Modelling and Simulation of Perturb and Observe MPPT Algorithm Based on The PI Controller for Photovoltaic System

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ABSTRACT

The most popular type of renewable energy is photovoltaic (PV) because it is a sustainable source and environmentally friendly. The power generated by a PV system varies with changes in ambient conditions such as temperature and sun radiation; therefore, tracking the maximum power generation from a photovoltaic system independent of temperature and radiation factors is very important. In the literature, a number of methods for achieving the maximum power point has been presented. In this study, the maximum power point tracking (MPPT) system employing perturb and observe (P&O) algorithm is implemented based on the Proportional and Integral (PI) a controller on proposed PV system to harvest the highest power production from (PV) system and enhance the system performance. The proposed PV system is composed of a Photovoltaic array, (DC to DC) boost type converter and an MPPT algorithm utilizing perturb and observe method. 1Soltech 1STH-220-P module type was chosen in this study for the simulation and proposed PV The array consists of 40 rows of PV modules connected in parallel, while each row consists of 10 modules connected in a series. MATLAB/Simulink was used for stimulating all elements of the PV system. The proposed model is used to simulate and optimize the photovoltaic array output current, voltage and power features under various environmental conditions including solar temperature and radiation. The simulation results showed that maximum power point tracking approach using perturbation and observation provide high efficiency to get the highest energy from the PV system regardless of variations in environmental conditions. DC toward DC boost type converter with perfect performance and more voltage increase is also successfully simulated on the developed PV system.

1. INTRODUCTION

Energy is a requirement around the world that contributes via economic progress and social development. Human dependency on nonrenewable resources such as fossil fuel for the generation of energy has created several environmental problems, such as carbon emissions, ozone, depletion and global warming [1, 2]. Over the last few years, energy policy and global warming have become major concerns on the global agenda. Climate change is an important thing that developed countries are planning to handle. Europe, for example, has set an objective to reduce carbon dioxide emissions by approximately 20% and generate at least 20% of its electricity from renewable sources [3]. To compensate for the damage caused by fuel consumption, it was directed to the consumption of an alternative source of energy, which is renewable energy resources, including hydro, solar, biomass, geothermal, tidal and wind [4]. Renewable energy is now being employed to generate electricity, and its demand increases with increasing consumption of electricity. Solar energy might be the most effective and the best of all renewable energy sources because it is the most sustainable, readily available, and cleanest energy source [1,5]. There are several applications for photovoltaic modules, including batteries, charging, water pumping, street lighting and grid-connected PV systems (hybrid systems). Most solar panels have an efficiency of approximately 20%, which indicates that only 20% of the received solar energy is changed into electrical energy and that the amount of energy a person needs in one year is equal to the amount of energy that the Sun gives off in one year [6, 7]. The photovoltaic conversion process allows converting solar energy into electricity without any environmental impacts and semiconductor materials such as germanium and uses silicon to perform photoelectric conversion [6]. Improving photovoltaic system efficiency to increase the energy provided is an important factor because it will raise profits and reduce the price of generated electricity to match the price of energy generated from additional resources. The main component of a solar energy production system is the photovoltaic module. Each unit consists of a series and parallel PV cells; these cells also consist of a p-n junction semiconductor device. The power generated by the PV module mainly depends on environmental conditions such as solar irradiation and cell temperature. Therefore, under different environmental conditions, the unstable power generated has been obtained from a photovoltaic array, and nonlinear characteristics for the current and voltage are produced [2, 8]. As a result, the optimal operating point for generating maximum energy from a solar system varies, and achieving the maximum power value is required for extracting the highest level of energy from the photovoltaic (PV) of the system and then delivering that energy to the load. Therefore, various algorithms for MPPT have been applied to achieve the maximum power point (MPP), enhancing the performance and efficiency of the PV system and minimizing the cost [7,9, 10]. Several algorithms are used to reach the highest level of energy generated from the photovoltaic system, including incremental conductance (IC), perturb and observe (P&O), the artificial neural network (ANN), fuzzy logic, a fractional short circuit current and a fractional open circuit voltage [8, 9, 11]. Among many methods for tracking the maximum power point of a photovoltaic system, the most frequently employed perturb observe (P&O) and incremental conductance due to its lower MPP tracking time, easy application and other economic aspects [8, 9, 12]. The PI controller-based Perturb plus Observe (P&O) algorithm was applied in the present research and represented programmatically using MATLAB/Simulink software. In this technology, the controller changes the output voltage from the photovoltaic array by a small amount and detects the power. The controller continues to make further changes in the same path if the power generated increases until the power stops rising.

2. MODELLING OF PV ARRAY

Modelling photovoltaic arrays for various environmental conditions is very important in designing a PV system size and its MPPT controllers. The main component of photovoltaic arrays is the photocell, which is a number of cells constructed in parallel and in series shapes to create the module [4, 11]. The single diode and double diode are the most common and popular photovoltaic modules [8]. The single diode module is used in this work to analyse the features of the PV modules. The single-diode identical circle diagram of a photovoltaic cell is presented in diagram 1. The main circuit involves a current basis (Iph), a diode (D), shunt resistance (Rsh) and series resistance (Rs).
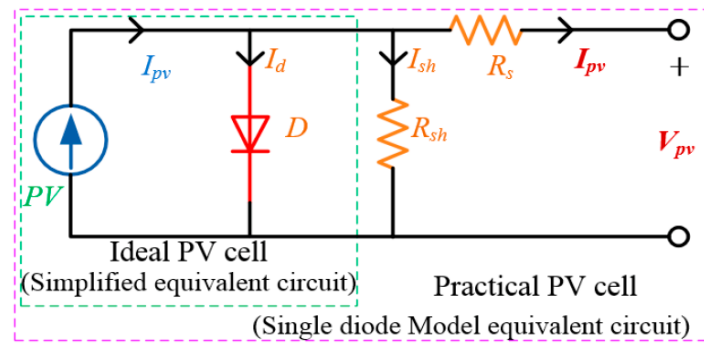
Figure 1: Diagram of the schematic of a single-diode model equivalent circuit for a photovoltaic (PV) cell[8].

