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Optimization of Panel PV Position Using Dual Axis Solar Tracker with Perturb and Observe Method in PV Tower - Laboratory Scale Microgrid System

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ABSTRACT

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Keywords: Photovoltaic System; Dual Axis Solar Tracker; Perturb and Observe; Microcontroller; Arduino UNO

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OPTIMIZATION OF PANEL PV POSITION USING DUAL AXIS SOLAR TRACKER WITH PERTURB AND OBSERVE METHOD IN PV TOWER - LABORATORY SCALE MICROGRID SYSTEM

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Abstract

PV systems should be designed for optimum power efficiency. Add a solar tracker to follow the position of the sun, it can optimize PV position. In this paper, MPPT method Perturb and Observe (P&O) will be adopted and implemented in a mechanical system of the dual axis solar tracker. P&O Method is considering the value of power that implemented into the microcontroller where the current and voltage sensor as the input, which is expected to make the position of PV panels on both axes are optimal, so it can maximize the power generated from PV systems. The analysis was then performed by comparing the value of the energy produced by the dual axis solar tracker system with fixed PV or non-optimization. The results of this experiments are the increasing percentage of 19.43% of the energy produced by PV panels. This method will be excellent when used for larger scale of PV system.

Keyword: Photovoltaic System, Dual Axis Solar Tracker, Perturb and Observe, Microcontroller, Arduino UNO

I. Introduction

As one of the renewable energy sources, solar energy is getting a lot of attention from various parties, especially to replace fossil fuels dwindling and pollution they cause. One of the utilization of solar energy is the conversion of solar radiation into electrical energy using solar cells or photovoltaic. PV system itself is a promising technology that is clean, environmentally friendly and has low maintenance costs [1]. However, the cost of an expensive investment and the value of low efficiency is still an obstacle for the PV system is to be used widely for the general public.

There are three different ways that can be used to improve the efficiency of the PV system: improving and developing materials design solar cell makers; using MPPT or

Maximum Power Point Tracker to address the nature of voltages and currents that are not linear from the PV itself; and optimizing the position of PV by adding a tracking device to follow the direction of the sun motion [2]. On the first way, silicon is the best semiconductor material which is used for producing a solar cell. But the material itself limits the efficiency of the PV cell, so to develop the performance of PV cells through good materials require long-term research which is not cheap [3].

On the second or static way, PV panels track the value of voltage or current to locate the point of maximum power from the PV panel itself. MPPT technique requires additional tools such as converters and continuous adjustments due to constant changes in environmental conditions. On the third or dynamic way, a device is used to make solar

tracker PV panels perpendicular to the sun so that energy is transferred from the panel to the system will be maximized.

Research on the solar tracker is developed based on a changing position of PV panels that will affect the output power of PV panels. In trials that have been done in previous studies, the changes of the position and angle of PV panels prove that the position of the PV panels greatly affects the output power of the PV panels themselves as a result of changing irradiance and temperature which is received by the PV panels [4].

In this paper, MPPT method Perturb and Observe (P&O) will be adopted and implemented in a mechanical system of the dual axis solar tracker. The expected value of using this method is to produce the most optimal position for both axis (x and y) of PV panel. Attaining the optimal position of the both axis is expected to be able to maximize the power which is generated by PV system.

II. Literature Review

A. Solar Cell

Basically, the solar cell is a diode semiconductor. When positive-negative junction from the diode exposed by the light there will be an energy conversion from light energy to the electricity. Where energy from the photon is enough to release the outer bonding of the electron in that material.

The current flows will occur when the solar cell is in short circuit condition with a load.

The ideal model of a solar cell.

Mathematically is showed in Equation (1).

$$I = N_p \cdot I_L - N_p \cdot I_o \left[\exp \left\{ \frac{q \left(\frac{V}{N_s} + I \cdot \frac{R_s}{N_p} \right)}{a \cdot n \cdot k \cdot T} \right\} \right] - \frac{V \cdot \frac{N_p}{N_s} + I \cdot R_s}{R_{sh}} \quad (1)$$

I = Current in the output (Ampere)

I_L = Current produced by solar cell

I₀ = Reverse saturation current

Q = Element Load

V = Voltage between output terminal

R_s = Serial resistance

N = Diode ideal factor

K = Boltzmann Constant

T = Absolute temperature

R_{sh} = Shunt resistance

N_p = Number of parallel solar cell

N_s = Number of serial solar cell

Before PV panel connected to the load, a PV will produce an open circuit voltage (V_{oc}) when the terminal of PV is being shorted the value of I_{sc} will occur. When a real load is connected, there will be a power that occurs because of the combination of current and voltage where the value depends on the characteristic of V-I. Maximum power value is a peak point from the end of I-V where it is a result of multiplying the maximum current with the maximum voltage (I_m and V_m)

The value of PV will be maximum when it is on the condition below the full sun (the sun at 1.0) When its characteristic is at the half, so the PV current will be reduced in the ratio of the radiation intensity of the sun, with the lower value of the irradiance (sun radiation) so the characteristic of I-V will be reduced too.

