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The Implementation of MPPT Perturb and Observe Method with Boost Converter on PV System

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Abstract. Solar panels can convert solar energy into electrical energy under direct current conditions. Changes in solar radiation cause the MPP characteristics of solar panels to be unstable so the electrical power generated by a solar panel is not optimal. Therefore, the Maximum Power Point Tracking (MPPT) system with the Perturb and Observe method is used to maximize the power received by the solar panels. The Perturb and Observe algorithm is implemented through a boost converter circuit by changing the duty cycle value on the Atmega328 Arduino Uno microcontroller as a frequency source. MOSFET inductors, capacitors, diodes, and resistors as obstacles to adjusting the input to regulate the DC-DC voltage by adjusting the pulses on the PWM generated from the microcontroller. The INA219 sensor is used to read the data of each system. The single-axis solar panel system uses a DC motor to move the panel supported by an LDR sensor to detect the highest light intensity. The test results of solar panels with a single-axis MPPT with Perturb and Observe methods and a single-axis tracking system produce 45,23W of power with an efficiency of 90.46%.

INTRODUCTION

In a country with a tropical environment, solar energy can be employed as a backup electrical energy source. In addition to the limitless energy of the sun, this electrical energy does not harm the environment in any way. It may be put anywhere as long as it is exposed to direct sunshine, simple to maintain using sunlight as a source of electrical energy and solar cell as solar energy to electrical energy converter energy [1]. Because of that, the management of solar energy for Solar Power Plants is a wise choice.

The benefit of using solar panels is that electricity can be consumed immediately and over a long period. Photovoltaic cells have non-linear power characteristics, which vary according to environmental conditions [2]. The variation in temperature and irradiance, for example, changes the voltage output, as well as the current generated by the PV module [3]. Consequently, the power generated varies as well. Therefore, the point of operation of the PV grid for maximum energy output changes. This operational point is referred to as the maximum power point (MPP) and the voltage at which the PV module can produce the maximum power is referred to as the maximum power voltage (or peak voltage) [4].

The Maximum Power Point Tracking (MPPT) system can be a solution to these problems. MPPT algorithms have been integrated with electronic power conversion systems, where the MPPT algorithms manage the duty cycle of the converter to deliver the load with the most power that is available [5]. MPPT uses a power converter to find the maximum power point on the solar panel PV characteristic curve. The MPPT system is operated to keep the operating point in maximum condition. Several MPPT algorithms have been found and written in international scientific journals such as Fuzzy Logic (FL), Incremental conductance (INC), Network (ANN), Perturb and Observe (PO), Particle

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Swarm Optimization (PSO), Constant voltage (CV) and are some of the MPPT algorithms that are widely used. Each of these algorithms has unique properties in terms of complexity, convergence speed, step responsiveness, stable state oscillations on MPP, and necessary electronic apparatus [6].

The algorithm used to perform this search is Perturb and Observe. According to Morale in his research, this algorithm generally consists of two stages, namely [7]: (1) perturb, sending changes to the solar panel reference voltage or current (2) observe, calculating the power caused by the perturb. This is done as a reference to reduce or increase the voltage in the next step to get the MPP value of the solar panel.

Based on a Perturb and Observe method that employs fuzzy logic as a PWM value controller and a constant voltage combination mechanism, the average efficiency of the developed MPPT hardware is 88.89% [8]. The MPPT usually uses static solar panels or uses a DC motor that moves according to the angle of incidence of light. Therefore, this research employs MPPT based on perturb and observe algorithm utilizing motor DC and Light Dependent Resistor sensor to drive the panel to track the optimal condition of the solar cell and create a solar cell function in optimal condition with higher efficiency.

SYSTEM AND METHOD

Characteristics of Solar Panel

The PV characteristic curve of solar panels with different solar radiation is shown in **FIGURE 1**. This characteristic illustrates the output power of solar cells and the voltage increases according to the value of light intensity. The magnitude of the output current from a PV is directly proportional to the amount of solar radiation received by cell, while the IV characteristic curve of the PV is determined by the characteristics of the diode. It also shows that the output characteristics of solar cells are non-linear and are strongly influenced by solar radiation, temperature, and loading conditions.

