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Research paper

Development Of An Automatic Sun Tracking System On Solar Panels As Electric Power Supplier At Smart Garden

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ABSTRACT

A solar panel is a device/tool that can convert energy from sunlight into electrical energy. This research aims to design a tool that can help solar panels move in the direction of the sun, determine the energy consumption used to run the tracking system that has been created and choose the output power results of solar panels with the tracking system and the output power of solar panels without a tracking system. This automatic sun tracking system was successfully designed using an Arduino Uno as a microcontroller, an LDR sensor as a light detector, and a servo motor as an actuator or driver of solar panels with a two-axis arrangement, namely the vertical and horizontal axes. The system that has been designed will consume 58.8 Wh of energy during the 7 hours of testing. Through outdoor testing results for five days, the average daily output power on solar panels without tracking is 43.10 W, 47.17 W, 10.06 W, 15.59 W, and 30.81 W, while the average daily output power on solar panels with a tracking system is 53.79 W, 57.27 W, 10.31 W, 16.61 W, and 32.40 W. These results show that using the automatic sun tracking system designed in this research can increase the average output power produced by solar panels.

1. INTRODUCTION

Solar energy is a crucial renewable energy source with vast potential for sustainable development and environmental benefits (Khalid, 2024). Solar energy's global significance is highlighted in research discussing its applications in agriculture, including greenhouse farming and irrigation, to meet the increasing demand for agricultural products sustainably (Ali Hussein, 2022). Solar cells are an environmentally friendly alternative power generation system that is very prospective as an alternative

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energy to replace electricity generation systems made from fossil fuels. Culp Archie explained that sunlight energy or solar energy could be directly converted into other forms of energy through three separate processes: heliochemical, helioelectrical, and heliothermal. Meanwhile, converting solar energy into electricity is a helioelectrical process. This process can take place if photovoltaics or solar panels are used (Wibawa et al., 2014)

Solar panels are crucial for converting sunlight into electrical energy, with factors like light intensity and cell temperature significantly impacting their output. Decreased light intensity leads to lower voltage and electric current production. Maintaining a normal cell temperature of around 25°C is essential for optimal operation, as excessive heat can weaken the voltage output (Voc) of the solar cell (Sharma et al., 2022). Additionally, the efficiency of solar panels is influenced by various parameters, including the number of solar modules and the weighted average amount of generated energy, as determined through regression analysis in ground installations (Hilorme et al., 2023). Evaluating the efficiency of photovoltaic panels under different climatic conditions is crucial, with simulation modeling helping to assess performance variations based on temperature ranges and heat flow on the panel's surface (Spodyniuk et al., 2023).

The sun's position moves across the sky all the time. Therefore, the intensity of light the solar panels receive will change, preventing them from absorbing maximum light. To maximize the energy produced by solar cell modules in Indonesia, the installed solar cell modules must be equipped with a solar tracker. The function of the solar tracker is to move the solar cell module so that it can move and face the sun continuously. By adding a solar tracker, the solar cell module can receive maximum sun so that the energy produced is maximum (Sutaya, 2015).

Tracking mechanisms are often incorporated into solar panel arrays to keep the array pointed toward the sun. A solar tracker is a device installed on which solar panels track the sun's movement across the sky to ensure that extreme amounts of sunlight hit the panels throughout the day (Ramya & Ananth, 2016). Yuliananda et al., (2015), in their research, explained that the sun's intensity affects the output power of solar panels, where if the intensity is low, then the power produced is low. In contrast, the power produced will also increase if the intensity is high. Therefore, it is essential to ensure that the solar panels have maximum intensity at all times, one of which is by using a tracking system applied to the solar panels. In their research, Bahari et al., (2017) explained that changes in the direction of the angle formed by the solar panels with the sun affect the size of the voltage produced.

Based on the literature the author has reviewed, research will be carried out on creating a device/tool that can automatically track sunlight to help solar panels increase output power, which will then be applied to intelligent garden universities (Smart Garden University).

2. METHOD

This tool was designed and assembled in the Electronics Laboratory, Physics Study Program, Faculty of Science and Technology. Testing was conducted at the university's Bright Garden (Smart Garden University) from August 2022 to November 2022 for five days.