The curve of I-V characteristic depends on the irradiance PV panel, consist of many serial connected PV cells. When half of the PV panel is shadowed, the result will make a voltage loss, but it still needs to be loaded by the panel current. The shadowed section of the panel will not produce any power, in fact, it will give a load to the system and bring losses I²R and heat. So the other PV section must work at a higher rate to cover the losses. Higher voltage value at the good PV will show lower current value at I-V characteristic curve. So when the losses exceed the critical point, the I-V curve will be at the under of the operation voltage. It will make the current drops, and make the panel lose all the power.

The effect of the shadowed section in a PV panel. With fixed current value, the voltage drops to ΔV

When we see from the material of the PV, the percentage efficiency that we got from converting the sun energy to the electricity with the PV panel with Mono-Si material a class in this PV panel is 15% until 18%. Besides that, for each PV module, the produce will supply some of the performance parameters, for example, it is the PV output rating where the value is produced by the STC condition with the value of the irradiance is 1000W/ 1.5, and the PV cell temperature is 25 Celsius

But in the reality, STC rarely occurs and almost impossible. So, the maximum rating will be difficult to be realized. By the literature [9] with the variation condition of the sunlight by the earth rotation, and by the effect of the clouds who could cover sunlight, the average power that produced by the PV panel is about 20% from its nominal power, within a year. That value could drop by 16% within 20 years because of the degradation of the PV material by 0.5% each year by its nominal power, although we do maintenance periodically.

B. Solar Tracker

A solar tracker is a device that is used for keeping the PV panel at its optimum place which is perpendicular by the sun radiation so it can increase the power collection. [12]

There is 2 main type of solar tracker, defined by its axis movement: single axis solar tracker and dual axis solar tracker. This 2 type is divided again by the technology of the tracking system, active, passive and chronological.

In single axis solar tracker, the tracker needs to follow the daily rotation of the sun from east to the west by its altitude. When dual axis

solar tracker needs to follow the azimuth and the altitude.

A passive solar tracker is designed for the thermal value of PV material, it will move by the response of the unbalance pressure between two points of the tracker caused by the heating process of the cell structure.

Active solar tracker moves by using a microprocessor and electrical-optical sensor to define its best position which is perpendicular to the sunlight.

For chronological tracker, it moves by the uniform value of the PV panel.

By the [14] literature, the percentage of the efficiency in the solar tracker can be analyzed by its increased power, current, average voltage with this formula as shown in Equation (2).

$$\% \text{efficiency} = \frac{\text{optimization value} - \text{non optimization value}}{\text{optimization value}} \times 100\% \quad (2)$$

By [15] literature, to define the tracking effect of the PV system, we could use the efficiency formula as shown in Equation (3).

$$\eta = \frac{ET - (EF - EC)}{EF} \times 100\% \quad (3)$$

ET is the energy produced by the tracking system, EF is the energy produced by the fixed PV, and EC is the consumed energy by the tracking system.

C. Maximum Power Point Tracker

The I-V characteristic of PV module is not linear, it only has an operation point that produced maximum output. But, the maximum point is constantly changed by the intensity of sun radiation and temperature. To obtain an optimal value, we need to do Maximum power Point Tracker (MPPT) method [16].

The MPPT method(s) is defined by its complexity, the number of sensors, the convergence speed, number of hardware, etc.

Basically, the mechanism of the MPPT method is how it automatically looking for voltage V_{mpp} or Current I_{mpp} , so the maximum power can be obtained.

Some of MPPT methods are Hill Climbing or Perturb and Observe, Incremental Conductance, Fractional Open Circuit Voltage, Fractional Short-Circuit Current, Fuzzy Logic Control, etc.

D. Perturb and Observe

Perturb and Observe or Hill Climbing Starch, is a popular MPPT method because of its simple algorithm which needs a low priced microprocessor. This method periodically giving disturbance (increase or decrease) the voltage value or current to the PV panel and comparing its power output to the previous power output. When the power output is increased the disturbance will be given continuously to the same movement. Vice versa when it's decreased, until they will have maximum power point.

