Modeling and Simulation of a Stand-alone Photovoltaic System

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Abstract— *In the future solar energy will be very important energy source. More than 45% of necessary energy in the world will be generated by photovoltaic module. Therefore it is necessary to concentrate our forces in order to reduce the application costs and to increment their performances. In order to reach this last aspect, it is important to note that the output characteristic of a photovoltaic module is nonlinear and changes with solar radiation and temperature. Therefore a maximum power point tracking (MPPT) technique is needed to track the peak power in order to make full utilization of PV array output power under varying conditions. This paper presents two widely-adopted MPPT algorithms, perturbation & observation (P&O) and incremental conductance (IC).*
These algorithms are widely used in PV systems as a result of their easy implementation as well as their low cost. These techniques were analyzed and their performance was evaluated by using the Matlab tool Simulink.

Keywords—Photovoltaic system; MPPT; Perturbation and Observation; Incremental conductance

I. Introduction

With industrials developments, the use of the power generation technology with renewable energy source is developing rapidly. The Renewable energy has an advance all over the world in the environment protection**,** since; it is clean, operating silently, long life time, low maintenance and absence of fuel cost and inexhaustible [1]-[2]. Renewable energy, and particularly the power generation from solar energy using Photovoltaic panels**,** has emerged in last decades since it has the aforesaid advantages. The increase in a number of Photovoltaic systems installed all over the world brings the need of proper supervision and control algorithms as well as modeling and simulation tool for researcher and practitioners involved in their application.

In photovoltaic (PV) power systems, maximum power point tracking (MPPT) is essential because it takes full advantage of the available solar energy. And since the output characteristics of photovoltaic (PV) system is nonlinear and changes with temperature and solar radiation, its maximum power point (MPP) is not constant. Under each condition PV module has a point at which it can produce its MPP. Therefore, maximum power point tracking (MPPT) techniques can be used to uphold the PV panel operating at its MPP and then to increase the PV system efficiency.

Many MPPT techniques have been proposed in the literature; examples are the Perturb and Observe (P&O) method [3], the Incremental Conductance (IC) method [3], the Artificial, the Fuzzy Logic method [4], etc.. The P&O and IC techniques, as well as variants thereof, are the most widely used. The ‘P&O’ method is that which is most commonly used in practice by the majority of authors [5], among others thanks to its simple feedback structure and its ease of implementation in hardware and software. An alternative to the ‘‘P&O’’ method is Incremental conductance (IC) which has proved to be better in terms of efficiency, thanks to ease of implementation because it does not need the mathematical model and characteristics of the PV panel, its response speed to track the MPP is fast and also it has no power loss due to oscillations.
In this work after the system modeling, simulation of the two MPPT techniques using MatLab/Simulink software was carried out. The reminder paper was structured as follow: the system modeling is presented in second part of this paper, in the third part the two MPPT techniques P&O and IC are detailed, the results discussion are presented in the last part of this paper and finally conclusion was given.

II. System Modeling

Fig. 1 shows the block diagram of the proposed system, composed of a PV Module, DC-DC converter, MPPT Techniques and a load.

A. PV Module Modeling

Because of its low thickness, a photovoltaic cell produces a very low electrical power of the order 1 to 3 W. So to increase the power, we assemble these cells either in series or in parallel or both to form a photovoltaic module and achieve the desired power. An association of cells in series increases the voltage of the module, while an association in parallel allows increasing the output current of the generator. The equivalent circuit of the PV module is shown in Fig. 2.

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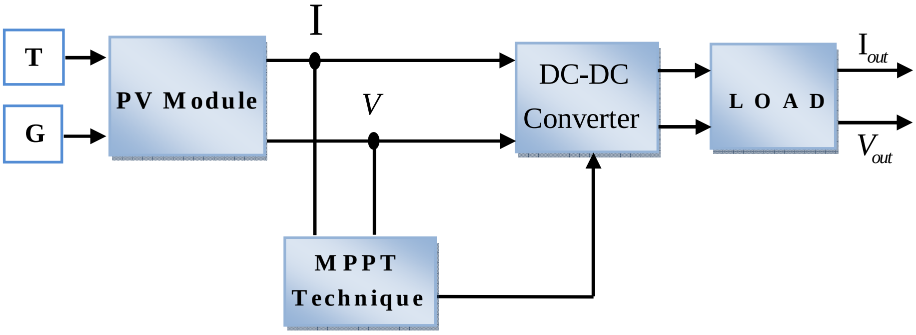


Fig. 1. Block diagram of the stand-alone PV system.

