SIMULATION AND ANALYSIS OF A PV SYSTEM WITH P AND O MPPT ALGORITHM USING A PI CONTROLLER FOR BUCK CONVERTER

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ABSTRACT

In the current decades, photovoltaic power generation has become more important. To enhance the energy efficiency, it is always important to work the photovoltaic (PV) system at its maximum power point, thus the Maximum Power Point Tracking (MPPT) strategy is used. The main purpose of this paper is to develop a system based on a photovoltaic (PV) module using a single-diode model of a solar cell, and to present a comparative analysis between constant duty cycle, the conventional Perturb and Observe (P&O) algorithm, and the proposed P&O method using a PI controller for extracting the maximum power from the PV array. These methods are implemented using a Buck converter.

Keywords: PV system, MPPT, P&O, PI controller, irradiance, temperature, buck converter.

1. INTRODUCTION

Domestic and industrial energy production is largely based on a limited resource: petroleum. The sources of oil are becoming increasingly scarce, as the world's energy demands rise steadily. It is estimated that world reserves will be depleted by 2030 if consumption is not radically changed. Since this form of energy covers a large part of current energy production, it is necessary to find an alternative solution to take over [1]. For this reason, much scientific research has been carried out in the sector of unlimited energy sources, such as wind power generation and solar energy transformation [2]. The energy through the solar photovoltaic effect can be viewed as the most necessary and vital sustainable resource due to the omnipresence, large quantity, and sustainability of solar energy. The design, optimization, and realization of photovoltaic systems are topical problems since they surely lead to a better exploitation of solar energy [3]. These photovoltaic systems generating electricity can be operated in different places: electrification of isolated sites, installation in buildings or direct connection to the electricity grid [4].

The output characteristics of PV array relies on upon the solar irradiance, cell temperature and output voltage of PV modules. Since PV array has nonlinear characteristics, it is important to model it and simulate for Maximum Power Point Tracking (MPPT) of PV system applications, to find the current or voltage at which a PV array should work to extract the maximum output power under a given temperature and irradiance. Quite recently, considerable attention has been paid to this issue, and many researchers have proposed various methods of MPPT [5]. These techniques can be characterized into three principal categories: lookup table methods, computational methods (neural networks, fuzzy logic, etc.) and hill climbing methods [6], [7]. These methods differ in many aspects such as required sensors, complexity, cost, and range of effectiveness. The most commonly applied MPPT algorithm is the Perturb and Observe (P&O) method, due to its ease of implementation, simplicity,

good performance, and easiness of application with different types of PV arrays, this technique is based on the "hill-climbing" principle, which consists of moving the operation point of the PV module in the direction in which the power increases [8], [9]. The main drawback of this method is: oscillations occur around the MPP. In this article, we propose an MPPT P&O algorithm based on a PI (Proportional Integral) controller to regulate the photovoltaic current and ameliorate the efficiently of energy. A Buck converter is used to transfer the power generated by the photovoltaic module to the load.

This paper presents a comparative analysis of a constant duty cycle, conventional P&O, and P&O based on a PI controller to perform the control of a Buck converter. The remainder of this article is organized as follows: After this introduction, an overview is given of the PV module and the Buck converter used in the simulation. In the next section, a comparative study of constant duty cycle, the conventional Perturb and Observe (P&O) algorithm, and the improved algorithm is given. An experimental set-up to verify the effectiveness of the algorithm is described next, and the results are complemented by a comprehensive discussion. The conclusion is provided in the final section.

2. BLOCK DIAGRAM OF TRACKING SYSTEM

2.1 Photovoltaic system

Photovoltaic (PV) cell is a semiconductor device which converts the light energy into electrical energy. A PV system consists of a multiples component, including the modules, mechanical connection, electrical interconnections, and mounting for other components. Photovoltaic cells are made of several types of semi-conductors using different manufacturing processes [10]. PV cell gives a voltage around 0.5 to 0.8 volts depending on semiconductor and the built-up technology. The numbers of PV cells are connected in series and parallel to get more amounts of voltage and current known as PV module and if many such modules are connected for any

application to get the desired amount of current and voltage then it is called as PV array [11].

For modeling the PV Module, we will, therefore, start from the basic element which is the cell. Figure-1 shows the equivalent electrical circuit of an ideal solar cell [12-14]. The equation that describes the voltage-current characteristic of the solar cell is given by equation (1) [15], [16].
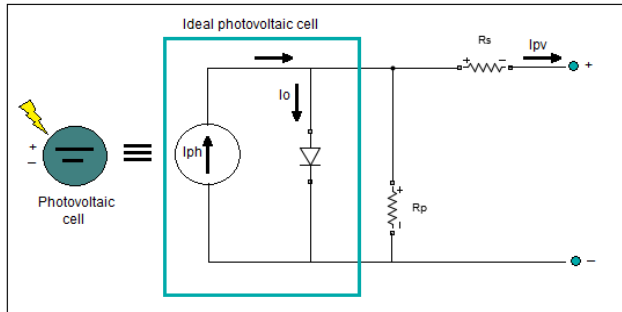