E. Microcontroller Arduino UNO

UNO Arduino Board is a microcontroller hardware that is integrated with IDE software. Microcontroller itself is a microcomputer in an IC (Integrated Circuit) which is consist of core processor, memory, and programmable intergrade.

Arduino UNO is divided into 2 big parts: the Arduino UNO Board, and the IDE software.

The board is a hardware that is used to build an object, and the IDE software is a special program that is used to command the Arduino UNO board with simple languages modeled by processing languages. When upload command is pressed, the languages will be translated to the C languages and forwarded to the microcontroller as a command.

III. Research Methods

A. Dual Axis Solar Tracker based on Perturb and Observe Method (P&O)

P&O method that will be used for the solar tracker, is adopted by P&O method that uses in electronic control charging named Maximum Power Point Tracker (MPPT). The difference of this two method is the interference or the other word perturb as seen in Figure 1. Perturb In the dual axis solar tracker system based on P&O method is meant DC motor movement to lead PV panel position both on x or y-axis to get an optimal position. With this, optimal power can be achieved. Voltage and current are produced by PV panel which will be sensed to be input in Arduino UNO microcontroller. This input will be processed in accordance flowchart (to be described later) for the next gave command actuation to DC motor via the motor driver.

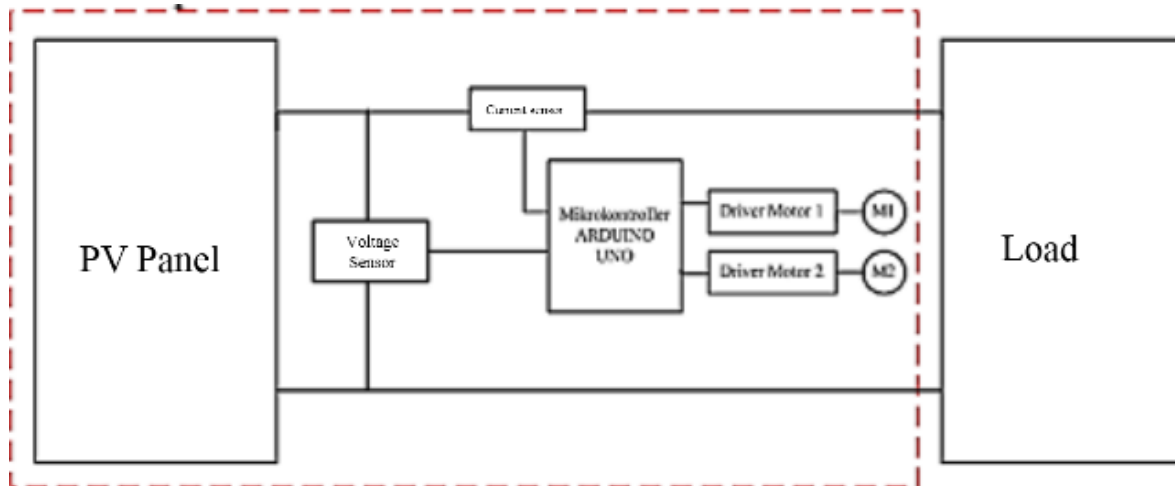


Figure.1 Diagram Block Dual Axis Solar Tracker Based On Peturb and Observe Method

The mechanical system consists of some equipment, there are two motor DC, PV framework with two axis movement, charge controller, and battery as power conservator. Current that flow from PV to the battery will be sensed by the current sensor and send to be processed in the microcontroller. Plant PV consists of two identical panel mounted in parallel. Detail of PV Panel Spesification is shown in Table 1.

Table 1. PV Panel Spesification

Specification	Value
Manufacture	CALTECH
Solar Module Type	SP – 200 W
Output Power (P_m)	200+5%W
Max Power Voltage (V_{mp})	36.459V
Max Power Current (I_{mp})	5.491A
Open Circuit Voltage (V_{oc})	44.706V
Short Circuit Current (I_{sc})	5.740A
Max Operating Voltage (V)	1000 V _{DC}
Cell Technology	Mono-Si
Application Class	Class A
Standard Test Condition	25°C, 1.5AM, 1000W/m ²

Dual axis PV used tower with a height of 2 meters above ground. The tower is used to avoid shadow form building and trees. The operation of solar PV used two degrees of freedom, there is axis x and axis y, which can make PV panel can be rotated and shift up and down [22]. Two DC motor as actuators of dual axis solar tracker systems based method P&O arranged by utilizing the polarity of the

