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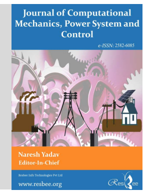

Comparative Studies between Some Maximum Power Point Detection Methods

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Abstract: Electricity generated by photovoltaic (PV) arrays is rapidly viewed as a viable alternative to fossil fuels. On the other hand, the conversion efficiency is often low, and the initial cost is still significant. In this work, compare the commands Maximum Power Point Tracking (MPPT)-PI and MPPT-FOPI- perturb and observe (P & O) and MPPT-PI-P & O. It allows you to see the Fractional order proportional integral (FOPI) fractional controller's increased value in comparison to the traditional PI controller. Based on this comparison, For 1000W / m2 irradiation, both controllers appear to operate similarly; both are fast and exhibit tiny oscillations around the optimal value; nevertheless, the FOPI controller performs slightly better than the Proportional Integral (PI) controller. This is because it's speedier and has fewer oscillations. The simulation is implemented numerically utilizing well-known platforms, such as MATLAB/Simulink software.

Keywords: Energy, FOPI, MPPT Technique, Photovoltaic, P&O-PI, Solar Panel.

1. Introduction

In the coming years, the globe is expected to face several issues relating to the depletion of certainenergy sources, particularly fossil fuels. It is also well known that various components of the rise inoil prices due to economic and political issues have contributed to economic crises in recent decades.Therefore, the hunt for renewable energy sourcesgrows increasingly urgent as a viable option for addressing the global energy dilemma. Photovoltaic (PV) solar energy is appealing credibility to enhance electricity generation among the perfect and green power sources. Solar energy has been increasingly appealing in recent years due to significant cost reductions in PV modules, primarily in tiny single-phase home systems linked to stand-alone and utility grid applications [1]. The photovoltaic effect is a direct conversion of lightinto electricity that can be used to generate electricity. Despite all of the above benefits, the efficiency conversion is low, and the initial cost is still high because MPPT techniques are required to maximize the harvested energy. It's vital to note that each curve has only one MPP at each temperature and irradiance level. MPPT aims to, under varied climatic conditions, harvest the possible electricity generated by the PV panel (solar irradiation and temperature). In terms of convergence of time speed, cost performance, implementation, and sensors, these approaches differ in several ways [2]. However, they have several flaws, including a slow tracking speed when the environment changes suddenly and a steady-state inaccuracy in the output of PV power around the MPP, which results in higher PV array power losses.

The main aim of this study is to present an experimentation with diverse methods to evaluate the efficiency of several MPPT approaches.

2. Literature Review

Although the objective of this study is limited to a comparison of the methodologies above, in the literature, there are other articles on MPPT, some of which are briefly detailed below to highlight the topic's importance. This article provides a simplified control strategy for low-power MPPT converters

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based on the output current's positive feedback effect. This article also goes through the characteristics and behavior of the PV module and a system efficiency analysis. In this article, an MPPT technique is applied to a PV system utilized to power electric racing cars. In the experimental vehicle, six PV panels are divided into nine portions; each one is connected to a tracker of MPP separately, and the output lines are parallel-connected to replace the battery [5]. The dc-dc converter's performance with PV and P&O systems is examined in this research. This approach is justified given the decreased number of sensors and the PV system's general complexity.

The research of Huang presents PV panels and a buck converter that functions as a tracker of MPP power in the pumping system. The output voltage is measured and contrasted with the open-circuit voltage in a look-into table to produce a relationship between these quantities to determine the specific voltage across the PV module. The PV system of the dynamic model constituted of the relationship of a dc-dc converter, asynchronous motor, and an inverter was used in this study to reach a suitable result on the output voltage using the same comparison technique used in a system of pumping [6]. Similarly, this research proposes an approach based on the voltage of open-circuit monitoring. The PV module voltage across is roughly 76% of the voltage of the open circuit. Therefore, it reflects the operating point near the Maximum power point.