Figure-1. Equivalent circuit of a photovoltaic cell.

$$I = I_{ph} - I_o \left[\exp\left(\frac{V_{pv} + R_S I_{pv}}{V_t a}\right) - 1 \right] - \frac{V_{pv} + R_S I_{pv}}{R_p} \quad (1)$$

The expressions of the photo-current (I_{ph}) and the saturation current (I_o) are defined by equations (2) and (3):

$$I_{ph} = (I_{sc} + K_i dT)\frac{G}{G_n} \quad (2)$$

$$I_o = \frac{I_{sc} + K_i dT}{\exp\left[\frac{V_{oc} + K_V dT}{V_t a}\right] - 1} \quad (3)$$

Thus, the following equation is obtained:

$$I = N_{pp}I_{ph} - N_{pp}I_o \left[\exp\left(\exp\frac{V_{pv} + \left(\frac{R_S N_{SS}}{N_{pp}}\right)I_{pv}}{V_t a} \right) - 1 \right] - $$

$$\frac{V_{pv} + \left(\frac{R_S N_{SS}}{N_{pp}}\right)I_{pv}}{R_p N_{ss}/N_{pp}} \quad (4)$$

Where:

I_{pv}, V_{pv}	Solar cell current (A) / voltage (V)
I_{ph}	Light generated current (A)
I_o	Diode saturation current (A)
q	Electron charge (1.6×10-19 C)
K	Boltzman constant (1.38×10-23 J/K)
T	Cell temperature in Kelvin (K)
V_{oc}	Open circuit voltage (V)
I_{sc}	Short circuit current
R_s	Solar cell series resistance (Ω)
R_p	Solar cell parallel resistance (Ω)
a	Ideality factor of the diode
V_t	The thermal voltage
N_{pp}, N_{ss}	Respectively the numbers of modules in parallel and in series

2.1.1 Different parameter used in standalone PV array

The PV module (KC200GT) [17] which is taken as the reference PV module for the simulation has the following electrical characteristics (at $25°C$, 1000 W/m²): N_{pp} = 3, N_{ss} = 2, T_{ref} = $25°C$, a = 1.3, q = $1.6e^-19$, k = $1.380658e^-23$, I_{sc} = 8.2 A, V_{oc} = 32.9 V, k_i = $3e^-3$ A/K, k_v = -116 V/K.

2.1.2 Model of the photovoltaic cell

The model of the PV cell is designed in Figure-2, and the calculation of I, I_{ph}, and I_o are presented as separate subsystems in Figure-3.
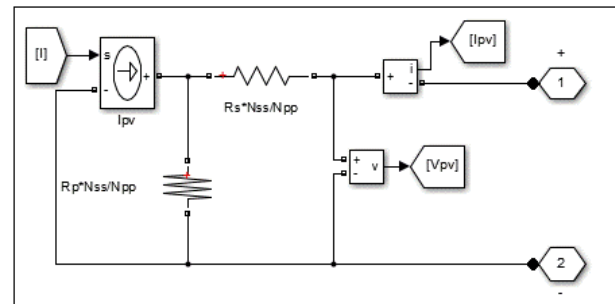

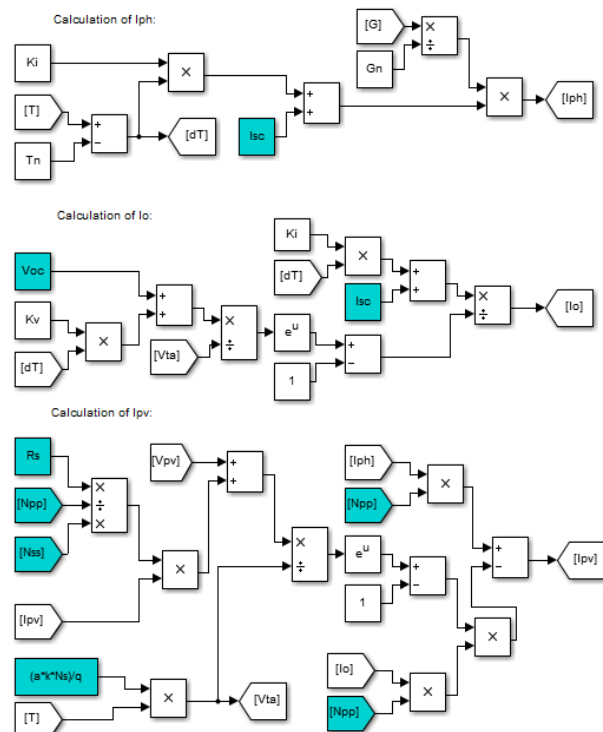**Figure-2.** Basic Simulink model of the equivalent PV cell.

Figure-3. Simulink model of the PV equations.