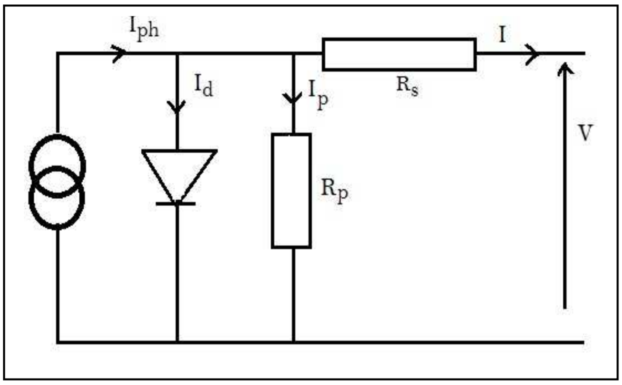


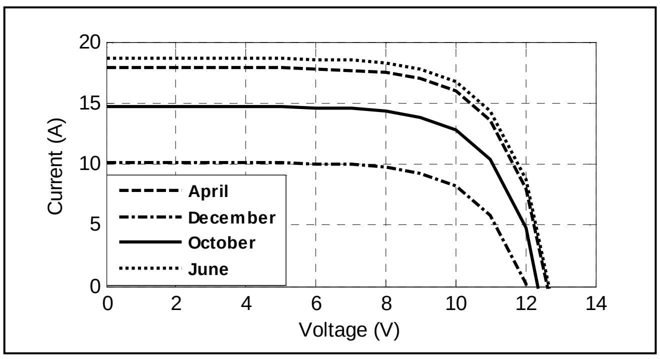
Fig. 2. Model of the photovoltaic module

The voltage-current characteristic is a complex and non linear function. Its equation is given as follows:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{q}{akT}(V + IR_S) \right) - 1 \right] - \frac{V + IR_S}{R_p} \quad (1)$$

Where Iph is the light-generated current or photocurrent, I0 is the reverse saturation current of diode, q is the electron charge (1.60217646*10-19 C), k is the Boltzmann constant (1.3806503*10-23 J/K), and T is the temperature of the p-n junction in K. a is the diode ideality factor, It depends on recombination mechanisms in the space charge zone. In the ideal case, Rs tends towards 0 and Rp to infinity. And in the real case, these resistors provide an assessment of the imperfections of the diode.

Fig. 3, [6] shows the behavior of a photovoltaic module simulation in accordance to solar radiation variation and constant temperature that are locally measured in Tetouan (Northern Morocco) [7] for the typical clear day of one month of every season.



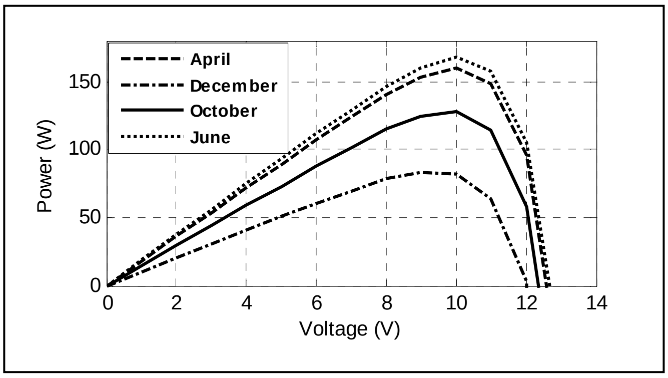


Fig. 3. I-V and P-V characteristics, Constant Temperature (25°C) and Varying Solar Radiation, [6]

TABLE I. MPP UNDER THE INFLUENCE OF SOLAR RADIATION FOR TYPICAL CLEAR DAYS OF ONE MONTH OF EACH SEASON

Months	Solar Radiation (W/m^2)	Constant Temperature T=25°C		
		P_{MPP} (W)	V_{MPP} (V)	I_{MPP} (A)
June (Summer)	903.65	61.74	12.67	1.86
April (Spring)	865.1	58.73	12.61	1.78
October (Autumn)	711.9	47.03	12.36	1.47
December (Winter)	490.17	30.70	12.02	1.012

As we can see in the curves of the figure above, the current and the power increase are highly affected by the solar radiation; Table 1 can sum up this, hence the need of using the MPPT techniques, to extract the maximum available power at any changes.

