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**Conference Paper** · December 2018



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Boudia Assam
Université de M'sila
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# Backstepping MPPT for photovoltaic system

Boudia Assam
LGE Laboratory, department of electrical engineering, Faculty of Technology
University of M'sila
M'sila, Algeria
issam_boudia@yahoo.com

Zemmit Abderrahim
department of electrical engineering, Faculty of Technology
University of M'sila
M'sila, Algeria
zemmit.mi@gmail.com

Messalti Sabir
department of electrical engineering, Faculty of Technology
University of M'sila
M'sila, Algeria
messalti.sabir@yahoo.com

***Abstract*— The studies in photovoltaic system are increasing in the last years, because of a large, secure, broadly available and clean, but the output powers photovoltaic is affected by the change of the irradiation, temperature and load. Therefore, to maximize the efficiency of photovoltaic system it's necessary to track the maximum power point (MPP). In this work backstepping algorithm MPPT has been applied to improve the performance of photovoltaic system by using BP SX150S solar module connected to the DC-DC derived by the Backstepping MPPT, a compared study has been applied between backstepping and P&O algorithm, the comparative study results proposed backstepping algorithms prove the effectiveness of the proposed algorithm compared to P&O MPPT.**

***Keywords*— Photovoltaic, MPPT, Backstepping, P&O, DC-DC converter.**

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## I. INTRODUCTION

Since the last century, energy consumption has increased significantly. But our resources in oil, coal or gas are not eternal and it is also better not to burn them more so as not to aggravate the pollution. The solution is the use of renewable energies such as hydro, wind or solar power. Use of this type of energy has increased by 12.5% since 1990.[1].

Solar energy is one of the most important renewable energy sources. As opposed to conventional unrenewable resources such as gasoline, coal, etc..., solar energy is clean, inexhaustible and free. The main applications of photovoltaic (PV) systems are in either stand-alone (water pumping, domestic and street lighting, electric vehicles, military and space applications) [2-3] or grid-connected configurations (hybrid systems, power plants) [4].

Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it offers many advantages such as incurring no fuel costs, not being polluting, requiring little maintenance, and emitting no noise, among others. The photovoltaic array is an unstable source of power since the peak power point depends on the temperature and the irradiation level.

Photovoltaic cells convert solar radiation directly into DC electrical energy. The basic material for almost all the photovoltaic cells existing in the market, which is high purified silicon (Si), is obtained from sand or quartz. Basically, three types of technology are used in the production of photovoltaic cells. Mono crystalline, polycrystalline, and amorphous silicon [5]. A maximum peak power point tracking is then necessary for maximum efficiency [6-7].

The V-I and V-P characteristic will vary with the change of the irradiation or the temperature, The V–P curve of PV characteristic has a maximum power point (MPP) which is the optimal operation point for efficient use of the PV array. It is necessary to extract the maximum power at any condition in order to minimize power loss from PV array. The boost DC–DC converter with maximum power point tracking (MPPT) keeps the PV array voltage on a maximum operating point.

This paper present a new method for MPPT controller, a nonlinear backstepping controller which modulates the duty cycle of a boost converter is proposed [8-10]. The global asymptotic stability is ensured by Lyapunov and the MPP is achieved even in the various environmental conditions.

The whole mainly system contain of three parts: the first part, a PV cell modeling is detailed and the climate effects to the cell, the second part, the model of PV system and that of boost converter are established ,in the last part, the backstepping and P&O methods is detailed and simulation results is presented.

## 1. PV CELL MODELLING.

The simplest way of representing the solar cell is the single diode model. It consists of a current source in parallel to a diode. The parameters required are short circuit current (Isc), open circuit voltage (Voc) and the diode ideality factor (a). The ideality factor of a diode is a measure of how closely the diode follows the ideal diode equation. Due to the presence of recombination losses, ideality factor other than ideal are produced. The basic model is improved for accuracy by introducing the series resistance (Rs).It does not prove to be efficient under temperature variations. To overcome this drawback, an additional shunt resistance (Rp) is included. This increases the parameters to a considerable level and the computations are increased. Although Rp is added, the model fails under low irradiation conditions.