3. Mathematical Model of Solar CELL

The basic model unit of the module of PV is the cell of PV, often known as a solar power cell. To generate the required current and voltage, several PV cells are connected in parallel or series. A current source produces a continuous current. The intensity of the light landing on the cell determines the current. Photovoltaic systems had a direct impact on weather and sun radiation. The solar system's yield and price are affected by external working circumstances and the variable conditions that affect the system's components' functioning at the ideal location. As a result, solar energy applications are crucial, while the photovoltaic system properly measures the performance of each constituent under diverse and shifting situations [3]. This circumstance also impacts system design and might cause electrical characteristics to change abruptly as a result of network modifications made over time in the case of a given event. The performance of a solar cell is required to comprehend the association between the cell's voltage and current. The operation of the inverter and the design of the control system are influenced by the characteristics of the solar cells.

In Fig.1, Single Diode Model, there is a current source (solar cell), a diode saturation current (I_0), a parallel diode, and a resistor (R_{sh}), as well as a resistor connected in series to them (R_s).[4]

The output equation of the single diode model of a photovoltaic panel is given below:

$$I = N_p \times \left(I_{ph} - I_{01}\left[\exp\left(\frac{N_pV + N_SR_S I_{pv}}{n\, V_{th}N_pN_S}\right) - 1\right] - \frac{N_pV_{pv} + N_SR_S\, I}{N_SR_{sh}} \right) \tag{1}$$

Where:

N_s= number of cells connected in series.

N_p= number of cells connected in parallel.

The modeling equation shows that the solar PV characteristic of the single diode gives five parameters ((I_{ph},01, R_s, $R_{sh,}$ and n-value).

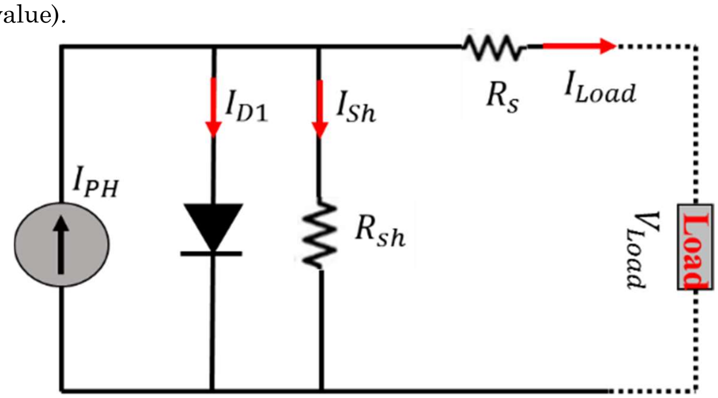

Fig.1. *Solar Cell Mathematical Model.*

4. MPPT Technique

This study presents an Experimenting with different ways to assess the efficacy of various MPPT algorithms. P&O [7]is the most extensively used algorithm in commercial converters. Even though IC has a level of performance comparable toperturbation and observation, the cost of higher implementation than perturbation and observation would not be acceptable by a performance advantage[8]. This research by Macaulay and his associates in 2018 focuses on several MPPT approaches based on a review of over 90 articles. Hill climbing (HC) and P&O methods are straightforward to implement in both analog and digital formats. On the other hand, IC is somewhat more complicated and necessitates the use of circuitry of digital.

This study uses mathematical expressions and a circuit technique to Validate MPPT models and PV arrays that are both user-friendly and generic. The PV array model provides characteristic curves for temperature and irradiance as input parameters. The MPP is also kept track of using HC [20]. The MPPT is affected by the partial shade of PV modules. The output power drops dramatically when one or more cells/modules in a PV array are shaded. Buildings, trees, and poles can all cause partial shadowing [21]. In addition, moving clouds may cause partial shadowing in big PV systems, altering the PV characteristics with several peaks and lowering the energy harvest from PV systems. Because of the existence of many peaks, some MPPT algorithms may become locked at local peaks [9]. Although it is limited to Connecting modules in parallel and PV cells to prevent a partial shade effect, it is anappealing method for low and medium-power applications due to the components and number of converters required to boost power. This researcher uses Distributed MPPT (DMPPT). Each PV module in the string is equipped with a dc-dc power converter and a Maximum Power Point Technique controller, doubling the array's total usable Power.

