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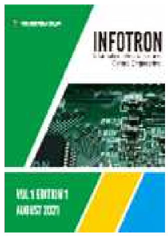

PV OPTIMIZATION WITH GENETIC ALGORITHM-BASED MPPT METHOD

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A B S T R A CT

This research designs and implements a Maximum Power Point Tracking (MPPT) system based on genetic algorithm (GA) on buck-boost converter using Arduino microcontroller to increase energy conversion efficiency on PV system. The GA algorithm is used to adjust the PWM duty cycle to achieve the maximum power point (MPP) optimally. Tests were conducted to analyze the performance of the GA compared to the Perturb and Observe (P&O) algorithm and the system without MPPT. The results show that the GA is able to achieve a maximum power of 26.16 W, higher than the P&O algorithm (23.77 W) and the system without MPPT (1.59 W). The GA also reaches MPP faster, maintains output stability, and reduces power fluctuations. Voltage and current sensor testing showed high accuracy with Mean Absolute Percentage Error (MAPE) of 0.291% and 0.206%, respectively. The system was shown to improve energy conversion efficiency under various lighting and load conditions dynamically. With these results, the genetic algorithm proved to be more effective in optimizing the output power of solar panels than conventional methods.

Keywords: MPPT; Genetic Algorithm; Buck-Boost converter; PV; Arduino

1. Introduction

The need for renewable energy sources is increasing in this day and age due to the dwindling availability of fossil energy sources and the negative impact of conventional energy use on the environment [1]. Many have switched to the use of renewable energy resources as a source of electrical power because the effects of climate change that can be produced by the use of fossil fuels and increasing CO2 emissions also encourage the growth of renewable energy technology [2]. Because fossil energy sources such as coal, petroleum, and others are depleting, so renewable energy is needed.

The renewable energy in question is energy that is easily obtained and environmentally friendly, such as solar energy. Currently, the use of solar energy to generate electricity is one of the technologies that must be developed in Indonesia. Solar panel or photovoltaic (PV) technology made from other semiconductors produces electrical energy from sunlight, this is called a solar cell [3]. The use of renewable energy is an excellent solution. One of the most promising solutions to meet sustainable energy needs is solar energy photovoltaic (PV) systems [4]. However, the non-linear characteristics of solar panels are caused by variations in power output caused by variations in irradiance, solar temperature, and an efficiency of less than 20% [5]. Therefore, it is necessary to obtain the optimal output power from the solar panel.

The most commonly used energy storage component in photovoltaic applications is the battery because it is able to capture energy variations, which improves the dynamic characteristics of the system. To charge and utilize the battery, a converter circuit is needed that is able to regulate the direction of energy flow [6]. So, a voltage converter is needed, one way to do this is by using a DC-to-DC converter. A buck-boost converter system can adjust its output voltage to be lower or greater than its input voltage [7][8]. A buck-boost converter is a combination of a boost converter and a buck converter, which allows the ratio of output voltage to input voltage to be greater or less than 1,

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depending on the duty cycle applied. The system is designed to manage voltage changes caused by variations in solar radiation intensity and temperature[9].

The solar panel output has a maximum power point (MPP), which produces electricity with the highest efficiency. Since the sunlight conditions change all the time, resulting in changing radiation and voltage, a Maximum Power Point Tracking (MPPT) method is needed to track the maximum power point and increase the power production of solar panels [10]. With MPPT control, maximum energy conversion is expected over a wide range of load conditions. The current and voltage values of photovoltaic cells will differ in the amount of their maximum output power.

PnO, IC, and constant voltage are some of the methods to generate MPPT controllers. These methods have drawbacks, such as limitations in dealing with complex and rapidly changing environmental conditions. In this article we use the genetic algorithm method which is one of the ways to create MPPT controllers to overcome the shortcomings of previous methods [11]. This algorithm can be used to find the best solution in a complex search space, taking inspiration from the natural evolutionary process. By considering solar radiation, temperature, and load conditions, GA can be used in photovoltaic systems to optimize the output of PV [12],[13]. With the use of GA, the system can proactively change plans to maximize power, and improve performance at load [14].