2.1 Tools and materials

The equipment used in this research is a 100-watt peak solar panel, Arduino Uno, LDR sensor, 10 KΩ resistor, SPT5435LV servo motor, voltage sensor, current sensor, BH1750 light intensity sensor, PCB, wooden board, microSD card module, RTC DS3231 module, push buttons, potentiometers, connecting cables, bearings, cables, drills and saws, wood glue, tin, PC/ windows.

2.2 Hardware design

The hardware design is presented as follows. The mechanical design of this sun-tracking system (Figure 1) was created using the *Sketchup application*.

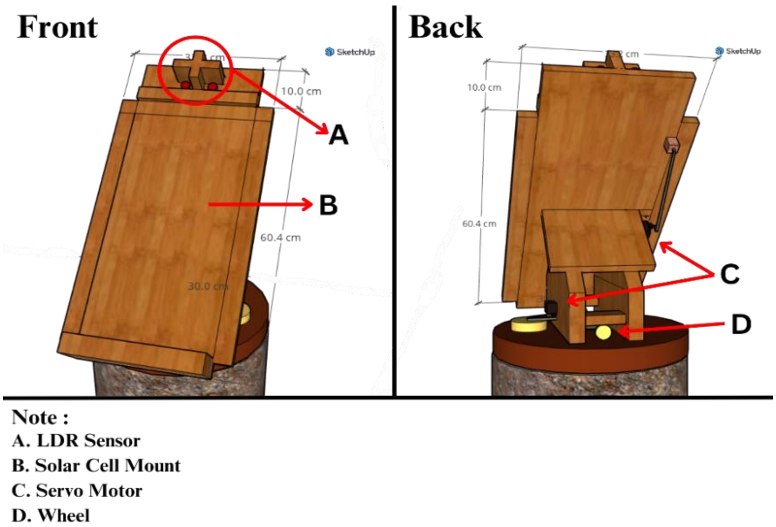


Fig 1. Mechanical design of automatic sun tracking system

2.3 Electronic schematic design

The Electronic schematic design of the automatic sun-tracking system is shown in Figure 2.

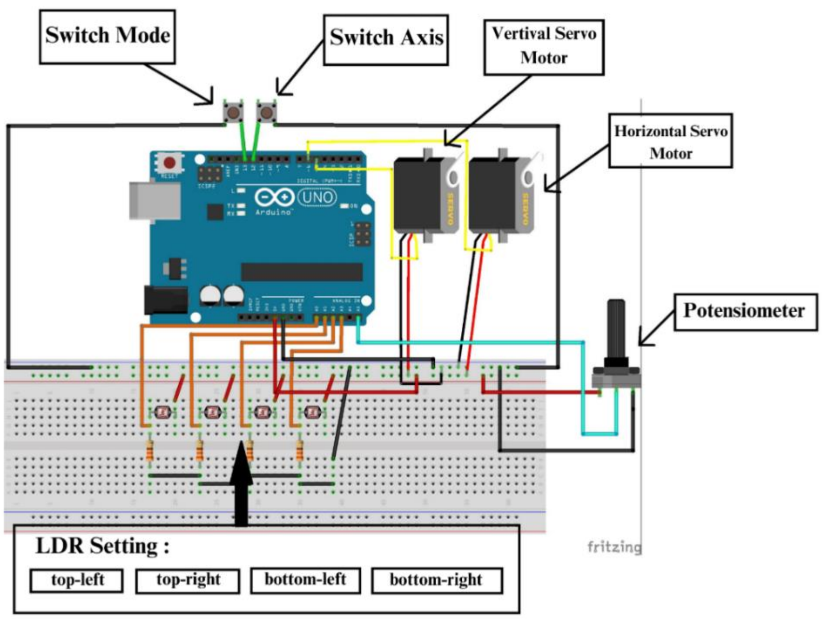


Fig 2. Electronic schematic design of automatic sun tracking system

This sun tracking system scheme (Figure 3)can be set into two modes; in the "automatic" mode, the Microcontroller changes the analog value obtained from the analog input value of the LDR sensor (pins A0 to A3) into digital. Then, the digital value controls two servo motors (horizontal and vertical) using 2 PWM or Pulse-Width Modulation signals (from pin five and pin 6) to track sunlight. Rotational movement occurs on two axes, in azimuth (horizontal angle) from east to west according to the daily sun path and elevation (vertical angle) from south to north according to the seasonal sun path. Meanwhile, in "manual" mode, a potentiometer (pin A4) is used to control the movement of two servo motors, with the help of a Push Button (pin 11), which is installed to connect the potentiometer with servo motor one and servo motor 2 (horizontal servo motor and vertical servo motor). Meanwhile, the Push Button on pin 12 is used to change the mode between the two modes (automatic and manual).

