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GREEN ENERGY SOLUTIONS: SIMULINK-DRIVEN MPPT ALGORITHM DEVELOPMENT FOR ARDUINO HARDWARE

[1]S. Chakma, [2]A. Das and [2]S. S. Chowdhury

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Abstract

The transition away from fossil-gasoline-based power generation towards sustainable and renewable energy sources has been driven by concerns about the environmental impact and long-term viability of traditional power generation methods. Among the various renewable energy sources, solar photovoltaic (PV) power has emerged as a prominent player in the energy sector due to its consistent growth and increasing contribution to the overall energy mix. To enhance the efficiency of solar PV systems, Maximum Power Point Tracking (MPPT) techniques have been employed, allowing these systems to optimize energy production under varying solar irradiation and temperature conditions.

This paper presents an investigation into the Perturbation and Observation (P&O) MPPT method, which is based on the derivative of the power-voltage characteristic of the PV modules. By modifying the signal of the power converter PWM controller, the MPPT algorithm can be implemented using a control unit microcontroller or DSP device. The iterative nature of the P&O MPPT approach enables it to approach the Maximum Power Point (MPP) with high precision, leading to improved overall system efficiency.

In this study, we propose a PV model for designing PV systems with a basic MPPT approach, aiming to achieve low-cost design, better performance, and high efficiency. To validate the proposed solution, an experimental platform is constructed using an Arduino Uno board, featuring a low-cost ATMega328 microprocessor. Through rigorous verification and validation processes, we demonstrate the effectiveness of the proposed controller, showcasing significant cost savings and financial competitiveness.

The experimental results reveal that the implemented P&O MPPT algorithm successfully achieves enhanced energy extraction from solar PV systems, particularly under fluctuating environmental conditions. The overall system efficiency and performance are improved, contributing to the increased adoption of solar PV power as a viable renewable energy solution. The findings from this research pave the way for broader integration of solar PV systems

[1] Mechatronics and Information Technology, Institute of Technology of Cambodia, Phnom Penh, Cambodia
[2] Energy Technology and Management, Institute of Technology of Cambodia, Phnom Penh, Cambodia

into public networks, further reducing reliance on traditional fossil fuel-based power generation and advancing sustainable energy practices.

1. Introduction

The fossil-gasoline-based, completely traditional power era is unsustainable. This has been one of the primary motivators for the considerable incorporation of renewable energy sources, including wind, solar photovoltaic (PV), hydropower, biomass electricity, geothermal energy, and ocean power, into public networks throughout the previous decade. Solar PV power output has persisted in developing excessively as one of the leading renewables in the last few years. It now occupies a large position in the energy era. The maximum power point tracking (MPPT) approach allows photovoltaic (PV) systems to maximize energy production under fluctuating sun irradiation and ambient temperature conditions. As a result, the overall efficiency of the PV energy-producing system increases. The PV module's power-voltage characteristic has a derivative, which is the foundation for the perturbation and observation (P&O) MPPT approach. The output voltage and current of the PV module or array are often sampled at successive sampling stages throughout the P&O MPPT process to determine the related output power and the power derivative with voltage [1-5].

The MPPT technique was implemented by modifying the signal of the power converter PWM controller. The P&O MPPT method, based on the procedure described in [1, 4, 5], can be executed using a control unit microcontroller or DSP device. This phase is repeated until the gradient value reaches a predetermined threshold, indicating that convergence close to the MPP with the requisite precision has been achieved. This study provides a photovoltaic (PV) model for designing PV systems with a basic MPPT to achieve low-cost design, better performance, and high efficiency. Verification and validation are carried out using an experimental platform based on an Arduino Uno board. To validate this solution, a hardware test bench is built utilizing the Arduino Uno board's low-cost ATMega328 microprocessor. Significant cost savings have been achieved, demonstrating the proposed controller's financial competitiveness.

2. Literature Review

2.1. PV Modelling

Figure 1 shows the ideal of the PV model; it includes the photocurrent source I_{ph} and a diode. The solar irradiance (G), measured in W/m^2, and the temperature (T), measured in degrees Celsius (°C), are the two most essential elements. The relationship between these two parameters and PV operational characteristics may be mathematically predicted [10-14]. According to, the photocurrent Iph in equation (1) is affected by both irradiance and temperature.

Vpv

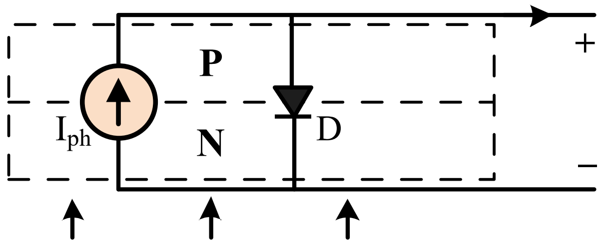


Fig 1. Ideal PV Model

$$I_{ph}(G,T) = [I_{scn} + K_i(T - T_n)]\frac{G}{G_n} \quad (1)$$

Where I_{scn}: Nominal short-circuit current, K_i: Current temperature coefficient, G_n: Nominal solar irradiance, typically 1000 W/m^2, and T_n:
Nominal cell temperature, typically 25 °C.