This research develops an MPPT system for solar panels by integrating a genetic algorithm (GA) into the duty cycle setting of an Arduino microcontroller-based buck-boost converter. This approach aims to optimize the achievement of maximum power point more adaptively and efficiently than conventional methods such as Perturb and Observe (P&O) and Incremental Conductance (INC). The main novelty of this research lies in the application of GA algorithm in the MPPT system, which enables global search of maximum power point, especially under dynamic and complex environmental conditions. The genetic algorithm is implemented to adjust the PWM duty cycle on the buck-boost converter, with the aim of maximizing the power output from the solar panel. The process involves the evaluation of a population of solutions representing various duty cycle values, selection of the best individual based on the resulting power output, as well as crossover and mutation operations to generate a new generation of solutions. Through these iterations, the system can adaptively find and maintain the maximum power point despite changing environmental conditions such as solar irradiance, temperature changes and partial shading. Thus, the application of genetic algorithms in this buck-boost converter-based MPPT system is expected to improve energy conversion efficiency, optimize energy utilization from solar panels, and reduce operational costs.

2. Method

Designing a buck-boost converter for 20 Wp solar panels (PV) requires a block diagram that contains stages to help the design process. Figure 1 shows the block diagram.

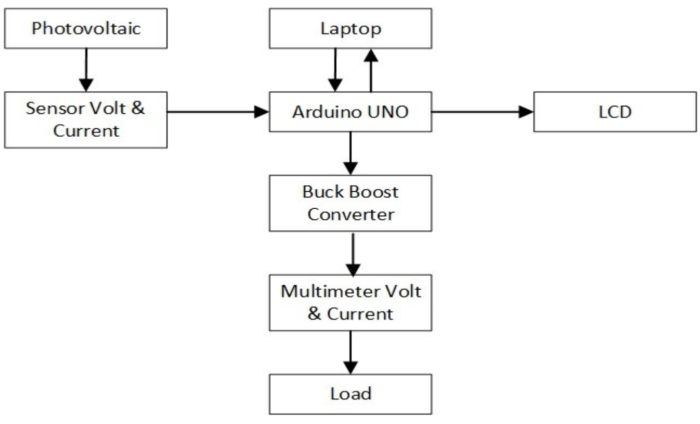

Fig. 1. System Block Diagram

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Informatics, Electrical and Electronics Engineering (Infotron)
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Figure 1 is an overview of how the genetic algorithm uses a buck-boost converter (power supply or adapter) to optimize the design of solar panels for solar panel systems. The power supply or adapter provides voltage to the Arduino UNO, and the voltage and current sensors detect the voltage and current of the photovoltaic output. Furthermore, the voltage, current, power, PWM, and dutycycle values of the photovoltaic output are displayed on the LCD. The Arduino receives a command from the program to run a genetic algorithm (GA) to send to the buck-boost converter circuit to get the best voltage, current, and power from the buck-boost converter output. We can use a digital multimeter to measure the voltage and current values of the buck-boost converter.

This research adopts genetic algorithm (GA) as an optimization method to find the maximum power point (MPPT) under various radiation and temperature conditions. The MPPT system is designed to optimize the output power from the solar panel, thus allowing the output of the converter to be maximized in efficiency. To adjust the output voltage of the panel, the system utilizes a buck-boost converter that regulates the duty cycle. The initial stage in designing this algorithm is the initialization of the initial population, which consists of a number of individuals (chromosomes) with random duty cycle values in the range (0 - 1). This population serves as an initial solution to find the Maximum Power Point (MPP) power point, taking into account the specification limitations of the Buck-Boost converter. Voltage (V) and current (I) data are obtained through sensors to calculate the output power, which is used as the basis for fitness assessment of each individual.