This research proposes a control method for a grid-connected PV system. A module of PV, a converter of dc-dc, and a converter of dc-ac are all part of the proposed system. The dc-dc converter performs MPPT, whereas the converter of dc-ac is driven using the hysteresis control approach. Using the Levenberg-Marquardt approach, this study estimates the PV array in the MPP under various environmental variables (temperature and sun irradiance). The PV module's single-diode-based model is used to estimate, and the relevant parameters are taken from the manufacturer's datasheet. As previously stated, various methods for achieving MPPT in PV systems have been presented[10]. Several MPPT strategies have been examined in the literature, and they can be classed as offline or online techniques. Off-line approaches necessitate precise PV array positioning in conjunction with irradiance and temperature readings. On the other hand, when large fluctuations in the extracted power are considered, such dimensions are not employed inonline procedures.

The specifications of the used PV module (XXR- SFSP-H50-62W) are given in Table 1. Also, Table 2 summarizes the specification of the BOOST. Table 3 illustrates the Battery specifications.

The profile of the irradiations used in 0.3 seconds for a fixed temperature of 25 degrees Celsius is presented in Fig.2. The maximum power corresponding to the profile of the considered irradiations is given in Fig.3. This power corresponds to the panel's power to provide the environmental conditions imposed by the irradiation profile and the chosen temperature.

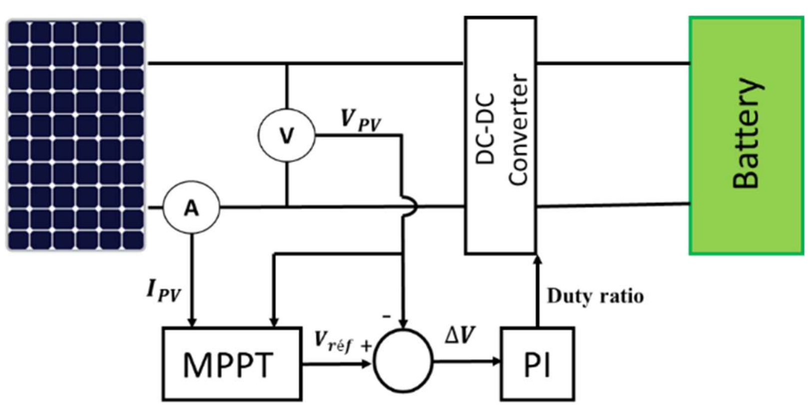

Fig.2. *Block diagram of the studied PV system*

Table 1: PV module specifications

Settings	Label	Value
Maximum power (W)	Pmp	62
Open circuit voltage Voc (V)	Voc	19
Short-circuit current Isc (A)	Isc	5.8
The voltage at maximum power point Vmp (V)	Vmp	13.3
Current, at the maximum PowerPoint	Imp	4.68
Cells per module (Ncell)	Ncell	32

Table 2: Specifications of the booster chopper converter (BOOST).