The diode's current I_d and voltage V_d are represented as an exponential relationship and are described in equation (2).

$$I_d(T,V_d) = I_s(T)\left[\exp\left(\frac{V_d}{aV_t(T)}\right) - 1\right] \quad (2)$$

Where I_s: Diode saturation current, a: Diode ideality constant, V_d: Diode voltage, and V_t: Thermal voltage of the semiconductor junction, the temperature-dependent diode saturation current is defined in equation (3).

$$I_s(T) = \frac{I_{scn} + K_i(T - T_n)}{\exp\left(\frac{V_{ocn} + K_v(T - T_n)}{aV_t(T)}\right) - 1} \quad (3)$$

Where K_v : Voltage temperature coefficient, V_{ocn}: Nominal open-circuit voltage. For the ideal model, the diode voltage V_d is the same as the PV voltage V_{pv}. In addition, the thermal voltage Vt is defined by equation (4) and depends on the temperature T.

$$V_t(T) = \frac{kT}{q} N_s \quad (4)$$

Where, k: Boltzmann's constant (1.3807 x 10^{-23} $J.K^{-1}$), q: Electron charge (1.60217662 x 10^{-9} C), and N_s: Number of PV cells in series. The relationship between the PV current I_{pv} and PV voltage V_{pv} for the ideal PV model is calculated using Kirchhoff's circuit rules. where equation (1) defines the photocurrent Iph and equation (2) defines the diode current Id. The PV output current is clearly connected to the solar irradiance G and temperature T, as shown by the PV current Ipv in equation (5).

$$I_{pv} = I_{ph}(G,T) - I_d(T,V_{pv}) \quad (5)$$

An output current and voltage (I-V) curve is commonly used to explain the properties of a PV cell. Fig. 2 shows the I-V curve using the PV cell parameters from Table 1. Power production is one of the essential measured values when running a PV cell. The output power can be estimated by multiplying the output current and voltage from the I-V curve, as illustrated in the same image.

The PV cell has the characteristics of a voltage source on the right side of the I-V curve, with an almost constant output voltage. On the other hand, the current source behavior is evident on the left hand of the I-V curve. There is a point at which the output power is maximized. This is known as a Maximum PowerPoint (MPP). Due to the PV cell's low efficiency (at the moment, 25%), PV systems must continuously operate close to the MPP to maximize energy gathering. As shown in Figures 2(a) and (b), environmental factors significantly impact the performance of PV cells. The short-circuit current is linearly related to the solar irradiation level, whereas the open-circuit voltage is strongly related to the cell temperature. Furthermore, partial shade caused by a passing cloud might influence the properties of the PV cell.

As a result, the operating point that meets the MPP criterion changes with the environmental circumstances. Thus, Maximum Power Point Tracking (MPPT) is required, which is a control algorithm that can track the MPP continuously during operation to maximize the power production of PV systems.

Table 1: Parameters of PV at the standard test condition used in this project

No	Parameters	Value
1	Maximum Power (Pmax)	390W
2	Output Tolerance	0~ ±3%
3	Current at P_{max} (IMP)	9.49A

4	Voltage at P_{max} (Vmp)	41.1V
5	Short-Circuit Current (Isc)	10.12A
6	Open-Circuit Voltage (Voc)	49.3V
7	Nominal Operating Cell Temperature (Tnoct)	45±2 ºC

2.2. Boost Converter Modelling

Consider a PV panel with a resistive load coupled to a boost-type converter. The converter's input and output voltages have the following relationship:

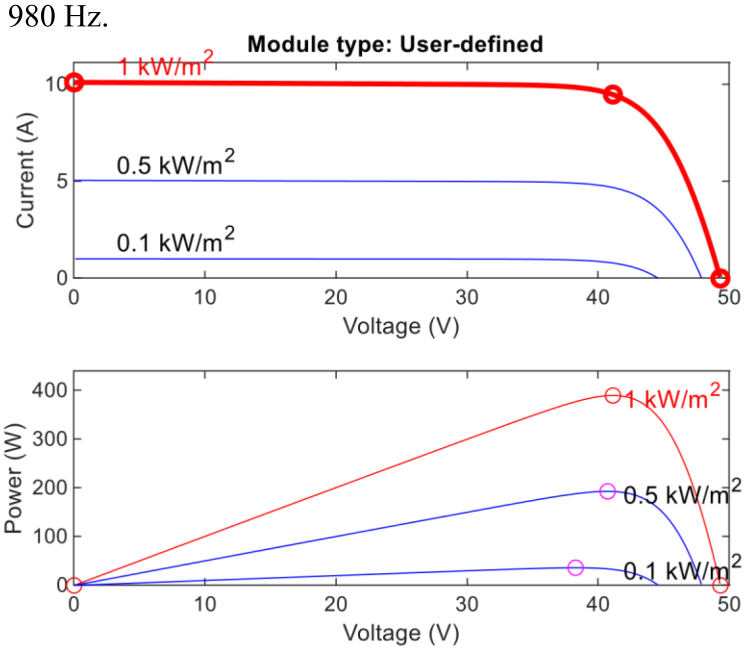
$$V_{out} = \frac{1}{1-D} V_{in} \qquad (6)$$

Where V_{in} is the input voltage, D is the duty ratio, and V_{out} is the output voltage. The power delivered from this PV panel, assuming the converter runs at 100% efficiency with a resistive load R_L, would be