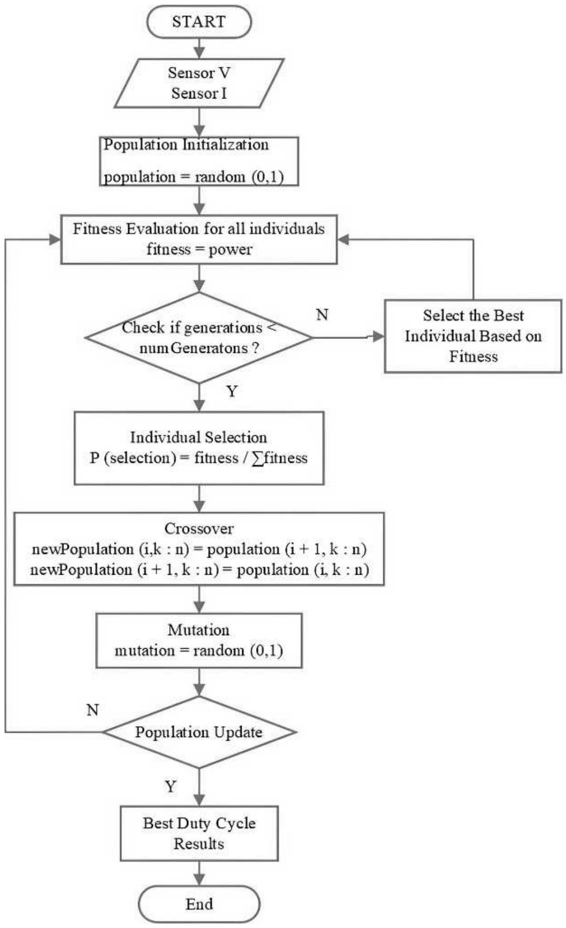

Fig. 2. Genetic Algorithm Flowchart

Individual evaluation is performed by calculating the fitness function using the formula $P = V \times I$, where P represents power, V is voltage, and I is current. This fitness function is used to determine

Informatics, Electrical and Electronics Engineering (Infotron)
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how close an individual is to the maximum power point. The reproduction process in genetic algorithms involves three main stages: selection, crossover, and mutation. Selection is done using the roulette wheel selection method, where individuals with higher fitness values have a greater chance of being selected as parents. The crossover process combines the characteristics of the two selected individuals to produce new offspring with the genetic combination of the two parents. Mutations are applied randomly to add variation to the population, maintain genetic diversity, and avoid premature convergence.

After passing the selection, crossover, and mutation stages, the population is updated with the new individuals generated, and then re-evaluated in the next generation. This process continues for several generations until convergence is reached or an optimal solution is found. The individual with the highest fitness value at the end of the process will be selected as the optimal solution, which is the duty cycle that produces the maximum power from the PV system. This optimal duty cycle is applied to the Buck-Boost converter to regulate the output voltage according to the load requirements. With this design, the MPPT system is expected to be able to adapt to changes in environmental conditions, such as fluctuations in solar irradiation intensity and temperature, so as to increase optimal power efficiency.

The genetic algorithm is applied to a system that includes solar panels, current sensors, voltage sensors, buck-boost converters, MOSFET drivers, and Arduino UNO-based MPPT microcontrollers. Figure 3 shows the overall system circuit. This research does not address the tilt angle of the solar panel, assuming that the solar panel is placed perpendicular to the sunlight.

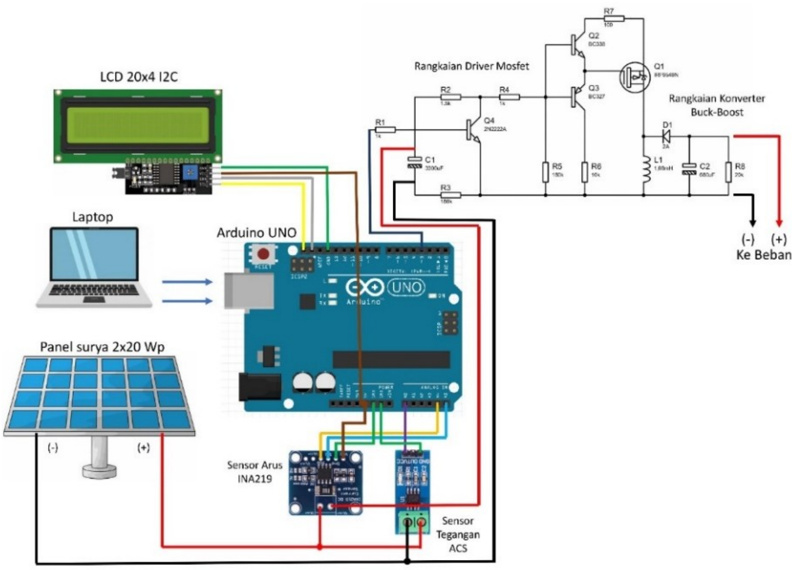

Fig. 3. Overall Circuit

The whole system circuit is designed to optimize the performance of solar panels using genetic algorithms along with buck-boost converters. A power supply, adapter, or laptop provides the required voltage to the Arduino UNO, while voltage and current sensors detect the voltage and current produced by the solar panel (PV) output. The program run on the Arduino then implements the genetic algorithm to regulate the buck-boost converter circuit, with the aim of obtaining the optimal voltage, current, and output power.

