International Journal of Electronics Engineering and Applied Science Vol. 2, No. 2, December 2024, pp. 42-49
***ISSN** 3032-7490*

Solar Panel Installation Engineering for Energy Conversion Optimization in Solar Power Plants

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ABSTRACTS

The sunlight absorption is the main technical factor of solar power plants performance because it affects to the amount of solar energy conversion. In order to optimize this absorption, the position of solar panel should be adapted to the direction of sunlight so it can improve the economic factor of solar power plants utilization. Furthermore, in this research, we have designed and tested three serial connection solar panels with single solar tracker (SST) to optimize the absorption of sunlight and its conversion to electricity, where the electrical current from panel with SST (1.41 – 2.52 A) is higher than panel without SST (0.89 – 1.59 A). Another parameter, namely electrical power of solar power plants, is proportional to electrical current and also higher than without SST (65.2 – 102.4 W), so the stored electrical energy in battery can be also increased. The utilization of Arduino Mega 2560, driver motor BTS7960, and linear actuator can optimize the solar panel absorption and finally this control circuit addition can increase the solar energy conversion to electricity. Besides that, this control circuit will reset the position of solar panel at 6.30 pm to the starting position. It means the solar energy conversion can be maximized by using SST and this advantage can increase the efficiency and support the transition to renewable energy.

KEYWORDS

Solar power plants, single solar tracker (SST), solar panel, energy conversion

1. INTRODUCTION

In the National Energy Strategic Plan, solar power plants are a priority program of the as a strategy to increase the mix of renewable energy by 23% in 2025 [1]. The utilization of solar power plants can be on-grid, connected to the electrical distribution network of PT. PLN (Persero) or off-grid, not connected to the distribution network [2]. In this research, the solar power plants used is off-grid because it will only be used as an additional lighting supply so that this system requires a battery, so that the electrical energy produced by solar panels during the day can not only be used directly but can also be stored for the use at night. In general, the solar power plants system consists of solar panels, inverters, installation cables and accumulators [3], [4]. However, the static position of the solar panel can be an obstacle in the form of suboptimal absorption of sunlight so that the conversion of electrical energy is reduced. Therefore, in this research, a control circuit was added to control the solar panel to be adjusted to the direction of sunlight so as to increase the absorption of sunlight and the conversion of light energy into electrical energy. The stored energy is used to charge the battery for lighting and supplying electrical energy in emergencies.

Solar tracking system or solar tracker is a tool that can detect the direction of sunlight by controlling the orientation of the solar panel following the direction of the incoming sun so that the intensity of sunlight can be absorbed to the maximum [5], [6]. The purpose of the solar tracker is to optimize the output produced by the solar panel. This solar tracker ensures that the position of the solar panel is always perpendicular to the direction of incoming sunlight. The drive system must be able to detect the amount of sunlight available. When the amount of light received by the solar panel decreases, the solar panel will automatically move until it gets the brightest amount of light. According to the type of control, solar tracker can be classified into microprocessor based, optic-electric sensor based, and time based [7], [8]. On the other hand, based on the orientation of control axes, solar trackers can be divided into single axis solar trackers and dual axis solar trackers [9], [10]. The single axis solar tracker can only rotate on one axis, the horizontal or vertical axis, while the dual axis solar tracker has horizontal and vertical axis, making it capable of tracking the actual movement of the sun in all directions [2][6].

Single axis solar tracker is a solar tracking system that can only track the direction of sunlight with one pivot point as the axis of rotation. This system can rotate the solar panel that rotates along one axis while the other axis forms a fixed or flat angle, so that the solar panel can rotate vertically (east to west) [7], [9], [13]. In this research, we used single axis soalr tracker to optimize the sunlight absorption and conversion of solar energy. The comparison of two different data (with SST and without SST) will be analyzed to show the optimization result of these different solar panel installation.