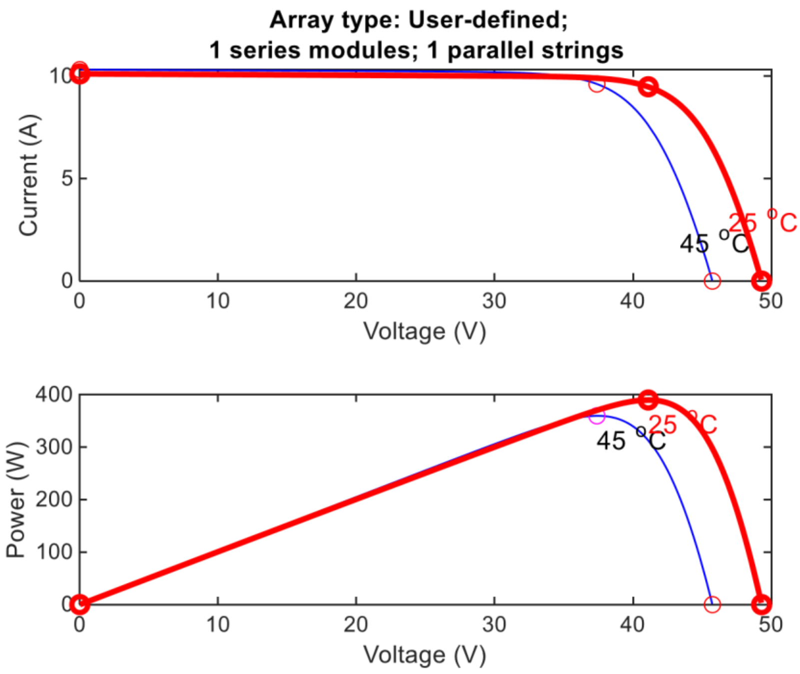
P=□□1−1D R□□□2 VinL2 (7)

□

The duty ratio command of the converter might be correctly adjusted to produce the maximum power. To operate the converter in continuous conducting mode, certain converter characteristics were chosen. The criteria chosen for this study are Cin=1000µF, Cout=1000µF, L=220 µH, load resistance of 150Ω, and switching frequency is 980 Hz.



(a) As a function of irradiation



(b) As a function of temperature

Fig 2. PV Characteristics

3. Methods

By progressively changing the DC-DC converter's duty ratio, MPPT algorithms maximize power production. There have been numerous developments and applications of MPPT techniques, including P&O (Perturb and Observing) and IC (Incremental Conductance) [6-10].

3.1. P&O Algorithm

The most common and widely utilized method of tracking the MPP is P&O. The flowchart of the P&O MPPT technique is shown in Figure 3. The idea behind this approach is to mess with the system's output voltage, which will mess with the generated power. We proceed in the direction of perturbation until we find the maximum power (when $\Delta P/\Delta V = 0$), if the new power is greater than the old. If this is not the case, we modify the direction of the perturbation to discover the maximum power.

