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Solar Tracking System Dual Axis using Proportional Integral Derivative (PID) Controller

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***Abstract*—The potential for renewable energy in Indonesia is very high, including solar energy. Photovoltaic systems convert sunlight into electricity, where the result depends on the type of solar panel, the solar irradiance of the area, the geographical location and other factors. One of the efforts to increase the capture of solar radiation is solar tracking systems, where the way it works is the solar panel detects and follows the direction of the highest intensity of sunlight to obtain maximum power. The movement of the motor when tracking is not smooth, causing the solar tracking system not to get the highest light intensity needed to charge the battery. Therefore, in this study, the linear movement of the actuator was controlled using the Proportional Integral Derivative (PID) method so that the movement was smooth. Based on the test results, the solar tracking system with the PID method can provide stable control. This is proven by the error resulting from the lux sensor reading on the X-axis of 0.3 and the Y-axis of 0.2, which means it is accurate. Then the gain of voltage, power and current is also greater than without using the PID method.**

Keywords—Solar Tracking System, Solar Panel, Lux Sensor, Proportional Integral Derivative (PID)

I. INTRODUCTION

Renewable energy potential in Indonesia is very high and most of it is solar energy potential [1], [2]. In recent years the use of solar technology has increased significantly to supply energy needs [3]. Solar energy is energy that can be utilized continuously without having to wait a long time for its formation like fossil energy. In addition, solar energy is simple to maintain, easy to install and beneficial for the environment [4]. However, currently, the use of solar energy in Indonesia is still very small, namely 0.08% of its potential [1], [2].

Photovoltaic systems convert sunlight into electricity, where the output of photovoltaic solar panels depends on the type of solar panel, the solar irradiance of the area, the geographical location and other factors [5]. Various attempts have been made to increase the capture of solar radiation, including using cooling techniques on the surface of the module, the maximum power point tracking (MPPT) with a regulator or solar tracking system [6]. Increasing the capture of solar radiation will certainly increase the energy produced by the photovoltaic module and this will certainly increase system performance [7].

In the research conducted, efforts to increase energy are carried out by making solar tracking systems. Solar tracking systems are an attempt to keep the surface of the module perpendicular to the light source for a longer period [8], [9]. In this case, solar tracking systems can be interpreted as an effort to maintain the angle of incidence between sunlight and PV panels within a certain value which helps collect as much energy as possible [10].

In this study, solar tracking works because the solar panel detects and follows the direction of the highest intensity of sunlight, with the aim that the solar cell is always in a position to get the highest light intensity and obtain maximum power from the sun.

Several studies have explored the comparison between fixed photovoltaic systems and tracking systems on solar panels. Agee et al. [11] proved that tracking systems with single-axis and dual-axis energy output were 26% and 39% higher than that of fixed photovoltaic systems. Then Abdallah et al. [12] compared the four types of sun tracking systems namely dual axis system, vertical single axis system, horizontal south-north single axis system and horizontal east-west single axis system. The results prove that the volt-amperes characteristic of the panel surface with a tracking system is greater than that of the fixed panel surface. In addition, the electric strengthening of the double axis system, horizontal east-west single axis system, vertical single axis system and south-north horizontal single axis system increased by 43.87%, 37.53%, 34.43% and 15.69% % compared to the performance of fixed panels with a tilt angle of 32°. Okoye et al. [13] compared the power generation under different tracking modes and believed that dual-axis tracking has the best benefit. Therefore, in the research conducted, the solar panel tracking used is a dual-axis system.

The design standard for making a solar tracking system begins with the correct selection of each component, the design of the controller and the solar path generation system. Controller selection is generally based on algorithm accuracy, implementation complexity, computational cost and commercial availability, without considering tracking error and power consumption [14]. Fuentes-Morales et al. [15] stated that at least one hundred controller proposals for two-axis solar trackers in the last twenty years, concluding that the most popular controls are On-Off, Proportional Integral Derivative (PID) and Fuzzy PID, classifying them as conventional controllers. Then Anto et al. [16] said that the PID method can eliminate overshoot which means a significant reduction in losses and reduced completion time which indicates a much faster system response. Then Aung et al. [17] have also proven the superiority of the PID method. In the research conducted, the solar tracking system was controlled by the PID method. This research aims to make a dual-axis solar tracking system which can direct the panel so that it is always in a position to get the highest light intensity from the sun. The PID method is used to make the actuator's linear movement smooth according to the desired set point.