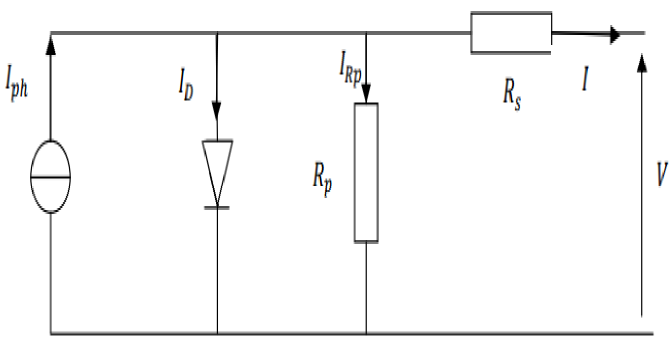



**Fig.1:** Equivalent Circuit of Single Diode Model.

A photovoltaic cell is a nonlinear device that can be represented as a current source model. Eq. (1) gives the V–I characteristic equation of a solar cell.

$$I = I_{ph} - I_o / \left[e^{\frac{v+IR_S}{nV_t}} - 1\right] - \frac{V+IR_S}{R_P} \quad (1)$$

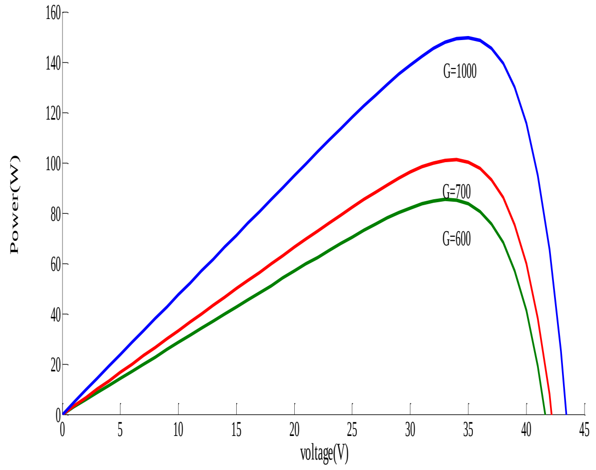
In this work we chose BP SX 150 as PV cell which generate 150W at maximum, the effect of temperature and irradiation is clear in Fig 2.

TABLE I. PV CELL SPECIFICATIONS BP SX 150.

| Parameter | Value |
|---|---|
| Maximum power ($P_{max}$) | 150W |
| Voltage at maximum power ($V_{mp}$) | 34.5 V |
| Current at maximum power ($I_{mp}$) | 4.35 A |
| Open circuit voltage ($V_{oc}$) | 43.5 V |
| Short circuit voltage ($I_{sc}$) | 4.75 A |
| Temperature coefficient of $I_{sc}$(a) | 0.065±0.015% /C° |

## 2.1. Irradiation influence.

Fig. 5 gives the P-V and I-V characteristics of a PV module according to the incident irradiation and at ambient temperature.