2.1.3 Simulation results of the PV array

The simulation results of I-V curve and P-V curve of the PV array (in our case containing two modules) for different solar irradiation and constant temperature (T=$25°C$) are shown in Figure-4.
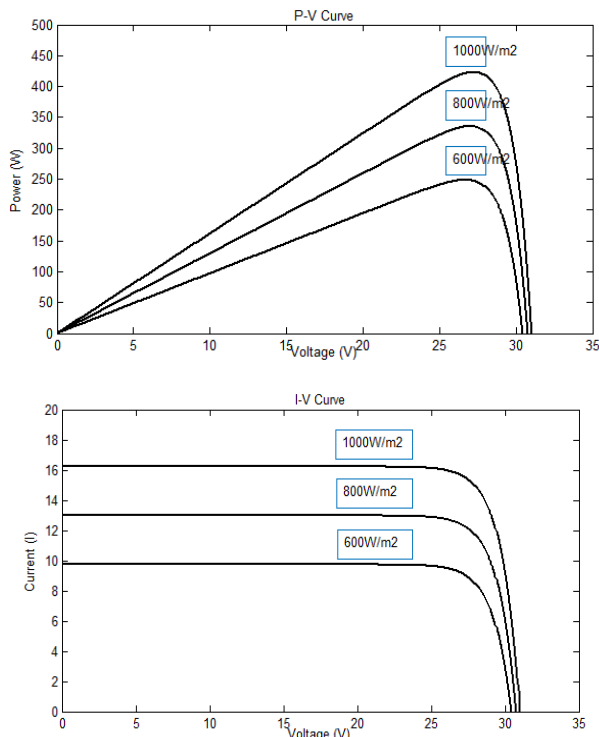
Figure-4. I-V curve and P-V curve for different solar irradiance.

From the above current and power curves for different solar irradiation and constant temperature, it can be observed that current and power of the PV array increases with increasing the solar irradiance.
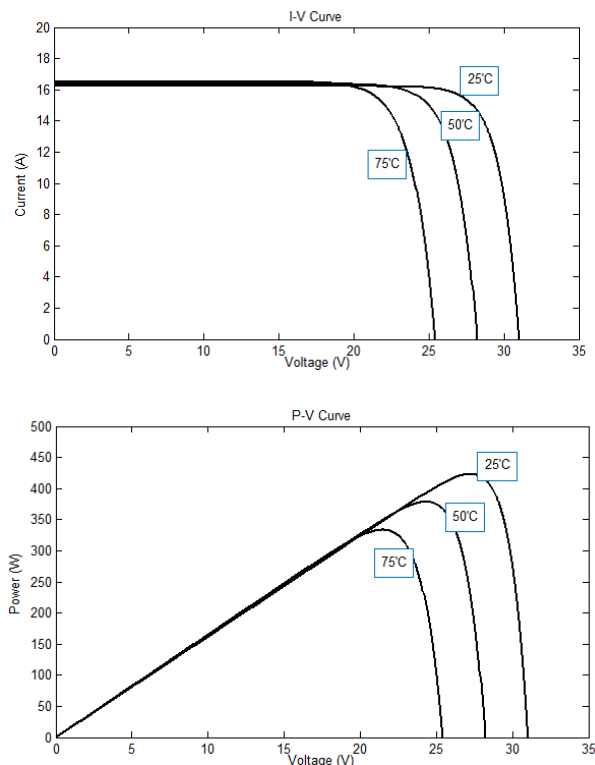

Figure-5. I-V curve and P-V curve for different cell temperature.

The simulation results of I-V curve and P-V curve of the PV array for constant solar irradiation (1000 W/m^2) and different temperature are presented in Figure-5. As can be seen, voltage and power of the PV array decrease with increasing the cell temperature.

2.2 Model of Buck converter
A Buck converter or voltage controller is also called a stage down controller since the output voltage is lower than the input voltage [15], where the conversion ratio V_{out}/V_{in} varies with the duty ratio of the switch [18].
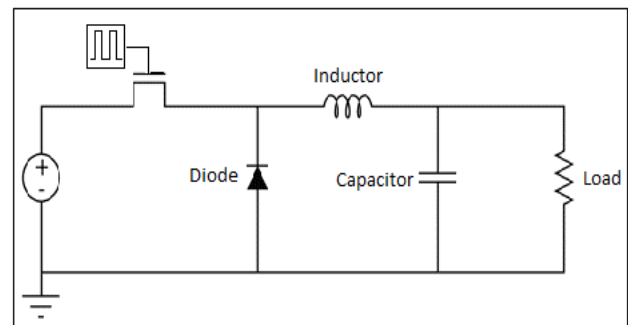

Figure-6. Circuit diagram of Buck converter.

In a simple case of a Buck converter, a diode is connected in parallel with the input voltage source, a capacitor, and the load, which represents output voltage. A switch is connected between the input voltage source and the diode and an inductor is connected between the diode and the capacitor [18].

2.3 Maximum Power Point Tracking (MPPT)
The conventional Perturb and Observe (P&O) algorithm [19], [20], has been largely used due to its reliability and simplicity to implement, it is based on the perturbation incrementing or decrementing the voltage V, or the current I and observing the result of this disturbance on the measured power (P = VI). When the maximum power point is reached, the system operating point will start to oscillate constantly around that maximum power point [21].Despite the advantages of this method, it is not free of drawbacks, the main one is the oscillation in the power output caused by forcing the operating point to go back and forth around MPP [22].

