

Assessing Under Varying Circumstances the Behavior of Photovoltaic Systems of Maximum Power Point Methods

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Abstract— In this article an extended literature surveying review is conducted on a set of comparative studies of maximum power point tracking (MPPT) techniques. Different MPPT methods are conducted with an ultimate aim of how to be maximizing the PV system output power by tracking $P_{\max}$ in a set of different operational circumstances. In this paper maximum power point tracking, MPPT techniques are reviewed on basis of different parameters related to the design simplicity and or complexity, implementation, hardware required, and other related aspects.

Index Terms— MPPT, PV array, constant voltage, incremental conductance, perturb and observe, DC-DC converter.

I. INTRODUCTION

The technology of solar systems has been booming for a while due to its ability to replace current fossil fuels like coal and gas for generation of electricity that produce air, water, and land pollution. In addition it decreased the issue of global warming and climate changes substantially due to being produced in a clean environmental manner and was proved to be an Eco-friendly resource of energy.

The photovoltaic systems' manufacturing process has been improving continuously over the last decade and photovoltaic systems have become an interesting solution. Precisely, PV systems are constituted from arrays of photovoltaic cells, choppers (mainly buck-boost or boost DC/DC converter), MPPT control systems and storage devices and/or grid connections. To improve the efficiency of such systems, various studies have been performed [1-2].

The demand of PV generation systems seems to be increased for both standalone and grid-connected modes of PV systems [3-4]. Therefore, an efficient maximum power point tracking (MPPT) technique is necessary to initialize the process of tracking the maximum power point MPP at all environmental conditions and then force the PV system to operate at that MPP point.

PV module is made up of several solar cells. Operating point of solar cells depends on varying factors such as irradiation, temperature, spectral characteristics of sunlight and so on.

Environmental conditions like cloudy weather and ambient temperature can change the output power from PV panel. Also the generated power from PV system is non-linear and fluctuates depending on the mentioned factors and do not have constant desirable efficiency [5]. The PV arrays have unique operating point that is capable of delivering the maximum power, which is called the Maximum Power Point (MPP). The locus of this point has a non-linear variation with solar irradiance and the cell temperature. So we are in an urge to increase the efficiency of the solar power. Improving the conversion efficiency of the solar panel, the automatic tracking system, the scientific storage battery charging technology and the MPPT solar technology are the methods to increase the efficiency [6]. For the operation of the PV array at its MPP, the PV system must contain a MPP Tracking (MPPT) controller. MPPT control is obligated for identifying maximum power from PV array and to utilize it so that it yields better efficiency [7]. Improving the tracking of the maximum power point (MPP) with new control technique is easy to be achieved based on the multi algorithms available to us and can be executed to PV plants, which are upgrading their control technique thus expanding the PV power generation.

The main task of this article is to offer an evaluation of MPPT techniques and provides an alternative spectrum of selection choices for those who are interested in the implementation of these algorithms in the control techniques of MPPT and thus using a proper MPPT technique will have the effect of reducing the solar array cost through the extraction of the desired output power.

II. ANALYSIS OF PV SYSTEM

The characteristic of Photovoltaic system has been touched based and developed in various models. As a general example, the single diode model was so popular in this regard. An equivalent circuit of a simple PV module is shown in Fig. 1.

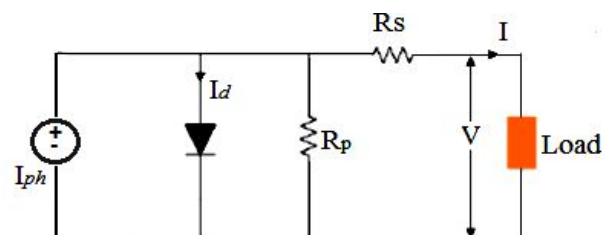


Fig. 1. A PV module equivalent model.

