Modeling and Simulation of PV System Controlled by Slinding Mode Control System using MPPT Techniques

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Abstract - Solar energy is a valuable resource because it is clean and inexhaustible. MPPT is crucial in photovoltaic power systems, maximizing power output, array efficiency, and cost reduction by finding and maintaining the maximum power point. This paper investigates a sliding mode control (SMC)-based MPPT for Boost-type DC/DC converter method, testing its robustness under rapidly changing solar radiances. The resilience of the controller is evaluated by comparing it with the P&O approach and the incremental conductance (IncCond) method. This evaluation is conducted using Matlab/Simulink to model the PV-MPPT system

Keywords-Photovoltaic system faults; P&O algorithm, IncCond algorithm; Sliding mode control based MPPT techniques; Boost converter.

I. INTRODUCTION

Photovoltaic is used to capture solar energy from the sun. A solar energy technology known as photovoltaic transforms solar radiation into electricity by taking advantage of the special characteristics of semiconductors. Photovoltaic is a "green," or environmentally friendly, technology that conserves nonrenewable energy sources while producing energy without polluting them. Photovoltaic (PV) systems make use of silicon wafers, also referred to as "cells," that are light-sensitive [1].

PV systems are adaptable and can be used for a variety of purposes. The modular design of PV system parts makes it simple to enhance their capacity. Almost every application that requires electricity and has access to the sun can employ a photovoltaic system [2]

Renewable energy, or clean energy, is generated from natural sources or processes that are constantly replenished.

Natural resources like sunlight, wind, and waves are considered renewable energy. Most nations invest significantly in renewable energy forms and strive to replace non-renewable energy as soon as possible on an economic scale [3], [4].

The PV technology directly converts sunlight into electricity, a phenomenon known as the photovoltaic effect. Furthermore, PV systems' optimum output power mainly depends on environmental factors such as temperature and irradiation, installation method, and efficiency of the PV cell. In practical operation, a PV system exhibits a peak point on its power-voltage curve known as the maximum power point (Boukenoui et al., 2016; Acakpovi et al., 2018).

MPPT algorithms determine the optimal efficiency of a photovoltaic system, with the PV array operating around this MPP for optimal performance [5]. And despite that, The operation of a system at Photovoltaic On point (MPP) is complex due to sun movement and intensity variations, necessitating the development of control strategies to maximize power extraction, enhance system efficiency, and minimize power losses. The most popular MPPT technique among conventional algorithms[3, 4], perturb and observe (P&O) and Incremental Conductance (IncCond),[6, 7].

Additional strategies in the field of artificial intelligence include fuzzy logic [8] and neural network techniques [2]. Due to the potential rapid fluctuations in weather conditions, the presence of a robust controller appears to be important in order to effectively and accurately track the optimal location. In recent times, SMC has garnered significant attention from researchers owing to its advantageous characteristics, such as its user-friendly nature [9], robustness, and exceptional performance across various domain

The SMC algorithm monitors and adjusts the system's maximum power point in two phases. [11]. The utilization of the sliding surface control rule is employed to maintain the system's trajectory on a predetermined surface, while a similar control rule is employed to guide the system toward its optimal power point. Providing a sliding surface and a corresponding control mechanism is crucial in the design of an MPPT control system that utilizes sliding mode control principles [12].

II. MATHEMATICAL MODEL OF THE PV ARRAY

A) PV System Description

Conformément à la "Fig. 1", un système photovoltaïque est composé de quatre blocs. Le premier bloc est la source d'énergie (un panneau solaire), le deuxième bloc est un convertisseur statique à courant continu, le troisième bloc est la charge et le quatrième bloc est le système de contrôle. La principale fonction du convertisseur statique est de s'adapter à l'impédance afin que le panneau fournisse la plus grande quantité d'énergie possible.

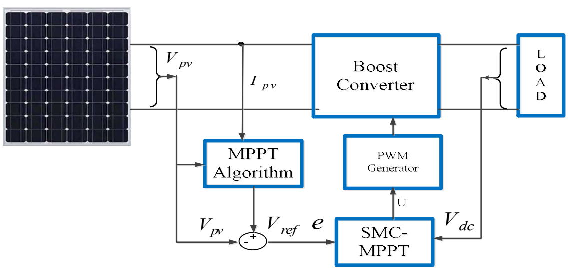


Fig. 1. Block diagram of simple photovoltaic system with SMC-MPPT**.**

B) PV Generator Modeling

La cellule solaire, est l'élément fondamental qui transforme directement l'énergie de la lumière en électricité grâce à l'effet solaire Pour expliquer cet effet. divers modèles basés sur le circuit électrique équivalent de la cellule photovoltaïque sont utilisés

Usually considered, the single diode model "Fig. 2" is the most classical model described in the literature.