The equations of the PV module's mathematical model characterizing the current-voltage (I-V) characteristics are given below [6,7, 9, 10]:

$$I_{pv} = I_{ph} - I_d - I_{R_{sh}} \tag{1}$$

$$I_{ph} = [I_s + K_i(T - T_r)]\frac{G}{G_r} \tag{2}$$

$$I_d = I_s\left[\exp(\frac{q(V_{pv}+I_{pv}R_s)}{KTA}) - 1\right] \tag{3}$$

$$I_s = I_{rs}(\frac{T}{T_r})^3\exp\left[qE_g(\frac{1}{T_r} - \frac{1}{T})\right] \tag{4}$$

$$I_{rs} = I_{sc}/\left[\exp\left(\frac{qV_{oc}}{N_sKAT}\right) - 1\right] \tag{5}$$

$$I_{R_{sh}} = (V_{pv} + I_{pv}R_s)/R_{sh} \tag{6}$$

In this model, shunt resistance R_{sh} has a negligible effect because its value is very high compared with the small value of series resistance Rs; therefore, the current passing through shunt resistance $I_{R_{sh}}$ can be neglected, and the output current of the PV module becomes:

$$I_{pv} = N_pI_{ph} - N_pI_s\left[\exp(\frac{q(V_{pv}+I_{pv}R_s)}{KTAN_s}) - 1\right] \tag{7}$$

where:

A: Diode Ideality factor (1−1.5).
E_{go}: band gap energy (1-1.8 eV).
G: Solar irradiance, W/m^2.

I_{ph}: Photo current measured by (A).

I_{pv}: Photovoltaic array output current measured by (A).

I_s: Diode reverse saturation current measured by (A).

I_{SC}: Short circuit current of the PV module at 1000 W per m^2 and 25 degrees Celsius.

I_{sr}: The current is in reverse saturation at the reference temperature of the photovoltaic cell, A.

K: Boltzmann's constant (1.3805 * 10^{-23} J/K).

K_i: Temperature coefficient of cell short circuit.

N_p, N_s: Number of coupled, which are connected in (parallel and series) cells.

q: Electron charge value (1.6*10^{-19} C).

R_s: Resistance in a series, Ω.

R_{sh}: Shunt resistance, Ω.

T: Cell operating temperature, °C.

T_r: Reference temperature (25 °C).

V_{oc}: Open circuit voltage, V.

V_{pv}: Photovoltaic Voltage, V.

Both P/V with I/V features of the photovoltaic system mainly depend on the temperature of the cells and solar irradiance. To display the nonlinear features of the photovoltaic module in various operational conditions, a 1Soltech, 1STH-220-P module was chosen in this study for the simulation. The developed array consists of 400 modules (10 series connection modules & 40 parallel connection units), and each module contains 60 cells. The module parameters of the PV scheme under standard conditions are shown in Table 1, while Figure 2 shows the P/V and I/V characterization of the solar panel.

Table 1: Photovoltaic Module Parameters.

Parameters	Symbol	Value
Output Power for each module	P_{out}	218.871 W
Open Circuit Voltage	V_{OC}	36.6 V
Short Circuit Current	I_{SC}	7.97A
MPP Voltage	V_{mp}	29.3 V
MPP Current	I_{mp}	7.47 A
Diode Saturation Current	I_0	2.9757*10^{-10} A
Diode - Ideality Factor	A	0.98928
Shunt Series	R_s	0.38174 ohms
Shunt Resistance	R_{sh}	350.2415 ohms
Cells per module	N_{cell}	60
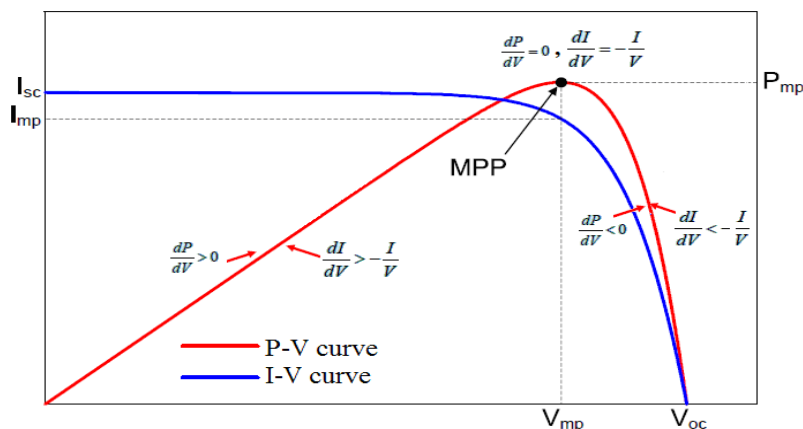
Figure 2: P/V and I/V characteristic curves of photovoltaic modules[13].