In contrast to the I-V characteristic curve in **FIGURE 2** [9], PV cells feature nonlinear I-V characteristics that vary with temperature and light intensity. The largest power point usually occurs at the knee of the curve, as shown, under the standard parameters of temperature (25 °C) and radiation level (1000 W/m^2) [10]. On the other hand, the current generated will increase as the temperature of the solar cell increases. Isc is more affected by irradiance than Voc. This is under the explanation of light as a photon particle. At irradiance (many photons) the resulting current is also large. Different temperature and irradiation values of each solar panel will produce different maximum output power. This will be obtained and known as Maximum Power Point (MPP).

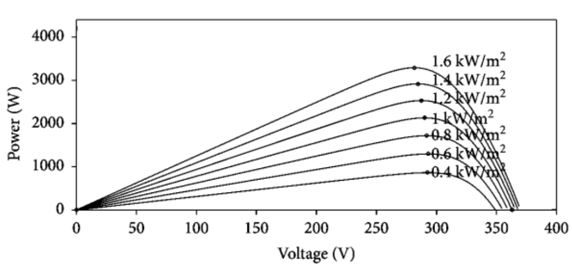

FIGURE 1. Power characteristics of a PV module [4].

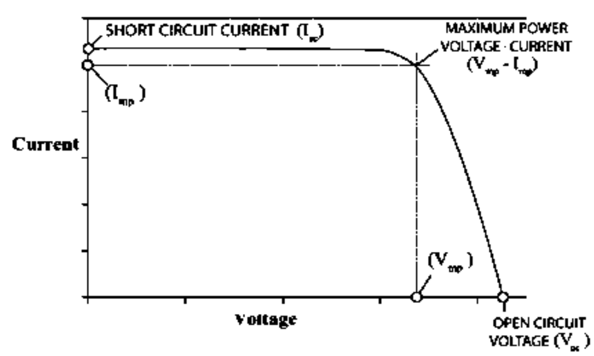

FIGURE 2. Current and voltage characteristic curve of solar panel.

Maximum Power Point Tracker using Perturb and Observe Algorithm

Maximum Power Point Tracking (MPPT) is a method to maximize the output power generated by solar panels. The MPPT functions to track the power generated by the solar panel so that it is at its maximum point with changing irradiation conditions and ambient temperature [7]. The tracking algorithm uses Perturb and Observe. An algorithm that looks for zero dP/dV as a sign of the peak of the Maximum Power Point (MPP) curve. Perturbation & Observation consists of two stages; perturbation is to change and observation is to calculate the change in power due to the action of the previous perturbation. If the change in power is positive then the perturb will stay in the same direction, whereas if the change in power is negative then the perturb will be reversed [11]. Regarding the V-P properties of the solar cell, P&O is also referred to as "hill climbing”.

As in **FIGURE 3**, P&O-based algorithms observe output power while perturbing the PV module’s output voltage. In the same direction, the voltage will be further perturbed if P>0, the voltage will increase and vice versa. However, if it is lower than 0, the direction of the voltage shift will be opposite. Periodically, these disturbances are introduced, and the entire process keeps repeating until the maximum power point is reached [12]. The operating point oscillates about the MPP as a result of the disturbances because they are periodic in character. This algorithm’s drawback is that it takes a long time to reach the MPP, which reduces efficiency, especially in situations when environmental factors are changing quickly. This algorithm’s ultimate result could also be changed in the output [4].

The flowchart of this algorithm is shown in **FIGURE 4**. The rectifier’s output voltage (V) and current (I) are read in the MPPT P&O algorithm and the power value P(k) at that moment is determined. The power value in the subsequent calculation P(k) is compared to the power value in the preceding calculation P(k-1). The duty cycle (D) value will be raised by ΔD if the power P(k) is larger than the power P(k-1). In contrast, the duty cycle (D) value will be reduced if the power P I is lower than the power P(k-1) value. The power value P(k) is then stored in memory and becomes the power value of P(k-1) during the next computation [13].

