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

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ABSTRACT

The production of photovoltaic energy has increased over the last decades. The maximum power point tracking (MPPT) strategy is used because it is always crucial to improve energy efficiency by operating the photovoltaic (PV) system at its peak power under all conditions of insolation variations and temperature. The main objective of this article is to develop a technique for improving and optimizing the control performance of a system composed of a photovoltaic panel, a boost converter, a PI controller, and a load, and to compare the standard Perturb and Observe (P&O) algorithm to the modified P&O approach employing a PI controller to extract the PV module's maximum power.

Keywords: MPPT, PI controller, boost converter, P&O, PV system.

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1. INTRODUCTION

Renewable energy sources will never run out on the scale of human time. Fossil fuels such as oil, coal, and gas are non-renewable sources whose reserves can be depleted quickly. Solar, wind, hydro, geothermal, marine, and biomass energy are renewable sources. Fossil energy reserves will run out if we do not develop their use because they are not renewable. Non-renewable energy sources are also responsible for global warming, which puts our planet and future generations at risk. Renewable energies are inexhaustible, clean, and can be used autonomously (because they can be used in the same place where they are produced). Moreover, they have the advantage of complementing each other. Photovoltaic solar energy produces electricity when there is little wind, but when there are clouds; wind turbines are responsible for producing the majority of electrical energy. Photovoltaic conversion, which involves the use of solar collectors to convert solar energy into electrical energy, is the simplest method of producing solar energy. To obtain sufficient voltage for electrical applications, the cells are attached to the solar panels or modules. The panels directly transform solar energy into direct current, which can be stored in accumulators if desired.

The solar irradiance, the cell temperature, and the power of the photovoltaic modules determine the output characteristics of the photovoltaic generator. The PV array should be modeled and simulated to track the maximum power point (MPPT) of the PV system due to its non-linear characteristic.

Researchers began a few years ago to design methods to extract as much energy as possible from renewable energy sources, in particular photovoltaic panels. They are intended for stand-alone and grid-connected systems. First, mechanical systems were created to move the photovoltaic panels so that they could absorb as much solar radiation as possible. Another type of tracker, known as a Maximum Power Point (MPPT) tracker, is based on shifting the operating voltage or current of the photovoltaic cell to obtain maximum power. To sweep PV power, this tracker usually requires a switching converter. There are currently a large number of MPPT algorithms and designs in the literature. Each method has its own specifications, limitations, and applications. The number of sensors required, the complexity, the cost, and the range of efficiency vary between these systems.

The author of the paper [1] compared the P&O algorithm with and without the usage of the PI controller, the latter demonstrating the efficiency of minimizing oscillations and successfully following the maximum power point. In the article [2] he made comparisons between two types of controls (P&O and fuzzy TS) the latter reduces the response time of the control system, on the other hand, it improves the MPPT performance. In article [3] the author presents the mathematical model and the global MATLAB Simulink model of the different components of a photovoltaic power plant connected to a network. In the article [4], a comparative study highlights the difference between the two techniques for controlling a PV system: One of the techniques uses MPPT fuzzy logic and fuzzy PI controllers in the control loop, as well as SOGI -PLL in network timing., the other was based on MPPT incremental conductance, classic PI controllers and classic PLL network timing, therefore the FLC technique proves to be fast, flexible and robust. In the paper [5], to harvest the most power from the PV system, a cockroach infestation optimization (RIO) technique is presented. In the paper [6], several MPPT processes have been tried namely GA, PSO, and CNFF. In the article [7], the author made the comparison between the P&O algorithm and conventional ICs and P&O and ICs based on PI. The paper [8], presents an improved SPInC algorithm, which reduces the output power ripple and increases the system efficiency. In the article [9], A clear comparison of typical

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MPPT approaches such as (VSS-P&O), (FOCV), (MIC), (VSS-RBFA), (AFLC), (FSS-RBFA), (PSO), and (CS) is offered. In the paper [10], the goal was to alter and propose two MPPT algorithms to increase monitoring of PV system efficiency, reaction time, and overall system efficiency (modified P&O and modified IncCond). In the paper [11], to forecast the variable step size of the CI-based MPPT technique, the author provided a proportional integral differential (PID) controller using a genetic algorithm (GA). In paper [12], a fuzzy logic controller with variable step size was used to implement a modified Maximum Power Point Tracking (MPPT) Perturbation and Observation (P&O) method.