DC motor for movement [23]. To make the system can generate operating current value, used the load in the form of batteries that were previously connected with charge controller. Electrical system used in this system is current and voltage sensor, motor driver, and microcontroller. Sensors will be used to retrieve the value of current and voltage and will be processed in the microcontroller to control two DC motor. A current sensor that used is ACS 712 hall current sensor 30A [25]. Voltage sensor that used is voltage divider with output 0 – 5VDC. This value is adapted to microcontroller analog capacity. Motor driver used in this system is EMS module with 30A H-bridge current capacity [27]. This module is used for handling motor rotation speed and directional control accordance with instructions of the program in Arduino UNO microcontroller.

The system design software is used to designing the logic of the algorithm used P&O as well as the allocation of the control system I/O pins on Arduino UNO Board microcontroller as a center data processing system.

Input-output configuration Pin used for operating are

- Analog Pin 0,1 : current and voltage analog signal
- Digital Pin 2,5 : output signal for direction motor A
- Pin digital 3,6 : output signal PWM

- Pin digital 4,7 : output signal for direction motor B

Flowchart of the control command system scheme of the dual axis solar tracker based P&O method is as shown in Figure 2.

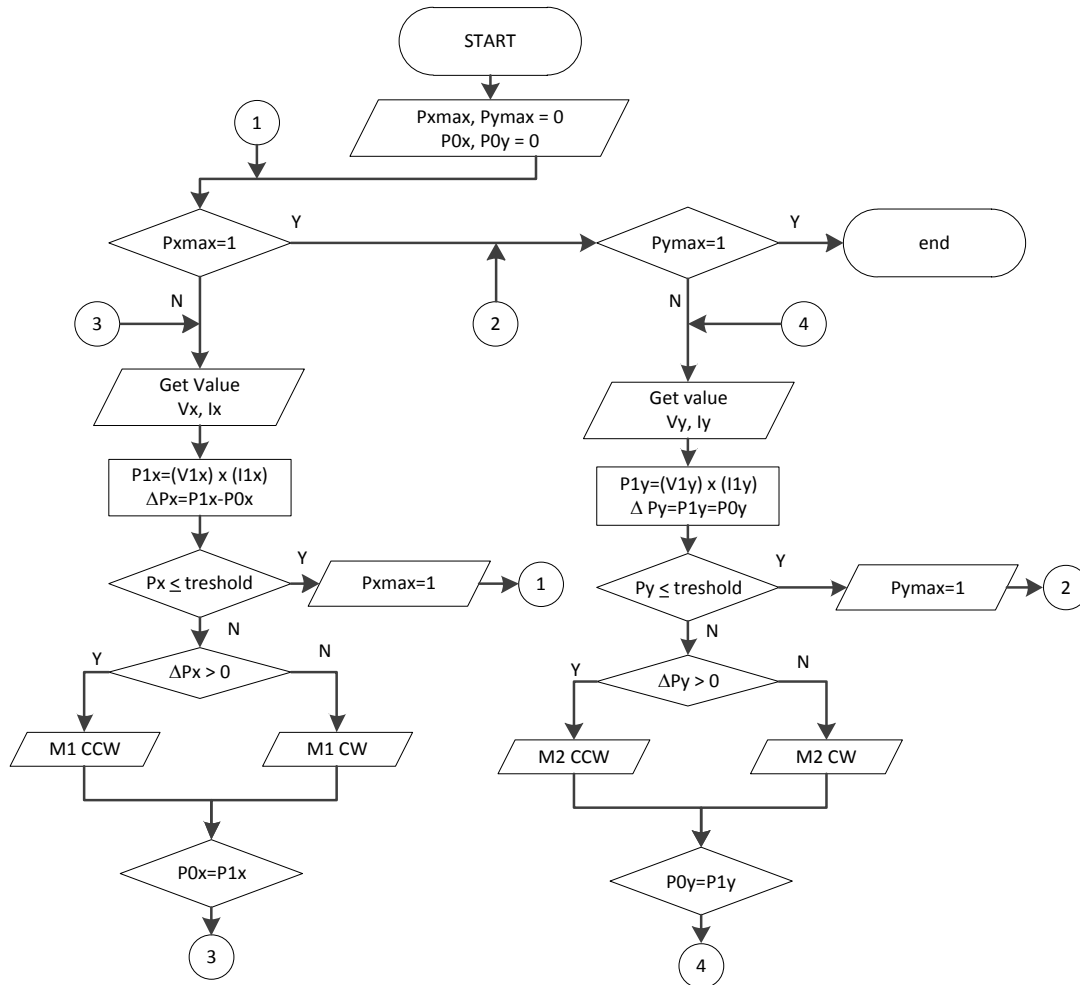


Figure 2. P&O Algorithm for Solar Tracker

Start from current and voltage data acquisition that obtains from output PV voltage and current that flow from solar PV to the battery through the charge controller. From two variable, the number of power can be calculated. The value of power is compared with the previous. If the value is outside from threshold PV panel will change the position. This action resulting in a change of voltage and current values. Movement of

the PV panel based on the comparison of power. If the power calculation from current and voltage is higher than the value before and between the threshold, the microcontroller will order motor DC to stop. Otherwise, PV panel will rotate and shift the position until the power value within the threshold and can be considered the PV panel

have reach maximum and the difference can be tolerable (to avoid oscillations). If the power value on the x-axis has a maximum value, then followed on the y-axis method the same one.