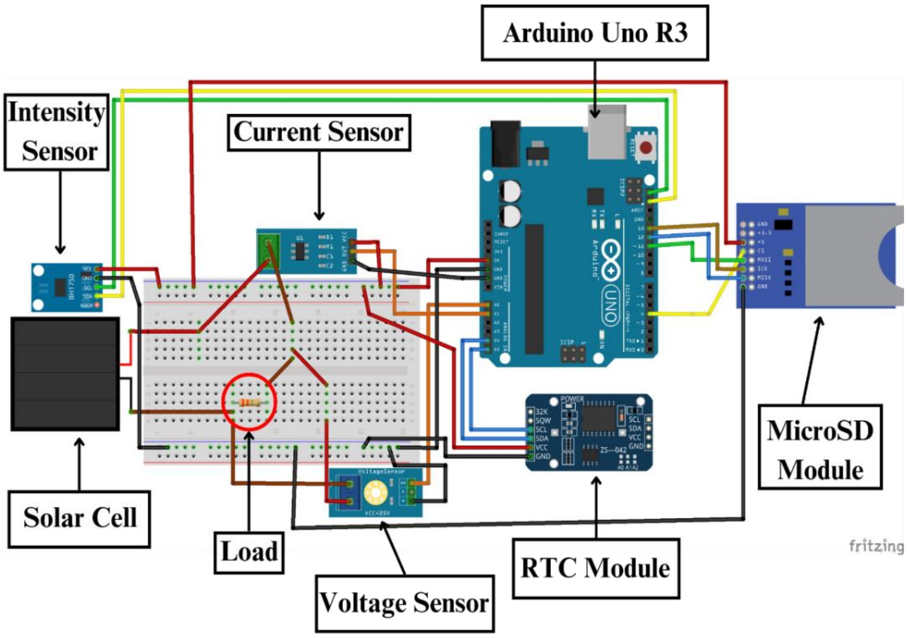


Fig 3. Electronic schematic design of data storage systems

The output from the solar panel will be connected to the ACS712 voltage sensor and current sensor to determine the current and voltage values produced from the solar panel. The values are entered into the Arduino microcontroller for processing in analogue form. With the ADC on the Microcontroller, the analogue values from the sensor can be converted into digital ones, which will then go through a data processing process. Apart from the current and voltage values obtained, the sunlight intensity value will also be read by the BH1750 sensor, which will then be connected to the analogue pin of the Arduino to read the analogue value before being processed by the ADC from the Microcontroller. Then, the voltage, current, power, and sunlight intensity values will be stored in the SD Card module for analysis and data processing purposes in this research. To record time during the testing process and data collection, we can use the RTC DS3231 as a real-time module that can produce digital time.

2.3 Data retrieval

2.3.1 Indoor Testing

Indoor data collection was carried out to determine the characteristics of the output voltage response of the LDR sensor used in the automatic sunlight tracking system (Figure 4). This test was carried out by shining the LDR sensor with an artificial light source (flashlight) at 30 cm and 45 cm at an angle of 0°-180° on the vertical horizontal axis.

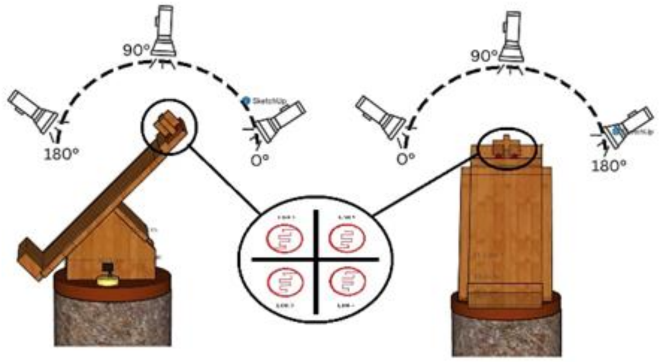


Fig 4. Scheme for testing the LDR sensor response on the tracking system

2.3.2 Outdoor Testing

The outdoor data collection was conducted to determine the effectiveness of using an automatic sunlight tracking system on solar panels and the difference in the output power of solar panels without a tracking system and the output power of solar panels with a tracking system. This testing was carried out for five days in August and November 2022.