Because of its high performance simplicity, and ease of usage with many solar array types, Perturb and Observe (P&O) is the most extensively used MPPT algorithm. The main disadvantage of this method is the following: there are oscillations close to the MPP point.

In this research, based on a PI (proportional integral) regulator, we present an improved MPPT P&O algorithm for solar current regulation and energy efficiency. A Boost converter generates power from the solar module.

In this post, we will look at traditional and upgraded P&Os that use a PI controller to regulate a Boost converter. The rest of this article is structured as follows: Following this presentation, there is a summary of the PV panel and Boost converter employed in the simulation. The following section presents a comparison of traditional and upgraded Perturb and Observe (P&O) algorithms. Then, an experimental device for testing the algorithm's efficiency is detailed, and the results are thoroughly analyzed. The final portion includes.

2. PV AND BOOST CONVERTER MODELING

2.1 Design of PV Systems

We begin with a basic model to model our photovoltaic panel that represents an elementary PV cell. Figure-1 shows the most commonly used equivalent circuit for a solar cell. This diagram includes a variable current source Ipv*, connected in parallel with a diode D, which characterizes the junction of the semiconductors constituting the solar cell, as well as a parallel resistor Rp. In addition, another resistor Rs is connected in series with the whole.

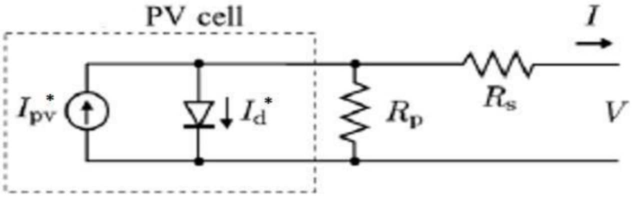

Figure-1. Equivalent photovoltaic cell circuit.

The photovoltaic panel is modeled by an elementary PV cell according to the equivalent diagram presented in Figure-1. Here are the equations governing this model:

$$I = \left(I_{pv,n} + K_i\,\Delta T\right)\frac{G}{G_n} - I_0\left[exp\left(\frac{q(V+R_sI)}{aNskT}\right) - 1\right] - \frac{V+R_sI}{R_p} \qquad (1)$$

$$I_0 = \frac{I_{sc,n} + K_i\,\Delta T}{exp\left(\frac{(V_{oc,n} + K_v\,\Delta T)}{aV_t}\right) - 1} \qquad (2)$$

Where the parameters and constants are defined as follows:

- a: The solar cell ideality factor, without unit.
- ΔT=T−Tn: The difference in temperature between the actual cell temperature (T) and the nominal temperature (Tn) in degrees Kelvin (K).
- T: The actual temperature of the cell.
- Tn: Nominal cell temperature under typical test conditions (STC): 1000 W/m2, 25°C and AM 1.5.
- G: Actual illuminating in W/m2.
- Gn: Nominal illumination under STC in W/m2.
- I0: Current of saturation in a reverse diode in Amperes (A).
- Ipv,n: Current generated under STC in Amps (A).
- Isc,n: Short-circuit current under standard test conditions in Amperes (A).
- Voc,n: Open circuit voltage under standard test conditions in Volts (V).
- Vt: Thermal stress, calculated by Ns·KT/q.
- Ns: the number of cells linked in series (here 36).
- K: Boltzmann constant (1.38 x 10^-23 J/K).
- Kv: Temperature coefficient of the open circuit voltage (= 80 ± 10 mV/°C).
- Ki: Short-circuit current temperature coefficient (= 0.065± 0.015) %/°C.
- q: Charge of the electron (1.6 x 10^-19 C).
- Rs: Series resistance (= 0.2365 Ω).
- Rp: Parallel resistance (= 415.405 Ω).