B. DC-DC Converter Modeling

The DC/DC converter should always operate in the maximum power point tracking to maximize the PV array efficiency and consequently increase the efficiency of the global system. A buck-boost converter (Fig. 4) is a DC-to-DC power converter with an output voltage either greater or smaller than its input voltage. The output voltage is controlled by controlling the switch-duty cycle. The term d is the duty ratio and defined as the ratio of the on time of the switch to the total switching period.

So, when the switch is turned-on, the input voltage source supplies current to the inductor and the capacitor supplies current to the resistor (output load). While when the switch is

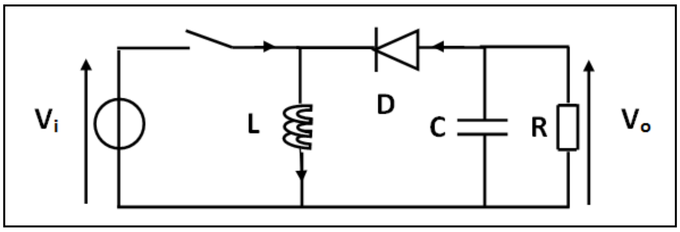


Fig. 4. Schematic diagram of a DC Buck-Boost converter.

Opened, the inductor supplies current to the load via the diode D.

III. Proposed MPPT Techniques

A. Perturbation and Observation Technique

The P&O techniques operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases, the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way.

From Fig. 5, it can be seen that incrementing (decrementing) the voltage increases (decreases) the power when operating on the left of the MPP and decreases (increases) the power when on the right of the MPP. Hence, if there is an increase in power, the subsequent perturbation should be kept the same to reach the MPP and if there is a decrease in power, the perturbation should be reversed. This algorithm is summarized in Table 2 and shown in Fig. 6. A common problem in P&O algorithms is that the array terminal voltage is perturbed every MPPT cycle; therefore when the MPP is reached, the output power oscillates around the maximum, reducing the generable power by the system.

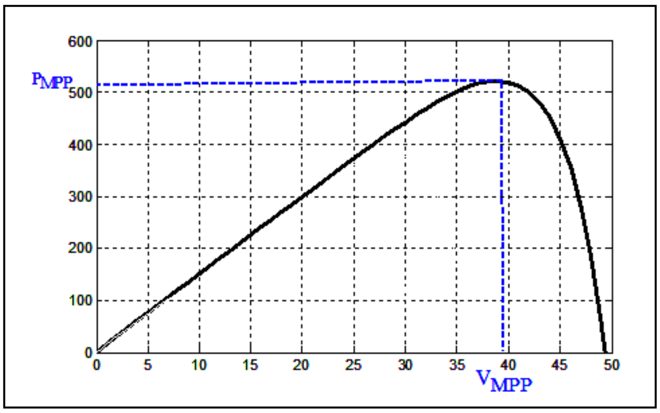


Fig. 5. Standard PV array power curve

TABLE II. SUMMARY OF P&O ALGORITHM

Perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

There are many different P&O methods available in the literature. In this paper we consider the classic one.

B. Incremental Conductance Technique

The incremental conductance method has been proposed in 1993 and expected to overcome the problems of previous method specially P&O. This method focuses directly on power variations, based on the output current and voltage of the photovoltaic panel to calculate the conductance and the incremental conductance, In order to compare the conductance $G=\frac{I}{V}$ and the incremental conductance $\Delta G=\frac{dI}{dV}$ and to decide when to increase or to decrease the photovoltaic voltage to reach the MPP, where the derivative of the power is equal to zero $\frac{dP}{dV}=0$. The IC method is effective to search the MPPT [8]-[9]. However, the implementation of the algorithm is complex and requires a high calculation capacity, which increases the system control period. The output power of PV array is given as:

$$\begin{cases} P = V.I \\ \dfrac{dP}{dV} = \dfrac{d(V.I)}{dV} = I + V.\dfrac{dI}{dV} \\ \dfrac{1}{V}.\dfrac{dP}{dV} = \dfrac{I}{V} + \dfrac{dP}{dV} \end{cases} \quad (2)$$