2. RESEARCH METHODOLOGY

2.1. Single axis solar system design

In order to maximize the absorption of light on the solar panel, the solar panel is made to be able to move following the direction of the sun. The movement of the sun is detected by the LDR light sensor then the resistance value received by the LDR will be forwarded to the Arduino Mega 2560. The Arduino Mega 2560 will process the information on the resistance value received by the two LDRs, compare it and then provide a signal to the motor driver so that the motor driver can adjust the direction of movement of the linear actuator. Subsequently, the sunlight received by the solar panel will be converted into electrical energy. The electrical energy which was originally in the form of DC electric current will be converted into AC electric current through an inverter. Afterwards, the solar charger controller acts as a voltage regulator on the battery. The electrical energy produced by the solar panel can be used directly by the community and the details of single axis solar tracker is explained in a block diagram of the system design, as shown in Figure 1.

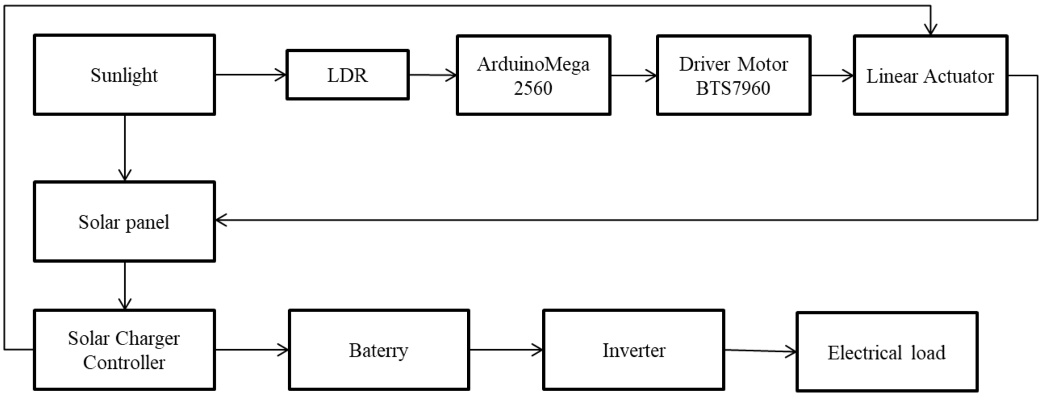

FIG 1. The block diagram of single axis solar system design where LDR and Arduino Mega 2560 will give signal to driver motor and linear actuator to change the direction of solar panel based on sunlight direction

The block diagram provides a comprehensive overview of the main components involved and the interactions between them in the system. Each component in the block diagram has its own role and function that support each other to achieve the goal of this system, which is to optimize the orientation of the solar panel to the position of the sun throughout the day. The solar panel functions as an object that is moved by the actuator to change its position, converting the sunlight received into electrical energy. Solar Charge Controller (SCC) functions as battery charging controller, the DC load output on the SCC is used as a source to drive the linear actuator and as a source for the microcontroller. Linear actuator controls solar panel by providing a push to the solar panel. Motor Driver regulates the movement of the linear actuator. LDR (Light Dependent Resistance): detects the intensity of sunlight and then makes it an Arduino input. Buck Converter: reduces the voltage from the DC source SCC (24V) to Arduino (5V). Microcontroller receives signals from sensors, so that the motor driver gets signals to move the linear actuator. Inverter: to convert direct current (DC) into alternating current (AC). Battery stores electrical energy generated by solar panels.

Work principle of single axis solar tracker is shown in Figure 2, where the detection of light intensity by LDR KY-018 converts light intensity will be received as resistance then it is read as an analog value by the Arduino Mega 2560. LDR KY-018 is placed on the solar panel in a position parallel to the solar panel, the two LDRs are separated by a partition so that they can detect the intensity of sunlight from each direction. The resistance of the two LDRs will be read by the Arduino as an analog signal, then the Arduino will compare the values of the two LDRs to determine which direction has higher light intensity. If LDR 1 (east) detects stronger light than LDR 2 (west), then the solar panel will move facing east, with the linear actuator position shortened. Conversely, if LDR 2 (west) detects stronger light than LDR 1 (east), then the solar panel will move facing west, with the linear actuator position lengthened. If both LDRs receive the same or almost the same light intensity, then the panel position does not change (stops).