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2.2 Boost Converter Design

This converter is a DC-DC boost converter designed to transform a fluctuating DC voltage due to climatic variations into an increased constant voltage, which can be connected to an inverter for integration into the electrical network and residential use. To achieve the desired output voltage, the converter is made up of a diode, a MOSFET, and a load element. The output voltage depends on the triggering duty cycle, which can be calculated using equation (3).

Equation (3) calculates the duty cycle of the MOSFET as follows:

$$T = [1 - (V(\min) * \eta / Vout)]$$

The operation of the converter also introduces residual current, as described in equation (4):

$$ti = iripple * iout * vout / vin$$

The output current of the converter can be determined using equation (5):

$$Iout = Converter\ Power\ Rating\ /\ Converter\ output\ voltage$$

The boost converter's inductance is determined by equation (6):

$$L = [v(vout\text{-}vin)] / (ti * fs * vout)$$

To ensure acceptable voltage changes, equation (7) is used:

$$Dv = vout / (dv\ percent / 100)$$

To reduce ripple, the output capacitor is calculated using equation (8):

$$C = Iout * T / (fs * dv)$$

Finally, the output resistance can be determined using equation (9):

$$R = Vout / Iout$$

This set of equations governs the behavior of the DC-DC boost converter, allowing it to maintain a stable and increased output voltage, making it suitable for integration with an inverter for residential and utility grid applications.

3. MPPT ALGORITHM

3.1 The MPP Tracker's Operating Principle

In photovoltaic systems, MPPT (Maximum Power Point Tracking) techniques are utilized to maximize the power generated by the photovoltaic array by continually tracking the maximum power point. However, getting to this stage is not easy, which is why research on MPPT approaches is a hot topic these days. The operational point is moved by increasing the voltage Vpv (by reducing the duty cycle) when Ppv/Vpv is positive or decreasing the voltage Vpv (by increasing the duty cycle) when Ppv/Vpv is negative, as shown in Figure-2.

3.2 Perturb and Observe (P&O)

The Perturbation and Observation (P&O) algorithm is an MPPT control technique that works by slightly perturbing the voltage Vpv around its initial value, either by increasing or decreasing it. This disturbance acts directly on the duty cycle of the signal which controls the DC-DC converter. By observing the impact of this disturbance on the output power of the photovoltaic panel, the algorithm can adjust the duty cycle if necessary. Figure-3 illustrates the flowchart describing the operation of the P&O algorithm.

However, this technique presents some problems related to oscillations around the Maximum Power Point (PPM) when it is in a steady state. Indeed, the periodic search for the PPM leads to permanent oscillations around it. To minimize these oscillations, it is possible to reduce the value of the disturbance increment. However, an increment value that is too low slows down the search for the PPM, which requires finding a compromise between precision and speed. This is why the optimization of this command turns out to be quite complex.

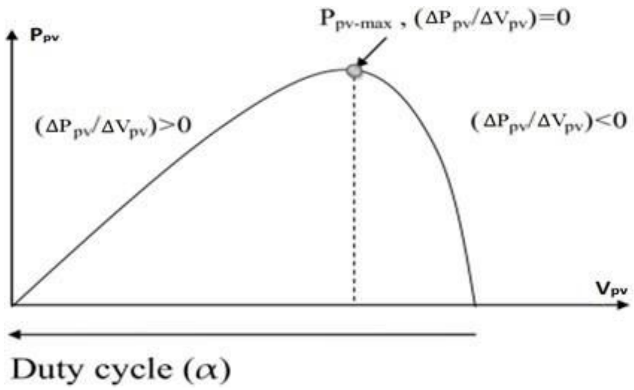

Figure-2. Process of locating the peak of PowerPoint.