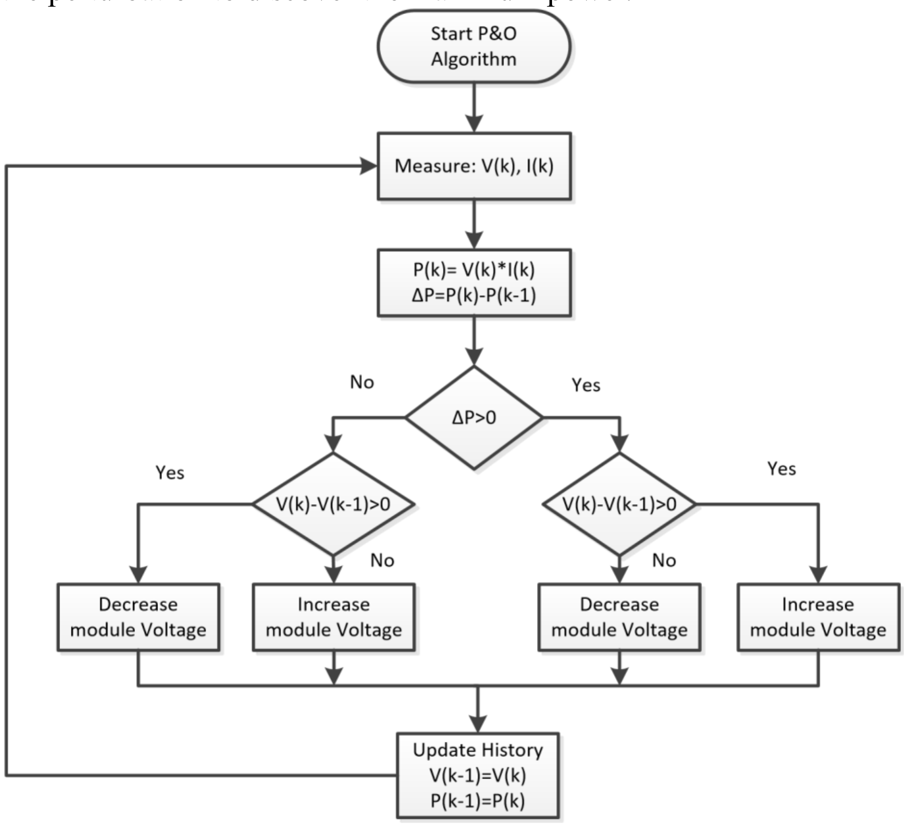


Fig 3. The flowchart of P&O

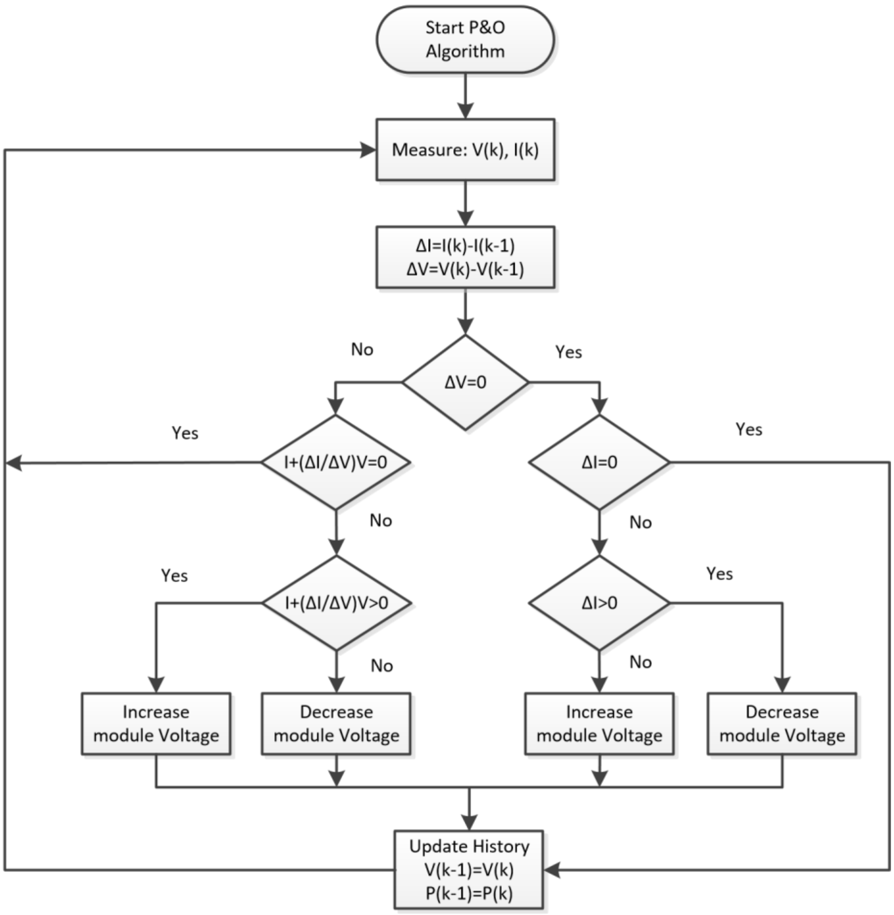


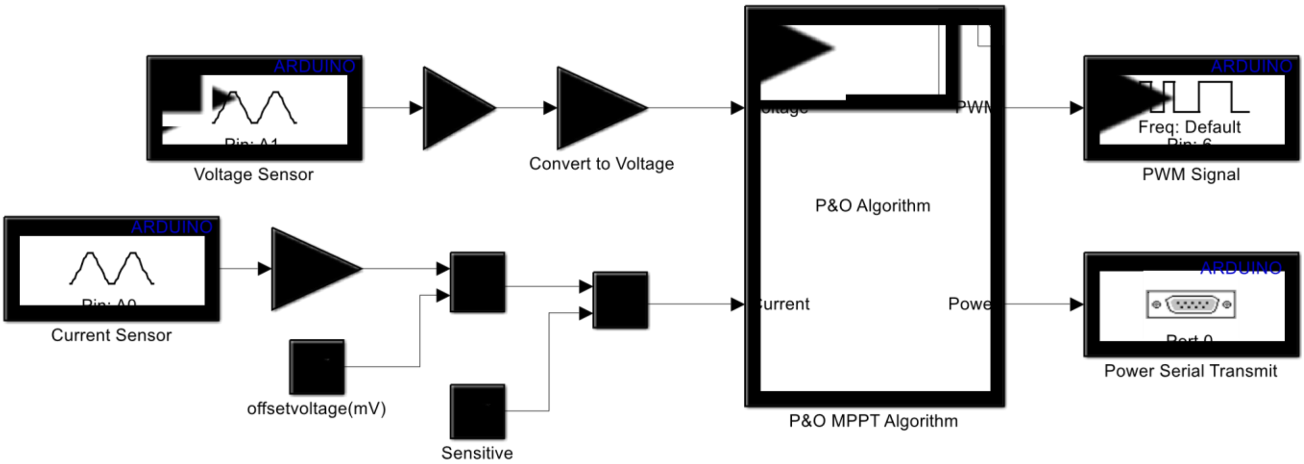
Fig 4. The flowchart of Incremental Conductance

(IC) **3.2. Incremental Conductance (IC) algorithm**

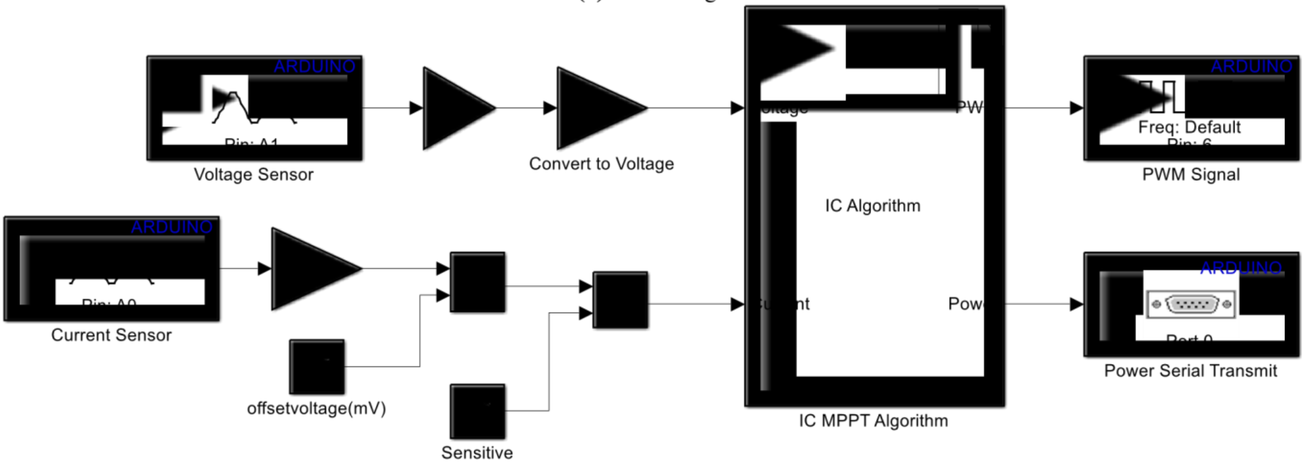
The incremental conductance (IC) method solves the drawback of the perturb and observes the process of tracking peak power under rapidly changing atmospheric conditions. This approach can identify whether the MPPT has reached the MPP and stops agitating the operating point. If this criterion is not satisfied, it is possible to determine the direction of the MPPT operating point's perturbation by analyzing the relationship between ΔI/ΔV and -I/V. The fact that ΔP/ΔV is negative when the MPPT is to the right of the MPP and positive when the MPPT is to the left of the MPP leads to this relationship. When the MPPT reaches the MPP, this algorithm decides when the P&O oscillates around the MPP. This is undoubtedly a benefit over P&O. Furthermore, incremental conductance is more accurate than the perturb and observe the method in tracking quickly increasing and decreasing irradiance circumstances. The technique is understood by the flow chart displayed in Figure 4.