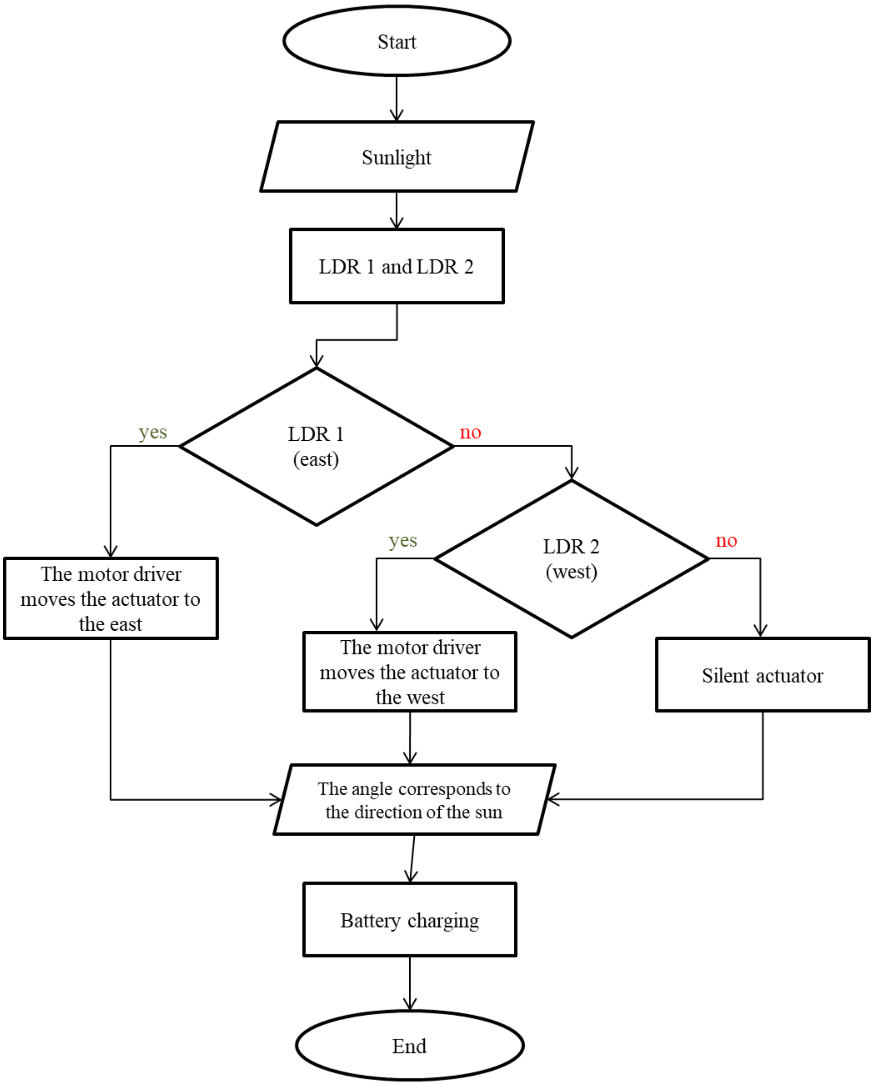

FIG 2. Flowchart of single axis solar tracker where the direction of solar panel is controlled by this tracker based on the sunlight direction