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This PV module consists of current source connected in parallel with a diode. The current source is denoted by I_{ph} and it represents the current generated by photons. Whereas R_s and R_p are the equivalent series and parallel resistances of the module respectively [8]. To further analyze the PV system we may incorporate the following mathematical formulas as follows: The output current I of this module can be formulated using Kirchhoff Current Law “KCL” where, I will be equal to;

$$I = I_{ph} - I_d - \frac{V_d}{R_p} \quad (1)$$

where I_d = diode current and V_d = diode voltage. The diode current will be equal to:

$$I_d = I_0 \left(e^{\frac{V_d}{aV_t}} - 1 \right) \quad (2)$$

where, a = ideal factor; I_0 = Reverse saturation current; V_t = thermal voltage. Thermal voltage is equal to:

$$V_t = N_s K T / q \quad (3)$$

where, N_s = Number of cells in series; k = Boltzmann constant; T = Cell temperature in Kelvin; and q = Electron charge.

The changes of MPP with respect to the irradiance and temperature are shown below in Fig. 2 and Fig. 3, respectively. The maximum power point (P_{max}) is the spot near the knee of the PV curve at which the product of current and voltage achieves its maximum [9-10-11]. As shown in the figures, MPP is detected at each level and it could vary and shift on curves as irradiation and cell temperature changes. When irradiation drops, current drops in direct proportion, and reduces the voltage. As the cell temperature increases, voltage diminishes generously while the short circuit current increments marginally.

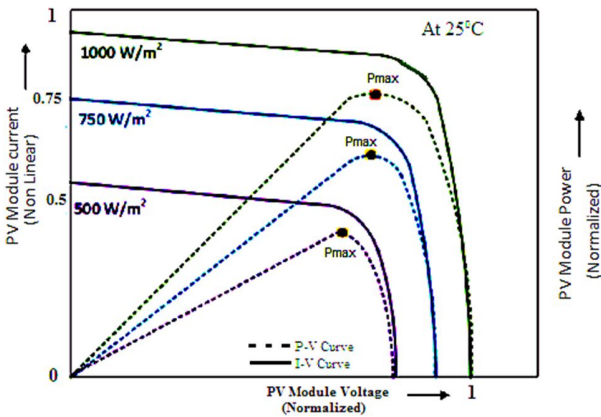


Fig. 2. PV array Characteristic with respect to irradiance.

When the PV array is directly coupled to the load, the operating point is determined by the crossing point between the load I - V curve and PV I - V curve [12]. Thus variation in load causes a change in the operating point. When temperature and solar irradiation changes the operating point may change. The MPPT is used to controlling the PV array's voltage and current independently. However the MPP location in the plane of the curves is unknown and must be tracked. As a result to seek the appropriate MPP a certain tracker should be implemented between the PV system and the load. One of the most essential parameters that we need to look at for example would be performance and fast response.

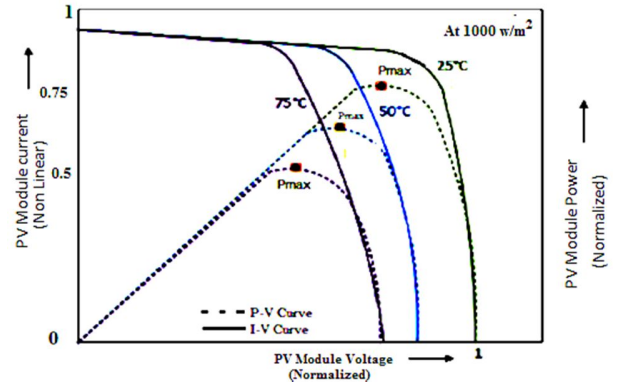


Fig. 3. PV array Characteristic with respect to temperature.

The changes and variation in the irradiance and temperature due to the environmental factors should be compensated through a controller which eventually will be responsible to track the MPP. An overview of the most well-known methodologies used in MPPT techniques will be discussed through the rest of this paper

III. EVALUATION OF MPPT TECHNIQUES

According to the literature multiple available tracking methods of MPPT are available to researchers and some are being constantly explored in the literature according to [13-14]. Since the literature is well enriched with many types of well-developed algorithms [15-16] we can make an emphasis on a narrow chunk of the commonly used techniques that are shown below:

- Constant Voltage (CV) Method [17]
- Incremental Conductance (IC) Methods [18]
- Perturb and Observe (P&O_a and P&O_b) Methods [19-20]

The above techniques are very popular and we shall commence to further analyzing some of their functional work along with showing how their algorithms are employed.