The proposed P&O MPPT algorithm that improves the conventional algorithm is based on a PI controller which works towards minimizing the error between the photovoltaic current and the current generated by the MPPT block. The simplicity of operation, ease of design, inexpensive maintenance, and low cost made PI controllers very popular in most systems. Figure-7 presents the block diagrams of the tracking system using different types of control: Constant duty cycle, conventional P&O algorithm, and the proposed algorithm based on a PI controller.
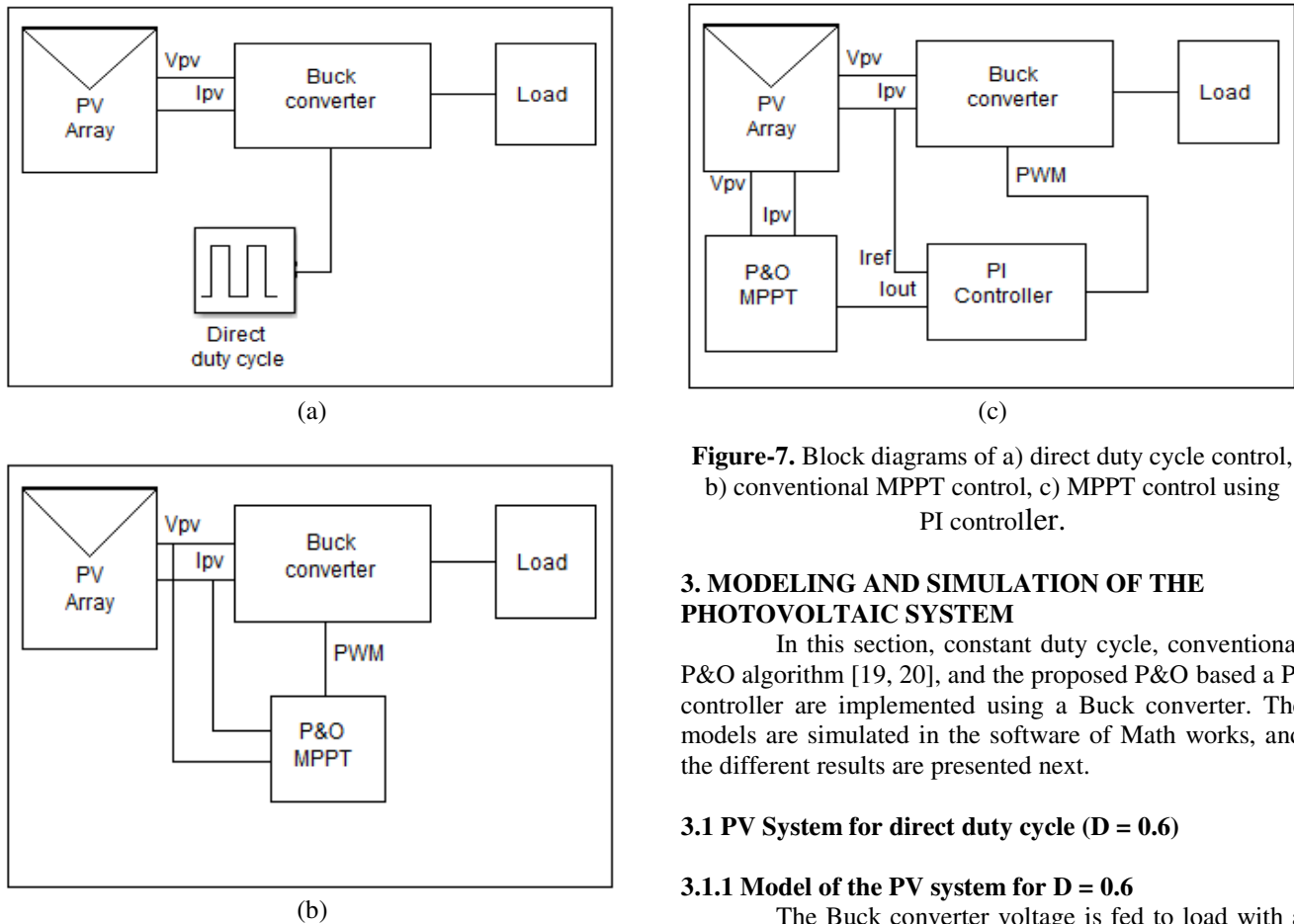
(a)

(b)

(c)

Figure-7. Block diagrams of a) direct duty cycle control, b) conventional MPPT control, c) MPPT control using PI controller.

3. MODELING AND SIMULATION OF THE PHOTOVOLTAIC SYSTEM

In this section, constant duty cycle, conventional P&O algorithm [19, 20], and the proposed P&O based a PI controller are implemented using a Buck converter. The models are simulated in the software of Math works, and the different results are presented next.