Settings	Label	Value
Switching frequency (kHz)	F	30
Booster inductance (H)	L	330×10^{-6}
The input capacitor (F)	VS	10^{-4}

Table 3: Battery specifications

Settings	Symbol	Value
Nominal voltage (V)	Vn	48
Nominal capacity (Ah)	Cn	10
The initial state of charge (%)	SOC	10

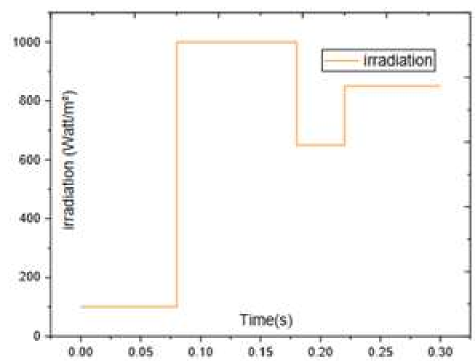

Fig.3. *Irradiation used during the simulations*

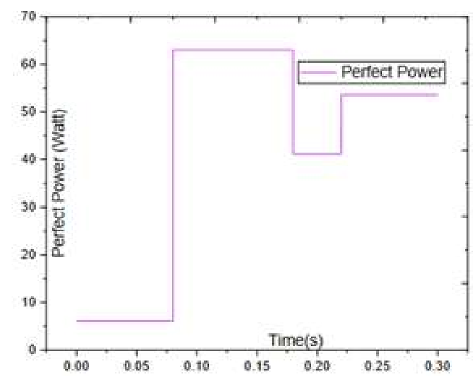

Fig.4. *Ideal power of the system used under Matlab*

4.1 MPPT command using a PI Corrector(MPPT-PI)

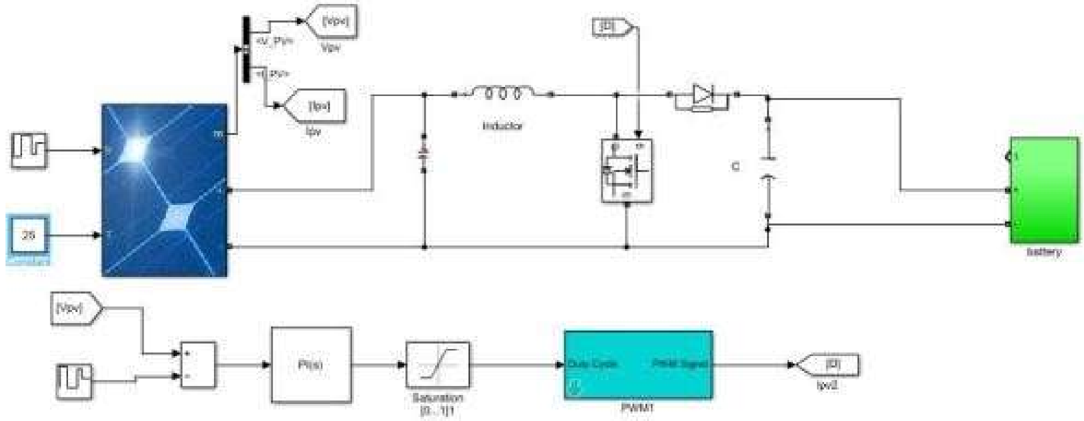

Fig.5. *MPPT-PI command diagrams*

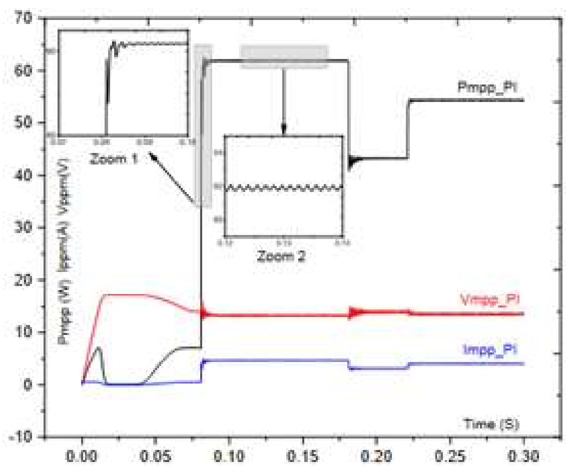

Fig.6. *Response in terms of the power of the PV module with the "MPPT-PI" algorithm.*