A. Constant Voltage (CV) Method

Constant Voltage (CV) Method principle is designed to be uncomplicated where the PV is supplied using a constant voltage. The two important factors, the temperature and Solar irradiance influences are not considered (neglected). Where the

reference voltage “ V_{ref} ” is acquired from the MPP of the P (i) characteristic directly.

We'll consider MPP voltage to be equal to 16.3V for the PV. Fig. 4 shows the CV algorithm function. The Constant Voltage “CV” method needs to have the measurement of the PV voltage only. A 1 kHz frequency is used for the purpose of evaluation of the MATLAB embedded function. In nutshell CV Method is not an effective technique due to missing solar irradiance impact and temperature's influence, and thus it will require further enhancements by incorporating the Open Voltage, “OV” and temperature methods.

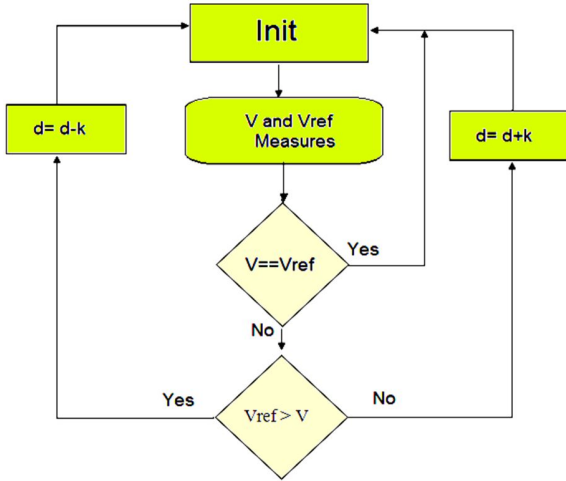


Fig. 4. Constant Voltage algorithm.

B. Incremental Conductance (IC) Methods

Incremental Conductance focuses on the observation of P-V characteristic curve. The design of this algorithm was intended to serve in overcoming the negative aspects of P&O algorithm. IC tries to improve the tracking time and to produce more energy on a vast irradiation changes environment [21].

MPP can be derived to be calculated by utilizing the relation between dI/dV and $-1/V$. dP/dV is zero at the point of maximum power. If dP/dV is negative then MPPT lies on the right side of recent position and if the MPP is positive the MPPT is on left side [22]. The equation of Incremental Conductance method is:

$$\frac{dp}{dv} = \frac{d(IV)}{dV} = I + V \frac{dI}{dV} \quad (4)$$

$$= I + V \frac{dI}{dV} \quad (5)$$

MPP is reached when $dP/dV = 0$ and;

$$\frac{dI}{dV} = -\frac{I}{V} \quad (6)$$

$$\frac{dP}{dV} > 0 \quad \text{then} \quad V_p < V_{mpp} \quad (7)$$

$$\frac{dP}{dV} = 0 \quad \text{then} \quad V_p = V_{mpp} \quad (8)$$

$$\frac{dP}{dV} < 0 \quad \text{then} \quad V_p > V_{mpp} \quad (9)$$

Fig. 5 displays the algorithm associated with Incremental Conductance. If MPP lies on right side, $dI/dV < -I/V$ and then the PV voltage must be decreased to reach the MPP [23].

