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IMPLEMENTATION OF P&O METHOD IN VARIOUS TYPES OF DC CONVERTERS TO TRACK THE MAXIMUM POWER POINT OF SOLAR ARRAYS

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Abstract- Photovoltaic systems are considered as one of the sources of clean and renewable electricity generation, which have a wide range and practical application due to their simplicity. The overall structure of a photovoltaic system consists of a solar panel, a DC/DC converter, an inverter or DC/AC converter, and a load that can be replaced by the mains. Batteries may also be used to power the load during dark hours. To get the most power out of the solar panel, methods called maximum power point tracking algorithms (MPPT) have been proposed. Based on the instantaneous parameters of the solar panel, (In most methods, current and voltage) generate DC/DC converter control signals. In this paper, a perturbation and observation (P&O) algorithm is proposed to track the maximum power point for a photovoltaic system using three common DC/DC converters: boost, buck and (buck-boost) converters. The main purpose is to compare the performance of the photovoltaic system in the state with MPPT and without MPPT, for all three converter structures and compare them with each other. Environmental conditions simulate temperature and radiation intensity. The simulations are performed in MATLAB/Simulink environment and the results are presented.

Keywords: PV Array, Solar Cell, MPPT, Perturbation and Observation method (P&O), Incremental Conductivity Method (INC), (Boost, Buck, Buck-Boost) Converter.

I. INTRODUCTION

Photovoltaic systems are systems that generate electricity directly from sunlight. Because the implementation of these systems is very costly, and the amount of power received from solar panels is highly dependent on changes in radiation intensity and temperature, these changes are also nonlinear. It is important to use methods that can be used to get more power from the panels. Because for every watt more power, about 1% of costs are reduced. For this purpose, methods for tracking the maximum power of solar panels are used, in order to reduce costs and Increase system efficiency by at least 30% by selecting a DC/DC converter and using the appropriate MPPT controller [1].

As we can see in Figure 1, the MPP point is in *I-V* diagram of a solar panel at its knee and in the *P-V* diagram is a solar panel at the top of the diagram. Because these graphs are highly dependent on the amount of radiation intensity and temperature of the solar panel, and these values are constantly changing, and these changes are nonlinear.

Therefore, finding the MPP point is a very difficult task and to solve this problem, various techniques have been proposed and implemented to track the maximum power of the sun.

The general principles of the methods can be divided into four categories.

1) The first category is methods that follow a basic algorithm. These methods include the P&O (perturbation and observation) method, as well as the INC (incremental conductivity). The performance of the perturbation and observation method is based on creating perturbations on the voltage and observing the output power. Which, if the power is increased, keeps the perturbation in the same direction, and if the power decreases, it reverses the next perturbation.

The successful chaotic and observational method detects the maximum power point without the need for solar cell parameters. However, the problem with this method is the constant perturbation of the system, as it operates with oscillations around the point of maximum (MPP) power.

The method of Incremental Conductivity (INC) is based on zero power derivative with respect to voltage, or relative to current, at the point of maximum power. And by performing instantaneous conductivity with increasing conductivity, the maximum power point is found [3].

2) The second set of methods is based on solar cell modeling. In these methods, by modeling the solar cell and establishing the existing relationships in the proposed model, the properties of the solar cell will be predictable and the system will be designed and implemented based on the model.

The main problem with these types of methods is the lack of flexibility or replacement of the solar cell with another cell. So that each implementation is specific to the same solar cell for which it was pre-designed. In addition to the stated problem, finding the model and parameters of the solar cell before its design is another problem [4].

3) The third category is methods based on the relationship between the operating point and the parameters of the solar cell.

Examples of this method include three methods:

I- A method that uses an almost linear relationship between the short-circuit current and the working point current, which is called the short-circuit current method.

II- Another method, known as open-circuit voltage, is based on the existence of an almost linear function between the operating point voltage and the open circuit voltage of the cell. Interrupting the open circuit voltage measurement period causes power loss in the system.

For the intermittent interruption problem, a method is proposed that uses a base cell as a guide to diagnose the behavior of the whole panel, which creates a new problem of uncertainty in measuring the base cell relative to the whole panel.

III- Another method divides linearization into three areas to improve system performance.

In any case, the relationship between the operating point and the parameter is completely nonlinear, and any linear approximation causes an error in the system. Also, the linear relationship is approximated or the search table also changes with the change of the solar cell [5, 6].