3. METHODS AND MATERIALS

3.1. Maximum Power Point Tracking Method (MPPT)

The maximum power point tracker, or MPPT, is a DC-to-DC electronic converter that enhances matching between the load and PV panel. The MPPT system modifies the electrical operating conditions of the panels so that they can supply the optimum amount of power. The MPPT method compares the panel output and battery voltage. Then, an algorithm is utilized for estimating the absolute extreme power that the solar system can produce [10, 14]. There are two groups that MPPT algorithms can be divided into: traditional algorithms such as perturb and observe (P&O), incremental conductance (IC), and fractional short circuit current with fractional open circuit voltage, while the second group involves modern algorithms such as the artificial neural network (ANN) and metaheuristic with fuzzy logic [6,10]. An effective MPPT technique must include the following features [10]:

- It must be able to accurately and truly present the universal maximum power point. An efficient PV system that uses precise MPPT technology.
- It must have a fast-tracking speed. PV systems with slow tracking speeds have less extracted power and are less efficient.
- It must be willing to work effectively in both partial shade and a homogeneous insolation situation. Under penumbral conditions, it is difficult to determine the maximum true global energy point because there are some local optimizations in the PV curves.
- It must be independent of the system, meaning it must operate effectively with a variety of PV systems.
- It must not be overly complicated. Simplicity has its advantages.
- The maximum power point should not oscillate around its desired value.
- It must be able to harvest the maximum PPT point effectively after rapid changes in operating conditions such as irradiation and temperature.

The photovoltaic array, DC-to-DC converter, MPPT control algorithm and load make up the majority of the developed MPPT system, as presented in Figure 3.
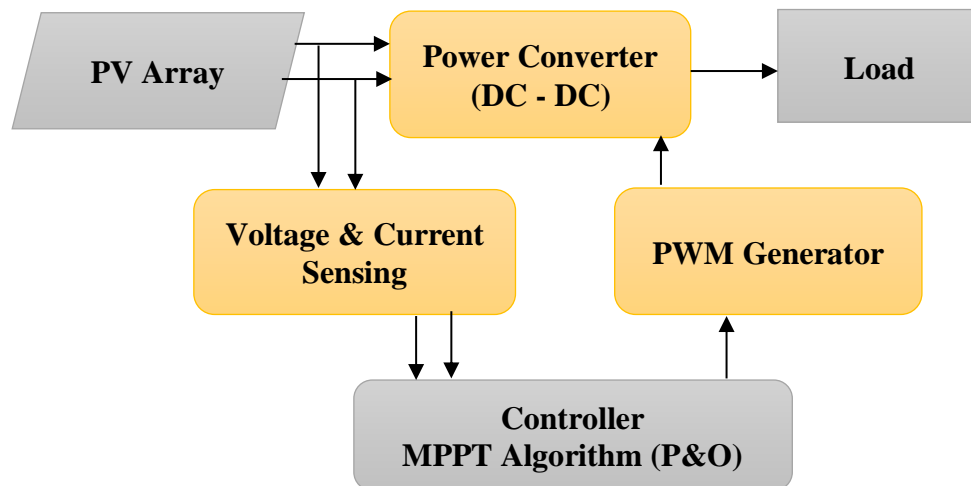

Figure 3: Diagram of the PV maximum power point tracking (MPPT) system.

3.2. Perturb and observe (P&O) control technique

This technique is also known as the MPPT "hill climb" method, which is one of the algorithms used in this study. To enhance the performance of MPPT, adjustable Perturb and Observe technology was created on the basis of a proportional and integrated controller (PI). This makes