2.4 Data analysis

The data obtained from indoor testing is the output voltage of the LDR sensor, which will be analysed to determine the characteristics of the LDR sensor output, which will be used to track light. In contrast, the data obtained from outdoor testing shows the intensity of sunlight, voltage, current, and power from the panel. Sun. This data will be analysed on the distribution of power difference data using standard deviation analysis, and the total estimated energy produced from solar panels with and without a tracking system will be analysed.

3. RESULTS AND DISCUSSION

3.1 Tracking system characteristics

The output voltage response on the vertical axis is observed as shown in Figure 5. At a test angle of 0°-75° the output voltage value of the LDR 3 and LDR 4 (lower side) sensors is zero, while LDR1 and LDR2 (upper side) increase to their peak at 90°. Meanwhile, at the test angle LDR3 and LDR4 work best at a vertical sunlight angle of 105°-180°, the opposite is true, the LDR 1 and LDR 2 sensor values are zero.

The output voltage response on the vertical axis can be observed in Figure 6. At a test angle of 0°-75°, the output voltage value of the LDR 2 and LDR 4 sensors (right side) is zero, while LDR 1 and LDR 3 (left side) increases to its peak at 90°. Meanwhile, at the test angle of 105°-180°, the opposite is true; the LDR 1 and LDR 2 sensor values are zero.

The difference between the two signals received by the light sensor (LDR) will be compared with the trigger value/threshold value set by the author to carry out the command to move the solar panel 9; the threshold value used by the author is 10 ADC/0.048V.

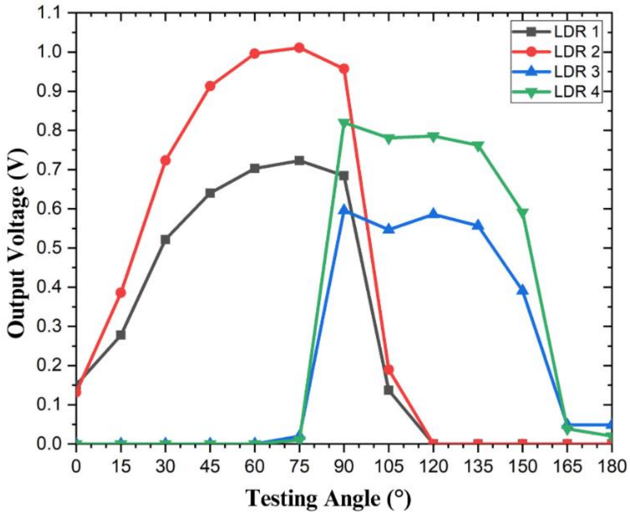


Fig 5. Plot the LDR sensor output voltage response graph on the vertical axis (distance 30 cm)

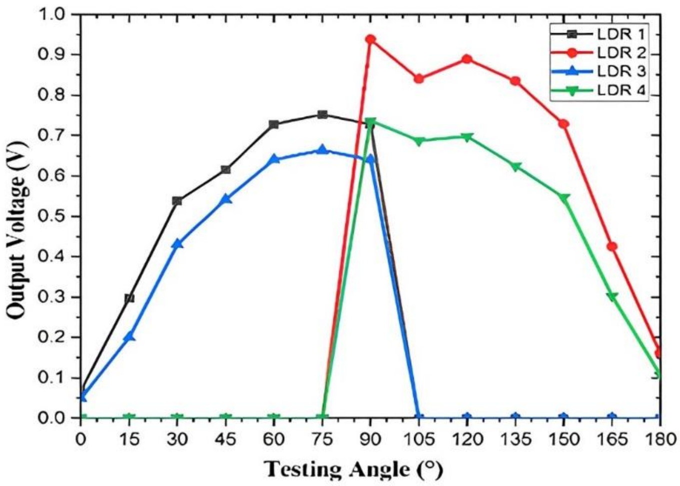


Fig 6. Plot the LDR sensor output voltage response graph on the horizontal axis (distance 30cm)

3.2 Calculation of the operating power of an automatic sun tracking system

This section will discuss the power and energy required to run the tracking system for the 7-hour test duration.

a. Arduino Uno
   Power = 9V ×0.8A=7.2 W
   Energy =7.2 W ×7h=50.4 Wh
b. Servo motors
   Power = 6V ×0.1A= 0.6 W
   Energy =0.6 W×7h×2 = 8.4 Wh
c. Total energy
   Total Power = 7.2 + (0.6×2) = 8.4 W
   Total Energy = 50.4+8.4 = 58.8 Wh

So, running the automatic tracking system in this research will consume ±58.8 Wh of energy.