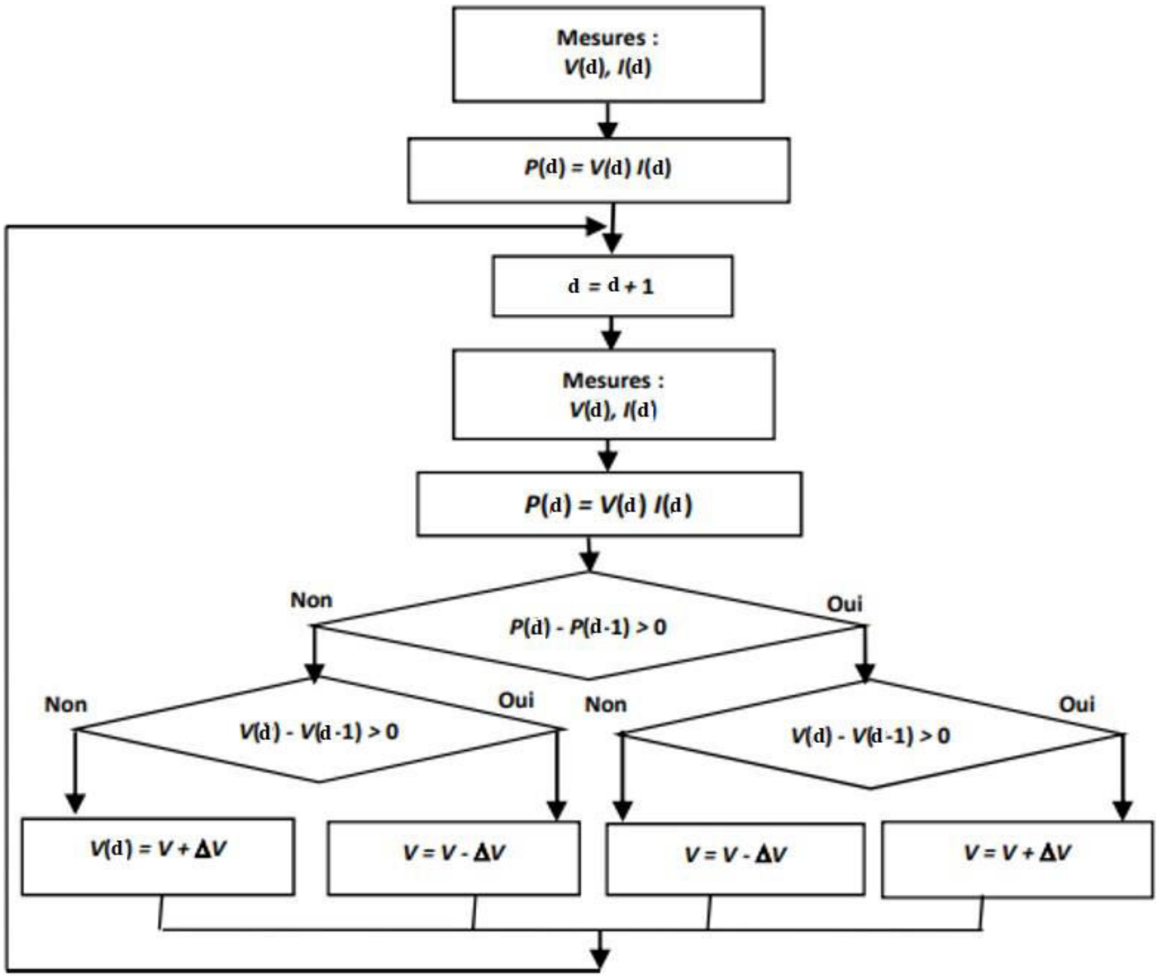

Figure-3. P&O algorithm flowchart.

4. SIMULATION RESULTS

4.1 The Traditional P&O MPPT Algorithm

In this section, we implement a classical P&O algorithm [13, 14] as well as a modified P&O algorithm based on the PI regulator employing a boost converter (Boost). MathWorks software is used to simulate the models, and the various findings are displayed subsequently.