The equivalent circuit for a photovoltaic cell includes a current generator to simulate how solar radiation is converted into electrical energy, a diode to account for the physical characteristics of semiconductor cells, two resistors, and a series [13]

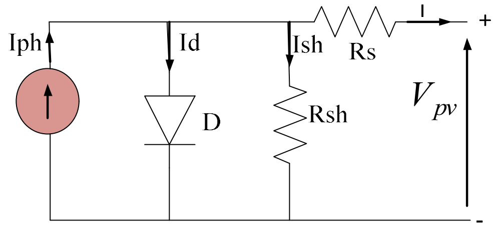


Fig. 2. Electrical circuit of PV cell.

$$I = I_{ph} - I_0.\left[\exp\left(\frac{q.(V_{pv}+I.R_S)}{n.K.N_S.T}\right) - 1\right] - I_{sh} \qquad (1)$$

$$I_{ph} = I_{sc} + K_i.(T - 298).\frac{G}{1000} \qquad (2)$$

$$I_0 = I_{rs}.(\frac{T}{T_n})^3.exp\left[\frac{q.e_{g0}.(\frac{1}{T_n}-\frac{1}{T})}{nK}\right] \qquad (3)$$

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{q.V_{OC}}{n.K.N_p.T}\right)-1} \qquad (4)$$

Voc: The cell voltage
R_s: The resistance series cell [Ω]
R_p: is the parallel resistance
Vt: the thermal voltage of the module: Vt=Ns kT/q, with
Ns the number of cells connected in series/ Np is the number of cells connected in parallel
T: The temperature of the cell [°K]
q: electron's charge e = $1.6 * 10^{-19}$ C
K: Boltzmann constant ($1.3854*10^{-23}$ J°K^{-1})
n =1.3 : represents the ideality factor of the diode.

C) PV Module Simulation

The Matlab/Simulink platform is employed to simulate the system under investigation in this study. PV cells with a Ns x Np configuration are utilized in the fabrication process. The maximum power output of each component is 40 watts at a voltage of 21.8 volts. Table 1 presents the electrical attributes of each photovoltaic (PV) module, as seen during standard test settings. In addition, the system incorporates a boost converter equipped with a P&O MPPT. A variety of operating settings are employed to conduct the simulations. The simulated pressure-volume (P/V) curves are depicted in Fig.3, Fig.4, correspondingly.

TABLE I. ELECTRICAL CHARACTERISTICS OF THE PV MODULE

	Electrical characteristics of PV module		
	Parameters	**Symbols**	**Values**
Technical specifications	Rated power	Pmp	40W
	Voltage at maximum power	Vmp	*18.24V*
	Current at maximum power	Imp	*2.20A*
	Open circuit voltage	Voc	*21.28V*
	Short circuit current	Isc	*2.35A*

Le système comprend également des convertisseurs de boost DC-DC équipés d'un dispositif de perturbation et d'observation (P&O) MPPT. The simulations are made under variable operating conditions. The simulated P/V curves are shown respectively in “Fig. 3” and “Fig. 4”.

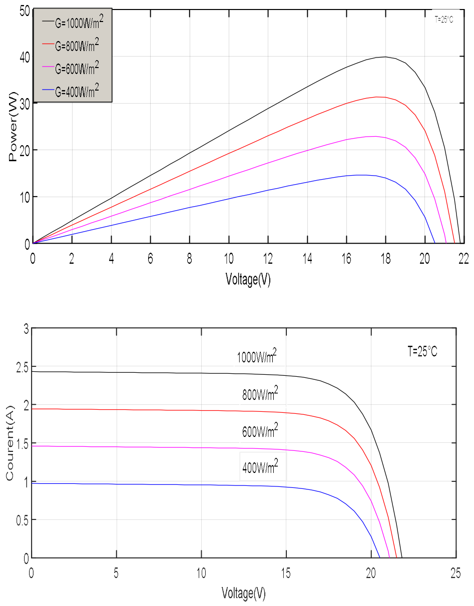
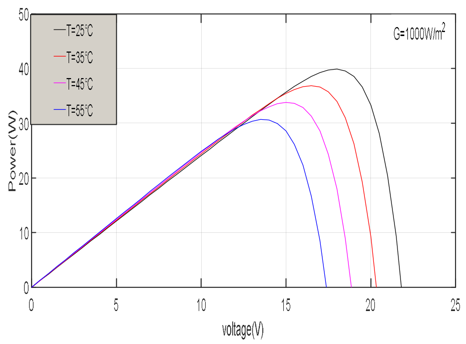