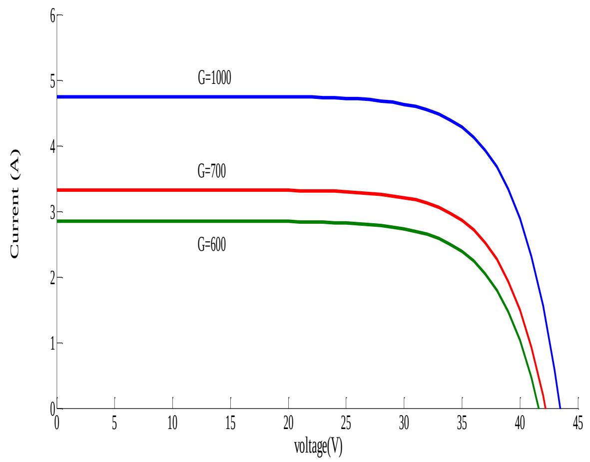
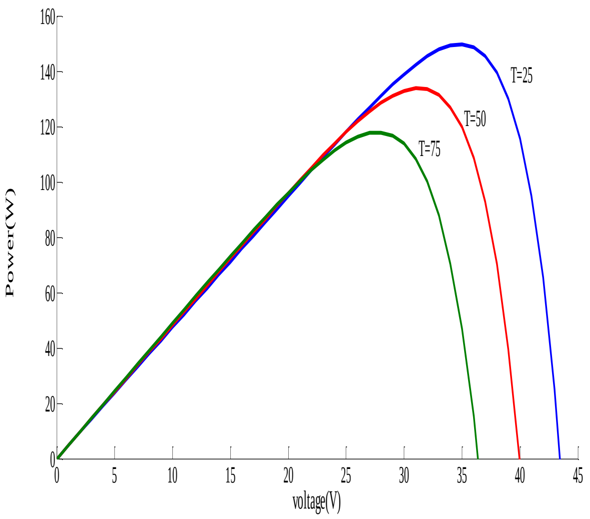




**Fig.2**: The P-V and I-V characteristics curve of a PV panel at different solar radiation and fixed temperature 25C.

This influence results in an increase in the power available in the PV modules whenever the irradiation increases and each of irradiation values is a maximum electric power that could provide a PV module.

## 2.2. Temperature influence.

Fig. 3 shows the P-V and I-V characteristics for a constant irradiation and to the various temperature values.



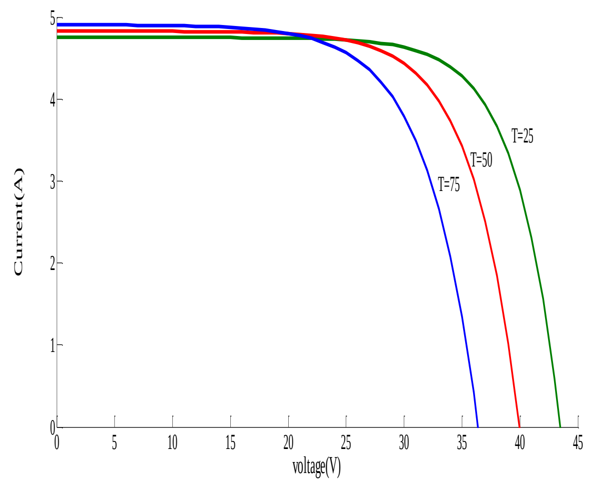



**Fig.3**: The P-V and I-V characteristics curve of a PV panel at different temperature and fixed solar radiation 1000 w/m$^2$.

By against the increase in temperature causes a reduction of the open circuit voltage and also results in a reduction of the maximum power available in the PV modules.

## 2. PERTURB AND OBSERVE (P&O).

Perturb and Observe is the most commonly used method in practice for its simplicity and ease of implementation [11-12]. In this method, the output voltage of the solar panel is perturbed periodically, and then the output power is compared to the previous cycle. Next, corrective action is taken to enforce the voltage to move toward the maximum operation output voltage. The comparison can determine the position of the operation point and the direction of perturbation [13-14].