II. Research Methods

A. Solar Panels

Solar panels are an important component in the conversion of solar energy into electrical energy. Solar cells can still produce electrical energy even though the weather is cloudy, drizzling, or rainy [18]. The energy generated from solar cells is DC electric energy. However, if needed, the generated DC electrical energy can be converted into AC electrical energy. The type of solar panel used in this study is a 30 WP monocrystalline panel.

B. Solar Panel Drive System

The propulsion system on solar panels generally consists of 2 types of drive, namely single axis and dual axis. In this study, a dual-axis drive system. The dual-axis drive system is a drive system that has two degrees of freedom (DOF). With two degrees of freedom, this system can move horizontally and vertically simultaneously. In other words, a dual-axis system is a system consisting of an X-axis and a Y-axis. Fig. 1 is an example of a dual-axis solar cell propulsion system.

Fig. 1. An example of a dual-axis solar cell propulsion system

C. Solar Tracking System

When the solar tracking system performs sun tracking, solar panels often experience offsets (bypassing the highest light intensity value). The movement of the motor when tracking which tends to be rough (not smooth) causes the solar tracking system not to get the highest light intensity needed to charge the battery. This research aims to create a dual-axis solar tracking system that can direct the panel so that it is always in a position to get the highest light intensity from the sun so that the linear actuator moves smoothly according to the desired set point.

Movement according to the set point can be realized with the help of the lux sensor. There are 4 lux sensors used with the shadow principle to make it easier for the sensor to find which side has the highest light intensity value. In this study, the PID calculates the results of the lux sensor readings which will be used as a set point. The linear motion of the actuator apart from the readings of the lux sensor is also determined from the readings of the voltage sensor and the current sensor to get the power value that has been successfully absorbed by the solar panel. If the power obtained by the solar panel is maximum, then the solar panel will be silent (not tracking). The dual-axis solar tracking system design can be seen in “Fig 2”. Then the block diagram can be seen in "Fig 3".

The description of the numbering “Fig. 2” are as follows:

1. The solar panel functions as an absorber of the intensity of sunlight.
2. The linear actuator on the X-axis functions as a vertical drive of the panel.
3. The shadow indicator (consisting of 4 lux sensors) functions as a light intensity reader to compare its value, then the largest value will be the set point.
4. The linear actuator on the Y-axis functions as a horizontal drive of the panel.
5. The panel box, contains several components, namely Arduino nano, current sensor, voltage sensor, RTC, Solar Charge Controller (SCC), battery and SD card. Where the SCC functions as a circuit breaker when the battery is full and the battery functions as a storage power that has been generated by solar panel.

Fig. 2. The dual-axis solar tracking system design

In "Fig 3" it appears that there are 4 inputs from the solar tracking system, namely:

1. The lux sensor functions as a reader of sunlight intensity.
2. The voltage sensor functions to read the voltage value absorbed by the panel.
3. RTC functions as a time indicator for the panel to return to its initial position.
4. The current sensor functions to read the value of the current absorbed by the panel.

Then the main processor used Arduino Nano. While the system output used there are 3, namely:

1. The SD Card functions as a data store for the readings of current sensors and voltage sensors.
2. The LCD functions to display sensor reading data and the amount of system accuracy obtained.
3. The linear actuator functions as a horizontal (x-axis) and vertical (y-axis) panel mover