it possible to improve the ability of PV panels to transform solar energy into electrical power. The performance of the solar system changes depending on the amount of solar radiation. Whenthe sunlight level is low, the PV panel cell efficiency is also low. The average efficiency is 12 percent. However, monocrystalline silicon cells may achieve up to 15percent efficiency. As a result, during irradiance variation, solar sheet systems need to be tuned to operate at extreme power generation [14]. The perturb and observe MPPT approach is applied in this study to maintain the MPP point for changing degrees of radiation. This algorithm worked by increasing or decreasing (alarming periodically), including introducing a disturbance in the power operating voltage. Both the current and voltage source are supplied to the photovoltaic cells to achieve the output power; the algorithm maintains the same direction (voltage increase) if the power is raised; otherwise, it changes the direction of movement. This approach is implemented at each step of the MPP tracing until the MPP is achieved. The algorithm automatically oscillates around the correct value once it reaches the MPP [5, 7, 9]. This indicates that the current or voltage changes in the opposite direction when the power decreases. The PV scheme is modelled using MATLAB/Simulink, and the MPPT algorithm is modelled using MATLAB/function System. The scheme of the Perturb and Observe algorithm used is shown in figure 4.
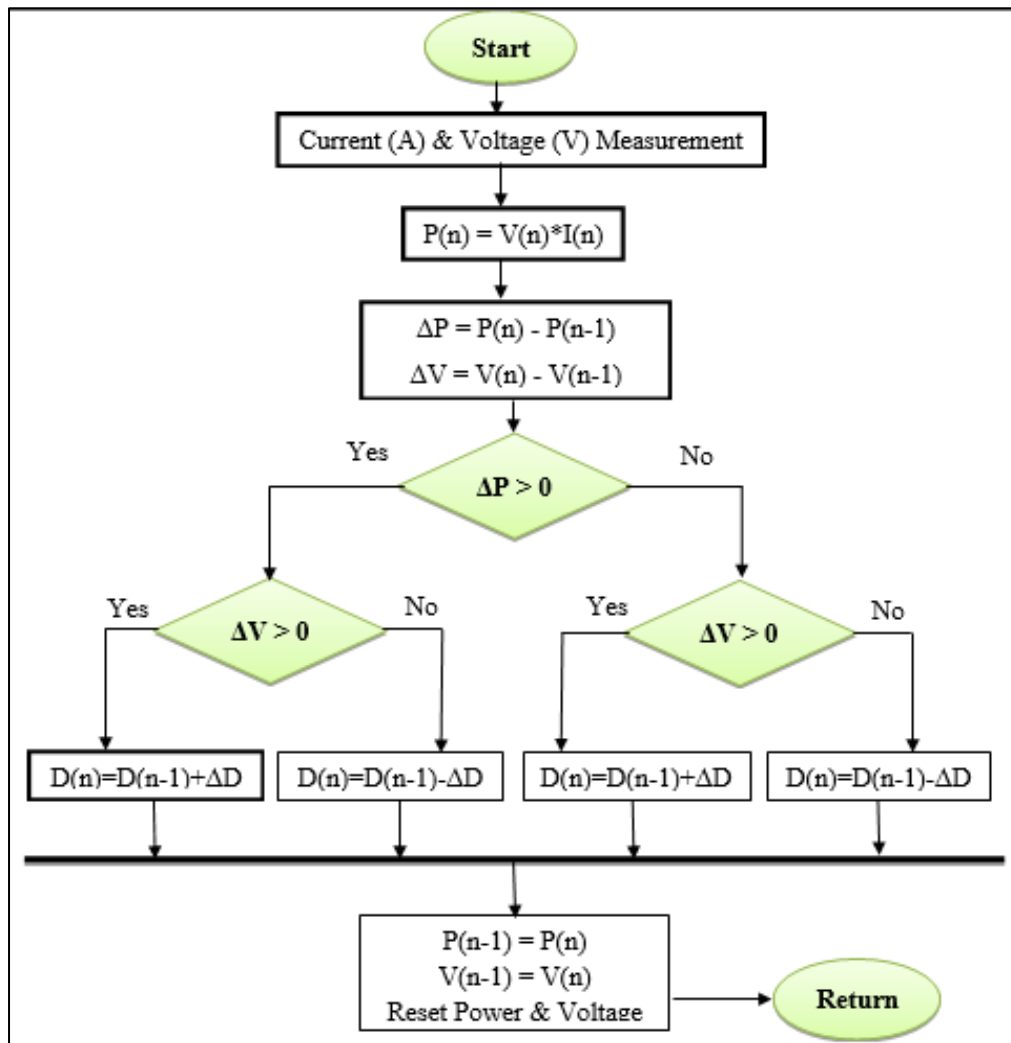

Figure 4: Flow diagram of the perturb and observe (P&O) algorithm.

The perturb & observe algorithm operates on the basic principle that on the maximum power value, the variation of photovoltaic power (ΔP_{PV}) and the variation of PV voltage (ΔV_{PV}) become zero [15]. Figure 5 shows thefundamental operation of the Perturb and Observe algorithm.
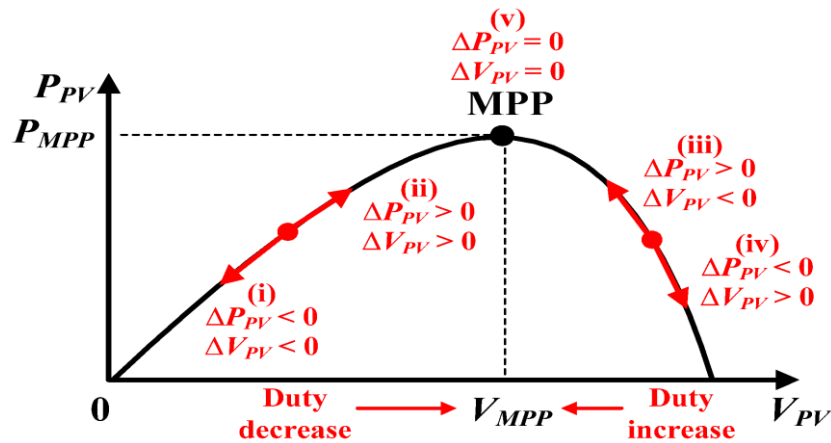

Figure 5: The operation concept of the perturbation and observation (P&O) algorithm [14].

3.3. (DC to DC) Boost Power Converter

The direct current voltage produced by the photovoltaic array was unstable throughout the day due to variations in irradiation level and temperature. Therefore,a uniform output voltage issuppliedfrom the photovoltaic system, which is connected to the DC-to-DC power converter and steps it up to a higher value required by the load. Maximum power point tracking (MPPT) is a load balancing issue, and a DC-to-DC power converter is required to modify the duty cycle to gain load resistance to the involvement resistance of the panel [6]. In this process, a boost converter is useful for stabilizing unbalanced voltage and adjusting the photovoltaic yield voltage. The DC-to-DC boost converter is designed to be 100% efficient; it states that the involvement power and the output power are equal, and when the MOSFET is turned on, at this point, both the current source and inductor current source could be equal. To maintain the stability of the boost converter output voltage, the duty cycle is adjusted, which determinesthe output voltage rate of the solar PV system in each switching cycle. [4,16]. All publications [4, 5, 8, and 17] represented the output voltage of the boost converter as follows:

$$\mathbf{V_O} = \frac{V_I}{1 - DC}(8)$$

where:
V_O:boost converter output voltage, V.
V_I:boost converter input voltage, V.
DC:duty cycle (0-1).