By defining the photovoltaic conductance and incremental conductance, yields:

$$\begin{cases} G = \dfrac{I}{V} \\ \Delta G = -\dfrac{dI}{dV} \end{cases} \quad (3)$$

We obtain:

$$\frac{1}{V}.\frac{dP}{dV} = G - \Delta G \quad (4)$$

Equation (4) explains the operating voltage is below the voltage at the maximum power point if the conductance is larger than the incremental conductance and vice versa. The task of this algorithm is to track the voltage operating point which conductance is equal to incremental conductance. Hence:

$$\begin{cases} \dfrac{dP}{dI} = 0 \Rightarrow \dfrac{dI}{dV} = -\dfrac{I}{V}, \Delta G = G, at\ MPPT \\ \dfrac{dP}{dV} > 0 \Rightarrow \dfrac{dI}{dV} > -\dfrac{I}{V}, \Delta G < G, left\ of\ MPPT \\ \dfrac{dP}{dV} < 0 \Rightarrow \dfrac{dI}{dV} < -\dfrac{I}{V}, \Delta G > G, right\ of\ MPPT \end{cases} \quad (5)$$

The equations (5) are used to determine the direction in which a perturbation must occur to shift the operating point toward the MPP and the perturbation is repeated until $\frac{dP}{dI}=0$.

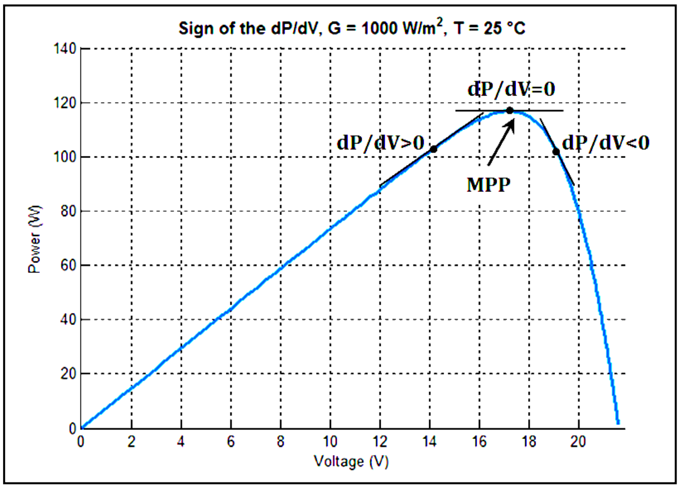


Fig. 7. Sign of the dP/dV at different positions on the P-V characteristic curve of a PV array.

Once, the MPPT is reached and continues to operate at this point until a change in current is measured which will correlate to a change in solar radiation on the array (Fig. 7). The principle of this algorithm is summered in Flow chart drawn in Fig. 8. The main advantage of this method is that it is compatible with rapidly changing of irradiance; furthermore it has less oscillation around MPP in comparison with P&O.

