Adaptive P&O MPPT Technique for Photovoltaic Buck-Boost Converter System

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ABSTRACT
Maximum power point tracking (MPPTs) play an important role in photovoltaic (PV) power systems because it maximize the output power & efficiency of PV systems. MPPTs find and maintain operation at the maximum power point. This work presents in details implementation of Perturb and Observe MPPT using buck-boost converter. Some results such as current, voltage and output power for various conditions have been recorded. The simulation has been accomplished in MATLAB/SIMULINK software. The obtained results and the theoretical operation confirm the reliability and performance of the proposed model. It is more efficient, accurate, used rapid and low cost technique without need for complicated mathematical operations and is independent of device physics.

Keywords
Photovoltaic Module, buck-boost converter, P&O Algorithm, Modeling, Simulation.

1. INTRODUCTION
Solar panels collect the sun's energy and convert it to electrical energy. Unfortunately, the sun is not consistent throughout the day due to cloud cover and the sun's angle relative to the position of the solar panel. In addition, the intensity of the sun varies according to season and geographical location. Furthermore the characteristic curve of a solar cell exhibits a nonlinear voltage-current relationship [1]. Therefore, a controller named the maximum power point tracker (MPPT) is an essential part of a photovoltaic (PV) system, to find automatically the maximum power operating point at all environmental conditions and then force the PV system to operate at this point (MPP), to ensure the optimal use of the available solar energy [1-2]. This function is implemented by suitably controlling the power processing circuit that is almost always used as an interface between the PV generator and the load or the energy accumulator. Peak Power Tracking algorithms provide the theoretical means to achieve the MPP of solar panels, these algorithms can be realized in many different forms of hardware and software [3]. In the last few years, several MPPT techniques have been developed to maintain the PV arrays operating at their MPPs and have been proposed in the literature; examples are the Perturb and Observe (P&O) method, the Incremental Conductance (IC) method, the Artificial Neural Network method, the Fuzzy Logic method [3-5], etc.... It became clear that perturb and observe (P&O) technique was widely used for its ease of implementation [6]. This paper present an adaptive perturb and observe MPPT for a photovoltaic module connected to the buck-boost converter (DC-DC converter). The DC-DC converter is able to draw maximum power from the PV module for a given solar radiation level and environment temperature by adjusting the duty cycle of DC-DC converter

2. THEORETICAL BACKGROUND
In this study the five parameter model (The single diode model for solar cells figure 1) is a very appropriate choice. Firstly, because most times the results have a high degree of consistency with experimental data, secondly, as they are not too complex, it is relatively simple to implement and analyze them [7-8]. The equivalent circuit consists of a photocurrent, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the current flow, as shown in Figure 1.

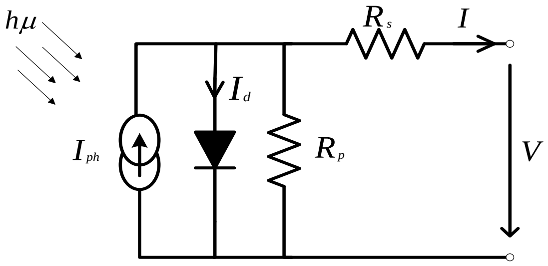

Fig 1: The equivalent circuit of practical PV cell.

The characteristic equation I-V is given by:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{V + IR_s}{A\,V_t}\right) - 1\right] - \frac{V + IR_s}{R_p} \quad (1)$$

Where

- I_{ph} : Photo generated current.
- I_0 : Saturation current of diode.
- R_s : Cell series resistance.
- R_p : Cell parallel resistance.
- A: Diode quality factor.
- V_t : Thermal voltage.

In this section, the PV model parameters; I_{ph}, I_0, R_s and R_p are determined based on electrical parameters; I_{sc}, I_{mp}, V_{mp}, V_{oc} and A. The aim is to find the model parameters such that the resulted I-V curve accurately matches the experimental curve. These parameters are obtained by solving the fundamental equation (1) for the key points. The values for I_{ph}, I_0, R_s and R_p are then determined through an iterative procedure [9-10].

Table 1 Main parameters of PV module ISOFOTON I-75

Parameters	Values
Open-circuit voltage V_{oc} (V)	21.6
Short-circuit current I_{sc} (A)	4.67
Voltage at MPP V_{mp} (V)	17.3
Current at MPP I_{mp} (A)	4.34
Maximum power P_m (W)	75.08
Quality factor A	1.3

2.1 Determination of R_s and R_p

The relation between R_s and R_p, the only unknowns of (1), may be found by making $P_{max,m} = P_{max,e}$ and solving the resulting equation for R_s.

$$R_p = \frac{V_{max}(V_{max} + I_{max} R_s)}{\left\{V_{max} I_{ph} - V_{max} I_0 \left[\exp\left(\frac{V_{max} + I_{max} R_s}{A N_s V_t}\right)\right] + V_{max} I_0\right\} - P_{max,e}} \quad (2)$$

In the iterative process R_s must be slowly incremented starting from $R_s = 0$. Adjusting the P-V curve to match the experimental data requires finding the curve for several values of R_s and R_p. Actually plotting the curve is not necessary, as only the peak power value is required [11].