3.3 Analysis of daily power output

The power of solar panels is shown in Table 1. The highest power output from a solar panel depends on the maximum intensity of solar radiation that hits the surface of the solar panel. The highest power of the entire tracking system test occurred on day 5, with a value of 87.69 W using the tracking system and 83.76 W without using the tracking system. According to the data sheet, solar panels have a maximum power of 100 W, but during testing, the maximum power produced reached less than 100 W. This can happen due to various factors, one of which is the temperature of the solar panels. During testing, the temperature of the solar panel will increase, so the increase in temperature from the average temperature of the solar panel will weaken the voltage of the solar panel.

Table 1. Highest power analysis of solar panels with and without tracking system

Days to	O'clock	Power No Tracker (Watt)	Power With Tracker (Watt)
1	12.30	67.07	72.12
2	09.30	67.63	76.80
3	09.30	21.08	20.50
4	10.30	65.23	67.41
5	09.30	83.76	87.69

3.4 Analysis of power and energy output of solar panels with and without a tracking system

Data on average power test results and estimates of the energy produced are shown in Table 2.

Table 1. Solar panel output power test result data with and without tracking system

Days to	Intensity	Average Power (W)		Energy (Wh)	
	Average	No tracker	With tracker	No tracker	With tracker
1	46769.20	43.10	53.79	151.72	186.27
2	46088.76	47.17	57.27	163.12	197.13
3	26234.12	10.06	10.31	35.01	35.73
4	21151.55	15.59	16.61	52.19	54.40
5	25589.11	30.81	32.40	98.19	102.36

Testing on day one and day 2 occurred in sunny conditions (indicated by higher average light intensity values) while testing on day 3, day four, and day 5 occurred in cloudy conditions/ mostly cloudy (indicated by lower average light intensity values). The sunlight's intensity will affect the solar panel's output power value (Yuliananda et al., 2015)

Based on the outdoor test results data presented in Table 2, the average output power of solar panels with an automatic sun tracking system is greater than that of solar panels without an automatic sun tracking system (Figure 7). This happens because solar panels with a tracking system can move in the direction of incoming sunlight with the help of a tracking system so that the intensity of solar radiation received by solar panels with a tracking system has a more excellent value. The tracking system can move optimally in bright conditions (day one and day 2) because the LDR sensor can track light. However, this is different when conditions are medium to thick cloudy (day 3, day 4, and day 5). In the test results on days 3, 4, and 5, the difference in power obtained by solar panels with a tracking system and solar panels without a tracking system is relatively small. This happens because, even though the tracking system is working optimally, whichever direction the solar panel moves, the intensity of solar radiation received by the solar panel with and without the tracking system is the same. The output power between the solar panel and the tracking system has a value that is almost the same, or slightly more significant, than that of the solar panel without the tracking system.

(a) (b)

Fig 1. Solar panel output power testing, (a) without a tracking system, (b) with a tracking system

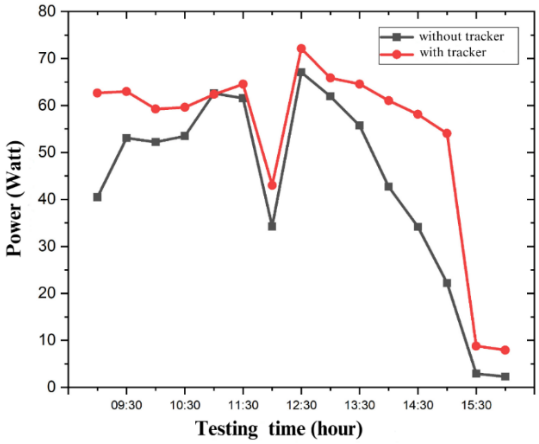
The estimated energy produced by solar panels is calculated by calculating the area under the curve between power and time using the trapezoid method approach. The calculation results for the estimated energy produced by solar panels without a tracking system for five consecutive days are 151.71 Wh, 163.12 Wh, 35.01 Wh, 52.19 Wh, and 98.19 Wh. Meanwhile, the calculation results for the estimated energy produced by solar panels with a tracking system for five consecutive days are 186.27 Wh, 197.13 Wh, 35.73 Wh, 54.4 Wh, and 102.36 Wh. The difference in sky conditions on days 1 and 2 and days 3, 4, and 5 dramatically influences the energy gain. It can be seen that the difference in energy between solar panels with trackers and without trackers on 1^{st} and 2^{nd} days are more significant. The addition number of days has no effect on the validity of the tracking system.