Figure6 shows the main schematic sketch of a DC-to-DC boost converter. Since the proportional & integral (PI) of the controller is operating, the output voltage and current may be regulated and brought back to their steady state levels after they were initially transient. In addition, it shows that the DC-to-DC boost converter works well when coupled to the battery charging system [18].
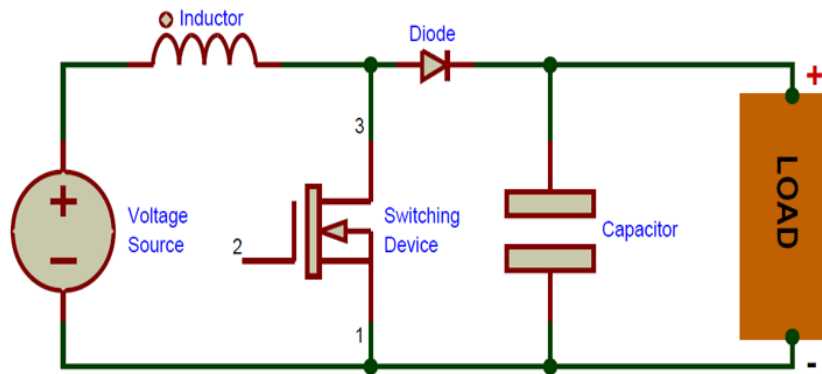
Figure 6: DC-DC boost converter circuit diagram [16].

4. RESULTS AND DISCUSSION

The major schematic sketch of the developed photovoltaic system is shown in Figure 7, which was designed based on mathematical models using MATLAB/Simulink. The simulation results for the PV module selected for this study are shown in Figure 8. The results are shown with characteristics of P/V and I/V at a constant cell temperature at 25 degrees Celsius and a different radiation level. The photovoltaic array consisting of 10 modules in series and 40 modules in parallel was also simulated under different operating conditions. Figure 9 shows the P/V plus I/V features of the photovoltaic array at a constant cell temperature of 25degrees Celsiusand different irradiances of 300 W/m^2, 500 W/m^2, 700 W/m^2, and 1000 W/m^2. Figure 10 displays the characteristics of P/V plus I/V curves of a photovoltaic array with a constant irradiance of 1000 W/m^2 and various cell temperatures of 15 °C, 25 °C, 40 °C, and50°C. The simulation results show that when the cell temperature is stabilized, the PV output current, voltage and power increase with increasing radiation and vice versa, while with increasing cell temperature and radiation stabilization, the PV output power, current and voltage decrease and vice versa.
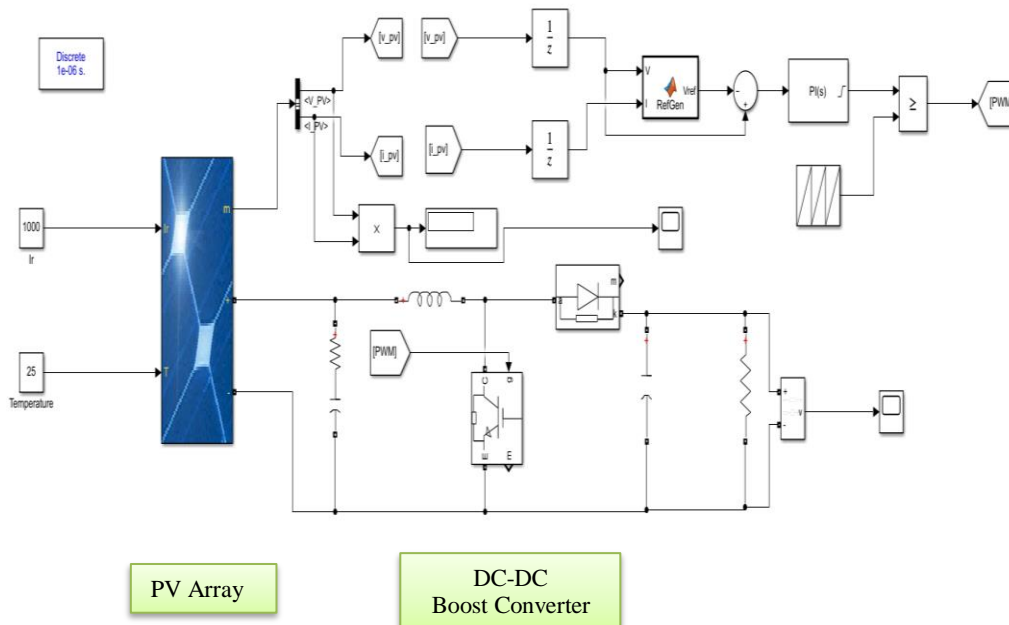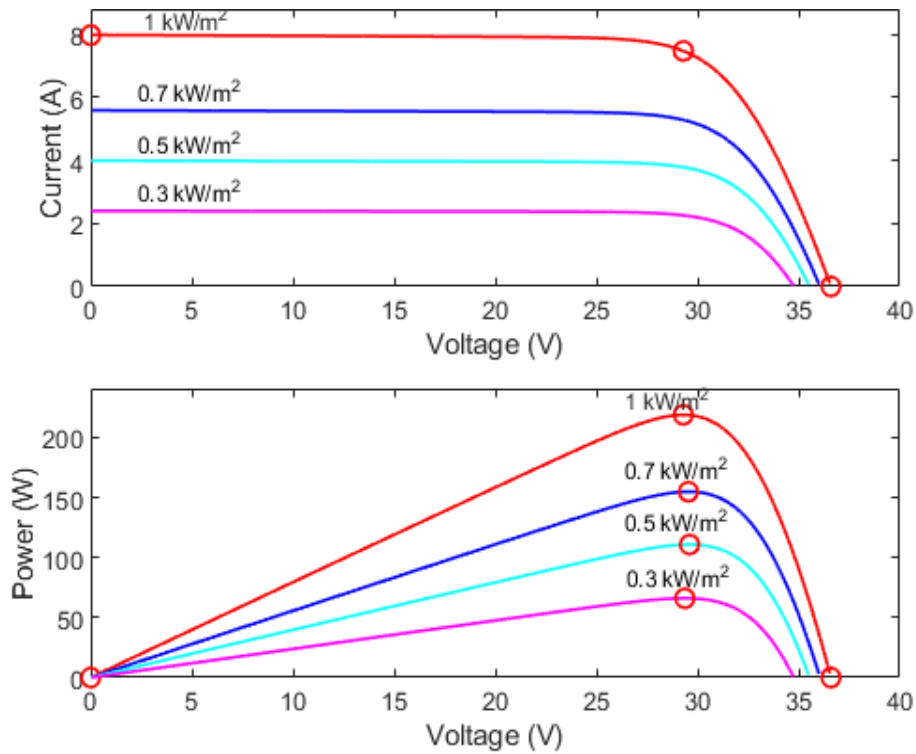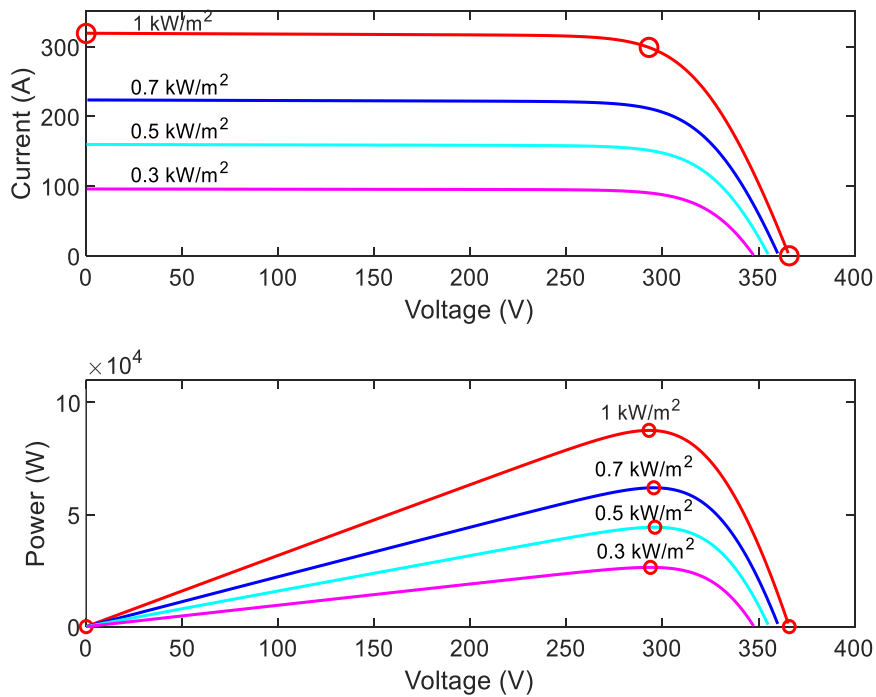