4) The fourth category is intelligent control methods. In these methods, control of fuzzy logic or fuzzy logic and artificial neural networks is used. Intelligent methods have an urgent need for the solar cell model used, which limits the control system to use in a designed solar cell.

In general, no method can be considered the absolute best method, while there are various criteria for choosing a tracking system, such as construction cost, tracking speed, accuracy in determining the working point, simplicity of implementation. A method in different capacities can be considered better and more effective.

In this paper, the conventional perturbation and observation (P&O) method is used to track the maximum power point in a solar photovoltaic system. The algorithm generates the duty cycle of the DC/DC converter used after the panel, based on the instantaneous values of current and voltage of the solar panel. This duty cycle is then converted to converter switch control signals with the help of conventional algorithms such as PWM. The DC/DC converters discussed in this paper are common Boost, Buck, Buck-Boost converters.

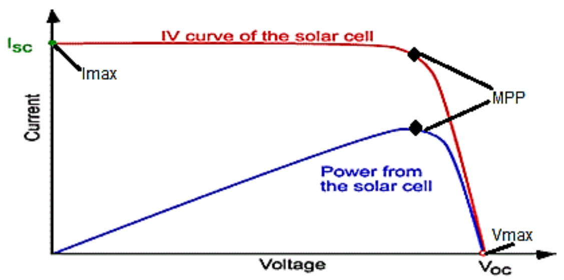

Figure 1. Voltage-current and voltage-power curve of a solar array [2]

2. PERTURBATION AND OBSERVATION (P&O) METHOD

This method is one of the simplest and most common ways to follow the maximum power point. In this method, first, the instantaneous value of the working voltage of the cell and the equivalent amount of power equivalent to the operating conditions of the cell is read. Then some amount of perturbation is created in the voltage (the amount of voltage is slightly changed by changing the duty cycle by the algorithm) and the power is read again from it. Now if the change in power relative to the change in voltage is a positive value, the voltage operator goes to the direction that achieves the maximum by the value of step (C). If the change in power relative to the change in voltage is negative, the opposite happens.

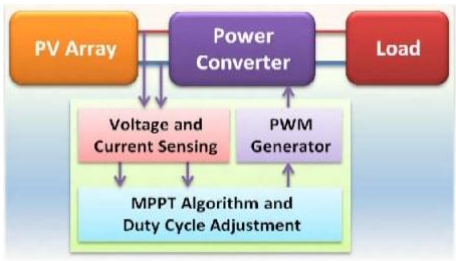

Figure 2. Control loop structure of a solar panel

As shown in the Figure 2, the P&O method is a closed-loop method that measures the voltage and current of the panel at any time and applies it to an algorithm, and after performing the calculations, at the output of the algorithm through a controller by PWM wave. Adjusts the switching time of the DC converter. The flowchart of the P&O method is shown in Figure 3.

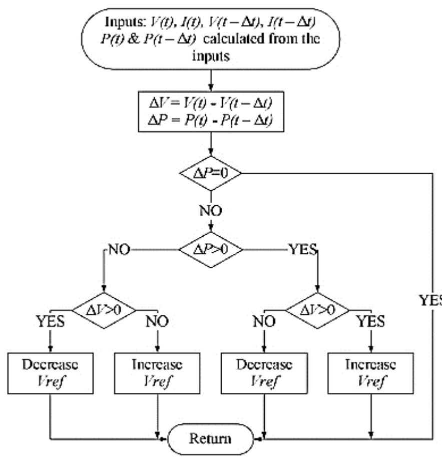

Figure 3. Control loop method P&O [6]

How the P&O algorithm works is based on the following steps:

I. Making a change in the operating point (voltage).

II. Measurement of P and V.

III. Comparing the new P with the old P with respect to V.

The result determines whether the slope is negative or positive and whether it approaches MPP.

The disadvantage of this method is that sudden changes in radiation cause this method to oscillate.

As shown in Figure 4, when we are at the MPP point, the ratio of power changes to panel voltage is zero. At this point, the maximum power is received from the panel. Now if we are not at the MPP point or we are on the left side of it, in which case the ratio of power changes to panel voltage is a positive value, and in this case increasing the panel voltage will lead to an increase in output power or to the right of the MPP point We have that in this case the ratio of power changes to panel voltage is negative and, in this case, reducing the panel voltage will increase the output power. The mentioned process is continued alternately until the MPP point is reached. The system then oscillates around the MPP, and these fluctuations can be minimized by reducing the size of the disturbance steps.