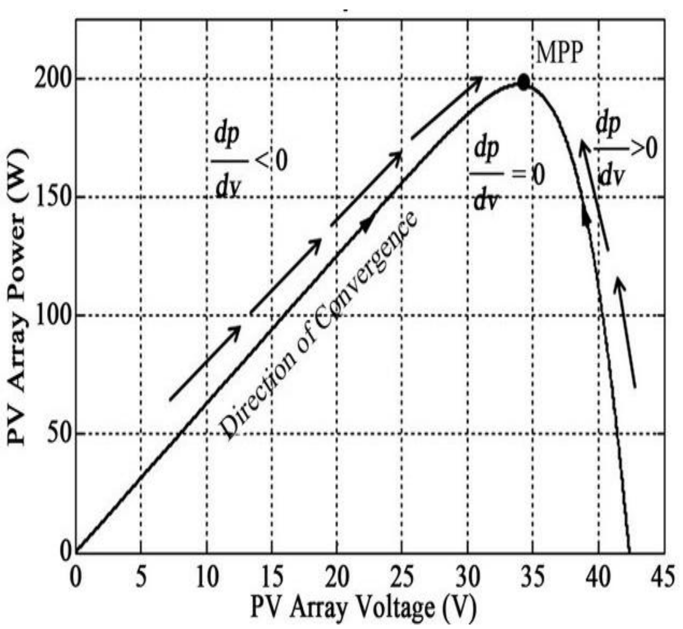



**Fig 4:** the algorithm of perturb and observe method.

## 3. BOOST CONVERTER MODELING

Applying the fundamental laws that govern the functioning of the boost converter; the averaged model is achieved. Fig5. Represents the scheme of the converter. The dynamic equations of this converter can be expressed as follows:

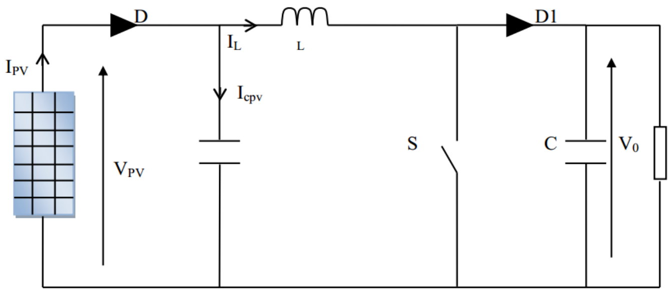



**Fig.5:** Boost DC-OC Converter.

$$\begin{cases} \frac{dx_1}{dt} = \frac{1}{C_{pv}} i_{pv} - \frac{1}{C_{pv}} x_2 \\ \frac{dx_2}{dt} = \frac{1}{L} x_1 - \frac{1}{L}(1-\alpha)V_0 \end{cases} \quad (2)$$

Where $x=[x_1 \; x_2]^T=[V_{pv} \; I_L]^T$, and $\alpha \in [0-1]$ is a switching signal control and M is averaging value of (1- $\alpha$)

$$M = 1-\alpha \quad (3)$$

## 4. BACKSTEPPING CONTROLLER

The base idea of Backstepping approach is stabilized the
system from the first sub system by stabilizing function known via a Lyapunov function selected, and then add to its input integrator. The same procedure for the next under increased system and so on for the successive subsystems to finally reach a global Lyapunov function giving overall control law that stabilizes the system.

The Backstepping technique is relatively a new control method. It allows sequentially and systematically, by choosing a Lyapunov function to determine the system control law [15, 18].

The purpose of the order is to achieve convergence towards zero errors thus achieving the stability and balance of the system which allows the output to follow a reference.

**Step1**:

The equations modeling the boost converter required for synthesis of backstepping control are shown in eq (2)

The first tracking error variable is:

$$e_1 = x_1 - v_{ref} \quad (4)$$

The tracking error derivative is written as follows :

$$\dot{e_1} = (\dot{x_1} - \dot{v_{pref}}) = \frac{1}{c_{pv}}(i_{pv} - x_2) - \dot{v_{pref}} \quad (5)$$

The following lyaponov function is considered:

$$V_1(e_1) = V_1 = \frac{1}{2} e_1^2 \quad (6)$$

The derivative versus time using equation (5)

$$\dot{v_1} = e_1 \dot{e_1} = e_1 \left( \frac{1}{C_{pv}}(i_{pv} - x_2) - \ddot{v_{pvref}} \right) \quad (7)$$

Judicious choice of $\dot{e_1} = -k_1 e_1$ permits writing $\dot{v_1} = -k e_1^2$ where $k_1$ is positive constant that represents a design parameter of backstepping controller.