The direction and speed of the linear actuator movement are controlled by the BTS9260 motor driver. On the BTS9260 motor driver there is a PWM (Pulse Width Modulation) pin and a motor activation pin (enable). Arduino activates the enable pin to move the linear actuator. If the Enable pin is not active, the motor will not move even though there is a PWM signal. The right pin (forward) is the pin for motor movement to the west, while the left pin (backward) is the pin for motor movement to the east. When the light intensity on LDR 1 (east) is higher than LDR 2 (west), Arduino activates the left enable pin, so that the motor starts moving eastward. When the light intensity on LDR 2 (west) is higher than LDR 1 (east), Arduino activates the right enable pin, so that the motor starts moving westward. If the panel position is optimal (the light intensity received by both LDRs is balanced), Arduino will deactivate the enable pin to stop the movement of the actuator. The PWM-R pin controls the speed and direction of the linear actuator movement when the motor moves westward. The PWM-L pin controls the speed and direction of the linear actuator movement when the motor moves eastward. The linear actuator will extend or retract to move the solar panel towards higher light intensity, adjusting the angle of the panel to always optimally face the sun throughout the day. Single axis solar tracker includes details of the installation and arrangement of each component pin on the arduino pin. This explanation includes how each component is connected to the arduino to ensure the system works optimally. In addition, an installation diagram is also included that explains the relationship between the pins of each component and the arduino pins. Circuit diagram of single axis solar tracker is shown in Fig. 3.

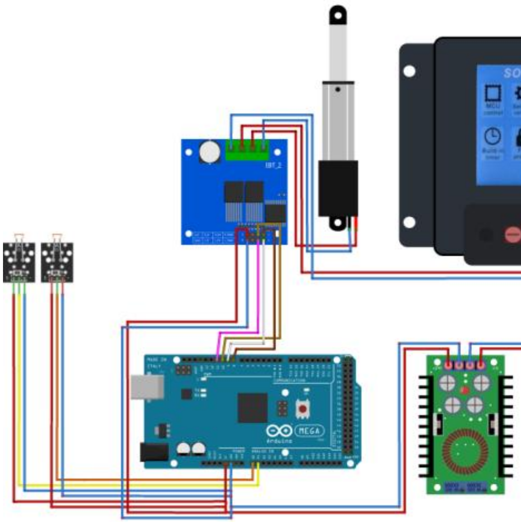

FIG 3. Single axis solar tracker circuit diagram consists of linear actuator, Arduino, LDR 1, LDR 2 and solar charge controller to optimize the absorption and conversion of sunlight.

2.2. Solar panel system design

The solar panel system design consists of mechanical and electrical design where the mechanical design of a single-axis solar tracker involves developing a strong and stable frame structure to support the load of the solar panels and ensure the movement of the solar panels. The frame design must consider factors such as material strength and the position of the linear actuator installation that allows movement on one axis. The design scheme of the single axis solar tracker in this study is shown in Figure 4a. The single axis solar tracker has one axis that is the reference for the movement of the solar panel. LDR 1 is placed at the initial position of the solar panel (east), while LDR 2 is placed at the west position. The position of the linear actuator is in the middle of the panel position so that it facilitates panel movement. The solar panels are arranged in parallel series and are designed to move following the direction of the sun. The movement of the solar panels is assisted by a linear actuator driven by a motor driver while other components are placed inside the panel box to be more protected (Figure 4b-d).

The motor driver used is the BTS7960 high current motor driver H-bridge module. The motor driver is used as a voltage controller that will be forwarded to the linear actuator and also as a changer of the direction of rotation of the linear actuator. Another component, namely LDR, will give a signal to the Arduino so that the actuator can move. The specification of LDR is KY-018 photoresistor module type with operating voltage 3.3-5 V. Next component, linear actuators, are used as solar panel drivers according to instructions from the motor driver and light sensor. The specification of linear actuator is Matrix actuator type HRL-3618+ with input rating DC 12V/24V/36V and stroke length 12” /18” /24”. On the other hand, we have to use buck converter to reduce the DC voltage from the SCC output by 24V to 5V for the Arduino input voltage.