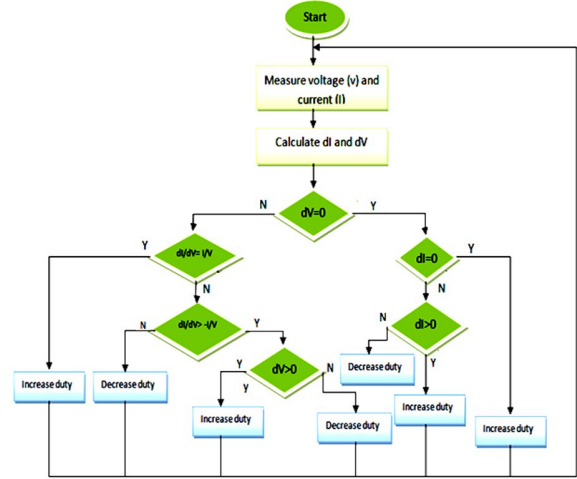


Fig. 5. A flowchart of the Incremental Conductance method.

IC methods can locate MPP, reduce power loss and system cost. Note that the main disadvantage of the IC method is related to the tracking time which is relatively slow and not being fast and this is due to the voltage adjustment factor (selection of decreasing and increasing it is running through a trial and error).

C. Perturb and Observe (P & O) Method

P&O is one of the most popular and used algorithms for MPPT. It searches for the MPP by changing the PV voltage or current and detecting the change in PV power output. The functioning is based on perturbing the voltage and the current of the PV regularly, and then, in comparing the new power measure with the previous to decide the next variation. P&O can have issues at low irradiance that result in oscillation. There can also be issues when there are fast changes in the irradiance which can result in initially choosing the wrong direction of search. Fig. 6 shows the P&O algorithm as shown in the following diagram.

Let's say that, after performing an increase in the panel operating voltage, the algorithm compares the current power reading with the previous one. If the power has increased, it keeps the same direction (increase voltage), otherwise it changes direction (decrease voltage). This process is repeated at each MPP tracking step until the MPP is reached. After getting the MPP, the algorithm would in a natural way oscillates around the correct value. It uses a fixed step to increase or decrease voltage. However, the size of the step determines the size of the deviation while oscillating about the MPP. As an important note; having a smaller step will help reduce the oscillation, but will slow down tracking, while on the other hand having a bigger step will help reach MPP faster, but will increase power loss when it oscillates.

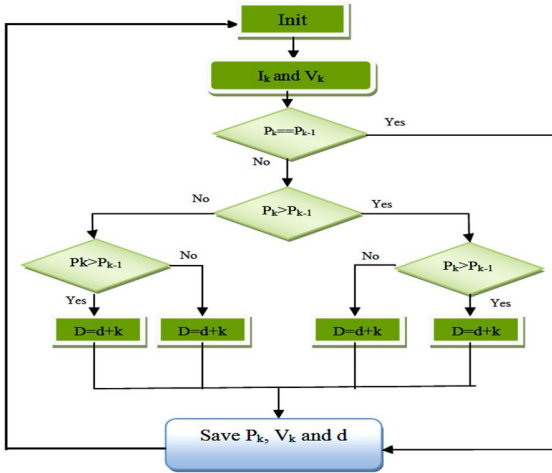


Fig. 6. Illustration of P&O algorithm.

IV. A COMPARISON OF WELL-KNOWN TECHNIQUES AND DISCUSSION EFFICIENCY

Among all the MPPT methods, Perturb & Observe (P&O) and Incremental Conductance (IC) are most commonly used because of their simple implementation and lesser time to track the maximum power point.

Under the sudden changes of irradiation level as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiation and sometimes ends up in calculating wrong MPP [24]. However this problem is eliminated in Incremental Conductance method as the algorithm takes two samples of voltage and current to compute MPP [25]. Furthermore, instead of more efficiency, the complexity of the algorithm is very high and hence the cost of execution increases.

The efficiency of the system would rely mainly on the converter. As a matter of fact, it is for a buck analysis it is rated at the maximum, and after that in buck-boost analysis and considered to be at the minimum for a boost analysis. A high efficiency is required at stationary and time varying atmospheric conditions [26]. To obtain a reasonable performance in PV one can select hybrid techniques, which as well can have less fluctuation for swift temperature and irradiance fluctuations, provide fast responses, with an ability to get no overshoot.