3.3. P&O and IC Algorithm Design With Simulink Support Package

In this section, P&O and IC algorithms are designed with the Simulink support package for Arduino hardware. The Simulink Support Package for Arduino Hardware supports the creation and execution of Simulink models on Arduino boards. A library of Simulink blocks for configuring and accessing Arduino sensors, actuators, and communication interfaces is included in the support package [15]. Figure 5 shows the design of MPPT-based P&O and IC algorithms. Both algorithms were designed based on the algorithms in Figure 3 and Figure 4 by using the s-function builder. To read the voltage and current from the PV module, the voltage sensor and current sensor are used. The voltage sensor is read by Analog pin A1, while the current sensor is read from pin A0 of Arduino hardware. The voltage and current are needed to be converted, then sent as a value to the P&O or IC algorithm for calculation. The PWM signal is generated using pin 6 with a frequency of 980 Hz. The power is measured and sent via serial transmission to display the value of power that obtain by the MPPT algorithm.



(a) P&O design

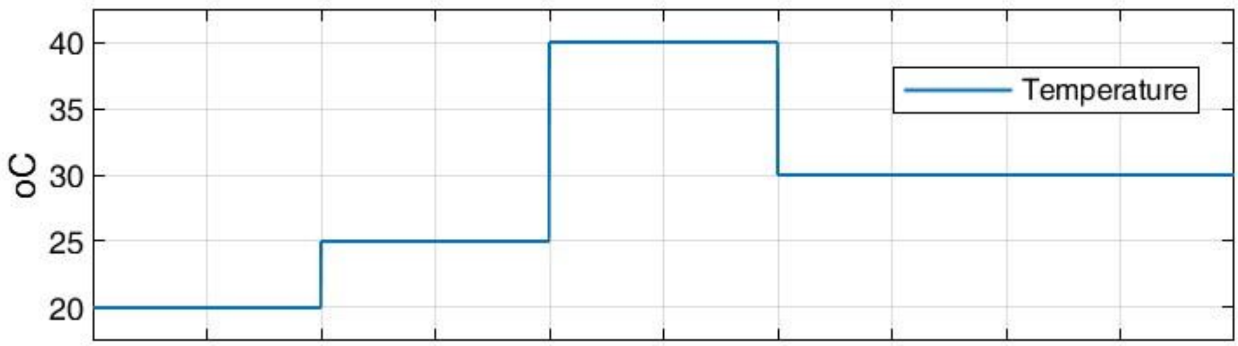


(b) IC design

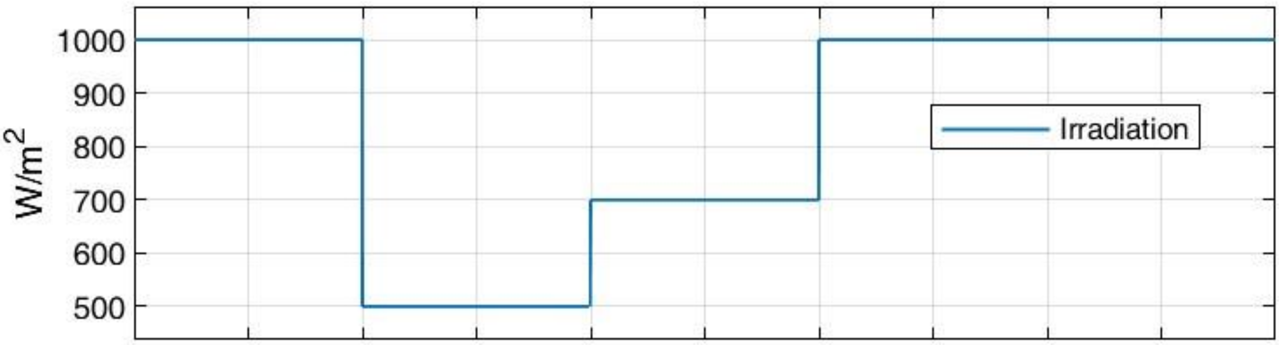
Fig 5. The algorithms design with Simulink support package for Arduino hardware