Fig. 3. P/V and I/V characteristic of the PV panel at constant temperature.



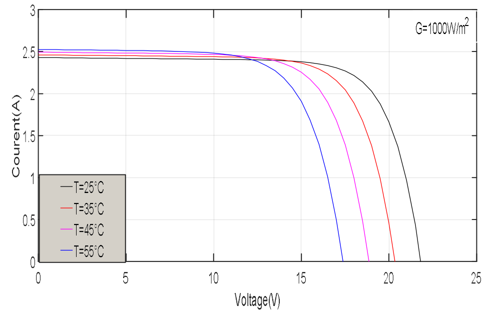


Fig. 4. P/V and I/V characteristic of the PV panel at radiance G=1000W/m²

D) Power Conversion Structure

DC/DC converters are commonly used in photovoltaic systems as intermediate between solar cells and the charge to reach the maximum power point (MPPT)

Pour les convertisseurs DC/DC, il existe une variété de topologies et de méthodes de design différentes. Il existe plusieurs types de convertisseurs DC/DC qui pourraient être utilisés dans le système photovoltaïque en fonction de l'installation prévue ; ces convertisseurs incluent les convertisseurs d'ascenseur, les convertisseurs de bas ascenseur et les convertisseurs d'ascenseur [4].

Converters control energy flow from solar modules to loads by opening and closing a switch, typically an electronic device (MOSFET or IGBT), which operates in conduction mode (on) or cut-off mode (off).

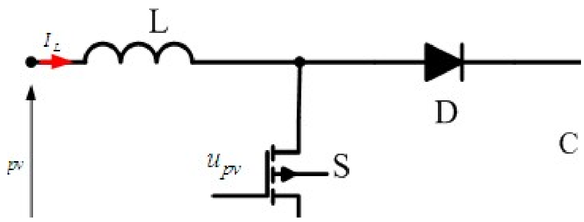


Fig. 5. DC-DC boost converter.

The use of DC converter is vital in solar systems. In order to maintain a consistent maximum output power, an MPPT controller is used. Fig. 5 depicts the boost converter.[14]

$$\begin{cases} V_{pv}=L\frac{dI_L}{dt}+V_{dc}(1-u_{pv}) \\ (1-u_{pv})I_L=C\frac{dV_{dc}}{dt}+I_{sh} \end{cases} \quad (5)$$

$$\begin{cases} \frac{dI_L}{dt}=\frac{V_{pv}-V_{dc}}{L}+\frac{V_{dc}}{L}.u_{pv} \\ \frac{dV_{dc}}{dt}=\left(\frac{V_{dc}}{C}+\frac{i_L}{C}\right)-\frac{i_L}{C}.u_{pv} \end{cases} \quad (6)$$

$$x = [x_1 \quad x_2]^{Tr} = [I_L \quad V_{dc}]^{Tr} \quad (7)$$

III. MPPT TECHNIQUES

A) Perturb and Observe Algorithm

Before Photovoltaic systems frequently use the Perturbation and Observation (P&O) technique to track the maximum power point (PPM).
The system adjusts the terminal tension of the panel regularly, either increasing or decreasing, and compares the photovoltaic output power with the previous perturbation cycle.

Si la perturbation entraîne une augmentation ou une diminution de la puissance du panel, la perturbation suivante est effectuée dans la même direction (opposite). Comme indiqué par l'algorithme présenté à la figure 6, le suiveur MPP recherche constamment la condition de puissance maximale.