Figure 7: Photovoltaic system simulation model.
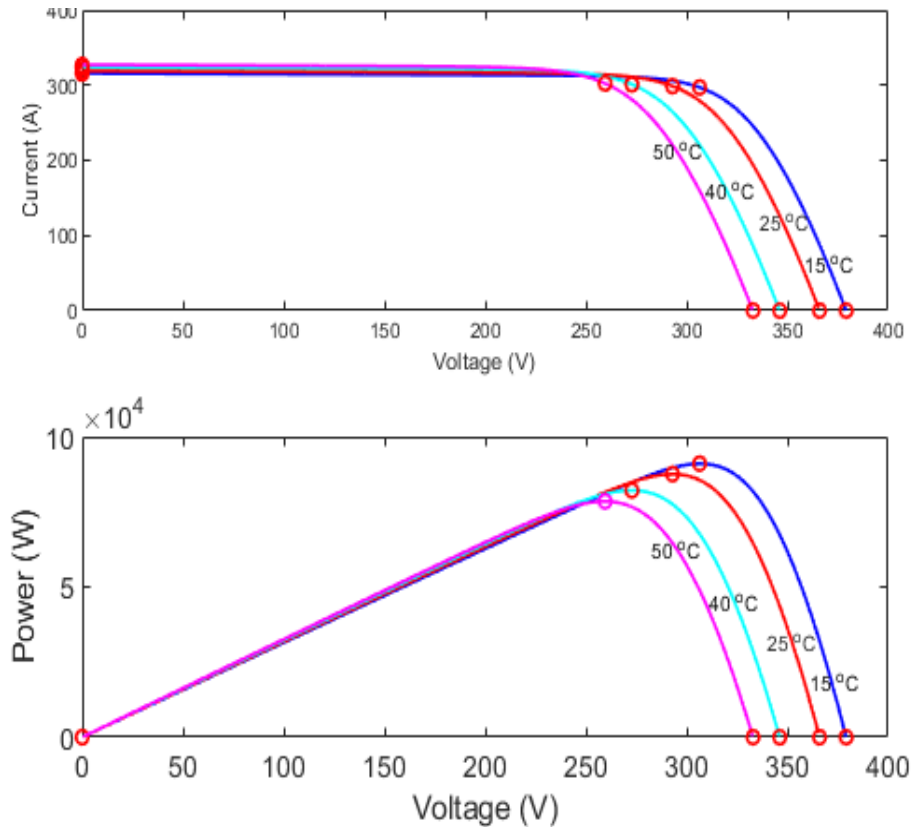
Figure 8: Photovoltaic module (1 Soltech-1STH-220-P) I/V and P/V features influenced by solar radiation at 25 °C.