3. Result and Discussion

After designing the solar panel system with Arduino UNO, the next step is to develop the design into a complete system. The system consists of solar panels as energy sources, current sensors

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Informatics, Electrical and Electronics Engineering (Infotron)
Volume 5, Number 1, (2025) pp. 38-48
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and voltage sensors to measure electrical parameters, buck-boost converters to regulate voltage, and Arduino UNO as a microcontroller that runs genetic algorithms (GA) for MPPT implementation. The display of system results is presented through a 20×4 LCD with a serial I2C interface, which is then connected to the load. The overall implementation of the solar panel system hardware circuit with Arduino UNO can be seen in Figure 4.

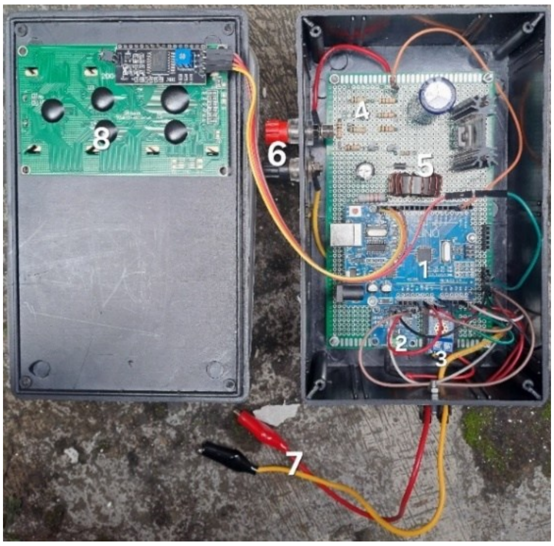

Fig. 4. Hardware research testing module

Figure 4 shows the hardware component for experiment setup. This research uses a voltage sensor with a voltage divider technique for measuring the voltage of solar panels. The voltage sensor used in this research is a 25 V DC voltage sensor, which is inserted into an electrical power source. Sensor testing is done with a multimeter and compared using the Arduino IDE serial monitor to read the sensor on a laptop and record the voltage sensor test results. Tests were conducted with 5V, 10V, 15V, and 20V voltage inputs, and twenty data were collected to be averaged.

Table 1. MAPE Voltage

Multimeter Voltage	Sensor Voltage	MAPE %
5,08	5,03	0,98
10,12	10,09	0,29
15,06	15,07	0,06
20,05	20,07	-0,049
Mean Absolute Percentage Error (MAPE)		0,35

The conclusion in Table 3 shows that the sensor measured the voltage with a MAPE value of 0.35%, which is almost the same as that measured by the multimeter. Since the MAPE value obtained was ≤5%, testing of the current sensor was performed.

In this study, an INA219 current sensor was used with 25mA, 50mA, 75mA, and 100mA inputs. A total of twenty data were collected for each voltage, and then the average was calculated. The MAPE value of each current was calculated and MAPE data was collected from the current sensor.

The conclusion from the current measurement results obtained from the INA219 sensor in Table 4 shows that the current measured by the INA219 sensor is almost identical to the current measured using a multimeter, with a MAPE value of 0.18%. Since the MAPE value obtained is in accorandce with the predetermined target, which is ≤5%, this research can be continued.

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Informatics, Electrical and Electronics Engineering (Infotron)
Volume 5, Number 1, (2025) pp. 38-48
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Table 2. MAPE Current

Multimeter Current	Sensor Current	MAPE %
25,25	25,20	0,19
50,59	50,42	0,33
75,44	75,35	0,11
100,14	100,05	0,09
Mean Absolute Percentage Error (MAPE)		0,18

The study was conducted under direct sunlight with a light intensity of 78200 lux to illustrate the changes in radiation. The test involved assembling a photovoltaic system with an energy source from sunlight, an input from the photovoltaic, and an output given to a 220Ω load.