4. Result and Discussion

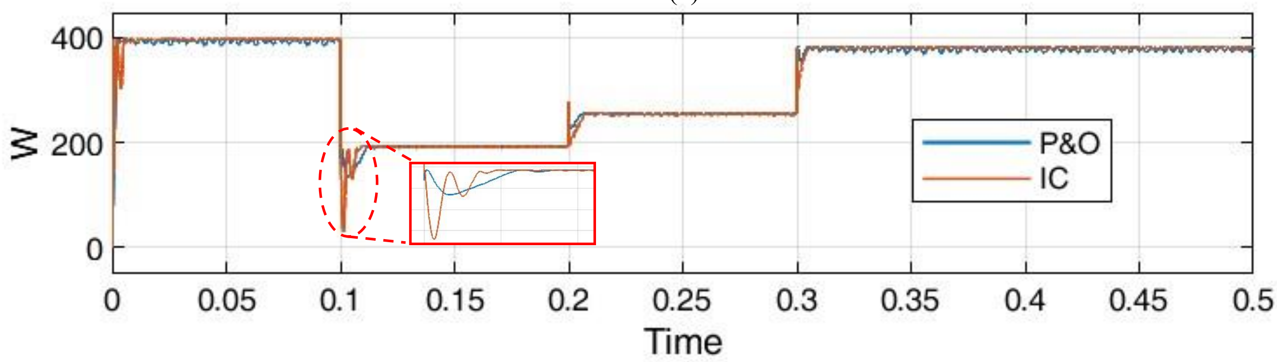
In this part, we show the simulation results on MATLAB Simulink. The system comprises a PV panel, DC/DC boost converter, MPPT (P&O, IC) controller, and load. This system will be tested with different variations in irradiation and temperature. Figure 6(a) shows changing temperature levels from 20 ºC to 25 ºC, 25 ºC to 40 ºC, and 40 ºC down to 30 ºC for comparison of P&O and IC algorithm performance. Figure 6(b) shows changing levels of irradiation from 1000W/m^2 down to 500W/m^2, 500W/m^2 to 700W/m^2, and 700W/m^2 to 1000W/m^2. Figure 6(c) shows the power generated by using P&O and IC algorithms. As a result of these figures, the performance and effectiveness of P&O and IC algorithms have been demonstrated. The maximum power operating voltage point can be tracked by P&O and IC MPPT. The P&O must be chosen for practical application due to its superior performance over the IC controller. As a result, the P&O has greater performance and is closer to the IC.



(a)



(b)



(c)

Fig 6. Temperature, Irradiation and Power generated by P&O and IC algorithms

In this section, we will use the Simulink Support Package for Arduino Hardware to perform experimental validation of the P&O and IC MPPT algorithms. The entire test bench is divided into three groups, which are as follows: (1) PV panel of 390 watts, DC/DC boost converter, resistance load; (2) Arduino Uno for control unit; (3) measuring by a computer equipped with MATLAB/Simulink.

4.1. Hardware Setup

The main controller board is the Arduino Uno, which is based on the ATmega328P. It contains 14 digital I/O pins (six of which are PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Figure 7 shows the Arduino Uno development board.

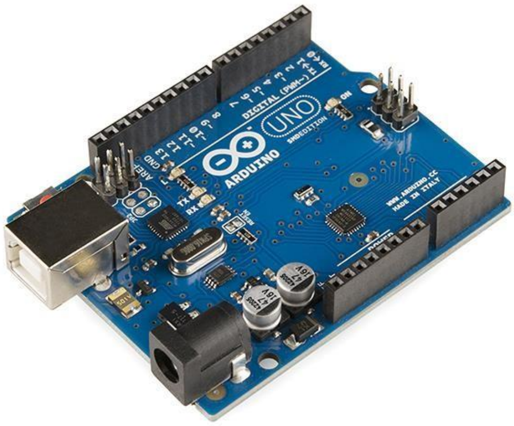


Fig 7. The Arduino Uno board

Figure 8 shows a block diagram of the proposed control board. For current measurement, we used the ACS712-20A sensor. This ACS721 current module is based on the ACS712 sensor, which can detect AC or DC current correctly. The maximum AC or DC that may be detected is 20A, and the current signal can be read using the Arduino's analog input/output interface.

As the DC Sensing Unit, a basic voltage divider circuit is utilized to convert the input DC voltages to a DC voltage in the 0 to 5 V range. This scaled-down voltage can be read by the Processor Unit and used to calculate the actual DC voltages. In this experiment, the voltage sensor is designed with a first resistor of 1MΩ and a second resistor of 10K that can measure DC input from 0 up to 500V. A boost converter is installed between a PV panel and a load. The experimental testing as shown in Figure 9.