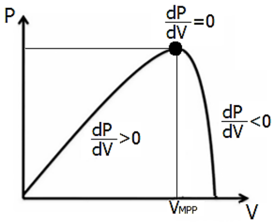

Figure 4. Effect of work point changes to achieve optimal work point using P&O method

A small perturbation (C) size can slow MPPT but is highly accurate. Also, the size of the large disturbance (C) has a high tracking speed but low accuracy. One solution to this situation is to use variable disorder steps.

For example, fuzzy logic can be used to optimally size the next perturbation steps. The main advantage of this method is its simplicity and low mathematical calculations. This has made it common in new control systems. In addition, this algorithm does not require prior knowledge of the features of the PV panel, and on the other hand, when the sun's rays do not change very quickly, it will show good performance. The obvious disadvantage of this method is the existence of large fluctuations around the operating point in the steady state. Because even when we are at the MPP point, the algorithm continues to fluctuate by disrupting the duty cycle. In this method, it is necessary that the weather conditions are constant or accompanied by slow changes. Because in the case of a sudden change in stress or wind energy that causes a sudden change in speed, it is not possible to use this control method [7].

3. DC/DC CONVERTERS

Figure 5 shows the symbol of a DC/DC converter that can be used as an interface between source and load. The task of the converter is to keep the PV converter operating point at or near the maximum power point (MPP) under all different operating conditions (changes in sunlight, temperature changes, load characteristics, etc.). The required transition from a resistive load to an optimum modulation resistance (to achieve MPP) will be achieved by the DC/DC converter [9]. The DC/DC converter does not regulate the output voltage, but more precisely, it delivers the input voltage to a constant voltage by the MPP regulator.

If the internal losses of the converter are small, the output voltage is automatically obtained from the equality of input and output. The DC/DC converters make it possible to convert a direct current with a certain voltage to a direct current with another voltage (more adjustable) or even to change the voltage polarity. In this article, we use buck, boost and buck-boost converters.

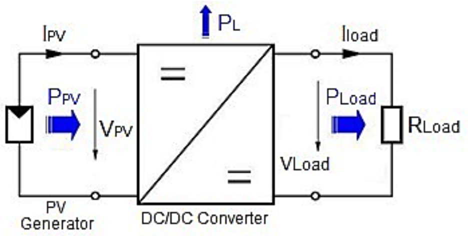

Figure 5. DC/DC converter as the interface between source and load [8]

4. MATHEMATICAL MODELING OF PV MODULES

The equivalent circuit of a PV cell is shown in Figure 6, where, I_{ph} current source represents the light current of the cell, R_{sh} and R_s are the parallel resistors and the intrinsic series of the cell, respectively, R_{sh} is usually a large value and R_s is a small value, so R_s is ignored in some models. A PV solar array actually consists of a series of modules connected in series or in parallel [9].

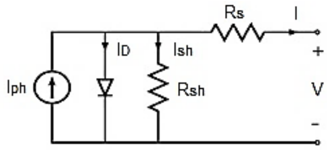

Figure 6. Equivalent circuit of a *PV* module

In the PV module simulation model in this paper, each PV array is designed as a block. Its input data is the amount of sunlight in terms of W/m^2, ambient temperature in °C and also the measured feedback voltage at both ends of the module and the output of this block is current [9].

In this paper, the effect of temperature on the output power as well as the efficiency of *PV* arrays is investigated. The specifications of our selected panel in this article are as follows (Table 1).

Table 1. Fixed values of PV module model [10]

Parameter	Value
k	1.3806488×10^{-23}
q	1.6021766×10^{-19}
K_i	1.33×10^{-3}
E_g	1.12
N_s	10
N_p	6
T_r	298.15
V_{oc}	$37.51/N_s$
I_{sc}	$8.63/N_p$

5. SIMULATION

The simulation results are shown in Figures 7 to 10. The *I-V* curve is plotted with changes in temperature and changes in radiation intensity in Figures 7 and 8.