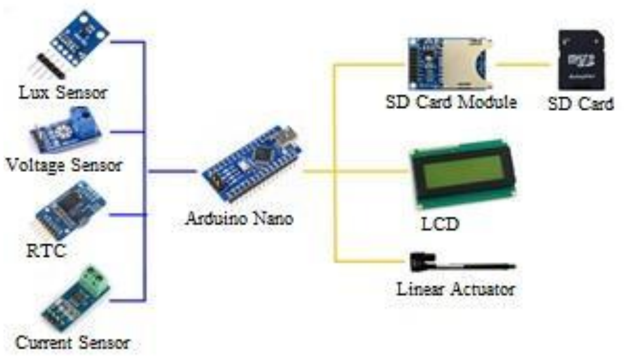

Fig. 3. Diagram block system

D. Lux Sensor

In the solar tracking system, a detector of the highest light intensity from the sun uses a lux sensor. The lux sensor functions as input to direct the solar panel to the position of the highest light intensity so that the solar panel can produce maximum power for charging the battery. In this study 4 lux sensors were used with the MAX44009 type. Fig. 4 shows the placement position of the four lux sensors on the solar tracking system. In the middle of the four lux sensors is a barrier with a height of about 5 cm. The function of this barrier is to block sunlight from hitting the lux sensor, so when there is a lux sensor that is not exposed to sunlight, it means that the position of the solar panel is not perpendicular to the sun. Then Arduino will give an order to the linear actuator to direct the solar panel so that it returns to a position perpendicular to the sun. The process of moving solar panels is controlled by the PID method so that the movement is smooth according to the desired set point.

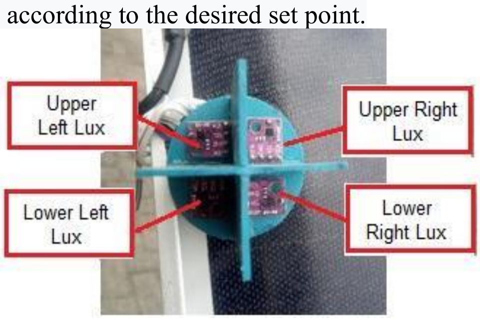

Fig. 4. The placement position of the four lux sensors

The PID method in this research functions to determine the movement of solar panels based on the highest light intensity value with the help of a linear actuator. In the PID calculation process, there is an equation to calculate the motor movement error on the X-axis and Y-axis, namely in equation (1) and equation (2).

$$X_{error} = X_1 - X_2 \quad (1)$$

$$Y_{error} = Y_1 - Y_2 \quad (2)$$

The X_1 value is obtained from the sum of the readings of the upper left lux sensor and the upper right lux sensor, while the X_2 value is obtained from the sum of the readings of the lower left lux sensor and the lower right lux sensor. Then the Y_1 value is obtained from the sum of the readings of the upper left lux sensor and the lower left lux sensor, while the Y_2 value is obtained from the sum of the readings of the upper right lux sensor and the lower right lux sensor. If the error calculation result is 0 then that value will be the set point value, but if the value is not yet then the system is considered to have not reached the set point and runs the PID process using equation (3).

$$PID_{motor} = (Kp * Et) + (Ki * Eint) + (Kd * Edif) \quad (3)$$

Where:

Kp	= Proportional Constant
Et	= Error
Ki	= Integral Constant
Eint	= Total Area
Kd	= Derivative Constant
Edif	= Change Error

The PID value obtained from the previous calculation will be used as a reference for the movement of the linear actuator. If the system PID calculation produces a negative (-) result, the linear actuator will move up or lengthen. On the other hand, if the value obtained is positive (+), then the linear actuator will move down or shorten. The PID output results will be used as a linear drive for the actuator in the form of a PWM value.

III. RESULT AND DISCUSSION

Solar tracking systems that have been produced are shown in “Fig. 5”. In “Fig. 5” shows the parts of the solar tracking system that were made, namely the lux sensor, solar panel, linear actuator and panel box. The shadow indicator consists of 4 lux sensors. The lux sensor serves as a reader of sunlight intensity. The solar panel functions as an absorber of the intensity of sunlight. The linear actuator functions as a horizontal (x-axis) and vertical (y-axis) panel mover. The panel box functions as a place for components, such as Arduino, current sensors, voltage sensors, RTC, SCC, batteries and SD cards.