3.1 PV System for direct duty cycle (D = 0.6)

3.1.1 Model of the PV system for D = 0.6

The Buck converter voltage is fed to load with a constant duty cycle. A PWM pulse generated by a constant D=0.6 generator is applied to IGBT/Diode. The simulation model of the PV system with Buck converter is shown in Figure-8.
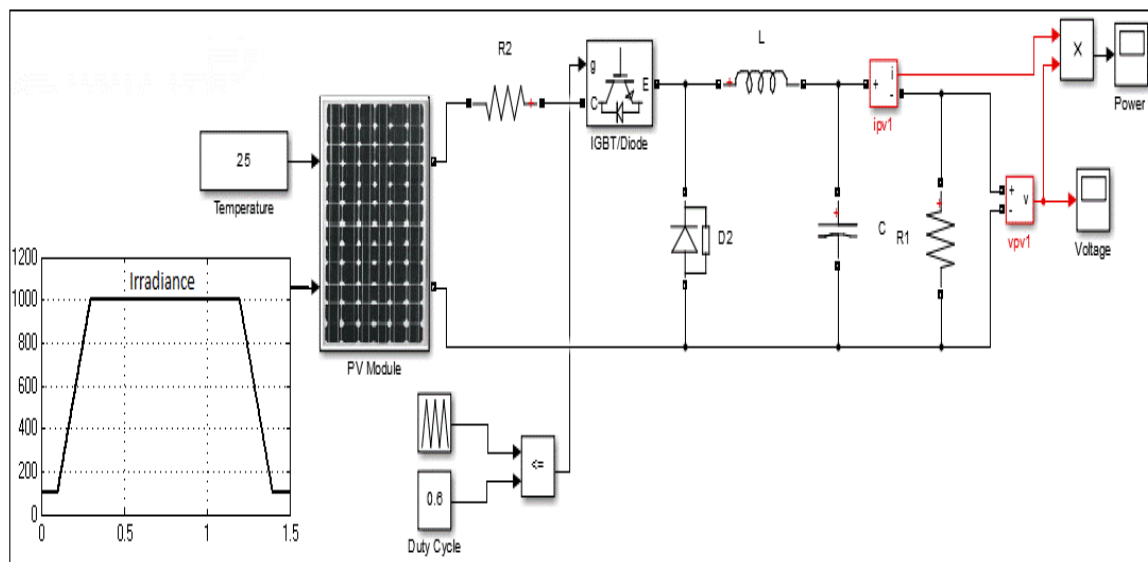

Figure-8. MATLAB/Simulink model of PV system for a constant D =0.6.

3.1.2. Simulation results

The results of the output power and voltage of the Buck converter for variant solar irradiance and constant temperature (T=25°C) are depicted in Figure-9.
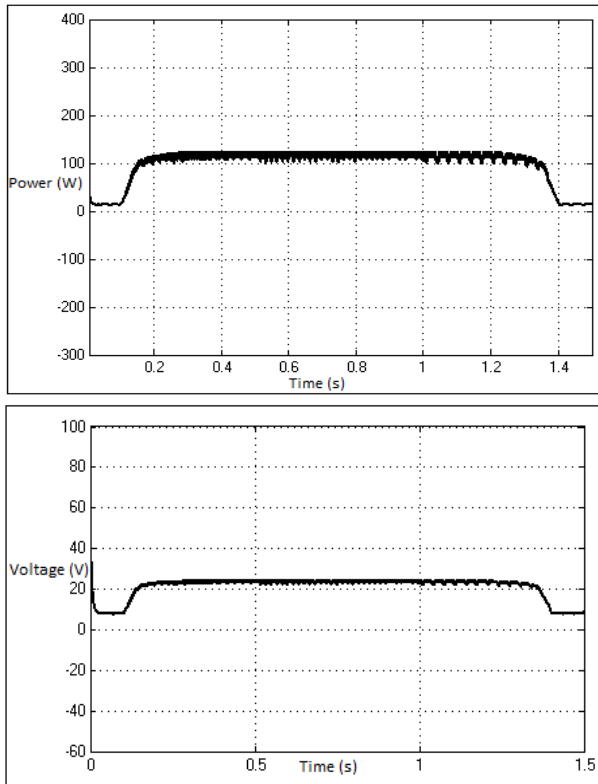

Figure-9. Power and voltage curves at the output of the Buck converter using a constant D = 0.6for a variant irradiance.