Fig.4 demonstrates the ideal power of the system utilized under the Matlab. Fig.5 illustrates the MPPT-PI command diagrams. The simulation results of the MPPT algorithm by a PI on MATLAB / SIMULINK under the conditions mentioned at the beginning of this chapter are presented in Fig.6. This Fig.is composed of three graphs representing the voltage at the output ofthe PV in Volt, the current of the PV panel in Amps, and the power of the PV in Watt, in a time interval of 0.3 seconds. The simulation results presented in Fig.6 show that the PI corrects the error between the referential voltage and the PV voltage. As a result, the voltage, current, and power values are better in the PI-MPPT method. But the major drawback of this method is that the referential voltage is taken from the ideal characteristics of the PV, which means that the system is not autonomous. For this, the method presented subsequently is the MPPT using a PI and P&O, which will make the system autonomous.

4.2 Command with a PI and P&O controller (MPPT-PI-P & O)

Unlike the MPPT command with PI corrector, at the level of the MPPT command with PI and P&O corrector, the referential voltage is obtained from the P&O algorithm. So that the system becomes autonomous by this method [11,12]. The schematic of the MPPT-PI-P&O method is shown in Fig.7.

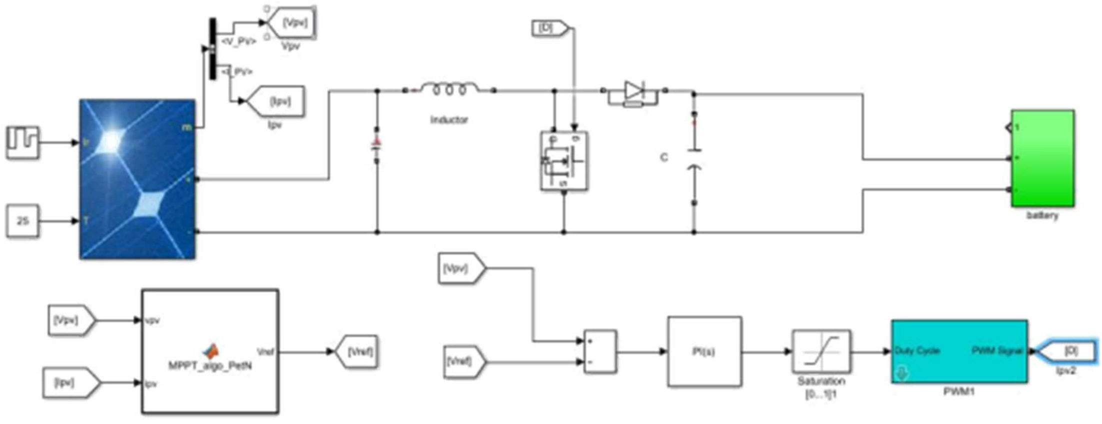

Fig.7. *PI-MPPT-P & O diagram on MATLAB*

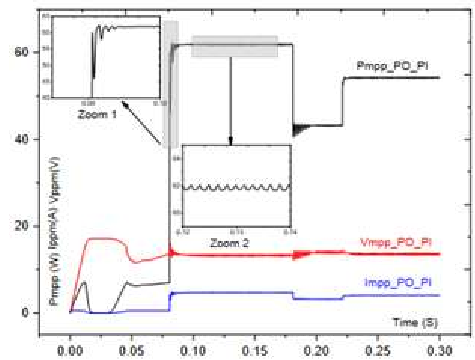

Fig.8. *Response in terms of the power of the PV module with the "MPPT-PO-PI" algorithm.*

The simulation results of the MPPT-PI-P & O algorithm on MATLAB / SIMULINK under the conditions mentioned at the beginning of this chapter are presented in Fig.7, composed of three graphs. The first represents the voltage at the output of the PV in volts. The second represents the current of the PV panel in Amperes. And the third represents the power of the PV in Watt, in a time interval of 0.3 seconds.