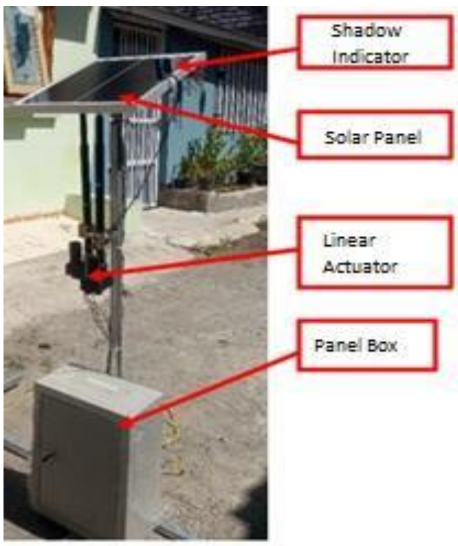

Fig. 5. Solar tracking systems that have been produced

In this study, the workings of the solar tracking system are linear actuators that move according to the readings from the lux sensor. In the morning the solar panels are positioned facing the rising sun, which here is called point 0. Then the solar panels will move to follow the highest sun intensity until the afternoon. In the afternoon at exactly 17.00 WIB, the solar panels will automatically return to point 0. The brighter the light intensity received by the solar panel, the higher the power obtained by the solar panel.

A. Lux Sensor Reading Accuracy Testing

Before applying to the solar tracking system, it is necessary to test the accuracy of the lux sensor readings which will later function as PID inputs to control the linear movement of the actuator on the X and Y axis. The lux sensor control experiment is intended to maintain the lux sensor to remain at a light intensity value which causes a difference between the upper lux sensor (Upper Left Lux + Upper Right Lux) and the lower lux sensor (Lower Left Lux + Lower Right Lux) and the difference between the left lux sensor (Upper Left Lux + Lower Left Lux) and the right lux sensor (Upper Right Lux + Lower Right Lux) is 0. If the difference value obtained has not reached a value of 0 or close to 0, then it is said that it has not reached the set point.

In Table I it can be seen the results of testing the accuracy of the lux sensor readings on the X axis. In this case, this means that the light intensity value being compared (error value) is calculated using equation (1). X-axis testing produces an average accuracy of lux sensor readings using the PID method of 99.9853%. Calculation of the accuracy of the lux sensor readings uses equation (4).

$$Accuracy = 100\% - \left(\left(\frac{Error}{Setpoint}\right) x\ 100\%\right) \quad (4)$$

TABLE I. THE RESULTS OF TESTING THE ACCURACY OF THE LUX SENSOR READINGS ON THE X-AXIS

Testing	*Upper Lux Sensor*	*Lower Lux Sensor*	*Error*	*Accuracy*
1	3947	3946.7	0.3	99.9924 %
2	4023.5	4022.8	0.7	99.9826 %
3	4087	4086	1	99.9755 %
4	4119.4	4118.9	0.5	99.9878 %
5	4221	4220.5	0.5	99.9881 %
Average Accuracy				99.9853 %

In Table II it can be seen the results of testing the accuracy of the lux sensor readings on the Y axis. In this case, this means that the light intensity value being compared (error) is calculated using equation (2). Y-axis testing produces an average accuracy of lux sensor readings using the PID method of 99.9860%. The calculation of the accuracy of the lux sensor readings on the Y axis also uses equation (4).

TABLE II. THE RESULTS OF TESTING THE ACCURACY OF THE LUX SENSOR READINGS ON THE Y-AXIS

Testing	*Left Lux Sensor*	*Right Lux Sensor*	*Error*	*Accuracy*
1	3630.7	3630.5	0.2	99.9945 %
2	3614	3613.2	0.8	99.9778 %
3	3590.3	3590	0.3	99.9916 %
4	3581.1	3580	1.1	99.9693 %
5	3583.4	3583.3	0.1	99.9972 %
Average Accuracy				99.9860 %

B. Solar Tracking System Testing

The test is carried out by comparing the gain of solar panel voltage, the gain of solar panel power and the gain of solar panel current without using the PID method and when it has used the PID method. Test result data on the solar tracking system was taken at the same time in 2 tests with a data collection scale (logger) every 1 minute. Testing times are from morning to evening. “Fig. 6” shows a graph of the solar panel voltage gain, “Fig. 7” shows a graph of the solar panel power gain and “Fig. 8” shows a graph of solar panel current acquisition data.

In “Fig. 6” it can be seen that the results of testing solar panels using the PID method produce a greater voltage when compared to the results of testing solar panels without using the PID method. This is because the PID can direct the solar panel at a point with a high light intensity to produce a relatively small difference in the lux sensor reading (error value). The range of voltages generated in testing with the PID method is 12.48 - 14.09 Volts, while for testing without the PID method, it produces a voltage in the range of 11.3 - 11.78 Volts.