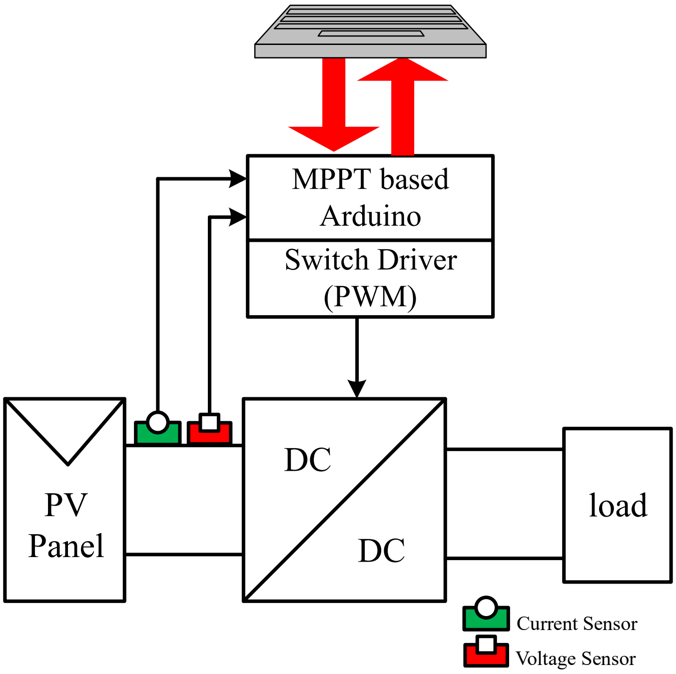


Fig 8. Block diagram of the proposed setup

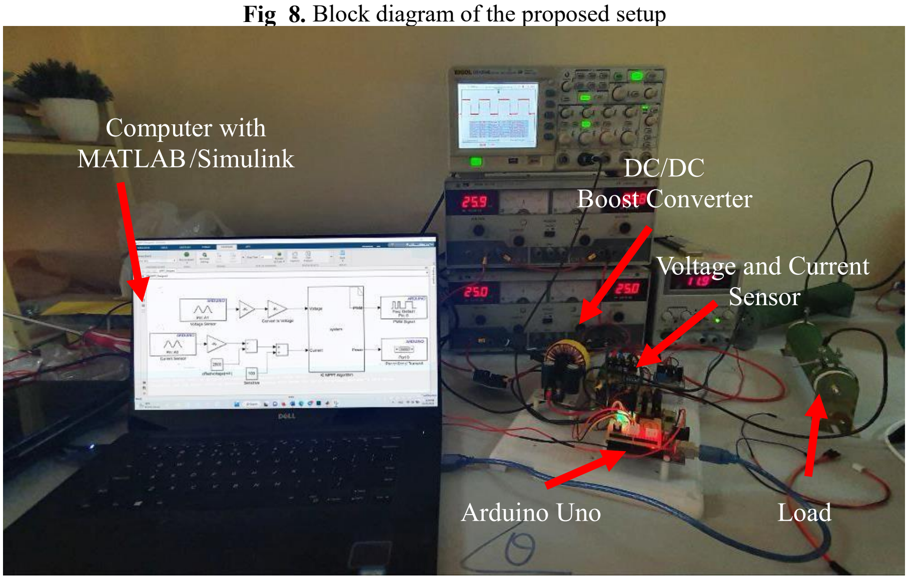


Fig 9. The experimental Setup

4.2. Experimental Result

The experimental test is performed to find the maximum power point (MPP). To monitor the signal, first go to MATLAB Simulink's model settings and select Hardware Implementation. On the hardware board, choose the Arduino Uno, and then, on the target hardware resources, set the host COM port to "automatically." Then, go back to hardware and click Monitor &Tune. Figure 10 shows the power produced by a PV panel of about 186.65W using the P&O and IC controller. According to the power plots, the P&O technique exceeds the IC strategy regarding steady-state performance, particularly regarding ripple around the maximum point. The power generated by the P&O approach is more significant than that produced by the IC method. Figure 11 shows the voltage of the PV panel. Figure 12 shows the current of the PV panel read by the ACS712 current sensor.