4.1.1 PV system simulation using the P&O algorithm

MATLAB/Simulink is used to generate the model of the solar panel with the Boost converter, as well as the detailed block diagram of the previously stated P&O algorithm. Figure-4 depicts the model.

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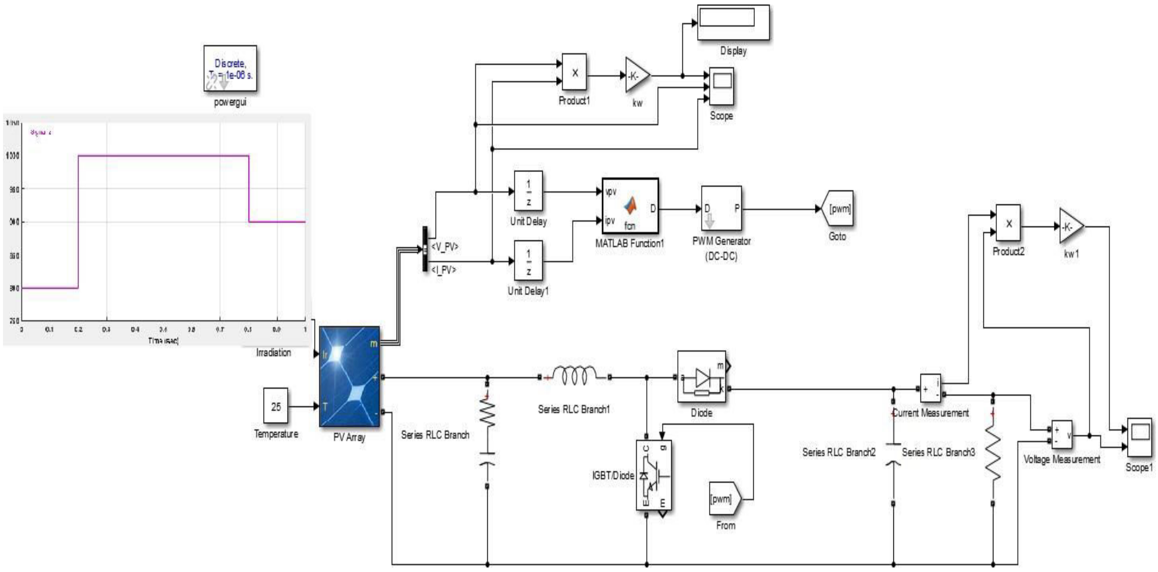

Figure-4. PV system MATLAB/Simulink model utilizing the traditional P&O algorithm.

4.1.2 The outcome of the simulation

The simulation results are depicted in the figure below:

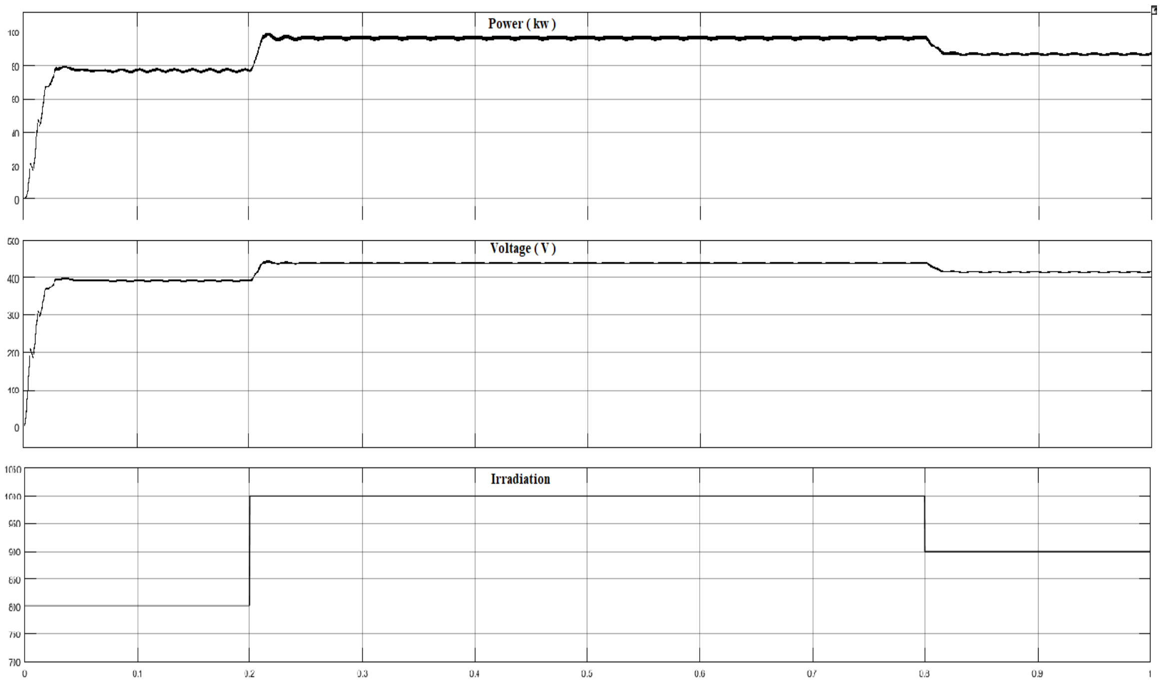

Figure-5. The power and voltage curves at the boost converter's (Boost) output using the MPPT algorithm.

The conventional P&O method exhibits significant oscillations, as illustrated in Figure-5.

4.2 P&O MPPT Algorithm Modification Using a PI Controller

Based on a PI regulator, we created an algorithm that improves the usual P&O Maximum Power Point Tracking (MPPT) approach in this study. The goal of this regulator is to lessen the difference in voltage between the reference PV voltage Vref and the voltage generated by the MPPT block, Vout. Verror is calculated by subtracting Vref from Vout and then passed to a PI regulator. The duty cycle utilized to operate the converter is determined by comparing the output of the PI regulator to a sawtooth wave. To ensure that the system operates at the required maximum power point, the duty cycle value of the Boost converter used in the implementation is limited. The values of the PI regulator are altered through trial and error. Figure-6 depicts the enhanced P&O algorithm based on the PI regulator idea.