V. MPPT ACCURACY, ERROR, AND EFFICIENCY

In many research studies it was evident that MPPT gain is large, however, the system needs to take into consideration the efficiency losses of DC-DC converters. Moreover, MPPT halts its main operation if the load does not have the ability to consume all the power delivered resulting in tradeoff between efficiency and the cost. Standalone or grid connected PV systems can get the maximum profit provided having a collective scale if MPPT efficiency needs to be improved through the following:

$$\eta_{MPPT} = \frac{P_{PV}}{P_{MPP}} \times 100 \quad (10)$$

where: P_{PV} : Power produced at output of PV Panel
 P_{MPP} : Power produced at MPP

During assessing MPPT method the maximum possible power that could be extracted from the panel $p_{\max}(t) = I_{mp}(t) V_{mp}(t)$ has to be calculated in every instant, t . Then, the efficiency of the method can be estimated with the following expression:

$$\eta_{MPPT} = \frac{\int_0^{T_i} P_{MPPT}(t) d\tau}{\int_0^{T_i} P_{\max}(t) d\tau} \quad (11)$$

where; $P_{mppt}(t)$ is instantaneous power obtained from the panel using the selected MPPT method.

T_i is the total period of time in which the aforementioned MPPT method is evaluated.

We have to stress out that the static and dynamic factors are affecting MPPT behavior and those would include:

- a) Power (irradiance level),
- b) Voltage (temperature; layout including well- or mismatched PV and MPPT voltage ranges),
- c) Fluctuations (clouds),
- d) PV technology (I-V curve shape)
- e) Need (battery state of charge, in case of charge controller with MPPT).

Three important parameters are addressed to describe how good the MPPT performs. Those are functions of time (even under static conditions, due to MPPT search movements) and of additional parameters.

i) Accuracy

Whether it is static or dynamic would indicate how close to MPP the MPPT operates the PV array and can be defined as a percentage of $I_{\max}$, $V_{\max}$, or $P_{\max}$:

$$a_{MPPT(X)} = \frac{X}{X_{\max}} \quad (12)$$

where, $X = I, V$, or P

ii) Efficiency

It indicates the ratio of actual to available PV array power (a particular case of accuracy) or energy:

$$\eta_{MPPT(P)} = \frac{P}{P_{\max}} \quad \text{and} \quad \eta_{MPPT(E)} = \frac{E}{E_{\max}} \quad (13)$$

iii) Error

Whether it is static or dynamic it indicates the absolute or relative difference between actual and MPP values of voltage, current or power:

$$\varepsilon_{MPPT(X)} = X - X_{\max} \quad (\text{absolute}) \quad (14)$$

or

$$\varepsilon_{MPPT(X)} = \frac{X}{X_{\max}} - 1 \quad (\text{relative}) \quad (15)$$

where $X = I, V$, or P

Table I below is listing some of the well-known techniques and their characteristics.

TABLE I. COMPARISON OF WELL KNOWN MPPT TECHNIQUE ALGORITHM

MPPT Technique	PV array dependent?	True MPPT?	Analog or digital?	Periodic tuning	Implementation complexity	Sensed parameter
Hill Climbing/P&O	No	Yes	Both	No	Low	Voltage, Current
Incremental Cond.	No	Yes	Digital	No	Medium	Voltage, Current
Voc	Yes	No	Both	Yes	Low	Voltage
Isc	Yes	No	Both	Yes	Medium	Current
Fuzzy Logic Control	Yes	Yes	Digital	Yes	High	Varies
dP/dV or dP/dI Feedback Control	No	Yes	Digital	No	Medium	Voltage, current
IMPP and VMPP computation	Yes	Yes	Digital	Yes	Medium	Irradiance, Temperature

VI. PV SYSTEM CONFIGURATION

The incorporated MATLAB/SIMULINK model for PV system is displayed and shown in Fig.7; the system that was modeled consists of PV panel developmental model, a step up DC-DC converter, and eventually a specific load. In addition, extra roles are addressed to continue our PV modeling configuration where we added an MPPT algorithm which is implemented by Simulink blocks, PID controller and eventually a PWM to derive the converter. The DC/DC boost converter is designed in a way where a dc link maintains an approximately constant voltage of 30V at the output of the converter. Table II shows the parameters of the DC/DC boost converter.