P&O algorithms often face issues with array terminal voltage perturbation, leading to maximum output power oscillations and power loss in the PV system

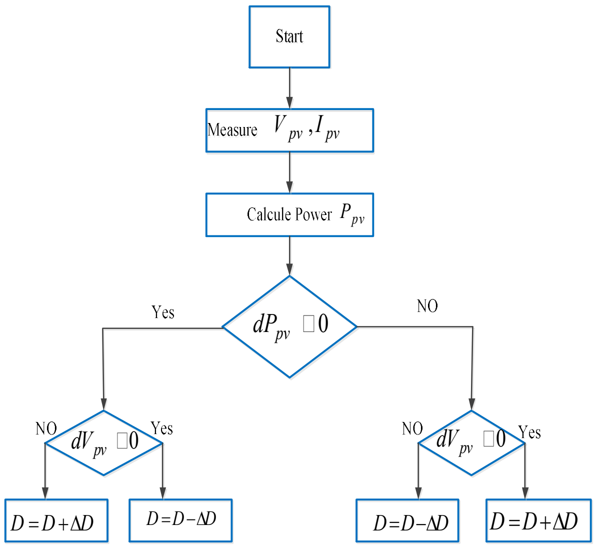


Fig.6. P&O Algorithm.

B) Incremental Conductance (IncCond)

This approach, as implied by its name, is based on an understanding of the fluctuation in the solar generator's conductivity and its location in relation to the maximum point of operation. "Fig. 7" gives the flowchart of the IncCond method [3].

$$\begin{cases} dI/dV = -I/V \ \ If \ \ P = MPP \\ dI/dV > -I/V \ \ If \ \ P is on the left of MPP \\ dI/dV < -I/V \ \ If \ \ P is on the right of MPP \end{cases} \tag{8}$$

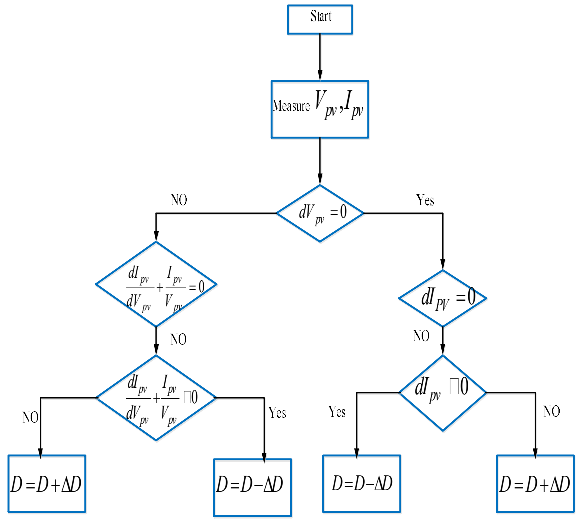


Fig. 7. Diagram illustrating the Incremental Conductance technique

C) Sliding Mode Controller SMC

Sliding mode control (SMC) is a highly effective nonlinear control technique that regulates the DC-DC converter using an MPPT controller, enabling MPP in diverse weather conditions. With more switching, the MPP tracking speed increases, but oscillations in the voltage and power output also rise. When compared to other traditional approaches, the SMC-based MPPT performs very well [12, 16].

The initial goal of sliding mode control is designing the switching surface, followed by creating a control law to drive and maintain system trajectories [4, 17], which can be expressed using power slope expressed as :

$$\frac{dP_{pv}}{dV_{pv}} = I_{pv} + \frac{dI_{pv}}{dV_{pv}} V_{pv} = 0 \tag{9}$$

Then, the switching function can be chosen as the slope of P-V characteristics

$$S(x) = \frac{dP_{pv}}{dV_{pv}} \tag{10}$$

Sliding mode control involves the use of discontinuous control methods that rely on the sign of the sliding surface Un. Additionally, a corresponding control Ueq is employed to characterize the movement of the system along the sliding surface.

$$u = u_{eq} + u_n \tag{11}$$

u_n u_n : relates to the non-linear component and is established to guarantee that the control variable is appealing to the sliding surface; u_{eq} : in order operation point in the switching surface should be maintained and displaced to the origin.