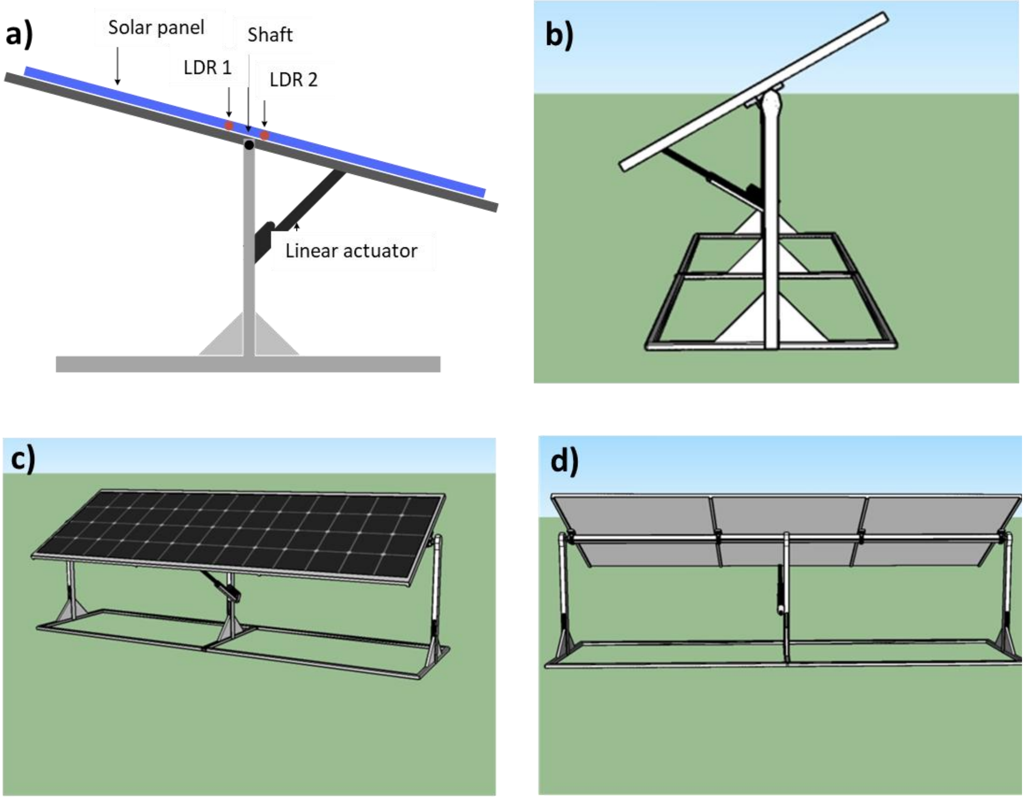

FIG 4. Single axis solar tracker design and off grid solar panel control system (a) The direction of solar panel is controlled by LDR1, LDR2 and linear actuator (c-d) Solar panels left side, front side, and back view

3. RESULTS AND DISCUSSION

This prototype test was conducted to compare the performance between statically installed solar power plan and dynamically installed solar power plan with a single axis solar tracker. The statically installed solar power plan test took place on July 29, 2024 and July 30, 2024. Meanwhile, the dynamic solar power plan test with a single axis solar tracker was carried out on August 8, 2024. The solar panel was tested at a tilt angle of 15°, the selection of the tilt of the solar panel was based on previous research related to the optimal tilt for 120Wp monocrystalline solar panels in Padang City. The study indicated that a tilt angle of 15° is the most effective angle in producing more maximum and stable energy compared to testing at other angles [14], [15].

3.1. Static testing of solar panel

The solar panel in static position was tested to obtain the data of voltage as shown in Fig. 5a, where the maximum voltage of static testing was 45.69 V on 29 July 2024 and 42.83 V on 30 July 2024. The average voltage generated by the solar panel in the test on July 29, 2024 was 37.224 V, while the average current was 1.065 A, and the average power generated was 41.32 W. Furthermore, it was also found that the voltage, current and power generated by the solar panel changed over time. The peak voltage of the solar panel was obtained at 12:00, which was 45.69 volts, while the peak current of the solar panel was obtained at 09:00, which was 1.74 A. The second test was carried out on 30 July 2024 and also the test was carried out from 08:00 to 17:00.