To start the iteration process, the suitable initial values (typically a low value-to ensure better results) for R_p and R_s are assigned. Hence, R_s is chosen to be zero and R_p is calculated by following equation:

$$R_{p,min} = \frac{V_{max}}{I_{sc,ref} - I_{max}} - \frac{V_{oc,ref} - V_{max}}{I_{max}} \quad (3)$$

The first term in equation (3) is the slope of the line segment between the short circuit and the MPP point, while the second is the slope of line segment between the open circuit voltage and MPP point.

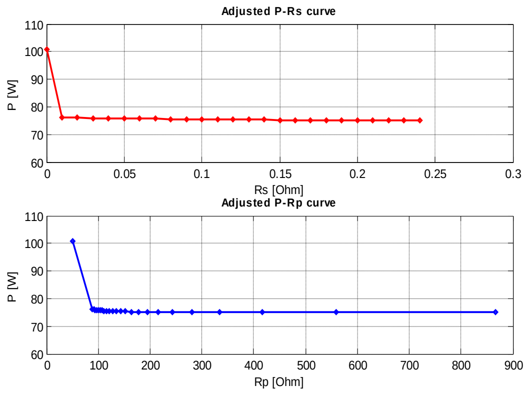

Fig 2. Series and parallel resistances; *Rs* and *Rp*.

The iterative method gives the solution R_s = 0.24 Ohm for the ISOFOTON I-75 panel. There is an only point, corresponding to a single value of R_s, that satisfies the imposed condition $P_{max,m} = V_{max} I_{max}$ at the (V_{max}, I_{max}) point, In accordance with the result of the iterative method. This plot may be an alternative way for graphically design shown in Fig.2 the solution for R_s.

Table 1: Parameters of Adjusted model of the ISOFOTON I-75 solar array at 25c°, 1.5AM 1000W/m²

ISOFOTONI -75W	Pmax(W)	Isc(A)	Rs	Rp
Experimental	75.08613	4.674295	–	–
Simulation	75.08500	4.67000	0.24	866.923

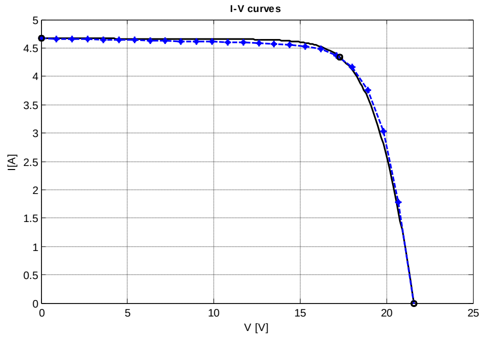

Fig 3. I-V simulated and Experimental curves of the studied PV module.

Figure 3 shows the experimental and simulated curves of the PV module ISOFOTON I-75 based on experimental input data. The I-V experimental characteristic is measured by an experimental bench composed of an I-V curve tracer, a Personal computer (PC), a temperature probe placed on the surface of the Panel and a pyranometer. In this figure, the simulated results have been compared to the experimental data. It is observed that the simulated and experimental results match accurately at three key points: open circuit V_{oc}, maximum power P_m, and short circuit I_{sc}. The curves are also reasonably close at other points. Thus the results are validated with experimental study.

When the solar module is used as an input power source, the optimum operating point tracker is often employed to exploit more effectively the solar module as an electric power source and to obtain the maximum electric power at all times even when the light intensity and environmental temperature of the solar module are varied.

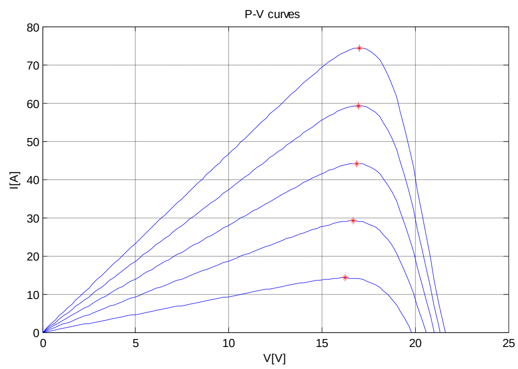

Fig. 4 I-V simulated curves of the studied PV module under different solar irradiation levels.