These elements were ascertained by taking into account the Lyapunov function V, which both in attractive mode and sliding mode satisfied the control purpose.

$$V = \frac{1}{2} S(x)^2 \quad (12)$$

$$\dot{V} = S(x) * \dot{S}(x) < 0 \;\forall\; S(x) \neq 0 \quad (13)$$

From the expression (1), I_{ph} and I_s cannot be established from generally available information. For this, we made some Premises that apply to silicon cells in general:

In an ideal case, the series resistance is neglected and the parallel resistance approaches infinity,

$$S(x) = I_{pv} + \frac{dI_{pv}}{dV_{pv}} = N_p I_{sc} - \left(N_p I_{sc} + \frac{N_p}{N_s.n.k.T} V_{pv}\right) exp\left(\frac{V_{pv} - N_s V_{oc}}{N_s.n.k.T}\right) \quad (14)$$

The derivative can be expressed as:

$$\dot{S}(x) = -(2 + \frac{V_{pv}}{N_s.k.n.T}) \frac{N_p I_{sc}}{N_s.k.n.T} \exp\left(\frac{V_{pv} - N_s V_{oc}}{N_s.n.k.T}\right) \frac{dV_{pv}}{dt} \quad (15)$$

When $S(x)$ f 0 $S(x) > 0$, Because the system functions to the left of the MPP, more voltage is needed to achieve the MPP $(\frac{dV_{pv}}{dt} > 0)$substituting in (18), it is evident that $\dot{S}(x) < 0$ and hence $\dot{S}(x).S(x) < 0$ When$S(x) < 0$, The voltage needs to be lowered so that the system operates properly $(\frac{dV_{pv}}{dt} < 0)$, which implies that $\dot{S}(x) > 0$therefore $\dot{S}(x).S(x) < 0$

In order to drive the path used in the convergence mode to reach the sliding surface, an explicit control approach is needed. This approach is known as the "law of assault". The constant rate reaches law is defined as:

$$u_n = -k_{eq} sgn(S(x)) \quad (16)$$

Where k_{eq} The scaling factor, or (positive constant), is adjusted during the design phase to modify the step size

Using Komurcugil's (2012) invariance requirements, the analogous control—first developed by Filippov Slotine in 1991—characterizes the dynamics of the system on the sliding surface:

$$S(x) = 0 \;\; and \;\; \frac{dS(x)}{dt} = 0 \quad (17)$$

$$\dot{S}(x) = \frac{dS(x)}{dt} = \left[\frac{\partial S}{\partial x}\right]^{Tr} \;\; \dot{x} = \frac{\partial S}{\partial x_1}\dot{x}_1 + \frac{\partial S}{\partial x_2}\dot{x}_2 \quad (18)$$

Thus the equivalent control can be written as:

$$u_{eq} = 1 - \frac{V_{pv}}{V_{dc}} \quad (19)$$

The overall control law can be expressed by combining (16)(18) the design of the sliding mode and the reaching mode

$$u = 1 - \left(\frac{V_{pv}}{V_{dc}}\right) - k_{eq} sgn(s(x)) \quad (20)$$

This formula is applied when the operating point moves in the correct direction toward the MPP; if the operating point deviates significantly from the MPP, the parameter k_{eq}has to be doubled. This idea serves as the foundation for the SMC approach, which has two alternative step sizes

IV. SIMULATIONS OF PROPOSED SYSTEM

This study suggests a brand-new MPPT technique for increasing photovoltaic module production. The method uses three alternative step sizes to apply sliding mode control to a Boost DC/DC converter, as shown in "Fig. 8".

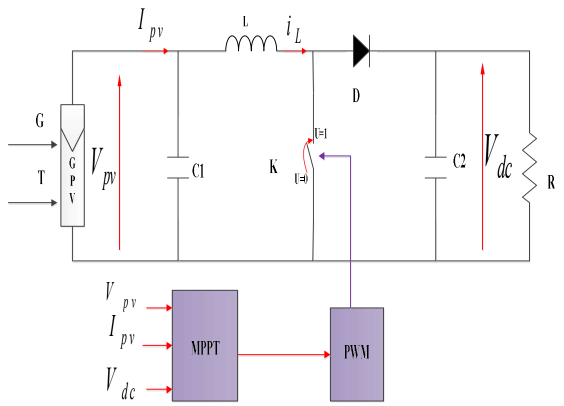


Fig. 8. Boost DC/DC converter

The purpose of the work is to evaluate how well the suggested MPPT tracker performs. The P&O and IncCond approaches are contrasted with the new approach. Evaluated and compared using Matlab/Simulink software, the simulations are made under variable operating conditions. "Fig. 9" shows

The photovoltaic system's simulation results for output power and voltage at constant temperature 25°C and with varying solar irradiation (1000W/m^2 600W/m^2, 800W/m^2, respectively).