Photovoltaic system testing is conducted to evaluate the performance of the MPPT system. This study aims to measure the power generated by the system based on the received light intensity, especially under changing radiation conditions, while analyzing the ability of the MPPT algorithm to track the maximum power point in the hardware implementation. After the assembly process, software and hardware preparation is performed, and the test results are analyzed to compare the performance of the system with the algorithm and without the algorithm.

Testing Photovoltaic System with MPPT Without Algorithm

Testing the photovoltaic system with MPPT without using the algorithm is done to determine the performance of the photovoltaic system in tracking the power point generated by the photovoltaic system based on the light intensity received, especially in rapidly changing radiation conditions. The results of the photovoltaic system testing are shown in Figure 6 without an algorithm to determine the performance of the photovoltaic system in the hardware circuit used to track the power point generated by the photovoltaic output module.

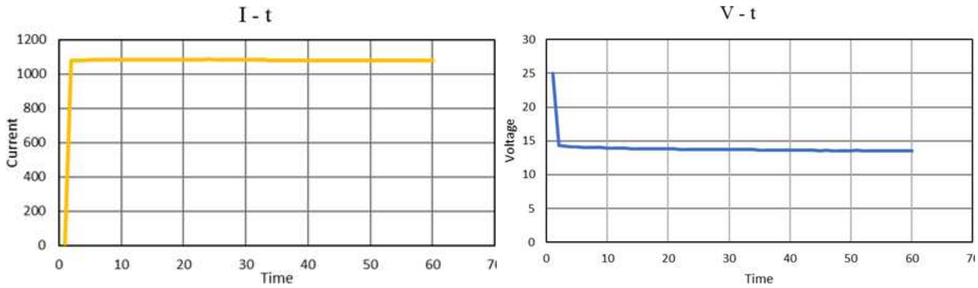

Fig. 5. Graph of current and voltage against time on photovoltaic without an algorithm

MPPT testing on the buck-boost converter without an algorithm shows a very fast current spike from 0 to about 1000 A in a short time, before stabilizing with small fluctuations. The voltage experienced a sharp drop from about 25 V to 14 V due to the drastic current surge, then stabilized at about 14 V. These results show that without the MPPT algorithm, the system relies solely on the natural response of the buck-boost converter to stabilize the current and voltage, without any maximum power point (MPP) finding mechanism. Although the converter can achieve steady-state conditions, the stability achieved is not at the optimal maximum power point. Thus, the use of MPPT algorithm is required to dynamically improve the system efficiency under various environmental conditions, so that the output power can be optimized more effectively.

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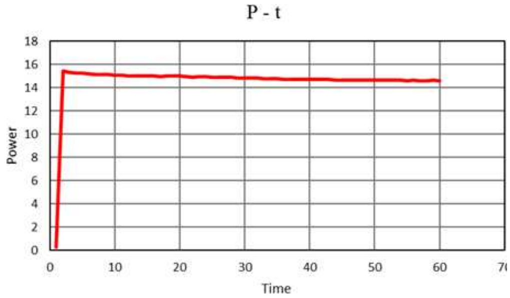

Fig. 6. Power Curve Against Time

Figure 7 shows the graph of power against time without the application of the algorithm. The peak power recorded at the output of the solar panel without algorithm is 1.59 W. The graph shows a rapid increase in power at the beginning before reaching a steady state with slight fluctuations. After reaching the initial working point, the power tends to stabilize without any dynamic adjustment due to the absence of the MPPT algorithm that serves to track the maximum power point continuously. This stability indicates that the system only works at one fixed working point which is not necessarily the maximum power point, resulting in less than optimal power conversion efficiency. The small fluctuations that occur are likely caused by changes in environmental conditions or the natural characteristics of the buck-boost converter. Overall, the performance of this system is not as efficient as the system with the MPPT algorithm due to its inability to adjust to changing conditions to optimize output power.