The simulation results of the MPPT-PI-P & O method in Fig.8 show that the method has the same advantages as the MPPT-PI method over conventional algorithms. The difference between MPPT-PI-P & O and MPPT-PI methods is that the system with MPPT-PI-P & O method is stand-alone.

4.3 MPPT command using fractional-order PI and P&O (MPPT-FOPI-P & O)

The transfer equation of a fractional PI:

$$C(s) = \frac{U(s)}{E(s)} = K_p + K_i \frac{1}{s^m} \text{ With } m \geq 0$$

Where C (s) is the transfer function of the controller, U (s) is the control signal, E (s) is the error signal, is the constant proportional gain, is the constant integration gain, m is the order of integration.K_p K_i. The fractional corrector synthesis that we will use is based on optimizing the parameters Kp, Ki, and m by an evolutionary algorithm (PSO). [15,16] The proposed MPPT control scheme using a Fractional Order PI with P&O (FOPI-P & O) on Matlab / Simulink is shown in Fig.9. The simulation results of the MPPT-FOPI-P & O algorithm on MATLAB / SIMULINK under the conditions cited at the start of this work are presented in Fig.10.

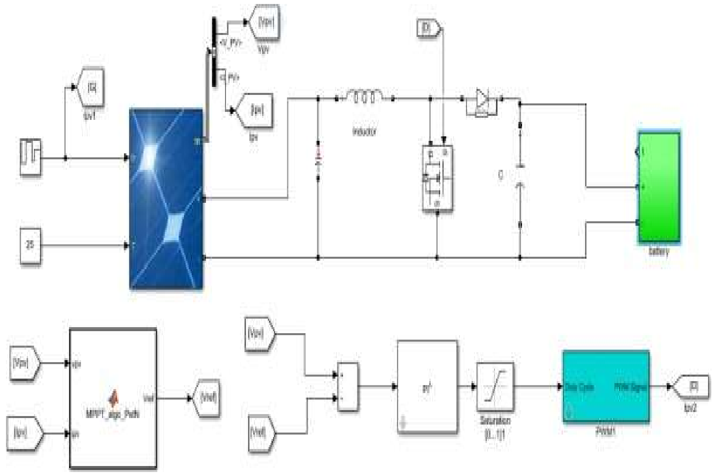

Fig.9. *MPPT-FOPI-P & O diagram on MATLAB*

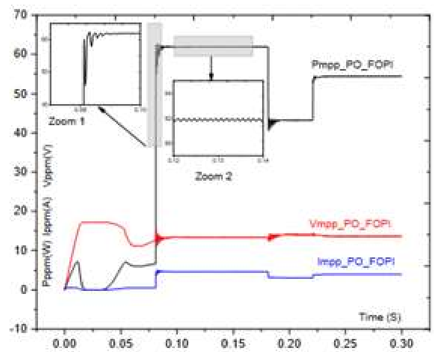

Fig.10. *Response in PV module power with the "MPPT-PO-FOPI" algorithm.*

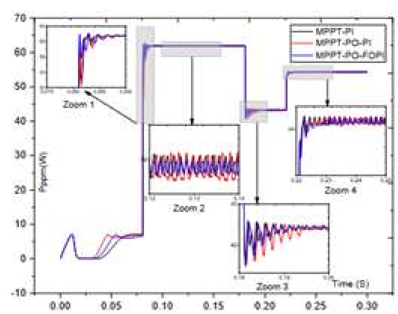

Fig.11. *Comparisons between MPPT-FOPI-P & O with MPPT-PI-P & O*

Fig.10 of the simulation shows that the photovoltaic system converges to the optimal values and oscillations around them. The comparison between the commands MPPT-PI and MPPT-FOPI- P & O and MPPT-PI-P & O is presented in Fig.11. It makes it possible to observe the added value of the FOPI fractional controller compared to the classic PI controller. Based on this comparison, we drew the following conclusions: Both controllers seem to have the same performance for 1000W / m² irradiation. Both are fast and have small oscillations around the optimum value (zoom 4). For other irradiations (zoom 1, 2 and 3), the FOPI controller is slightly better than the PI controller. It is faster and less oscillating.

