10^4
35	9.5×10^4
25	10×10^4
15	10.4×10^4

B. Condition 2: Fixed Irradiation'

The output from the Simulink model for MPPT in fixed irradiation with different temperatures has been illustrated in Figure 10. From Table II, when different temperatures are used, such as 15°C, the output power is 10.4×10^4 Watt. When the temperature is 25°C, the output power is reduced to 10×10^4 Watts. When the temperature is 35°C, the output power is 9.5×10^4 Watts. When the temperature is 55°C, the output power is 8.6×10^4 Watts. Here we see that the output power curve does not decrease so much as different irradiations.

TABLE II. EFFECTS OF DIFFERENT TEMPERATURES AT 1000 W/M^2

Irradiation (W/m^2)	Power (Watts)
1000×10^4	10.002×10^4
800×10^4	8.01×10^4
600×10^4	6.01×10^4
400×10^4	3.90×10^4
200×10^4	1.05×10^4

C. Partial Shading Effect

A photovoltaic (PV) array with partial shading effect occurs when not all the solar panels in the array receive uniform sunlight, resulting in different parts of the array being shaded or exposed to varying light conditions. Partial shading can be caused by a variety of factors, including obstructions such as trees, buildings, nearby structures, cloud cover, or even dust and debris on the solar panels themselves. Shading reduces the amount of sunlight reaching the shaded panels, resulting in lower power output.

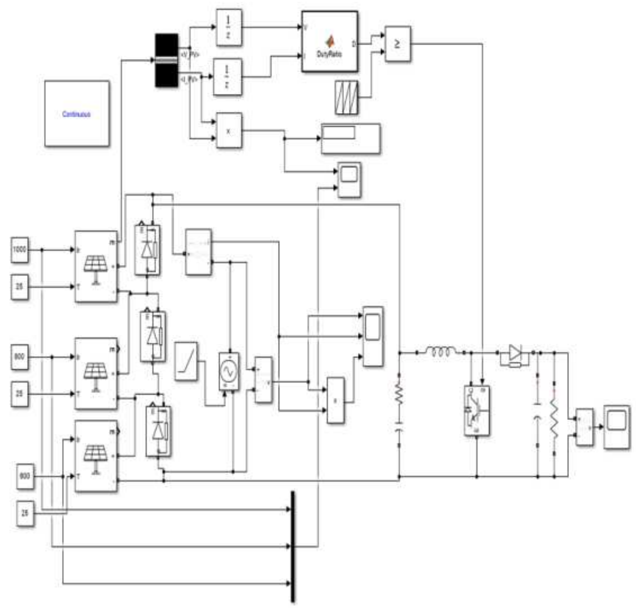
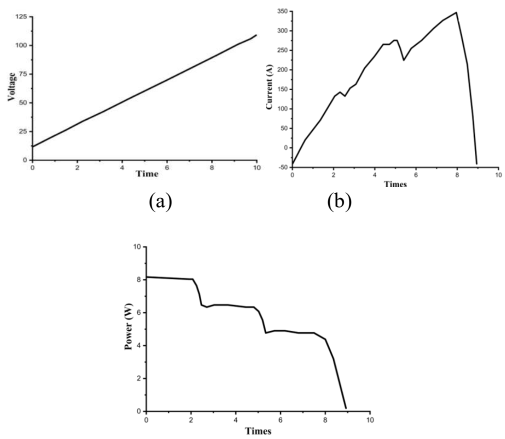


Fig. 11: Simulink model for MPPT with shaded panels

Partial shading can lead to hot spots on shaded cells, which may cause long-term damage to the panel. Bypass diodes that help mitigate the effects of partial shading (Figure 11 & Figure 12. When a portion of a panel is shaded, these diodes redirect the current around the shaded area, allowing unshaded cells to continue producing electricity.



(a) (b)

(c)

Fig. 12: Output for MPPT with shading effect (a) voltage, (b) current, (c) power

IV. Discussion

In this paper, the MPPT algorithm and boost converter are more helpful in specific scenarios when the temperature is relatively steady, the cost is minimal, and the voltage is stable. Regardless of the sun's irradiance, the power output was optimized. The perturbation and use of MPPT in PV arrays have increased solar PV systems' efficiency and output power. When constant irradiance is fed into the PV array (Figure 7), the MPP tracks the boost voltage, although there are some ripples since there is no rise or drop in variable irradiance. As a result, there is disruption. The PV array's input voltage and current compute instantaneous power. The maximum power point is determined using the MPPT algorithm, and the converter's duty ratio is adjusted accordingly. The duty ratio has been set this converter's power input becomes nearly equal to power delivered to the load.

V. Conclusion

In this work, MATLAB and Simulink have been used to model a freestanding photovoltaic array. A boost converter (DC to DC) has been employed to track MPP. According to experiment findings, the system functions at MPP for varied irradiance at constant and constant irradiance at different temperatures. The highest power is observed, and fluctuations in solar output power are avoided by utilizing the MMP Tracking algorithm and the converter at a tracking efficiency of 99% at the required maximum output power. Under certain irradiation and temperature conditions, MPPT approaches are designed to optimize the voltage VMPP and current IMPP automatically. Future works include stabilizing the voltage, connecting the inverter circuit, storing charges in the battery, and connecting to the national grid.

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