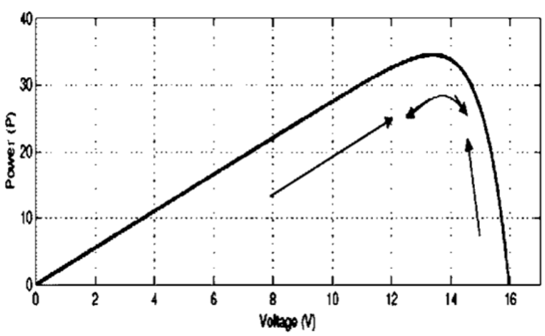

FIGURE 3. P-V graph for perturb and observe algorithm [14].

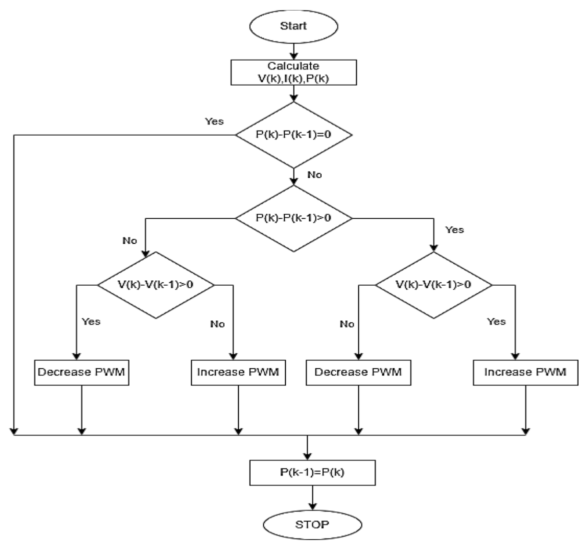

FIGURE 4. Flow diagram of perturb and observe algorithm.

Design of Boost Converter Circuit

The boost converter is another switching converter that operates by periodically opening and closing an electronic switch. It is called a boost converter because the output voltage is larger than the input [15]. The voltage change is done by adjusting the duty cycle on the PWM through the Arduino Uno Atmega328 microcontroller. This converter can increase the solar panel output voltage while running the Perturb and Observe. The output voltage Boost Converter will be connected to the solar charger and ACCUMULATOR as a load as well as charging the battery in series to 24V. The Boost Converter and Driver used in this study are shown in **FIGURE 5** (see **TABLE 1**).

The value of the duty cycle and the critical value of the inductor and the capacitor in the boost converter can be determined using the following equation [15]:

$$D = \frac{Vo - Vs}{Vo} \quad (1)$$

$$L_c = \frac{D(1-D)^2 R}{2f} \quad (2)$$

$$C_c = \frac{D}{R(\frac{\Delta Vo}{Vo})f} \quad (3)$$

Where D is Duty Cycle (D), Vo is Output Voltage (V), Vs is Input Voltage (V), R is Resistance (Ω), f is Frekuensi (Hz), Lc is Crisis Inductor (H), and Cc is Crisis Capacitor (C).

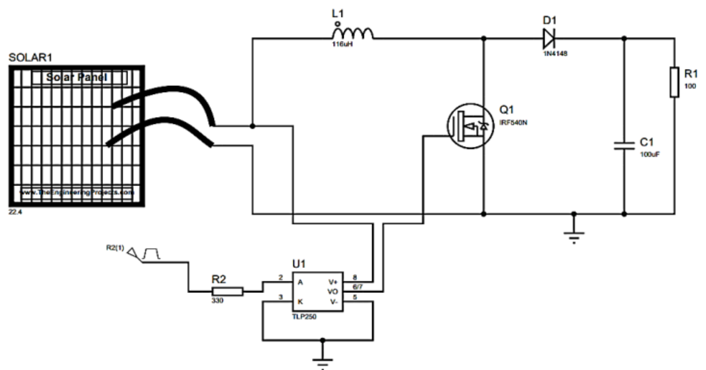

FIGURE 5. Boost converter circuit using TLP250.