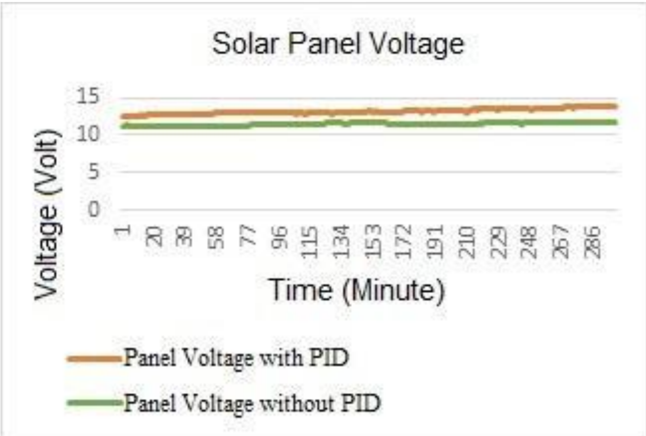

Fig. 6. Graph of comparison of solar panel voltage gain

In “Fig. 7” it can be seen that the total power obtained when testing solar panels with the PID method is 114.0276 watts while testing without PID produces a total power of 98.883 watts. The range of power gain per minute is between 0.41 to 104.07 Watts. In addition to the voltage and power obtained by the solar panel, the amount of current generated by the solar panel accompanied by the PID method and without the PID method also has significant differences. In "Fig 8" it can be seen that the current range generated by solar panels using the PID method is 0.26 - 7.95 Amperes, while the test without the PID method produces currents in the range of 0.02 - 1.19 Amperes.

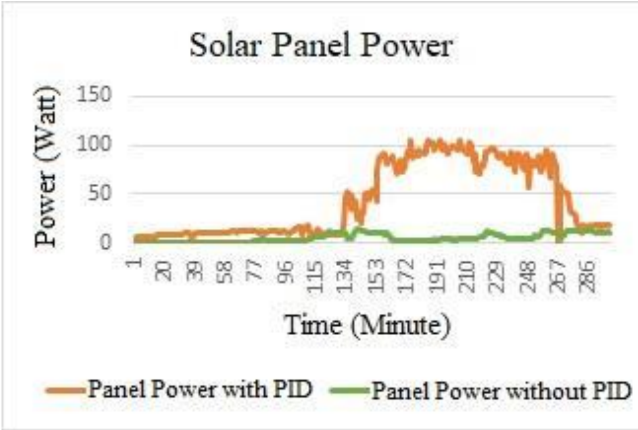

Fig. 7. Graph of comparison of solar panel power gain

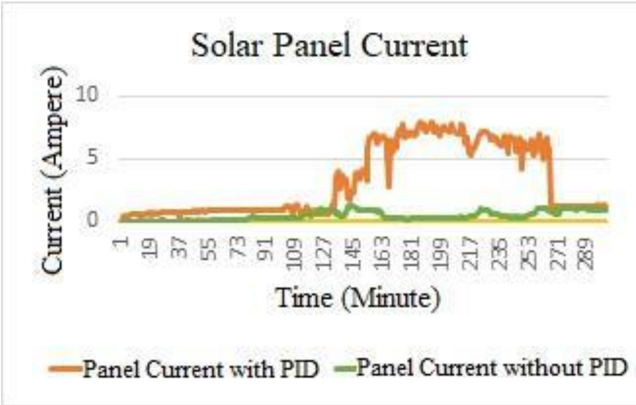

Fig. 8. Graph of comparison of solar panel current gain

IV. CONCLUSION

A solar tracking system with the PID method can provide stable control. This is proven by the error results resulting from the lux sensor reading which is close to the desired set point value and this means the level of accuracy is very high. The lowest error value generated by the X-axis is 0.3, while the Y-axis is 0.2. Then the gain of voltage, power and current generated by solar panels when using the PID method is greater than when without using the PID method. Natural conditions greatly affect the output of the solar tracking system, the greater the solar radiation, the greater the power generated by the solar panels.

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