The average voltage generated by the solar panel in the test on July 30, 2024 was 33.983 V, while the average current was 1.728 A, and the average power generated was 57.15 W. The peak voltage generated by the solar panel was recorded at 14:00, which was 42.83 V. Meanwhile, the peak current was achieved at 09:00 WIB with a value of 3.73 A. This variation shows how lighting conditions and the position of the sun throughout the day affect the performance of the solar panel in generating electrical energy. There is no change of solar panel tilt angle in the static testing (Fig. 5b), where the linear actuator was not activated.

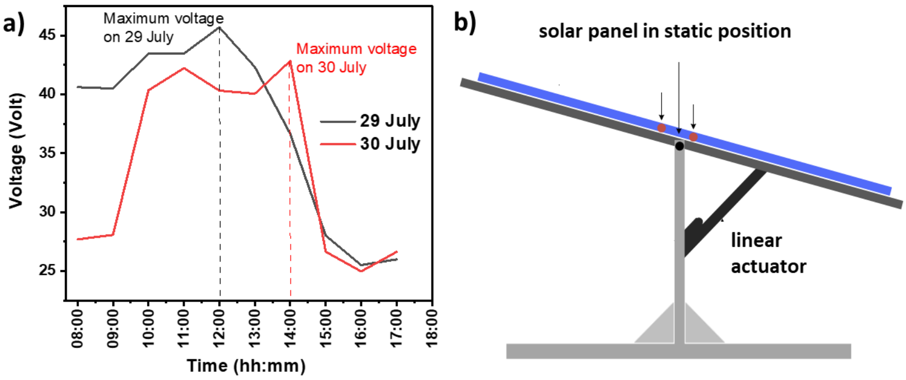

FIG 5. (a) The fluctuation of voltage in different day (29 and 30 July 2024) and (b) The static position of solar panel in the measurement of voltage

3.2. Dynamic testing of solar panel

The dynamic testing used linear actuator to change the direction of solar panel according to sunlight direction. The solar energy that can be converted to electricity is larger than static position based on the power measurement as shown in Fig. 6a. The dynamic testing with a single axis solar tracker was carried out on August 1, 2024. In this test, the movement of the solar panel was limited to one axis of freedom, namely the east-west axis, with a movement angle limit between 35° to the east and -30° to the west. The test started at 08:00 and ended at 17:00, this test aims to observe the effectiveness of the solar tracking system in maximizing solar energy capture throughout the day.

The average voltage generated by the solar panel in the test on August 1, 2024 was 40.876 V, while the average current was 1.935 A, and the average power generated was 79 W. Fig 6a shows that the voltage, current and power generated by the solar panel change over time. The peak voltage generated by the solar panel was recorded at 14.00 WIB, which was 43.1 V. Meanwhile, the peak current was reached at 12.00 WIB with a value of 2.52 A. The variation of solar panel directions are illustrated in Fig. 6b, c and d. This higher power can increase the efficiencies of solar panel utilization and gives more advantages to user. The amount of electronic devices which utilize solar energy can be enhanced and decrease the electricity consumption from PT. PLN.