TABLE 1. Boost converter specification.

Parameters	Value
Minimum Input voltage (Vs_{min})	5V
Maksimum Output Voltage (Vs_{max})	22,4V
Boost converter Output Voltage (V_o)	24V
Inductor (L)	116μH
Capacitor (C)	100μF/160V
Load Resistance (R_L)	100Ω/60W
Duty cycle (D)	6,7%-79%
Voltage Ripple (ΔV_o)	0,01%
Switching Frekuensi (f_s)	31,25kHz

Single Axis Design

This research uses a DC motor as a component that drives the solar panel. Using a single axis, a sun tracking system tracks the sun from east to west, changing course automatically as the sun's intensity drops. A DC motor turns the panel while a microcontroller serves as the system's primary processor. An LDR light sensor tracks the sun's course [16]. Sensor LDR (Light Dependent Resistor) is a type of resistor whose resistance is influenced by the intensity of the light received. Each LDR sensor has a different resistance when exposed to uneven light radiation.

In **FIGURE 6**, there are 4 LDR sensors placed on one side of the solar panel. However, each LDR is given a barrier so that the light intensity that is read is more accurate. The microcontroller will read the resistance value for each LDR. After that, the DC motor will move following the highest intensity until the entire LDR gets the same value. If the LDR resistance value is the same the motor will stop and the solar panel can get maximum light irradiation.

FIGURE 6. The physical form of LDR, DC motor, and solar panel.

EXPERIMENT RESULT AND ANALYSIS

The Experiment of MPPT Perturb and Observe with Boost Converter Circuit

The first experiment was to determine the effect of load changes on the P&O algorithm. The loads used are 82Ω, 110Ω, and 220Ω. In experimental conditions using a power supply of 10V the test uses a boost converter as the implementation of the P&O algorithm and the INA219 sensor to read the power obtained every second.

The comparison of the output power generated by the system using MPPT P&O was tested by changing the load value. MPPT data retrieval is done with a sampling time of 1 second. Tests were carried out to analyze the effect of changes in load on power with the MPPT system as shown in **FIGURE 7**. The initial load used is 82Ω then the load is changed to 110Ω and 220Ω with a sampling time of 18 seconds. Through the graph shown, it can be obtained that the power is quite stable when there is a change in resistance. Although of course there is a change in power every time the load changes, the power produced is not much different. If calculated the average power obtained by the MPPT system at a resistance of 82Ω is 1.111W. The power at 110Ω resistance is 0.837W and 0.609W when 220Ω. This power result also proves that the greater the resistance or load used, the smaller the power generated under the same experimental conditions. The MPPT system can maintain the power value at its maximum point when there is a load change. **FIGURE 8** shows the boost converter using the MPPT P&O system that has been built.

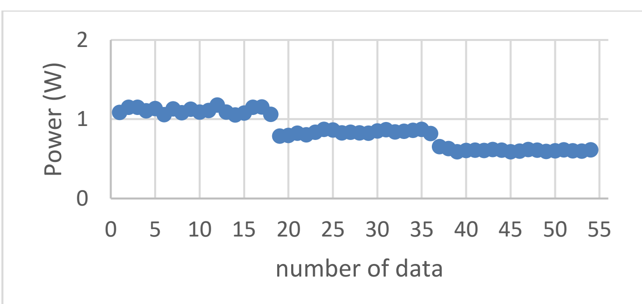

FIGURE 7. MPPT P&O power data with 82Ω,110 Ω, and 220 Ω loads.

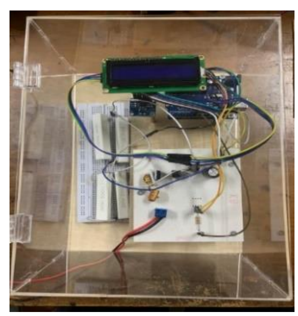

FIGURE 8. Boost converter using MPPT in a real system.