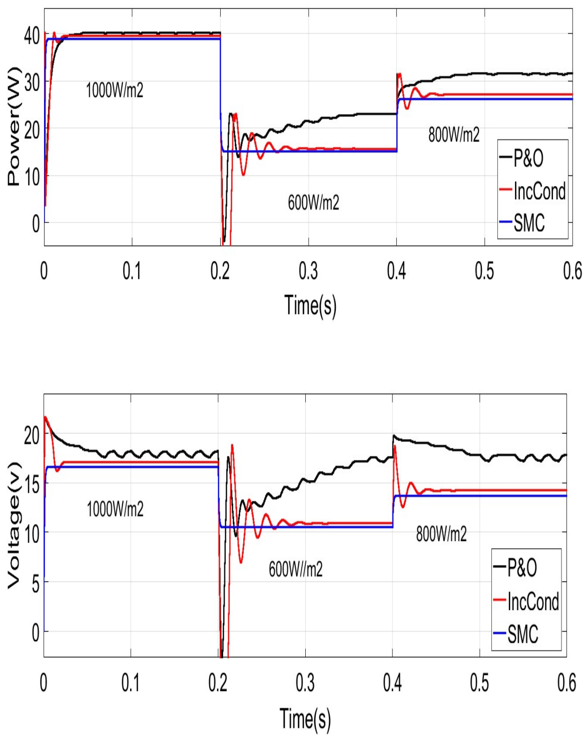


Fig. 9. PV panel output power and voltage under varying radiance.

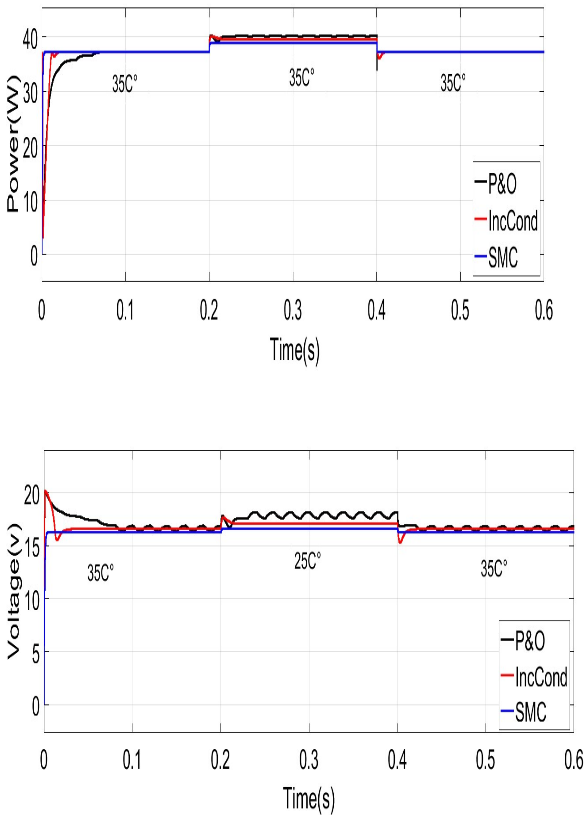


Fig. 10. PV panel output power and voltage under varying temperature.

The simulation results are presented in Figure 10, illustrating the effects of two distinct temperature variations under a consistent solar irradiance.

The results demonstrate that the SMC approach starts up faster than the others and has an excellent dynamic reaction time. The graphs of the simulation results reveal that, in both steady state and dynamic state scenarios, the recommended MPPT strategy outperforms the P&O and IncCond approaches. Stated differently, the proposed MPPT system indicates excellent conversion efficiency since it can follow the expected behavior of the maximum power fast and with less deviation.

V. CONCLUSION

MPPT controllers are commonly utilized in photovoltaic systems to optimize operation by minimizing the error between operation power and maximum power.

This article discusses the main PV system elements. The principles of three MPPT techniques—P&O, IncCond, and Sliding Mode Control—were then shown. Lastly, we concluded with a simulation of the various methods.

Simulations of P&O, IncCond, and Sliding mode control techniques under various weather conditions show sliding mode control algorithm provides better results

However, it is concluded that the controller based on sliding mode control is quicker, behaves well, and performs better than the other approaches. The P&O algorithm, on the other hand, is the most commonly utilized of all these algorithms.

The SMC controller offers good performance and exhibits extremely strong dynamics in comparison to her tactics when lighting changes, allowing it to better track the maximum power point with lower power losses.

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