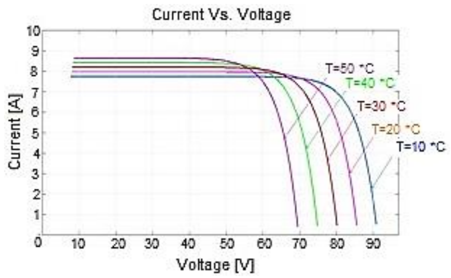

Figure 7. *I-V* curve for boost converter with temperature changes with MPPT controller for radiation intensity 300 W/m^2

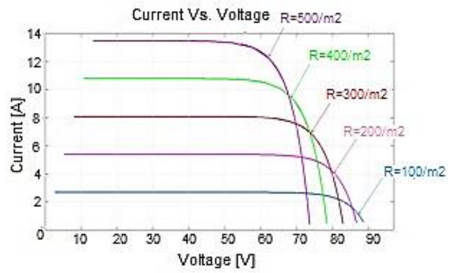

Figure 8. *I-V* curve for boost converter with intensity changes Irradiation with MPPT controller at 25 °C

Also in this case, the *P-V* curve with changes in temperature and radiation intensity can be seen in Figures 9 and 10, respectively. Figure 9 shows *P-V* curve for boost converter with temperature changes with MPPT controller for radiation intensity 300 W/m^2.

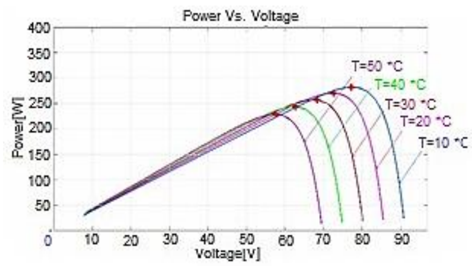

Figure 9. *P-V* curve for boost converter with temperature changes with MPPT controller for radiation intensity 300 W/m^2

As can be seen in the figures, as the temperature rises from 10-50 °C, the maximum voltage and power point received from the solar panel decreases.

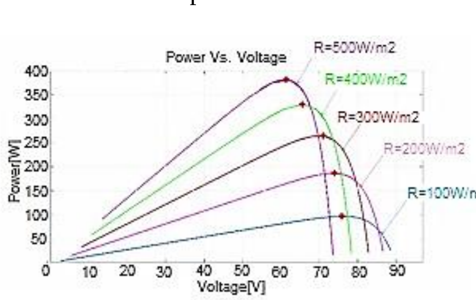

Figure 10. *P-V* curve for boost converter with intensity changes Irradiation with MPPT controller at 25 °C

It can also be seen that as the radiation intensity increases, the output current of the panel increases and the maximum power point also increases. The results of power changes in terms of voltage per 5 different temperatures considering the constant radiation intensity of 1000W/m^2 can be seen in Table 2. The same result is presented in Table 3 if MPPT is implemented.

Table 2. The amount of output power of the panel for 5 different temperatures in Constant radiation intensity 1000w/m^2 regardless of MPPT

	D=5%	D=15%	D=25%	D=40%
Temperature	Power	Power	Power	Power
10 °C	137 W	139 W	226 W	227 W
20 °C	133 W	135 W	217 W	218 W
30 °C	126 W	128 W	208 W	209 W
40 °C	121 W	123 W	198 W	199 W
50 °C	116 W	118 W	191 W	192 W

Table 3. MPP point in boost converter for 5 different temperatures Considering MPPT

Temperature	Power
10 °C	345 W
20 °C	330 W
30 °C	315 W
40 °C	300 W
50 °C	290 W

As the results of Tables 2 and 3, and Figure 11 show, considering MPPT, the output power of the panel is about 51% higher than the maximum value of the output power of the panel in the case without using MPPT. Therefore, the effect of the MPPT model on the solar system is that more power can be received from the panel under the same conditions.

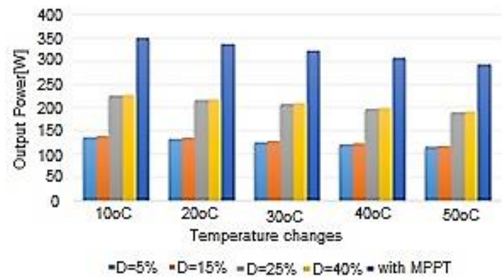

Figure 11. Graph comparing changes in panel output power in use mode MPPT with mode without using MPPT in boost converter

5.1. Simulation of Photovoltaic System Converter

In this case, a *PV* module with a buck converter is simulated and connected to a resistive load. In this case, the proposed MPPT model, the P&O method, has not yet been applied to it. Power changes in terms of voltage for 5 different temperatures considering the constant radiation intensity of 1000 W/m^2 can be seen in Table 4. The same result is shown in Table 5 when the MPPT is implemented.