Figure 9: TheI/V and P/V characteristic curves of the photovoltaic array (1 Soltech-1STH-220-P, 10 modules in series and 40 modules in parallel) affected by solar radiation at 25 °C.

Figure 10: I/V and P/V characteristic curves of the photovoltaic array (1 Soltech-1STH-220-P, 10 modules in series and 40 modules in parallel) affected by cell temperature at 1000W/m².

In this work, an MPPT-based proportional and integral (PI) controller algorithm is implemented on the developed PV array and simulated under different operating conditions to achieve the maximum power of the photovoltaic array. Figures 11 and 12 show the pattern of radiation changes throughout the duration of the day and the energy generated by the photovoltaic system at various levels of radiation, respectively, using the Perturb and Observe algorithm, while Figures 13 and 14 show the pattern of temperature changes throughout the duration of the day and the energy produced by the Photovoltaic system atdifferent temperature levels, respectively, using the Perturb and Observe algorithm. Then, the simulation results of the perturb and observe technique were analysed and compared with the photovoltaic output power to determine the tracking efficiency, as shown in Table 2. The results show that with continuous variations in temperature and irradiance, the Perturb and Observe algorithm has good performance, and tracking efficiency remains high and reaches 99.9%, except under conditions of 300 W/m² and 25 °C, in which the algorithm does not give high performance and tracking efficiency.
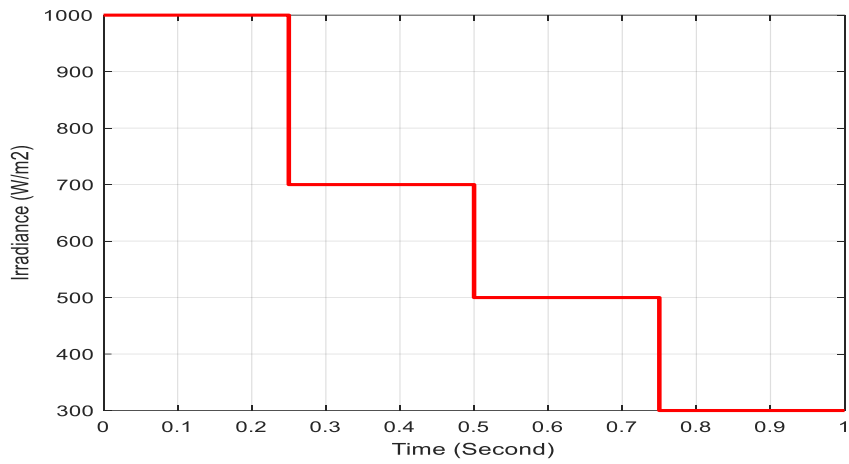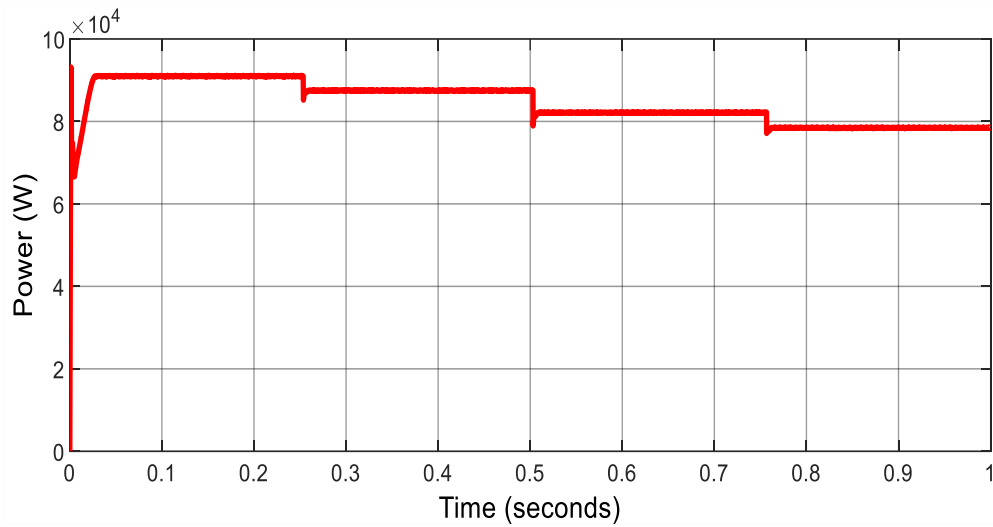
Figure 11: Sun irradiance variations.
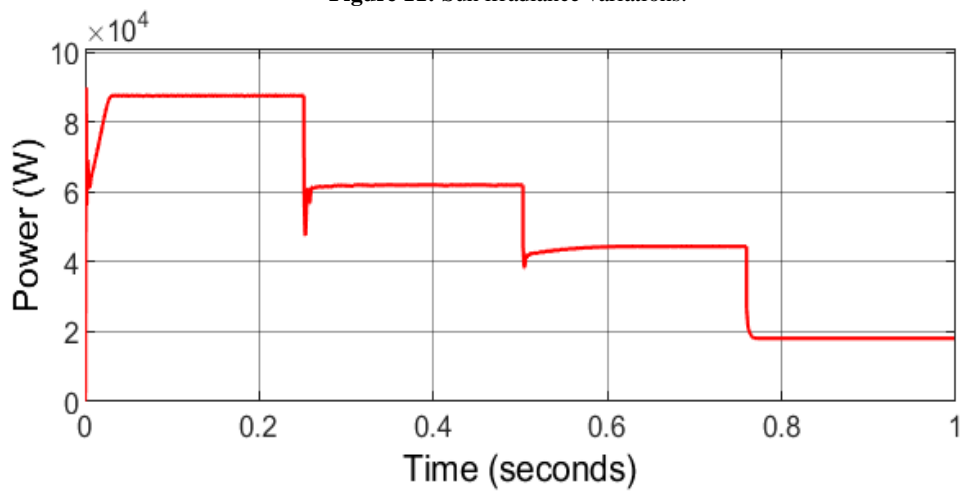
Figure 12: The PV system output power at different levels of irradiance and 25 °Cusing theP&O MPPT algorithm.
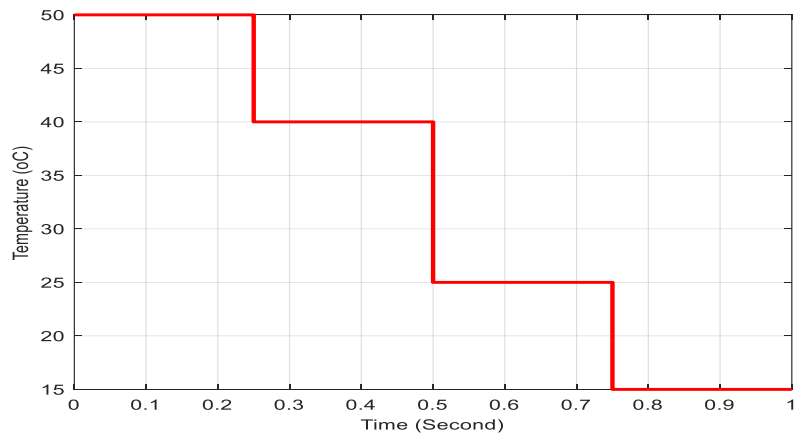