5. Performance Comparisonof Processed MPPTAlgorithms

Under shifting conditions, such as evolving load,temperature, and solar irradiance, invert solar to amplify the electricity created by PV systems. The control of the algorithm is the voltage to keep the system running at its "highest power point" on the bend of power voltage. MPPT algorithms are used byengineers constructing PV systems to generate electricity, which is amplified by solar inverters. On the power voltage bend, adjust the voltage of the algorithms to keep the system PowerPoint "maximum PowerPoint" [17]. In PV system controller design, MPPT algorithms are commonly utilized. To ensure that the system of PV at all times provides maximum power, the algorithms take into account variables such as temperature and fluctuating irradiance.

Here are the two most commonly used algorithms for MPPT:

5.1 Perturbation and observation (P&O)

The "POC" algorithm is the most widely used for PV solar cells due to its simple development. In this algorithm, the module voltage is measured and then it will be continuously disturbed and compared with the previous measurement. Due to these fluctuations, the power generated by the PV module will also fluctuate. If the power increases, the disturbance willcontinue to develop in that direction. After reaching the peak, the power variation at the MPP is zero and then decreases, causing the disturbance to reverse in that direction [18].

5.2 Increment Conductance I&C

This technique compares the system of PVinstantaneous conductance to incrementalconductance, as seen below. The outcome depends on rising or lowering the voltage until the maximum power point is attained. The voltage does not change when a maximum power point is gained, unlike the Perturbation and observation technique[19].

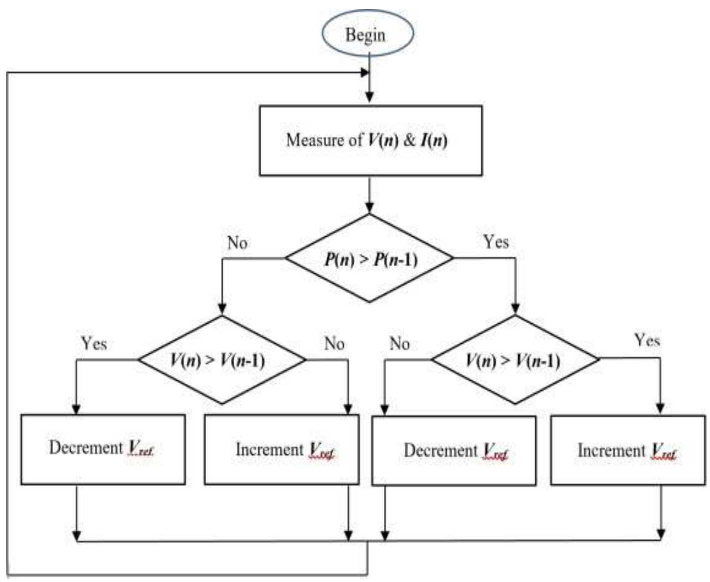

Fig.12. *Algorithm of the "Disturb and Observe"*method.