Table 4. The amount of output power of the panel for 5 different temperatures at a constant radiation intensity of 1000 W/m^2 regardless of MPPT

	D=5%	D=15%	D=25%	D=40%
Temperature	Power	Power	Power	Power
10 °C	13.3 W	9.8 W	5.7 W	4.3 W
20 °C	13.0 W	9.6 W	5.5 W	4.1 W
30 °C	12.8 W	9.3 W	5.3 W	3.9 W
40 °C	12.4 W	9.1 W	5.1 W	3.7 W
50 °C	12.1 W	8.9 W	4.9 W	3.5 W

Table 5. MPP point in buck converter for 5 different temperatures considering MPPT

Temperature	Power
10 °C	20.9 W
20 °C	20.6 W
30 °C	20.3 W
40 °C	20.1 W
50 °C	19.8 W

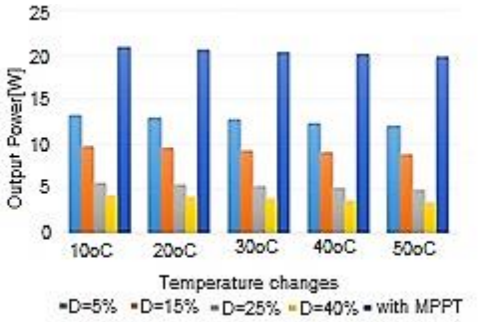

Figure 12. Graph comparing changes in panel output power in use mode MPPT with mode without using MPPT in the buck converter

The results presented in Tables 4 and 5, and Figure 12 which are related to the buck converter, show that with increasing temperature, the output power of the panel decreases, on the other hand, considering the MPPT, the output power of the panel about 58% more than the maximum output power of the panel without MPPT. Therefore, the effect of the MPPT model on the solar system is that more power can be received from the panel under the same conditions.

5.2. Simulation of Photovoltaic System with Buck-Boost Converter

In this case, a *PV* module with a buck-boost converter is simulated and connected to a resistive load. In this case, the proposed MPPT model, the P&O method, has not yet been applied to it. Power changes in terms of voltage for 5 different temperatures considering the constant radiation intensity of 1000 W/m^2 can be seen in Table 6. Also, for the case where MPPT is implemented, the results are shown in Table 7.

Table 6. The output power of the panel per 5 different temperatures at a constant radiation intensity of 1000 W/m^2 without considering MPPT

	D=15%	D=35%	D=55%	D=75%
Temperature	Power	Power	Power	Power
10 °C	43 W	67 W	105 W	149 W
20 °C	41 W	63 W	102 W	144 W
30 °C	38 W	60 W	99 W	140 W
40 °C	35 W	56 W	97 W	135 W
50 °C	33 W	54 W	95 W	130 W

Table 7. MPP point in buck-boost converter for 5 different temperatures considering MPPT

Temperature	Power
10 °C	523 W
20 °C	504 W
30 °C	484 W
40 °C	464 W
50 °C	443 W

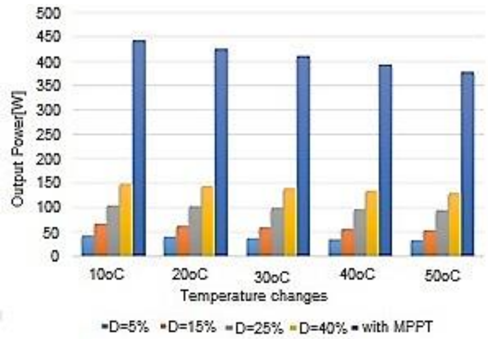

Figure 13. Comparison diagram of panel output power changes during use MPPT with no MPPT mode in buck-boost converter

6. CONCLUSION

As can be seen in Tables 5, 6 and Figure 13, after applying the MPPT algorithm, the amount of output power has increased significantly. Therefore, using the simulation results, it can be concluded that in areas with high radiation intensity, it is better to use a back-boost converter because its MPP point is obtained for more radiation. Boost converter is the second priority because at approximately equal voltages, its maximum power is obtained for more radiation. The third result is that in our selected panel, when using MPPT, buck-boost converter, boost converter and buck converter give us more power, respectively, which means that the simulated panel model can be used with the help of buck-boost converter in some areas. Which have a higher radiation intensity, used. This is not a general rule and other results may be obtained by changing the parameters of the simulated panel or using another standard for the simulation.

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BIOGRAPHY

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