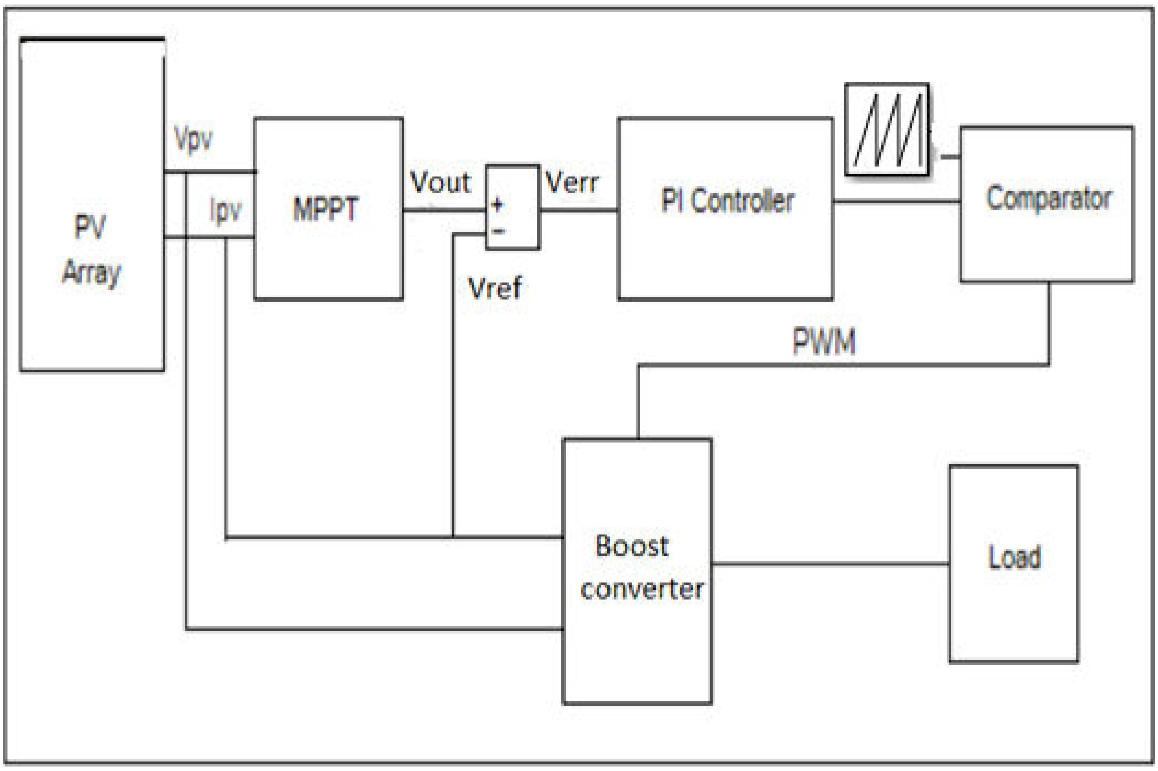

Figure-6. Principle of P&O M with PI controller.

4.2.1 PV system simulation with the P&O method and the PI controller

The suggested Disturb and Observe maximum power point tracking technique's MATLAB/Simulink design with a PI regulator is shown in Figure-7. The duty cycle used in the Boost converter is provided by the PI regulator output.

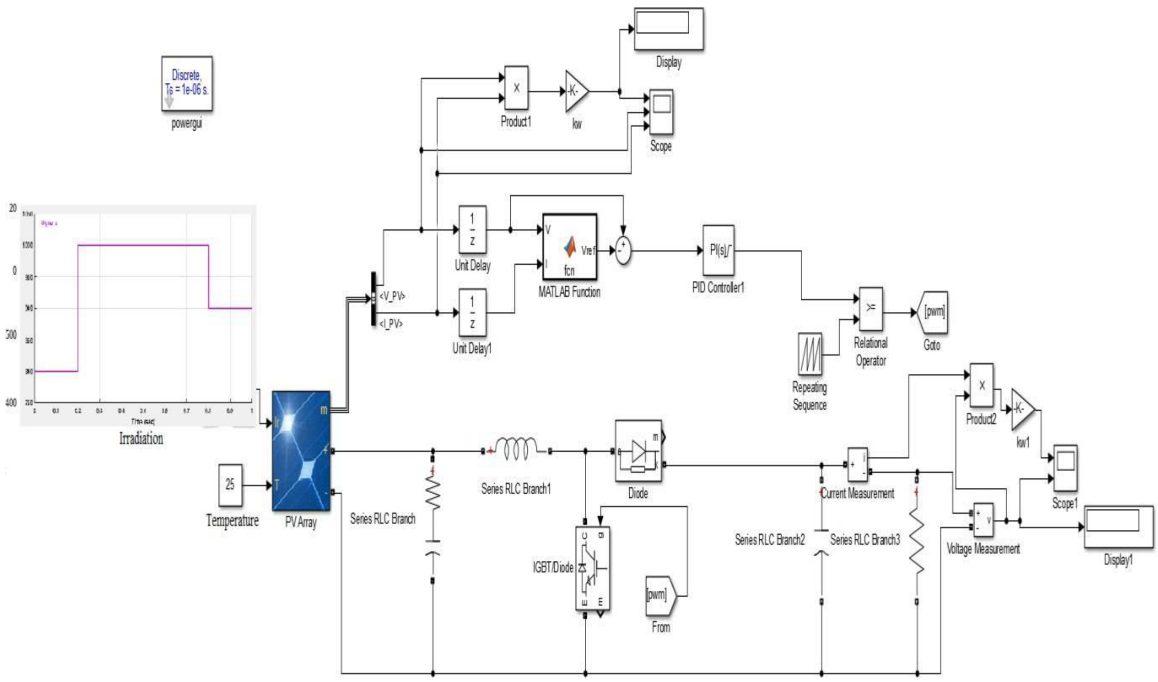

Figure-7. PV system MATLAB/Simulink model using the modified P&O technique.