Figure 13: Sun irradiance variations.

Figure 14: PV system output power at different levels of cell temperature and 1000 W/m^2 irradiance using the P&O MPPT algorithm.

Table 2: PV and MPPT output power comparison.

Constant cell temperature of 25^{0}C			
Solar Irradiance (W/m^2)	PV represents output power (W)	PV power using (P&O) MPPT (W)	Tracking Efficiency (%)
300	26420	18010	68.17
500	44330	44328	99.995
700	61930	61924	99.99
1000	87550	87505	99.95
Constant Irradiance of 1000 W/m^2			
Cell temperature (^{0}C)	PV represents output power (W)	PV power using (P&O) MPPT (W)	Tracking Efficiency (%)
15	91020	90996	99.97
25	87550	87505	99.95
40	82140	82131	99.99
50	78470	78404	99.92

The developed system effectively simulates a boost converter (DC to DC) with higher voltage gain and performance, and the simulation results are shown in Figure 15.
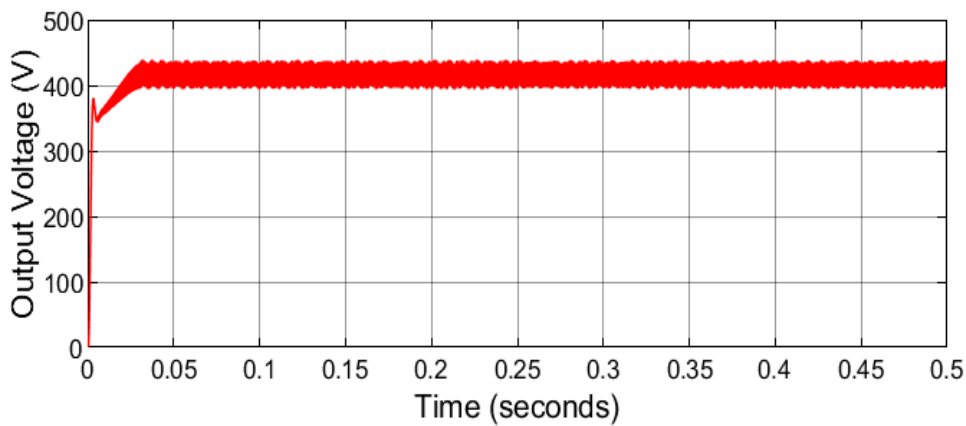
Figure 15: The boost converter DC-to-DC output voltage under standard condition (25ºC & 1000W/m^2).

5. CONCLUSION

In this research, the mathematical plan with simulation of the PV array is developed using MATLAB/Simulink, and then under various environmental conditions, including cell temperature, solar radiation, and characteristics of the I/V plus P/V curves to the module and the panel are evaluated and analysed. MPPT technology using a perturb and observe algorithm is proposed in this work toobtain the maximum power output from the photovoltaic scheme, and the proposed algorithm is applied based on the proportional and integral (PI) of the controller to improve the performance of the system. The proposed solar system and DC-to-DC converter have been connected for the purpose of controlling the output voltage of the photovoltaic system and then step it up to the higher level required by the load. System design and the related algorithms are created using MATLAB/Simulink and MATLAB/function. The simulation results show that the implemented MPPT scheme responds speedily and accurately with high tracking efficiency when solar radiation and temperature conditions change rapidly over time. The DC-DC converter has also been successfully applied to the proposed system with high voltage gain and efficiency.

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