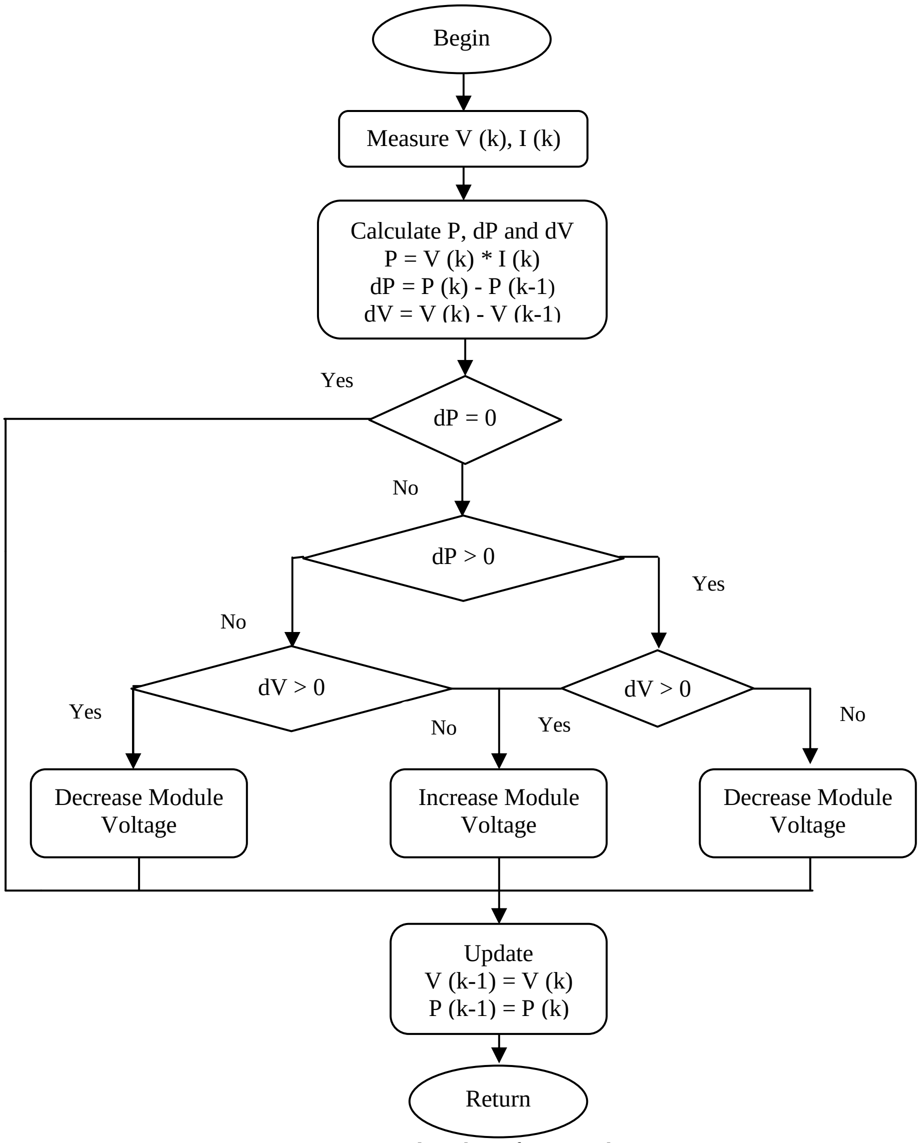


Fig. 6. Flow chart of P&O Technique

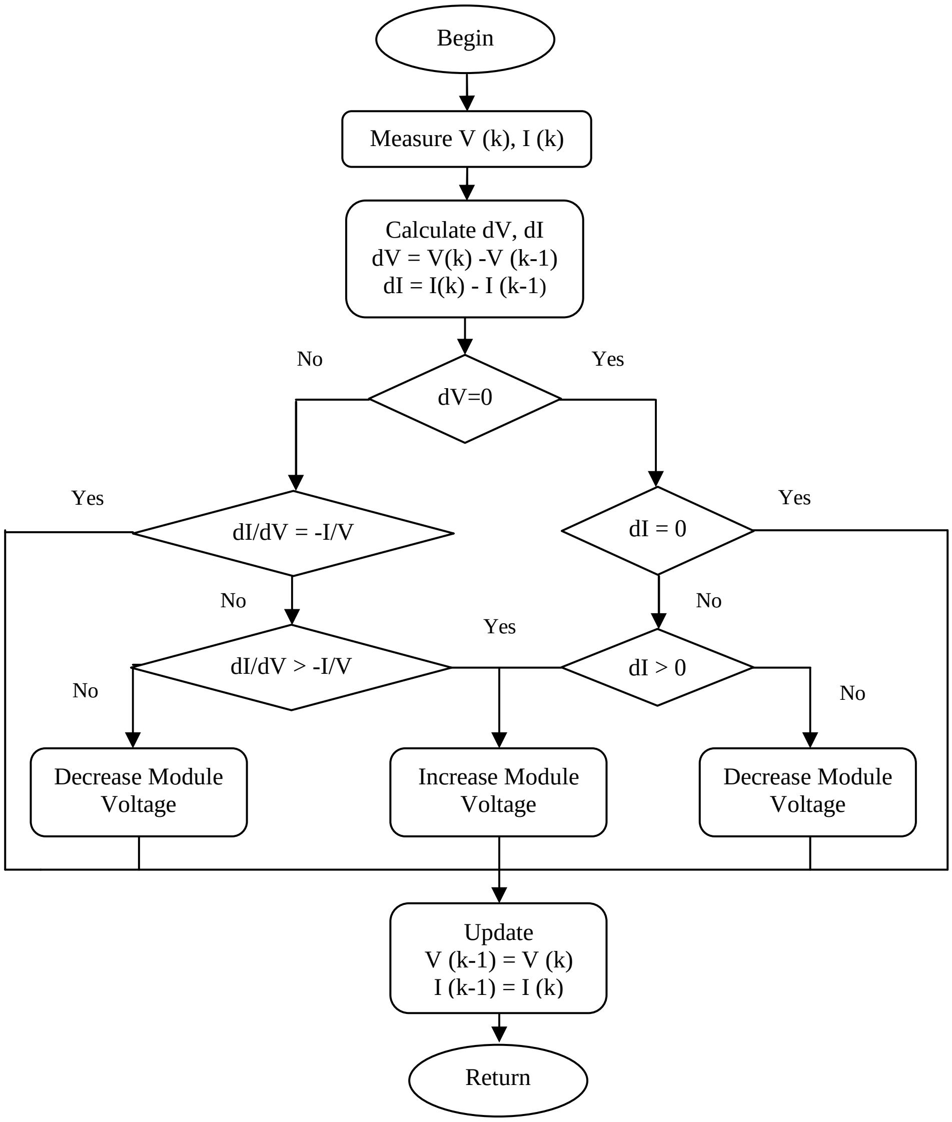


Fig. 8. Flow chart of IC Technique

IV. Results and Discussion

The theoretical analysis of our system is to be validated and done by simulation using the Simulink platform and the real data collected from Tetouan/Morocco.

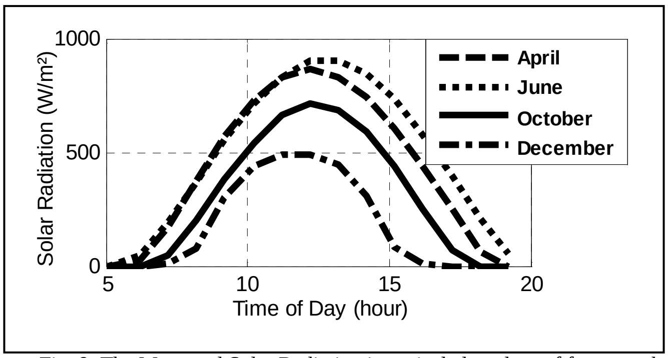


Fig. 9. The Measured Solar Radiation in typical clear days of four months on local time Tetouan/Morocco

Fig. 9 shows the variation of solar radiation for the typical clear day of one month of every season used in this paper [6].

A. Simulation of PV Module without MPPT Technique

The output voltage, current and power waveforms of the PV module without MPPT technique are shown in Fig. 10, 11 and 12.