Photovoltaic system testing with MPPT that implements the P&O Algorithm was conducted to measure the power generated by the photovoltaic system based on the light intensity received, especially in rapidly changing radiation conditions. This test is to determine the comparative performance with no algorithm. The results of the testing of the photovoltaic system that implements the P&O algorithm were conducted to assess the performance of the photovoltaic system in a hardware circuit that serves to track the maximum power point generated by the photovoltaic output module.

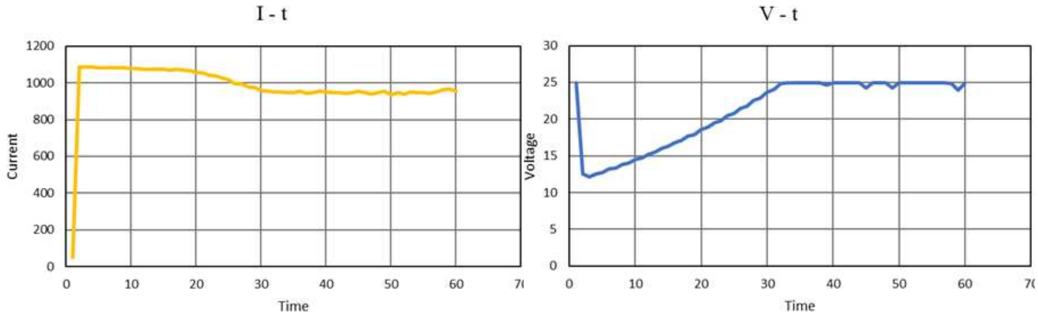

Fig. 7. Current and Voltage Graph Against Time in Photovoltaic Based on P&O Algorithm

MPPT testing with the Perturb and Observe (P&O) algorithm-based buck-boost converter showed that the initial current increased sharply to around 1000 mA, then decreased slightly and stabilized at around 900 mA. The voltage graph initially shows a decrease from 25 V to around 13 V, before gradually increasing again and stabilizing at around 25 V. The voltage drop at the beginning of the test is due to the process of finding the maximum power point by the MPPT algorithm. After a few iterations, both current and voltage become more stable, indicating that the system has found and maintained the maximum power point. The small fluctuations seen in the graphs are characteristic of the P&O algorithm, which works by interrupting and observing power changes to ensure the system remains in an optimal state. The results of this test show that the P&O algorithm

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Informatics, Electrical and Electronics Engineering (Infotron)
Volume 5, Number 1, (2025) pp. 38-48
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is able to optimize power by dynamically adjusting current and voltage, thereby increasing the energy conversion efficiency of the photovoltaic system.

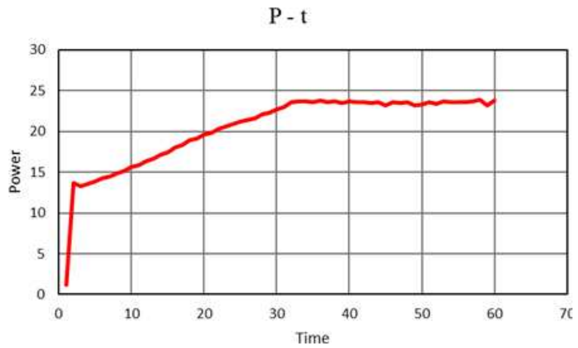

Fig. 8. Power Curve Against Time (P&O)

Figure 8 shows the graph of power against time with the application of the P&O algorithm on the solar panel. Without the algorithm, the peak power recorded is 3.77 W at 60 seconds, while with MPPT the power increases to about 25W and stabilizes with little fluctuation. This pattern reflects the effectiveness of the P&O algorithm in adjusting the voltage and current to reach the maximum power point. The test results prove that the system is able to optimally follow changes in light radiation, improve energy conversion efficiency, and generate higher power than without the algorithm.

Testing the photovoltaic system with MPPT that implements the Genetic Algorithm is used to measure the power output received by the converter based on the incoming light intensity, especially in rapidly changing radiation conditions. This test aims to determine the performance and effectiveness in optimizing the output power. To illustrate the real-world changes in irradiance the system is controlled by a genetic algorithm, dynamically adjusting the maximum power point of the system to maximize energy conversion efficiency, even when the light intensity changes. The test is conducted by monitoring the changes in output power based on variations in light intensity. The test results were analyzed in depth to evaluate the system performance, assess the superiority of the AI based method over the conventional method, and determine the effectiveness of MPPT under dynamic lighting conditions.