In (3), $x_2$ behaves as a virtual control input, for i $x_2 = x_{ref}$ we can find the stabilizing function:

$$x_{ref}=k_1 c_{pv} e_1 + \dot{i_{pv}} - c_{pv}\dot{v_{pref}} \quad (8)$$

**Step 2:**

The second error variable that represents the difference between the $x_2$ state variable and its desired value $x_{ref}$ is defined by:

$$e_2 = x_2 - x_{ref} \quad (9)$$

Then the system equations in the errors space $(\dot{e_2})$ are deduced:

$$\dot{x_{ref}} = k_1 c_1 \dot{e_1} + \dot{i_{pv}} - c_{pv}\ddot{v_{pref}} \quad (10)$$

$$\dot{e_2} = \dot{x_2} - \dot{x_{ref}} = \frac{1}{L}(x_1 - Mv_0) - k_1 c_1 \dot{e_1} - \dot{i_{pv}} + c_{pv}\ddot{v_{pref}} \quad (11)$$

The new Lyapunov function:

$$v_2 = v_1 + \frac{1}{2}e_2^2 \quad (12)$$

The derivative can be expressed by:

$$\dot{v_2} = \dot{v_1} + e_2\dot{e_2} \quad (13)$$

$$\dot{v_2} = -k_1 e_1^2 + e_2\left(\frac{1}{L}(x_1 - Mv_0) - k_1 c_1 \dot{e_1} + \dot{i_{pv}} + c_{pv}\ddot{v_{pref}}\right) \quad (14)$$

In this step command $M$ is chosen so as to obtain the following expression:

$$\dot{e_2} = -k_2 e_2 = \frac{1}{L}(x_1 - Mv_0) - k_1 c_1 \dot{e_1} - \dot{i_{pv}} + c_{pv}\ddot{v_{pref}} \quad (15)$$

Hence the expression of command M to be produced by the backstepping controller:

$$M = \frac{L}{v_0}\left[\frac{x_1}{L} - \frac{e_1}{C_{pv}} + k_2 e_2 - k_1 c_1 \dot{e_1} - \dot{i_{pv}} - c_{pv}\ddot{v_{pref}}\right. \quad (16)$$

With $k_2$ >0 leads to negative derivative of the Lyapunov function:

$$\dot{v_2} = k_1 e_1^2 - k_2 e_2^2 < 0 \quad (17)$$

Which ensures that the error variables *($e_1$, $e_2$)* converge asymptotically to the origin, implying that $X_1$ converges asymptotically to the origin $V_{pvref}$ thus extracting the maximum power from the PV array is performed.

## 5. SIMULATION RESULTS.

To review the validity and effectiveness of the available backstepping controllers, simulations are taken to illustrate their performance. The system controlled is a boost DC-DC converter **Table2**.

TABLE 2: DC-DC AND BACKSTEPPING PARAMETERS.

| Parameter | value |
|---|---|
| $C_{pv}$ | 3e-4F |
| L | 2e-2H |
| $C_{dc}$ | 2e-4F |
| R | 15 ohm |
| k1 | 20 |
| k2 | 5 |

In order to check the performance of backstepping controller MPPT, a comparative study between perturb and observe P&O and backstepping is carried out, we began firstly with the irradiation changes rapidly in three steps G=600, 700 and 1000 w/m$^2$ with keeping the temperature constant at 25°C, in **Figs 6-9**, secondly, with G=1000w/m$^2$, T=25,50 and 75C **Figs 10-11**.