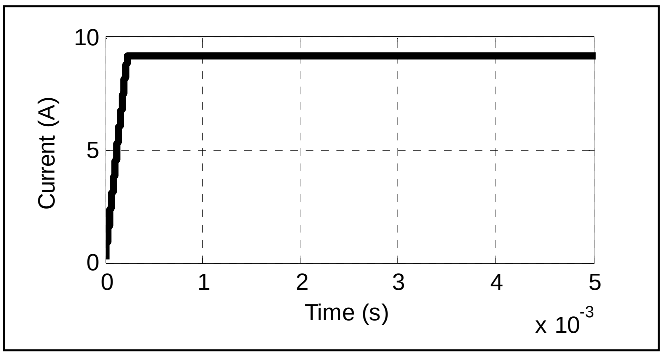


Fig. 10. Output current of PV module

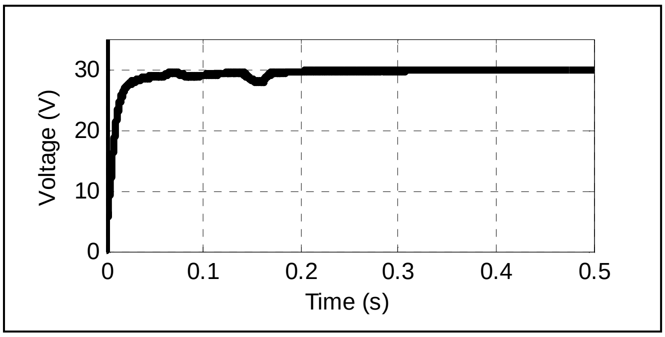


Fig. 11. Output voltage of PV module

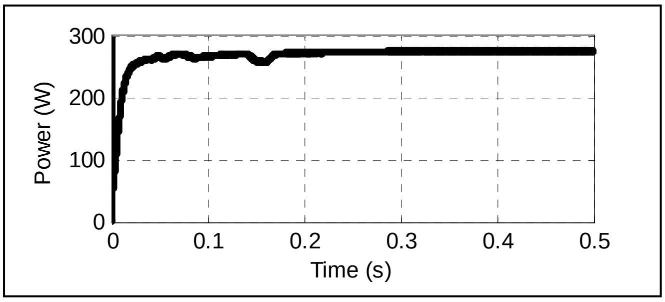


Fig. 12. Output power of PV module

B. Simulation of PV Module with P&O Technique

The output voltage, current and power of the PV array with Perturb & Observe maximum power point tracking (MPPT) technique are shown in Fig. 13, 14 and 15.

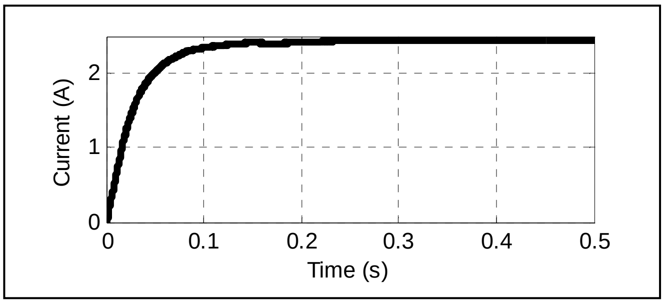


Fig. 13. Output current of MPPT+DC-DC converter

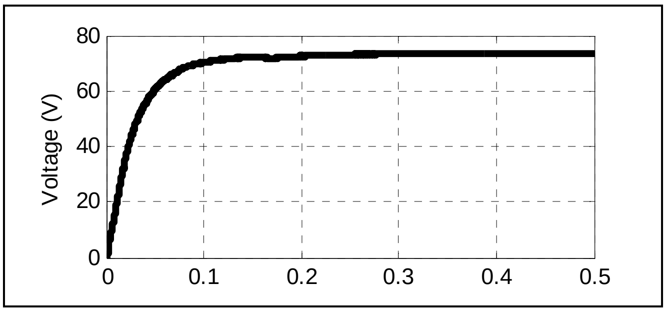


Fig. 14. Output voltage of MPPT+DC-DC converter

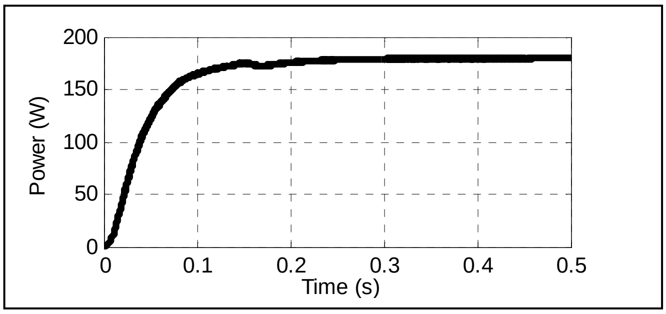


Fig. 15. Output power of MPPT+DC-DC converter

The output current and voltage from a PV array is given as input to MPPT of Perturb and Observe and track the output power and the duty is given as a control signal to converter and the output power is drawn from the converter by connecting the resistive load. Fig. 16 shows the output response of both the PV power and the power from the MPPT connected to the DC-DC converter.

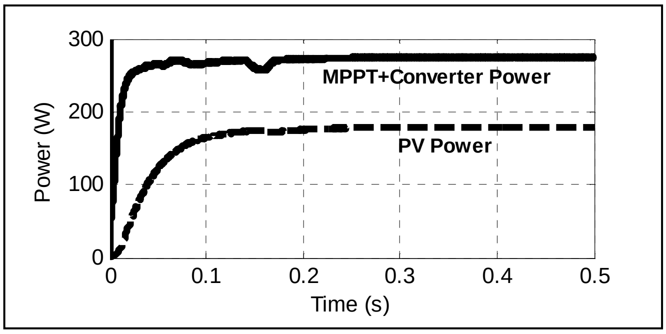


Fig 16 : PV-Output power with and without MPPT+DC-DC converter

C. Simulation of PV Module with IC Technique

The output voltage, current and power of the PV array with Incremental Conductance maximum power point tracking (MPPT) technique are shown in Figures 17, 18 and19.