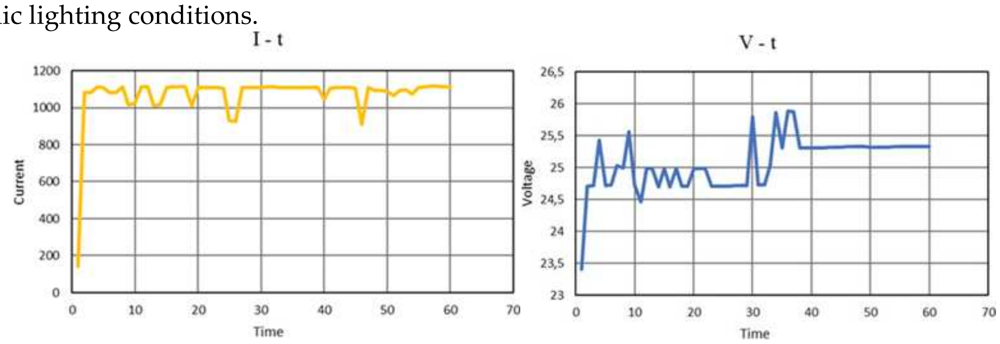

Fig. 9. Current and Voltage Graph Against Time in Photovoltaic Based on Genetic Algorithm

Testing the genetic algorithm-based MPPT with buck-boost converters shows that the initial current has a sharp increase up to about 1000 A before stabilizing with small fluctuations. These fluctuations reflect the process of searching for the maximum power point, where the genetic algorithm continuously adjusts the duty cycle of the converter to achieve the optimal condition. The voltage graph shows an increase from about 23 V to 25.5 V, with small oscillations before reaching stability, indicating that the system is adjusting to find the optimal maximum power point. The fluctuations are part of the algorithm's mechanism of evaluating and adjusting parameters to ensure

Informatics, Electrical and Electronics Engineering (Infotron)
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the system works at its highest efficiency. These results prove that genetic algorithms are capable of adaptively adjusting current and voltage, maintaining system stability, and improving power conversion efficiency under various environmental conditions, such as in solar panel applications.

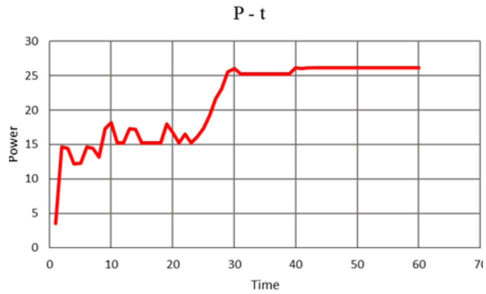

Fig. 10. Power Curve Against Time (GA)

Testing the genetic algorithm-based MPPT with buck-boost converter shows that the initial power increases gradually from 10-15 W with small fluctuations due to the algorithm's exploration process in finding the maximum power point. Over time, the power continues to increase until it reaches 26.16 W at the 40th second, indicating that the system has found the optimal power point and is able to maintain it stably. The power stability after 40 seconds shows that the genetic algorithm effectively tracks and optimizes the energy conversion from the solar panel, even under varying lighting conditions. The initial power fluctuation is part of the algorithm's search mechanism before finding the optimal condition. These results prove that genetic algorithms can improve the efficiency of solar power systems by adaptively adjusting the output power, ensuring more maximum and stable energy utilization than conventional methods.

This photovoltaic system test uses a genetic algorithm to compare the performance and effectiveness of the AI-based MPPT method with the conventional P&O (Perturb & Observe) method under rapidly changing radiation conditions. The tests were conducted under sunlight to ensure real and equivalent conditions for both algorithms. The main objective of this test is to optimize the output power of the photovoltaic system and to determine the extent to which the genetic algorithm is able to improve efficiency compared to the P&O method. The test data is presented in the form of power, current, and voltage comparison graphs. In the graph, the P&O-based MPPT test results are displayed in blue, while the genetic algorithm-based MPPT test results are displayed in red.