3.5 Analysis of the effectiveness of automatic sun tracking systems

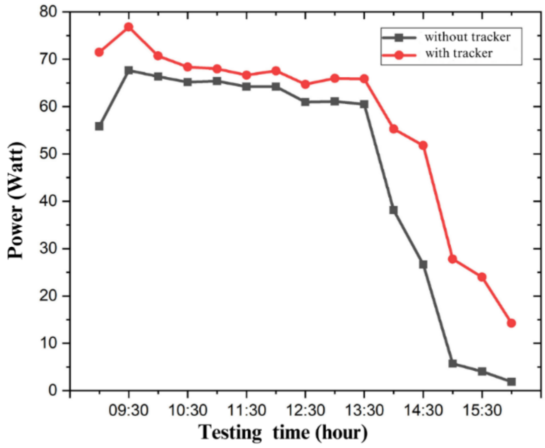
The results of testing the output power of solar panels with a tracking system and solar panels without a tracking system are plotted into a graph to see the increase in power at each time (09.00-16.00), with a data collection interval of 30 minutes showed at figure 8.

The average increase in output power and average energy produced by solar cell tracking systems compared to solar cells without tracking is presented in figure 9.

The average power percentage on solar panels with a tracking system increased by 19.87% on day 1, 17.63% on day 2, 2.42% on day 3, 6.14% on day 4, and 4.90% on day 5. Even though there was an increase in power on the solar panels with the tracking system, the percentage increase was not very significant or very small on the third day, fourth day, and fifth day of testing (percentage increase in power <10%). The percentage of energy produced by solar panels with a tracking system increased by 18.55% on day 1, 17.25% on day 2, 2.01% on day 3, 4.06% on day 4, and 4.07% on day 5. The most significant percentage increase in energy occurred on days 1 and 2, while on days three and onwards, the percentage increase in energy was minimal <10%. Furthermore, you also need to know that energy is required to run this automatic ray tracking system around ±58.8 Wh for 7 hours of testing, as discussed previously.



a.



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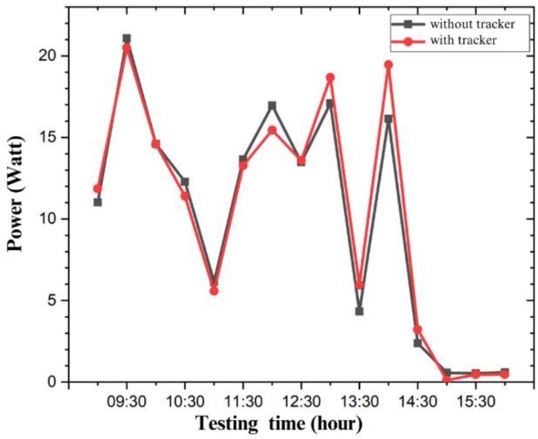

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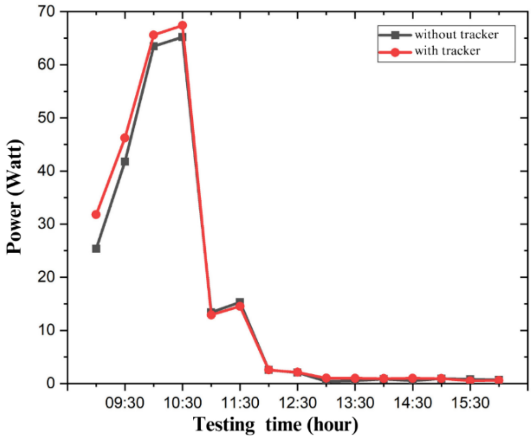