Figure 4 shows the I-V characteristics for different illumination, the solar irradiation is changed from low to high. The maximum power point changes depending on the solar irradiation level [12].

3. SYSTEM DESIGN

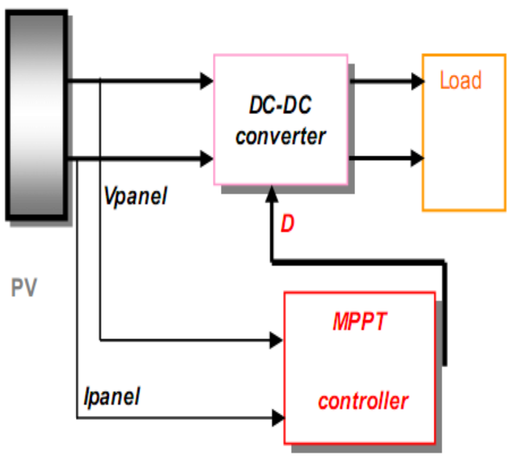

Fig 5: The proposed system.

The basic design for the photovoltaic system peak power tracker consists of the solar Panel, DC-DC converter (Buck-Boost) connected in a series, the microcontroller, Voltage and current sensors and the load (R). This model is known to have better accuracy when the irradiance varies slowly that allows for a more accurate prediction of PV system performance.

The Peak Power Tracker is a microprocessor controlled DC/DC converter used by a photovoltaic power system. The microprocessor tries to maximize the output power from the solar panel by controlling the conversion ratio of the DC/DC converter to keep the solar panel operating at its MPP [13]. A DC-DC converter acts as an interface between the load and the module. The Buck-Boost mode DC/DC converter is the last and most important type of switching regulator. In this converter, the buck and boost topologies are combined into one. The buck-boost converter steps the voltage down when the duty cycle is less than 50% and steps it up when the duty cycle is greater than 50%. The Peak Power Tracker uses an iterative approach to finding this constantly changing MPP [14].

4. CONTROL ALGORITHM

The perturb & observe (P&O) algorithm, also known as the "hill climbing" method, is very popular and the most commonly used in practice because of its simplicity in algorithm and the ease of implementation [15].

The concept behind the "perturb and observe" (P&O) method is to modify the operating voltage or current of the photovoltaic panel until you obtain maximum power from it. For example, if increasing the voltage to a panel increases the power output of the panel, the system continues increasing the operating voltage until the power output begins to decrease. Once this happen, the voltage is decreased to get back towards the maximum power point. This perturbation continues indefinitely. Thus, the output power oscillates around a maximum power point and never stabilizes [16].

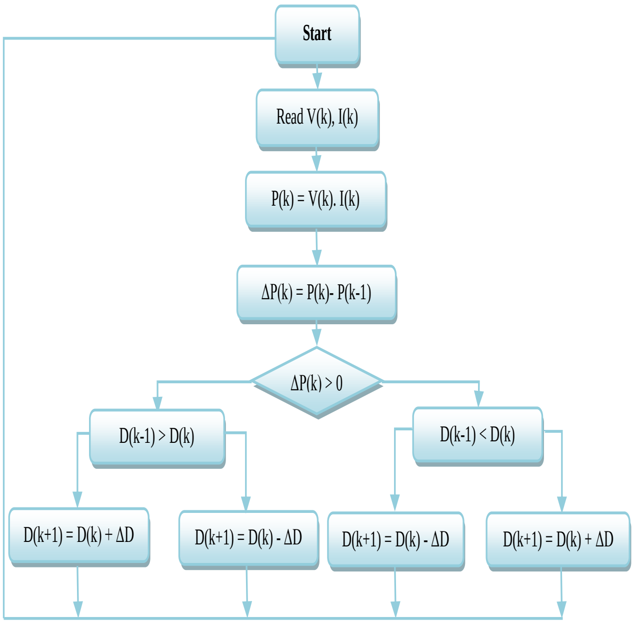

Fig 6: Algorithm flowchart.

The P&O technique has been widely used due to the simple feedback structure, reduced number of parameters and thus can be implemented quickly [15-16].

5. RESULTS AND DISCUSSION

This section presents in details implementation of P&O MPPT technique using buck-boost converter. Some results such as current, voltage and output power for different solar irradiation levels have been recorded. The simulation has been accomplished in MATLAB/SIMULINK software.