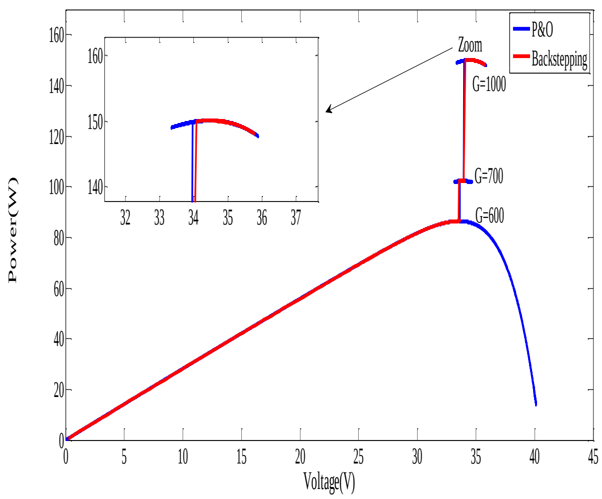



**Fig.6**: The P-V characteristic curve different solar radiation G=600, 700 and 1000 w/m$^2$ and fixed temperature 25C.

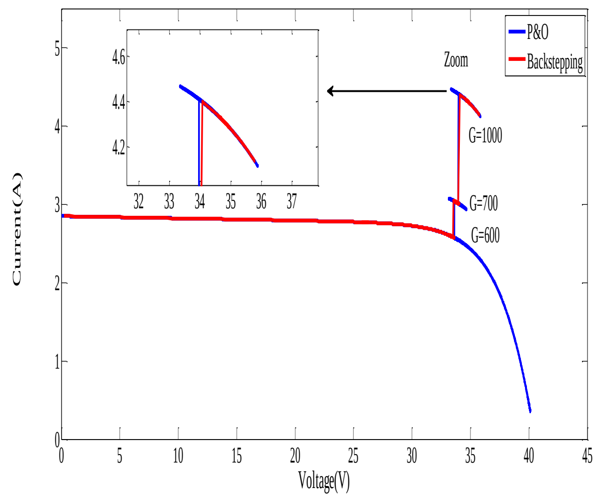



**Fig.7**: The I-V characteristic curve different solar radiation G=600,700 and 1000 w/m$^2$ and fixed temperature 25C.

**Figs 6-7** show the P-V and I-V curves with irradiation changes between backstepping and P&O, the results show clearly that backstepping and P&O track the maximum point in the three steps, however backstepping show less oscillation around the maximum point in the three steps which is clearly in the zoom in the two figs.

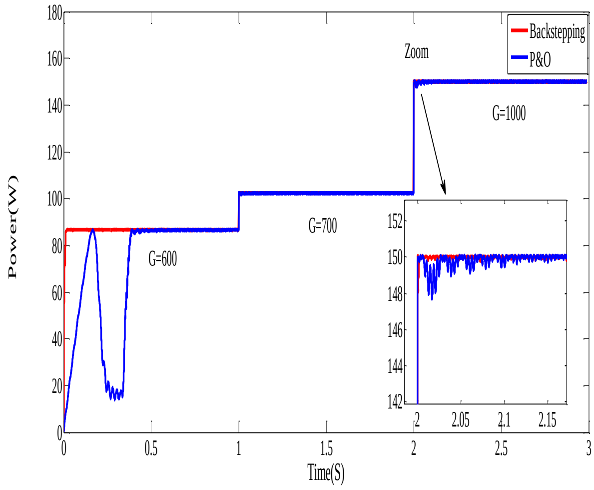



**Fig.5**: PV Output power for different solar radiation.

**Fig 5** shows that backstepping provides the a fast response time less than 12 ms to track the maximum power point with high stability and less oscillation compared to P&O which shows a lot of oscillation in the three steps, this result confirm how the backstepping can truck the MPP with high performance.