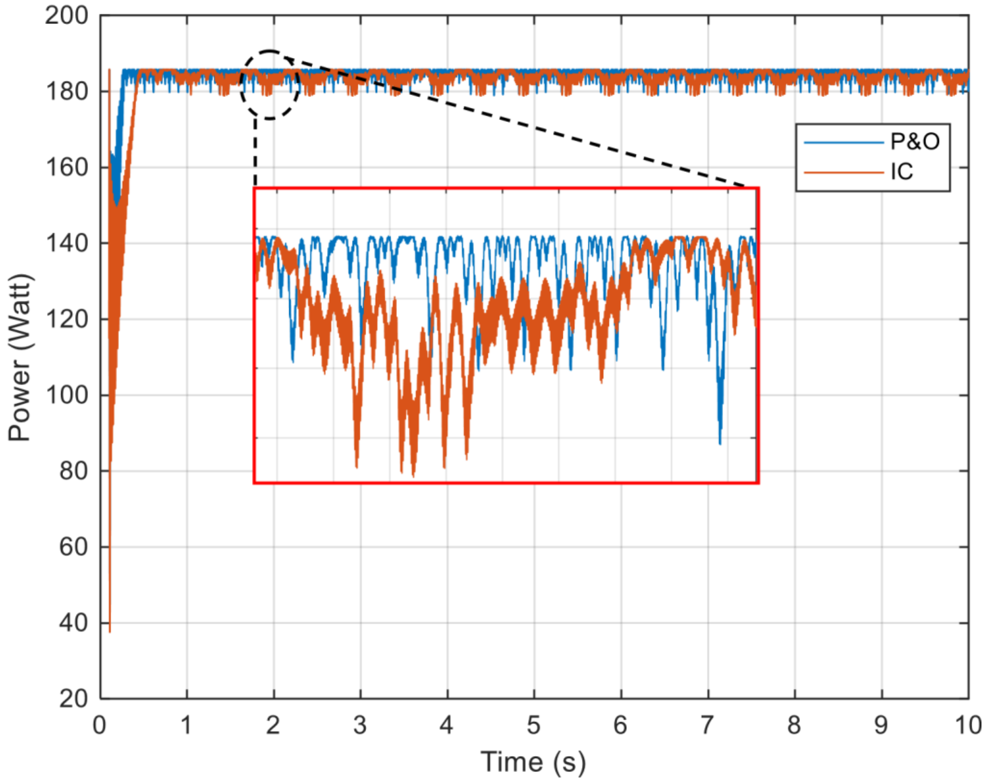


Fig 10. The Power generated using P&O and IC tracker

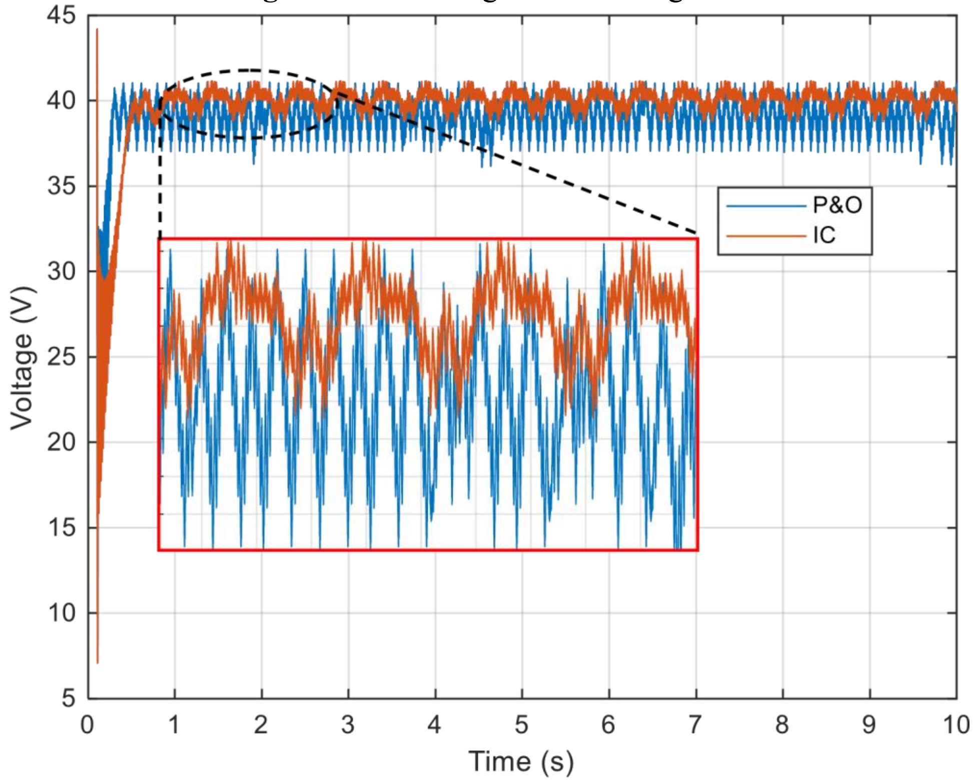


Fig 11. The voltage waveform of PV panel

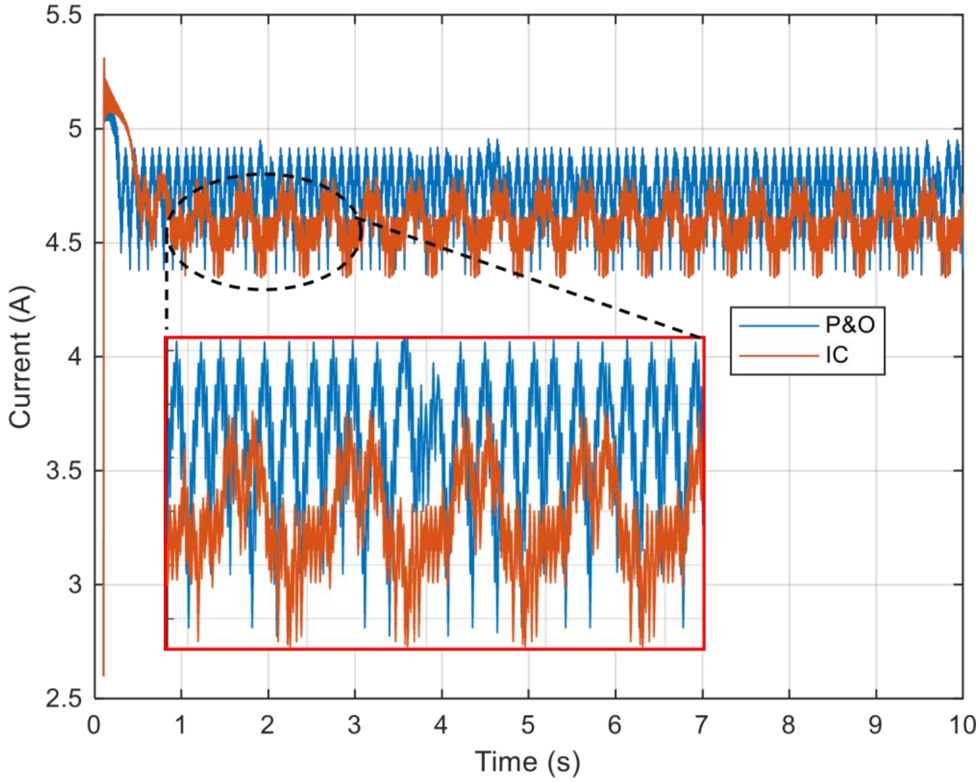


Fig 12. The current waveform of PV panel

5. Conclusion

In this research, we presented two methods for monitoring a PV panel's MPP. The system was tested and designed to show the benefits of the P&O method over the IC method, and its performances were analyzed through simulation and experimental implementation. The P&O MPPT demonstrates its sensitivity to atmospheric changes and provides a quick response time with a very low relative ripple rate. This experiment shows the capability of P&O and IC algorithms on the Arduino Uno board for real-time monitoring and application using the Simulink support package for Arduino hardware. Furthermore, this research presents the way for fast, easy, and customized control design.

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