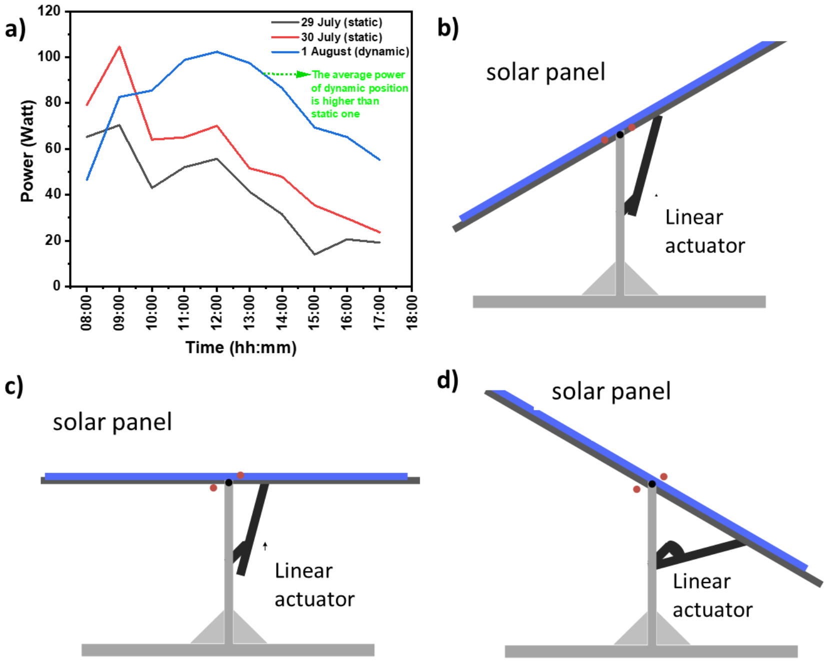

FIG 6. (a) The power comparison of static and dynamic position of solar panel (b), (c) and (d) The dynamic position of solar panel in the measurement of voltage

Based on the PLTS power measurement data, the power difference between static position and dynamic position with a single axis solar tracker is obtained based on the following calculations:

1. The difference in total power in the static PLTS test on July 29, 2024 with the dynamic PLTS test with a single axis solar tracker on August 8, 2024.

$$
\begin{aligned}
\Delta P_{total} &= P_{total\ dynamic} - P_{total\ static} \\
&= 790 - 413.2 \\
&= 376.8 \text{ Watt} \\
\%\,\Delta P_{total} &= \frac{376.8\ Watt}{413.2\ Watt} x\ 100 \\
&= 91.19\ \%
\end{aligned}
$$

2. Difference in total power in the static PLTS test on July 30, 2024 with the dynamic PLTS test with a single axis solar tracker on August 8, 2024.

$$
\begin{aligned}
\Delta P_{total} &= P_{total\ dynamic} - P_{total\ static} \\
&= 790 - 571.5 \\
&= 218.5 \text{ Watt} \\
\%\,\Delta P_{total} &= \frac{218.5\ Watt}{571.5\ Watt} x\ 100 \\
&= 38.23\ \%
\end{aligned}
$$

It means the increase in dynamic solar panel power with a single axis solar tracker is 38.23% - 91.19%, depending on the light intensity and weather conditions at the time of measurement. However, solar panels with a single axis solar tracker have a linear actuator as a solar panel driver, this linear actuator requires power consumption. The power consumption spent by the linear actuator is 14.4 Watt.

4. CONCLUSIONS

How to maximize the absorption of sunlight on solar panels can be done by providing control on the solar panels by moving the panels according to the direction of sunlight so that sunlight, in this final project the control used is the control of solar panels on one axis of freedom (single axis solar tracker). The installation of this single axis solar tracker provides an increase in power of 38.23% - 91.19%, this depends on weather conditions and sunlight intensity at the location of the solar panel installation. Based on the tests conducted by the author, the total power generated in the static solar panel test on July 29, 2024 was 413.2 W, in the test on July 30, 2024 it was 571.5 W, while in the dynamic PLTS test with a single axis solar tracker it was superior, namely 790 W. The installation of this single axis solar tracker provides a power increase of 38.23% - 91.19%, this depends on weather conditions and sunlight intensity at the location where the solar panels are installed.

ACKNOWLEDGMENT

The authors gratefully acknowledge the research support from Polytechnic State of Padang, Ministry of Higher Education, Science and Technology, the Republic of Indonesia. The authors also thank the people around Mushalla Al Barkah, Padang City, West Sumatra, for the use of the location to measure the solar intensity and testing the solar panel.

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