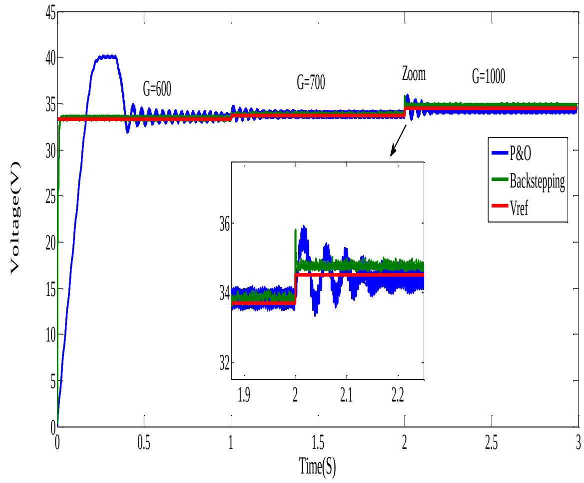



**Fig .6:** output voltage curve for different irradiation.

**Fig 6** shows output voltage of photovoltaic panel with backstepping and P&O, it's very necessary that the MPPT always follows the voltage reference, in this case the backstepping follows the reference with little error and oscillation and fast response time compared to P&O which shows a lot of oscillation and overtaking in each changes.

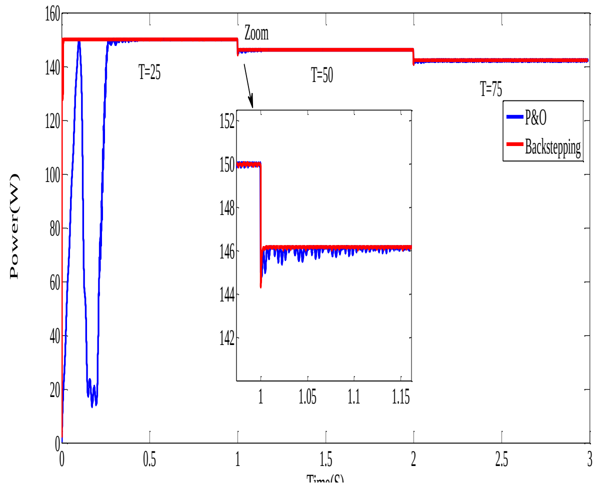



**Fig .7:** PV output power curve with different temperature.

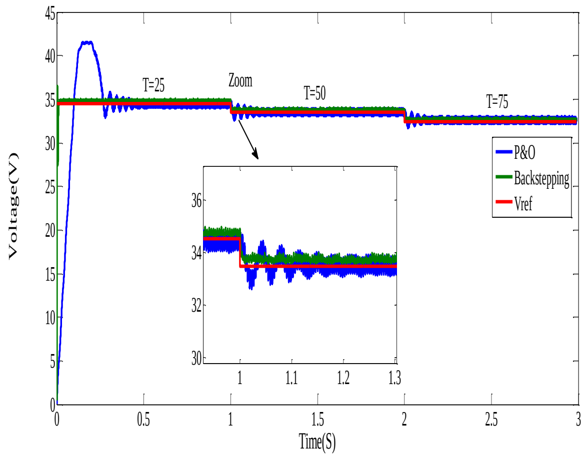



**Fig .6:** output voltage curve for different temperature.

**Figs 6 and 7** show the $P_{PV}$ and $V_{pv}$ curves with fixed irradiation and variable temperature the result obtained in the two figs show the effectivenes of the backstepping compared to P&O, the same notes obtainde with irradiation changes are obtained with temperature changes.

## 6. CONCLUSION.

In this paper, backstepping method was presented to trucks the maximum power point of photovoltaic system, backstepping is robust method used the system parameter to provide the command, in this case backstepping used DC-DC and PV parameter to provide the duty cycles, the result was presented with comparative study between backstepping and P&O, The simulation results obtained in this paper showhow the backstepping can provide the maximum point in every changes temperature or irradiation with high performance in stability or response time or oscilation, backsteppping is mathematic method used the DC-DC parameters to provid the duty cycles

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