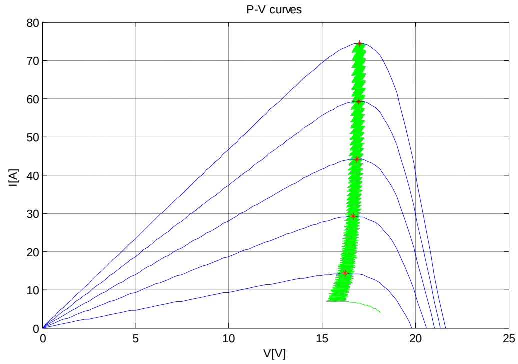

Fig 7: Tracking power under different solar irradiation and a temperature of 25◦C.

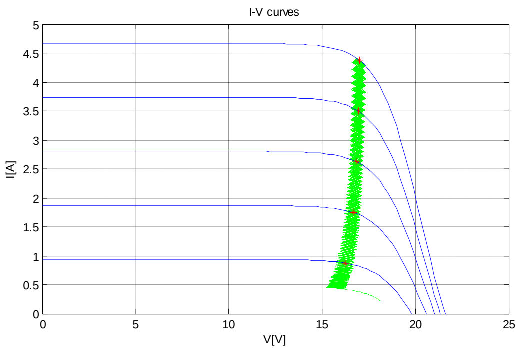

Fig 8: Tracking voltage and current under different solar irradiation and a temperature of 25◦C.

The MPP changes depending on the solar irradiation level. In the case of a perturbation caused by the change in lighting, the system converges towards MPP and remains stable. The system is unaffected by the disturbance, the power remains stable and does not undergo significant fluctuation. Therefore, an MPPT controller is also required to track the new modifier maximum power point in its corresponding curve whenever a variation in irradiance occurs, as shown in figure 7 and 8.

In these figures (8, 9), we have noticed some oscillations around the MPP in steady state operating and this causes power loss. The P&O algorithm is simple to implement, its functioning depends on the tracking step size applied to the voltage reference [16-17]. Could be minimized the oscillations and consequently the power loss, if the tracking step is continuously get smaller. Nevertheless, the response of the algorithm becomes slower.

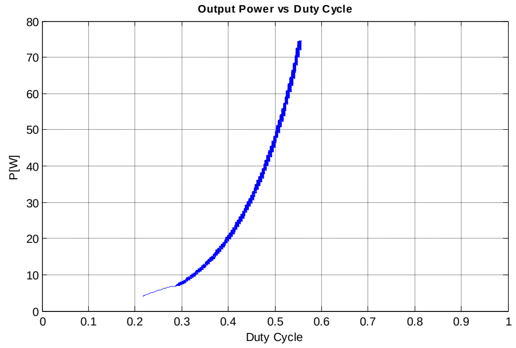

Fig 9: Output power vs. Duty cycle.

The P&O algorithm determines the new duty cycle where the system should move next and also replaces old values with the new ones. Once peak power is reached the algorithm will stay and oscillate around the MPP. The P&O algorithm is used to control the duty cycle of the buck-boost converter which sets its voltage for keeping the solar panel operating at its MPP.

The P&O algorithm was responsible for regulating the system and assuring the voltage applied to the load would deliver maximum power.

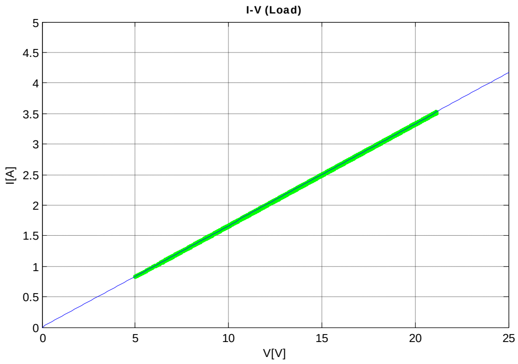

Fig 10: I-V characteristic of R_{Load}

Figure 10 shows the I-V characteristic of load. The MPPT ensure the optimal operation of the photovoltaic system. The obtained results show the effectiveness of P&O algorithm. Hence, the main function of a maximum power point tracker is to adjust the module output voltage to a value in which the module transfers maximum energy to the load.

6. CONCLUSION

The aim of this work was to propose a design of PV system peak power tracker and to realize a simple digital controller capable of optimizing the amount of power recovered from a solar panel over a range of environmental conditions. The basic design of the peak power tracker is to read the voltage and current levels at the solar panel simulator output, process these values using the P&O algorithm, and then adjust the voltage in order to obtain maximum power. The obtained results and theoretical operation are confirmed the effectiveness of peak power tracking technique.

Future considerations for this project would include using a higher level language for the implementation of the algorithm. With this higher level language, logical and syntax errors would be easier to correct. Such languages could include C or C++. With more time and properly functioning software, the entire system could be tested to verify it is working in all aspects.

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