TABLE II. DC-DC BOOST CONVERTER PARAMETERS

Parameter	Value
L	50 mH
C1	680 μ F
C2	1640 μ F

The dc voltage transfer function for the boost converter can be written as:

$$V_{PV} = V_0(1 - D) \quad (16)$$

where V_{PV} is the voltage across the PV module at any weather condition; V_0 is the output voltage of boost converter; D is the duty ratio, which serves as a control input.

The controller algorithm adjusts the DC/DC converter duty ratio to track the operating point to the maximum output power delivered from the PV module.

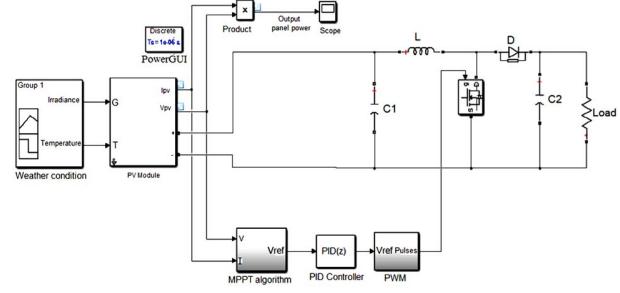


Fig. 7. PV system configuration.

VII. SIMULATION MODEL AND RESULTS

To analyze and compare the performance of the MPPT method, we carried out the simulation for two cases. The first case, the temperature is maintained constant (25°C) and the irradiance decreases from 1000 W/m² to 800 W/m² and then decreases to 600 W/m². Fig. 8 shows the output power under a set of various irradiances and with/without P&O algorithm, the operating point was close to the MPP during the simulation and the response was very rapid, while with no P&O algorithm the output power was less.

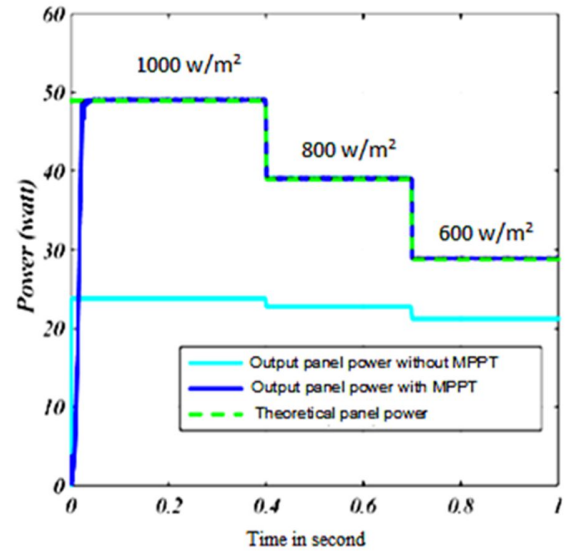


Fig. 8. Output power under different irradiation using P&O algorithm.

In Fig. 9, the output power shows under different irradiance with and without incremental conductance algorithm. The second case, the irradiance is maintained constant 1000 W/m² and the temperature increases from (25°C) to (35°C) and then increases to (45°C). It is also shown that the output power without MPPT is lower than with MPPT. Fig. 10 shows the output power under different irradiance with and without using incremental conductance algorithm whereas Fig. 11 shows output power under different irradiance with and without P&O algorithm.

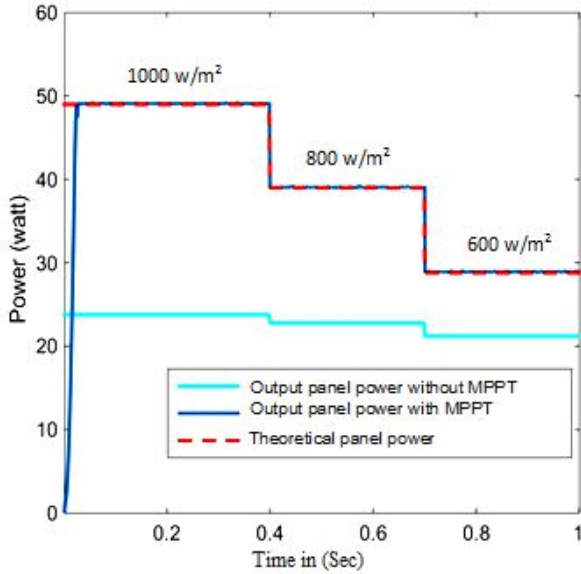


Fig. 9. Output power under different irradiation using IC algorithm.