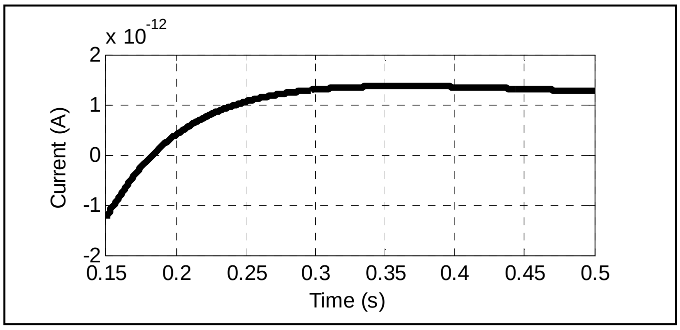


Fig. 17. Output current of MPPT+DC-DC converter

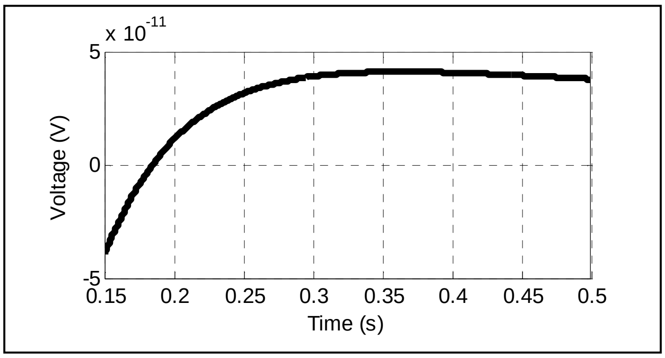


Fig. 18. Output voltage of MPPT+DC-DC converter

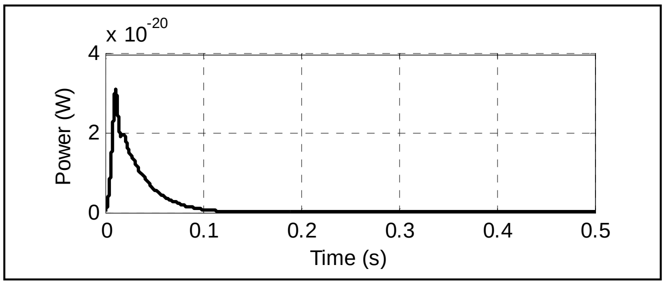


Fig. 19. Output power of MPPT+DC-DC converter

The output current and voltage from a PV array is given as input to MPPT of Incremental Conductance and track the output power and the duty is given as a control signal to converter and the output power is drawn from the converter by connecting the resistive load. Fig. 20 shows the output response of both the PV power and the power from the MPPT connected to the DC-DC converter.

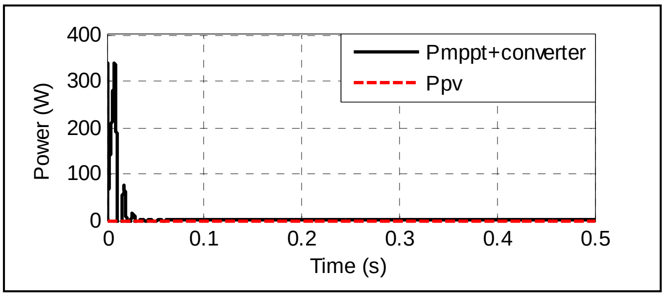


Fig. 20. PV-Output power with and without MPPT+DC-DC converter

V. Conclusion

In this work, we presented a modeling and simulation of a stand-alone PV system. One-diode model for simulation of PV module was selected; Buck-Boost converter is studied and applied to test the system efficiency. Two Maximum Power Point Tracking techniques, P&O and IC, are presented and analyzed. The proposed system was simulated using the mathematical equations of each component in Matlab/Simulink. The simulation analysis shows that P&O method is simple, but has considerable power loss because PV module can only run in oscillation way around the maximum power point. IC method has more precise control and faster response, but has correspondingly higher hardware requirement. In practice, in order to achieve maximum efficiency of photovoltaic power generation, a reasonable and economical control method should be chosen.

The following of this work is based on optimizing the performance of PV modules and stand-alone systems using more efficient algorithms to minimize the influence of the meteorological parameters on the PV energy production.

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