3.2 Conventional P&O MPPT algorithm

As shown in Figure-10 [21], the P&O algorithm works on the idea of introducing perturbation to the system's operating point to generate maximum output power. The PV array is perturbed by adding small increments until the maximum power point is reached. Initially, P (power output) is calculated by measuring the values of V and I of the solar array. Then a small perturbation is added in the form of ΔV. Then P is calculated by measuring the new values of V and I. If the second P reads positive, the system will keep perturbing in the same direction. Once it reads negative, the algorithm will bring the output power value back towards the maximum power point by adding a negative increment. When the maximum power point is reached, the system operating point will start to oscillate constantly around that maximum power point. The controller will track this operating point and try to bring the V of the solar array to perform at this MPP [21], [23].
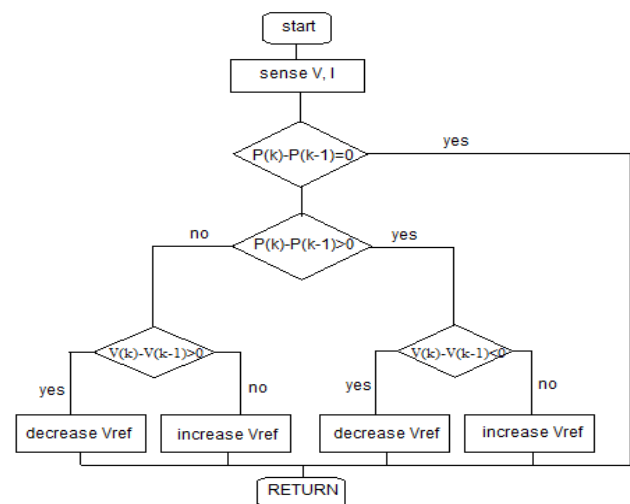

Figure-10. Flowchart of the conventional P&O algorithm.

3.2.1 Model of PV system using P&O algorithm

The model of the PV array with the Buck converter and the detailed block diagram of the P&O algorithm mentioned above are constructed using MATLAB/Simulink, the model is shown in Figure-11.
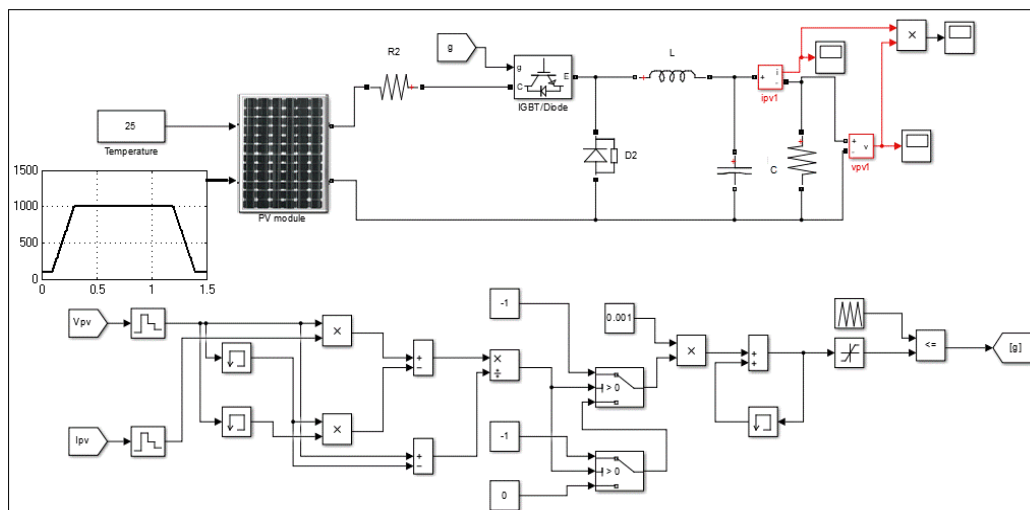

Figure-11. MATLAB/Simulink model of the PV system using the conventional P&O algorithm.

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3.2.2 Simulation result

The results of the simulation are depicted in Figure-12.
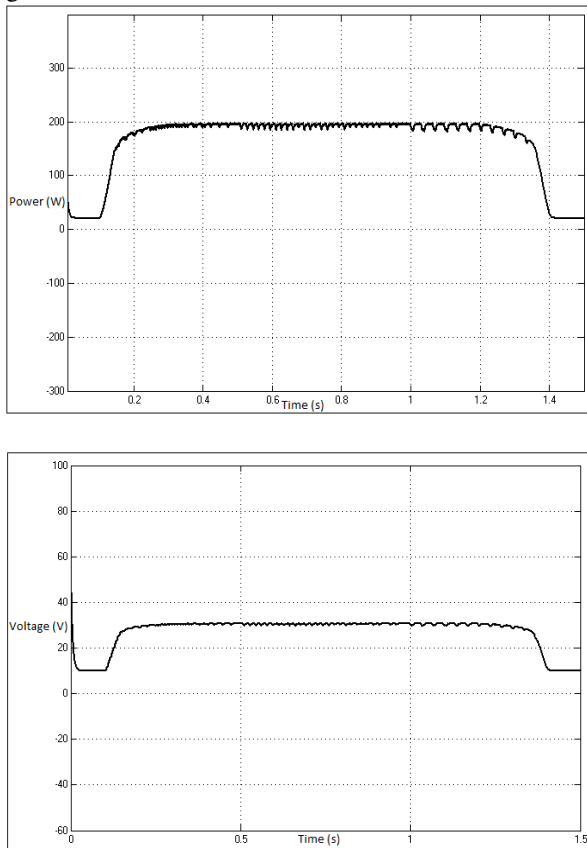

Figure-12. Power and voltage curves at the output of the Buck converter using MPPT algorithm for a variant irradiance.