The Experiment of Static Solar Panel System

The light intensity received by static solar panels is not always in its maximum state. Changes in the weather every second cause the light received by the panel also vary so that the voltage, current, and power obtained are not constant. Therefore, a test was carried out to see the power generated by the solar panel at rest.

Static solar panel testing is carried out by taking data on the voltage, current, and output power of the panel connected to the solar charger and 24V accumulator. The light intensity when this test was carried out was in the range of 9000-16000 LUX. The graph of the static solar panel power data is shown in **FIGURE 9**. In this test, the maximum power obtained is 7.908W. However, the maximum power (Pmax) of the panel is 50W. The difference in power generated is very far because solar panels in a static state do not get the same optimal light intensity all the time.

The Experiment of the Single-Axis Solar Panel System

Testing of a single is carried out by taking data on voltage, current, and panel output power with a 12V accumulator load. The value reading is carried out by the INA219 sensor. The light intensity when the test was carried out was in the range of 9000-19000 LUX. Data retrieval is carried out every 5 seconds within 2 minutes.

It can be seen from the graph in **FIGURE 10**, that the difference in each power is not too big because of the influence of the movement of the panel towards the highest light intensity. Therefore, the received power is the maximum power from receiving the maximum light intensity when taking data. The power generated reaches 45.434W close to the maximum panel power.

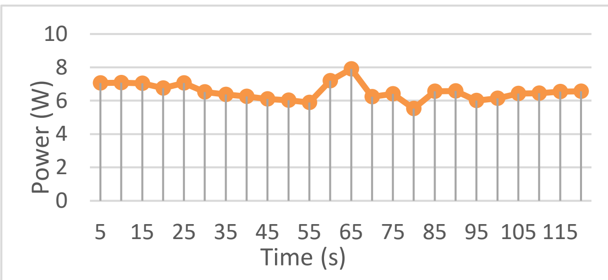

FIGURE 9. Static solar panel power data.

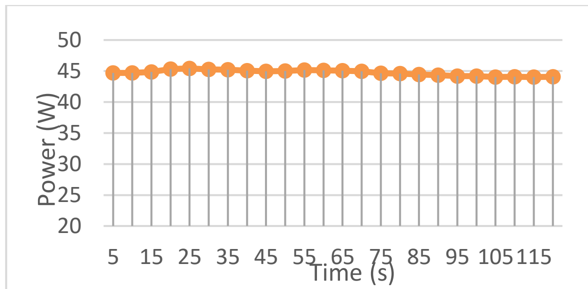

Figure 10. Single-axis solar panel power data.

The Experiment of MPPT using Single Axis Solar Panel System

In this test, solar panels are connected to a boost converter as an implementation of the MPPT Perturb and Observe. MPPT algorithm seeks solar panels to produce maximum power. Voltage regulation is carried out by the Arduino Uno microcontroller to increase or decrease the duty cycle. As a result of this change, the resulting voltage will vary according to the regulated algorithm. Conditions and weather are variable so the data obtained is not constant. In addition, the DC motor as the driving force of the panel will run horizontally (right-left). The movement of the panel supported by the LDR as a light sensor will go to the highest light intensity.

The MPPT and single axis are carried out by taking data on voltage, current, and panel output power with a boost converter and solar charger connected to a 24V accumulator. Data reading is carried out by the INA219 sensor. The light intensity when the test was carried out was in the range of 9000-19000 LUX. Data retrieval is carried out every 5 seconds within 2 minutes.

The boost converter will adjust the voltage following the specified algorithm so that the power generated is close to the maximum panel power. The algorithm works by comparing the power and voltage values of the solar panels. The data obtained from the INA219 sensor will be processed to see the difference in power or voltage. Changes in the duty cycle occur so that the voltage will be increased or decreased. And so on until $\Delta P=0$. However, this situation is almost impossible because of the condition of the intensity of the sun's light that changes every second. The power difference will continue to exist so that the algorithm continues to repeatedly track the highest power of the solar panel. The highest power value obtained is 49.396W as shown in **FIGURE 11**.