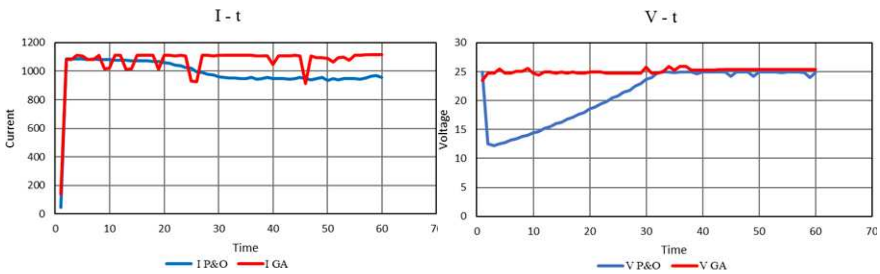

Fig. 11. Comparison Graph of Current and Voltage in MPPT Using Genetic Algorithm and P&O Algorithm

The current and voltage comparison graph between the genetic algorithm (GA) and Perturb & Observe (P&O) shows that the GA is able to reach the maximum current faster, close to 1100 mA, and maintain it steadily. Although there were slight fluctuations in the beginning, the GA current was more stable in the long run than P&O, which only reached around 900 mA and experienced more frequent fluctuations. These fluctuations occur because the P&O algorithm continuously perturbs to find the maximum power point, causing greater variations in current.

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Volume 5, Number 1, (2025) pp. 38-48
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On the voltage graph, GA shows an advantage in response speed, instantly reaching a maximum voltage of about 25 V in a short time and maintaining it without significant fluctuations. In contrast, P&O takes longer to reach the maximum voltage, with gradual increases and larger fluctuations before finally stabilizing. This shows that the P&O algorithm has a longer transient time than the GA.

These results prove that GA is more efficient in finding and maintaining the maximum power point with better stability and shorter transient time. Thus, GA provides more optimal performance in buck-boost converter-based MPPT systems, increasing the output power efficiency on solar panels compared to the P&O algorithm.

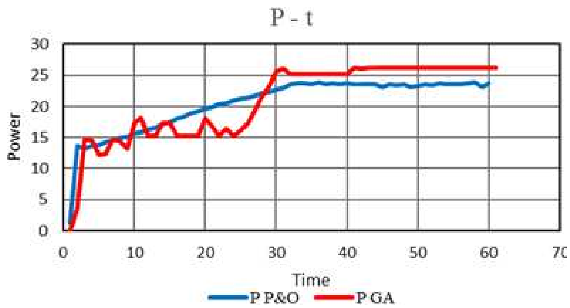

Fig. 12. Power Curve Against Time

The power graph shows that the genetic algorithm (GA) performs better in MPPT optimization than the Perturb & Observe (P&O) algorithm. The GA reaches a peak power of about 26 W quickly and maintains it stably, indicating high efficiency in maintaining the maximum power point (MPP). In contrast, P&O experienced a gradual power increase with larger fluctuations before stabilizing at around 23 W, due to the continuous MPP search process.

The results from the current, voltage, and power graphs show that GA has a faster response, better output stability, and higher power conversion efficiency than P&O. While P&O shows more frequent fluctuations and longer transient times, GA is able to adjust the system more optimally. In conclusion, the genetic algorithm is more effective in optimizing the output power of solar panels, making it a superior solution for buck-boost converter-based MPPT systems.

4. Conclusion

Based on the design, testing, results, and analysis that have been carried out in this study, it can be concluded that from the design, the solar panel system with MPPT using genetic algorithms shows quite good performance. The test results show that the mean absolute percentage error (MAPE) for the input sensor is below 5%. In addition, the buck-boost converter output voltage value increases with load time and input voltage. This indicates that the genetic algorithm-based MPPT system has the ability to optimize power regulation and improve energy conversion efficiency on solar panels, especially when the changing conditions of irradiance and load are dynamically adjusted. The test results show that the MPPT algorithm can significantly increase the output power of solar panels compared to the method without algorithm. This result is demonstrated on a buck-boost converter with sunlight of 78500 lux. If there is no algorithm, the peak power only reaches 1.59 W. However, with the P&O algorithm, the peak power increases to 23.77 W in 60 seconds, while the genetic algorithm gives the best result with 26.16 W in 40 seconds. This shows that the genetic algorithm is better at finding the maximum power value (MPPT) than other methods..

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