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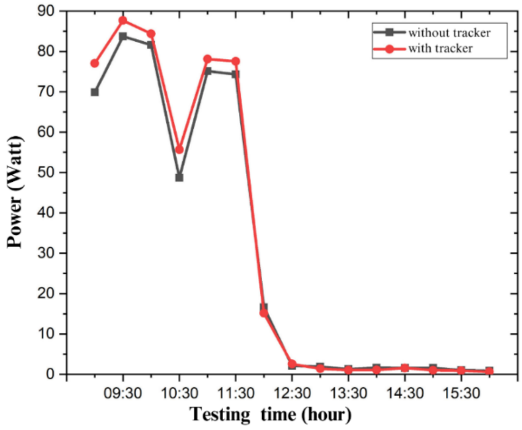

e.

Fig 8. Comparison of solar panel output power on a. 1st day testing; b. 2nd day testing; c. 3th day testing; d. 4th day testing; e. 5th day testing

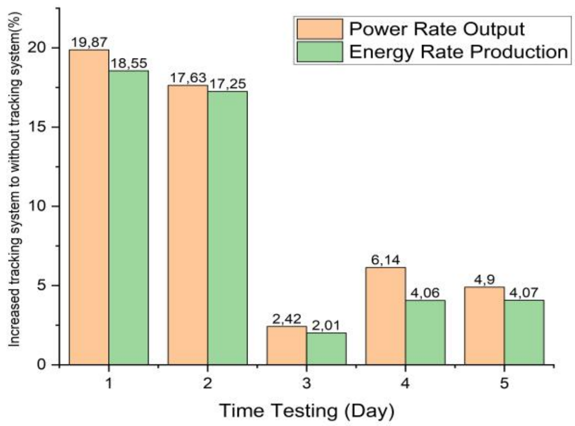

Fig 9. Increased Power Rate output and Energy Rate Production with tracking system to without tracking system.

Suppose the energy consumption of this tracking system is taken into account. In that case, the net energy obtained by solar panels with a tracking system is less than that without a tracking system. Suppose there is a loss of energy; then overcome the loss of energy by using the tracking system. In that case, increasing the maximum output of the solar panels used is possible, with a percentage increase of around 18% -19% if the maximum output can be increased. Then, the amount of energy gained will also be more significant and can cover the energy lost due to the use of the tracking system.

Kumar et al., (2021), with a single-axis tracking system, showed in practical tests that they produced an increase in solar panel output efficiency of 15%-20% compared to a stable system. Lazaroiu et al., (2015), in their research, showed that there was an increase in the energy produced by 12% -20% compared to solar panels without a tracking system. Meanwhile, Das et al., (2015), through their research results showed an increase in the power output of solar panels with a tracking system of 19.73% compared to fixed solar panels/without tracking. The hybrid algorithm of tracking system of sun consistently yields the highest voltage increment of up to 14% on cloudy days and up to 13% on sunny days(Tharamuttam & Ng, 2017)Click or tap here to enter text.. In this research, there was an increase in power of 17.63%–19.97% and an increase in energy of 17% - 18% in solar panels with a tracking system tested in bright conditions; this shows the suitability and similarity of the results of the effectiveness of using the tracking system in increasing the percentage of panel output solar ranges between < 20%.

With higher efficiency, the tracking system with Arduino can be implemented on a large scale. The proposed solar tracking system could make optimal use of solar energy for all weather conditions, thereby greatly reducing carbon emissions and cutting electricity costs for the public and private organizations. Although long-term research related to system wear due to the influence of weather and time of use still needs further research.

4. CONCLUSION

The design of an automatic sunlight tracking system was successfully created using an Arduino Uno as a microcontroller, 4 LDR sensors as input, which will detect the direction of sunlight, and a servo motor of the SPT5435LV type used as a driver for a solar panel module with two axes, namely the vertical and horizontal.

The power used to run this automatic sun tracking system is 8.4 Watts, with an estimated use of the tool during a measurement time of 7 hours (09.00 to 16.00); this sun tracking system will consume energy of ± 58.8 Wh.

Based on tests that have been carried out for five days, the output power on solar panels without a tracking system is 43.10 W, 47.17 W, 10.06 W, 15.59 W, and 30.81 W, while the output power on solar panels with a tracking system is 53.79 W, 57.27 W, 10.31 W, 16.61 W, and 32.40 W. These results show that using the automatic sun tracking system designed in this research can increase the average output power produced by solar panels.

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