As clearly shown in Figure-12, large oscillations are encountered in the conventional P&O algorithm.

3.3 P&O MPPT Algorithm using a PI Controller

In this study, we developed an algorithm that improves the conventional P&O MPPT method, based on a PI controller which works towards minimizing the error between the PV current I_{ref} (I_{pv}) and the current generated by the MPPT block I_{out}. An error current (I_{error}) is measured by subtracting I_{ref} from the I_{out}, which is next fed to a PI controller. The output of the PI controller is compared to a sawtooth waveform to provide the duty cycle adopted next to drive the converter. The Buck converter used to accomplish the implementation is forced to operate using this value of the duty cycle ensuring that the system operates at the desired maximum power point. The PI controller values are adjusted by trial and error method. Figure-13 illustrates the P&O algorithm based on the PI Controller principle.
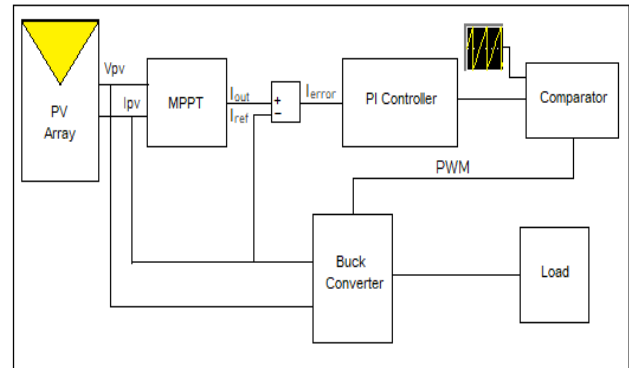

Figure-13. P&O with PI controller principle.

3.3.1 Model of PV system using P&O algorithm with PI controller

Figure-14 gives the MATLAB/Simulink diagram of the proposed Perturb and Observe maximum power point tracking algorithm, using a PI controller to regulate the photovoltaic current. The output of the PI controller gives the duty cycle adopted in the Buck converter.
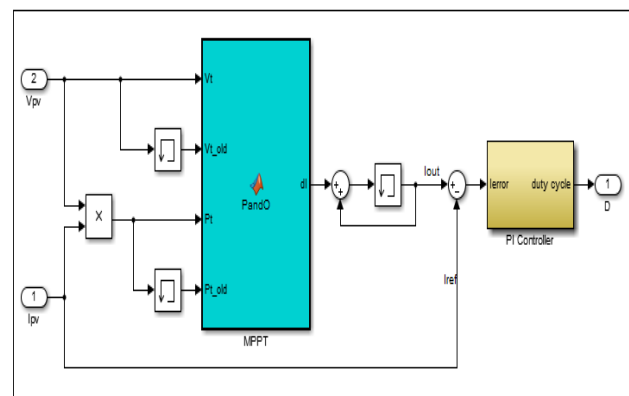

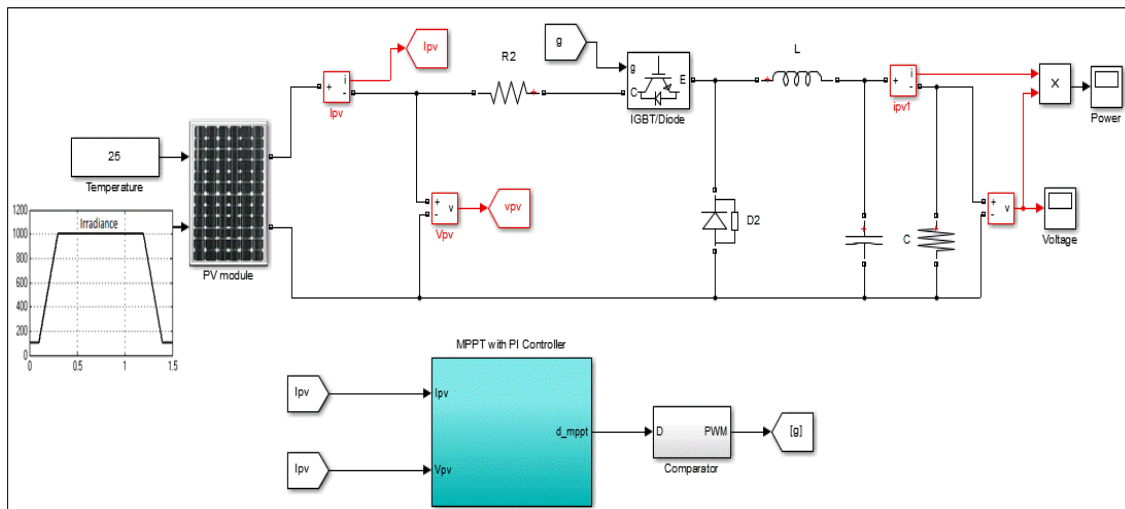**Figure-14.** Simulink model of P&O MPPT with PI controller.