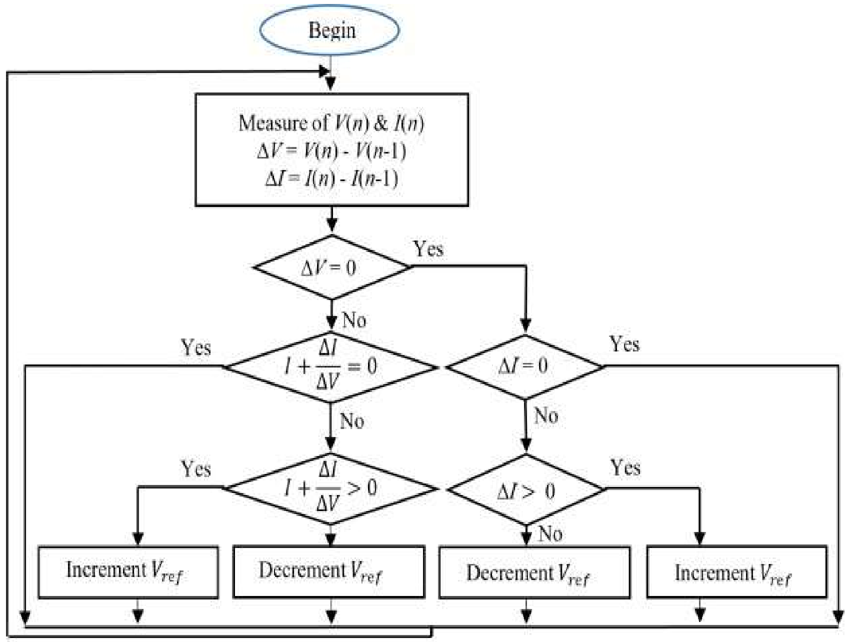

Fig.13. *Algorithm associated with the I&C method*

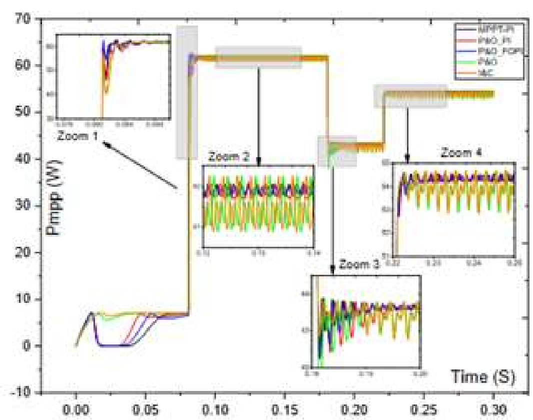

Fig.14. *Comparative results between MPPT algorithms*

Table 4: Calculated performance parameters

MPPT method	ConvergenceTime τc (ms)	Oscillation deviation εo(W)
1 : MPPT-P&O-PI	0.0846	0.32
2: MPPT-P&O-FOPI	0.0842	0.22
3: P&O	0.0871	1.15
4: I&C	0.0863	1.15

5.3 Comparative study between the different methods treated

The comparison between MPPT-PI and MPPT- FOPI-P&O and MPPT-PI-P&O and P&O and I&C controllers is presented in Fig.14. It allows us to observe the added value of the fractional FOPI controller compared to the classical PI controller. Based on this comparison, we have drawn the following conclusions: Both controllers seem to have the same performance for different irradiation values, both are fast and have small oscillations around the optimal value (zoom 2). For the other irradiations (zoom 1, 2, and 3), the FOPI controller isslightly better than the PI controller. It is faster and less oscillating.

The results in this table show that the best of the five algorithms is the "MPPT-P&O -FOPI". It has almostzero oscillations and a static deviation of less than 0.28 at a steady state. Table 4 summarizes the parameters of the calculated performance.

6. Conclusion

MPPT was an approach used for with variable-power sources, namely wind, solar, and ocean, to increase energy extraction in all circumstance. The basically utilized P&O and incremental conductance (INC) techniques have benefits, like ease of implementation, however they also have the issue of choosing the most optimized perturbation step or increment size when taking into consideration of the trade-off among convergence time and oscillation. This study looked at four MPPT techniques for getting the most power out of PV modules. The performance of popular maximum power point techniques is investigated in this research. While simulation results were also produced from a PV array, maximum power was extracted. Based on this comparison, we came to the following findings: For 1000W / m2 irradiation, both controllers appear to work similarly; they are both quick and have slight oscillations around the optimum value (zoom 4). The FOPI controller outperforms the PI controllerfor different irradiations (zoom 1, 2, and 3). It's speedier and has fewer oscillations.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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