IV. Analysis & Result

The experiments were performed on the same day and the same weather conditions with time interval 1-hour start from 09:00 until 15:00. Then the results of the data that retrieved and monitored from serial monitor [28] IDE Arduino built into graphical form as shown in Figure 3.

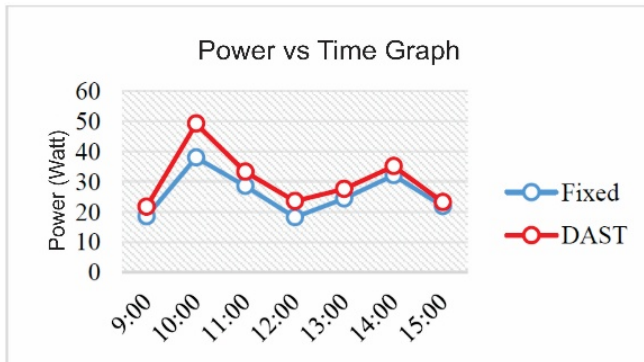


Figure 3. Power vs Time Graph for Fixed PV compared to Dual Axis Solar Tracker based P&O method



Figure 4. Fixed PV Position



Figure 5. PV Position after Optimization with Dual Axis Solar Tracker based P&O method

The percentage of increasing power efficiency for dual axis solar tracker system based P&O method compared to without optimization of fixed PV for each hour of the day can be seen in the following graph as shown in Figure 6.

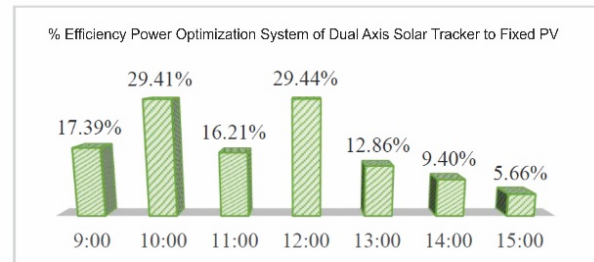


Figure 6. Power efficiency graph in system with Dual Axis Solar Tracker compared to Fixed PV per hour

To determine the effect of tracking the performance of existing PV system, it can be done by finding the value of energy efficiency as shown in Table 2.

Table 2. Comparison value of Energy with Optimization and without it.

	Energy (Wh)
Fixed PV (without optimization)/ E_f	229.37
Dual Axis Solar Tracker based method P&O (optimization) / E_f	273.94

By performing optimization system with dual axis solar tracker based P&O method, the efficiency energy can be increased by 19.431% or equal to 44.57 compared to without optimization. Performance of optimization system in real time is showed as in Figure 4 and Figure 5. Thus value still can be increased by improving the PV conditions. The influential factor of that value is the location of PV tower which is able to cause a partial shading and also the efficiency of the material itself.

V. Discussion & Conclusion

In this paper, PV panel position optimization analysis using dual axis solar tracker based on Perturb and Observe (P&O) method on the laboratory scale microgrid system has been showed. P&O method on electric MPPT can be applied on the dual axis solar tracker. This method can improve and optimize current, voltage, and PV power for 15.4%, 3.01%, and 19.431% respectively with power differences up to 44.57Wh. The efficiency of PV vary depends on materials, performance, and material degradation. Within this result, it can be concluded that P&O method is decent to apply for its simple algorithm and real-time operation.

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