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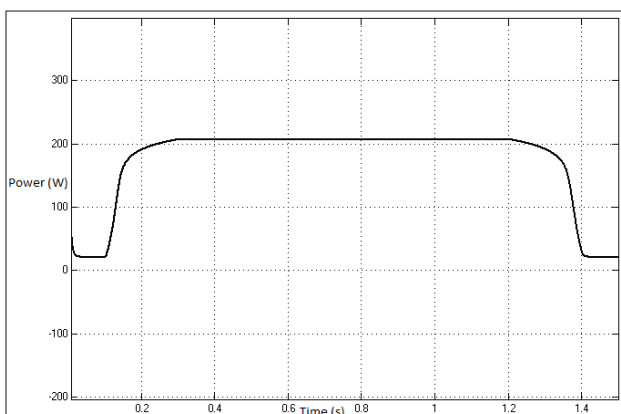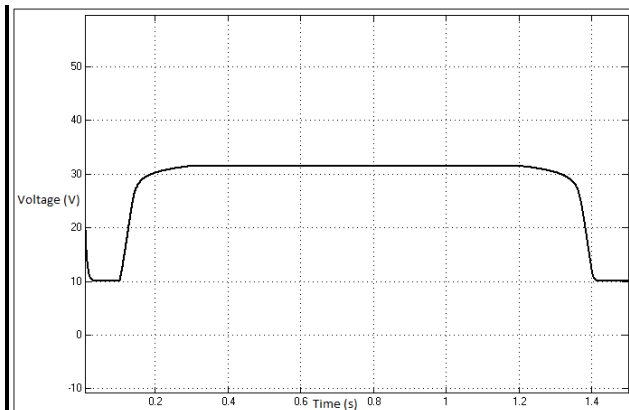**Figure-15.** MATLAB/Simulink model of PV system using the proposed P&O algorithm.

Figure-16. Power and voltage curves at the output of the Buck converter using the proposed P&O algorithm.
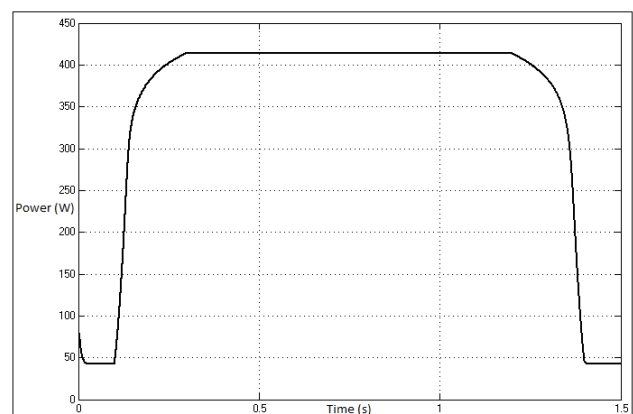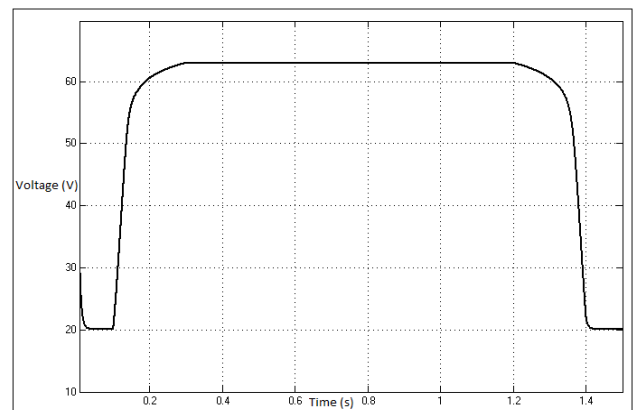

Figure-17. Power and voltage curves at the output of the PV array using the proposed P&O algorithm.

The model that we have adopted in this paper is indicated in Figure-15, containing the PV array, the Buck converter, and the proposed MPPT algorithm. This model is simulated for a constant temperature (25°C) and a variant irradiation (between 100W/m^2 and 1000W/m^2). As can be seen from the results obtained in Figures 16 and 17, the output voltage and power of the Buck converter changes with changing solar irradiance. It is also

remarkablethat the output of the PV panels decreases due to the used converter (a Buck converter in our case).

As clearly observedin the result presented in this article, using the constant duty cycle or the classical P&O strategy exhibits large oscillations to the Buck converter output value, and this is the main drawback of using these techniques. While, the proposed P & O algorithm based on the PI controller gives the optimum duty cycle to track the irradiance profile almost perfectly, to eliminate squarely the oscillations in the converter output value, and to extract the maximum power from the PV system.

The approach presented in this article show the performance and the effectiveness of the method proposed to generate and monitor the MPPT.

4. CONCLUSIONS

In this paper, P&O algorithm of MPPT with current regulation is implemented using a Buck converter. The model of the PV system is simulated in the software of Math works for a variant temperature and irradiance profiles, it is shown that the output power increases with the rise in solar irradiance. The comparison between the conventional P&O algorithm and the one proposed in this article show the effectiveness of the last to eliminate the oscillations and to track the maximum power point successfully when the external environment changes.

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