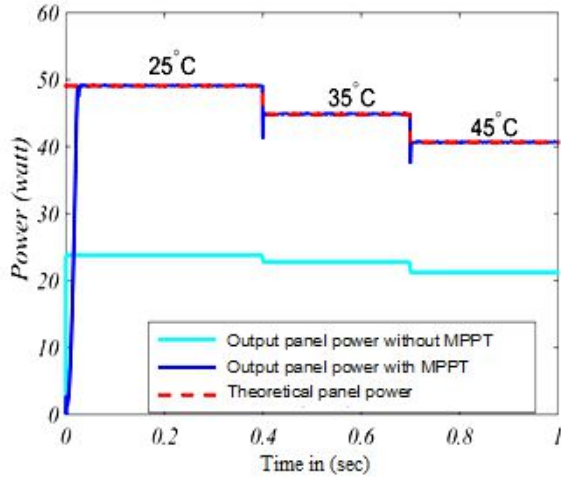


Fig. 10. Output power under different temperature using P&O algorithm.

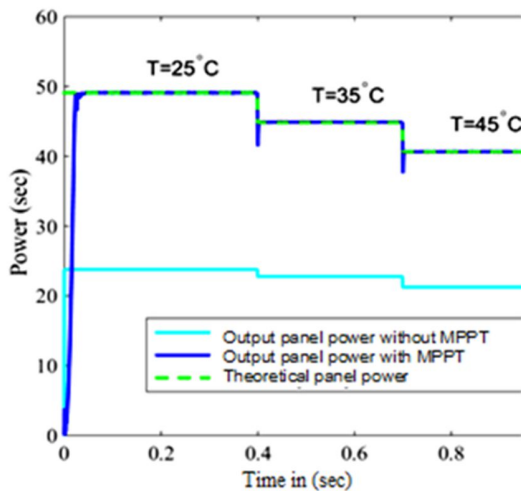


Fig. 11. Output power under different temperature using IC algorithm.

In order to validate the effectiveness of two MPPT methods, a comparative study is done between P&O and incremental conductance based on PID. The static tracking efficiency of two MPPT methods under different irradiance was simulated. The static MPPT efficiency is given by [27]:

$$\eta_{static} = \frac{P_o}{P_{max}} \quad (17)$$

where; P_o represents the output power of the PV module under steady state; P_{max} is the maximum power of the PV module under certain conditions.

From the results in Table III the static tracking efficiency of Incremental Conductance method is higher than Perturb and Observe method.

TABLE III. TRACKING EFFICIENCY OF MPPT DURING IRRADIANCE

Irradiance	Tracking efficiency of P&Q Algorithm	Tracking efficiency of IncCond Algorithm
1000 W/m ²	99.85%	99.94%
800 W/m ²	99.82%	99.93%
600 W/m ²	99.80%	99.90%

VIII. CONCLUSIONS

Photovoltaic systems were briefly introduced in this paper. The various sorts of tracking models have been highlighted and some of the most common ones were analyzed regarding seeking MPPT. This paper proposed a selective comparison between Perturb & Observe and incremental conductance methods based on PID controllers. A simulation was conducted through the usage of MATLAB/SIMULINK tool. A simulation of the real PV module is constructed to demonstrate the nonlinear characteristic of PV module which would take place due to changing the weather condition (irradiance and temperature). The experimental results show that, Perturb and Observe method and Incremental Conductance method based on PID controller have fast response to reach the MPPT with solar radiation change; however the efficiency of IncCond method was higher than that of P&O method.

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