4.2.2 The outcome of the simulation

The simulation results are depicted in the figure below:

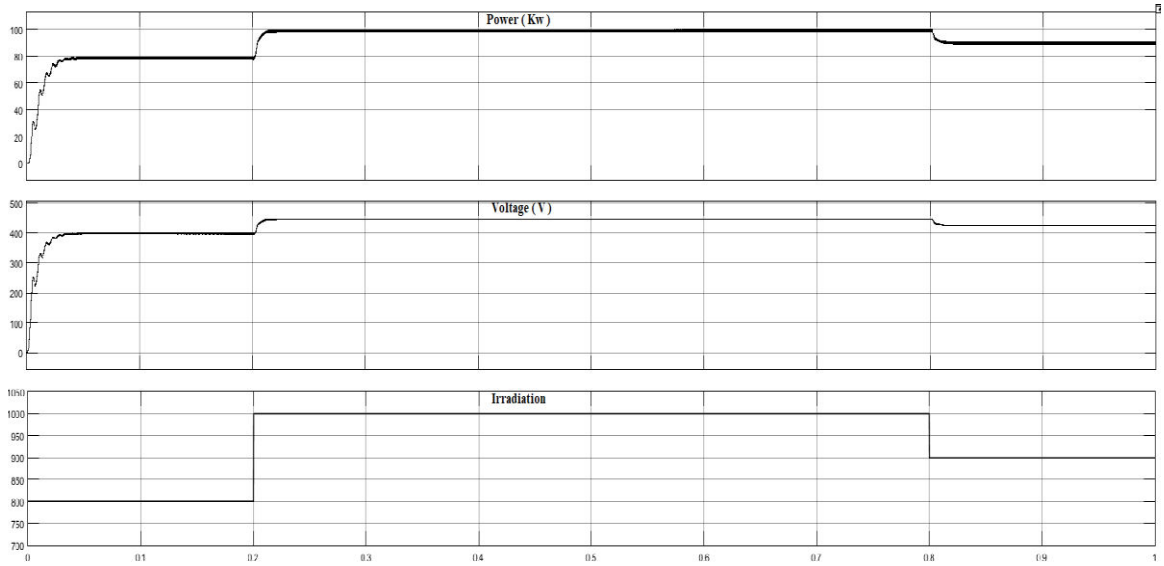

Figure-8. The power and voltage curves at the boost converter's output (Boost).

Figure-7 depicts the model used in this paper, which comprises the solar panel, the Boost converter, and the MPPT algorithm presented. This model is run at a constant temperature of 25°C with a light intensity of 1000 W/m2. The use of the usual P&O method results in significant variations in the output value of the Boost converter, as demonstrated by the findings reported in this article, which is the primary disadvantage of using these strategies. The proposed P&O algorithm, on the other hand, is based on the PI regulator and gives the best duty cycle to virtually precisely follow the irradiance profile, preventing oscillations in the converter output value and obtaining the maximum power from the PV system.

This paper's approach exhibits the performance and efficiency of the proposed method for generating and monitoring the MPPT.

5. CONCLUSIONS

To overcome the constraints of the classic MPPT P&O tracking method, this study develops and implements a modified maximum power point tracking (MPPT) perturbation and observation (P&O) algorithm employing a PI controller.

The results of the MATLAB simulation show a shortened response time and an improvement in tracking the overall system efficiency (99.95%) compared to the initial techniques.

Moreover, the suggested model increases the speed of power convergence as it eliminates oscillations around the maximum power point (MPP).

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