Power Comparison

After testing each system, a power comparison is made to see the difference in the power increase of each system. The LUX difference of each system is due to data collection on different days. The load used is a 24V accumulator in each experiment of the solar panel system. This comparison will prove the use of solar panel systems that work more optimally. The average power gain of each system will be calculated and determine the efficiency of each solar panel system. The value of the efficiency of the solar panels is calculated by comparing the output power of each system with the maximum power of the solar panels, which is 50W. The power comparison graph is shown in **FIGURE 12**.

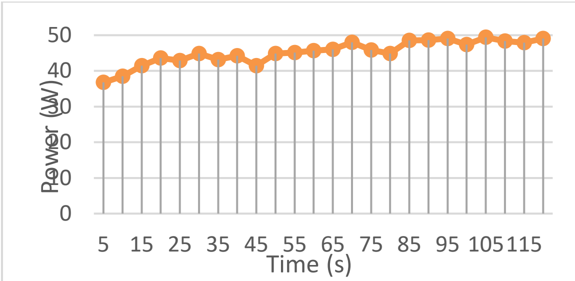

FIGURE 11. Single-axis MPPT solar panel power data.

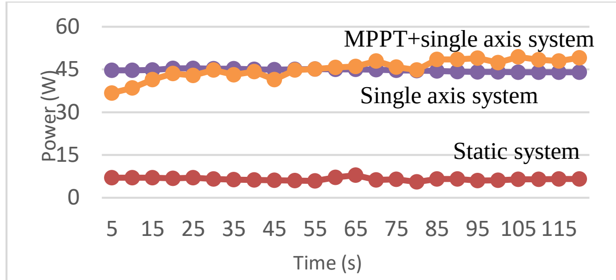

FIGURE 12. Solar panel system power comparison.

Through the three graphs displayed, the static solar panels produce the lowest power of the other systems. The average power generated in the experiment is 6.53W. Static solar panels do not receive maximum light intensity in certain areas. At rest, the solar panel can be covered with something so that it blocks the sun's light. Because of that, the power generated is not too large. The single-axis power gain of a solar panel system is close to that of an MPP panel at 50W. The average power generated is 44.72W. The horizontal movement of the solar panel causes the panels to receive maximum light. When there is a change in the direction of the light, the LDR resistance value will differ from one another. This causes the DC motor to move and then stop when the LDR value returns to the same.

MPPT system single axis produces an average power of 45.23W. This average power is the largest in the solar panel system test. The algorithm will find the difference from the input power after it is slowly increased to approach Pmax. After the difference in power changes is small or zero, the algorithm will keep the output power at that point. However, the ever-changing intensity of sunlight makes it impossible for a change in power to be equal to zero. Converter boost works to increase the voltage so that the power obtained is close to Pmax, the tracking moves the solar panel to keep receiving maximum light. Therefore, it is not surprising that this system is capable of producing large amounts of power and can increase solar panel efficiency. The data for calculating the average power and efficiency of solar panels can be seen in **TABLE 2**. The increase in efficiency from the static solar panel system to the dynamic solar panel system is 76.38% and the single axis is 77.4%. The MPPT solar panel system single axis has the highest efficiency and average power.

TABLE 2. Comparison of solar panel systems.

Solar Panel Systems	Average Power (W)	Efficiency (%)
Static Solar Panel	6.53	13.06
Single Axis Solar Panel	44.72	89.44
MPPT Perturb and Observe with Single Axis Tracking	45.23	90.46

CONCLUSION

Referring to the research results, it is concluded that the perturb and observe algorithms can be implemented through a boost converter. Static solar panels produce an average power of 6.53W with an efficiency of 13.06%. The dynamic solar panel system (single axis) produces an average power of 44.72W with an efficiency of 89.44%. The MPPT Perturb and Observe movement single axis produces 45.23W of power with an efficiency of 90.46%. The test results prove that solar panels with the MPPT Perturb and Observe with a single axis produce the highest average power with the greatest efficiency.

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