UTILIZATION OF A DUAL-AXIS SOLAR TRACKER TO INCREASE THE EFFECTIVENESS OF SOLAR PANELS IN THE STORAGE OF POWER IN LITHIUM-ION BATTERIES

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Abstract
This study was conducted to determine the effectiveness of utilizing the Dual-axis Solar Tracker in harnessing solar energy and storing it in lithium-ion batteries in terms of voltage and milliamps per hour gained. This study utilized two solar panel systems, the Static Solar Panel System and the Dual-Axis Solar Tracker and aimed to prove the significant difference generated by solar panel systems in terms of voltage and milliamps per hour. This study employed an Applied Experimental Research Design utilizing Arduino Uno, light-dependent resistors, micro servos, and solar panels to create the Dual-Axis Solar Tracker. The data gathered from the electric quantities during the seven-day sun exposure were tabulated, analyzed, and computed using mean tests, standard deviation, and T-tests to find the significant difference between the two solar panels. Based on the analyses of the data, it was revealed that the Dual-Axis Solar Tracker was superior in terms of voltage and milliamps per hour generated compared to the Static Solar Panel System. Moreover, computations using the T-test found that in terms of voltage and milliamps per hour generated, there was a significant difference between the Dual-Axis Solar Tracker and the Static Solar Panel System. Based on the findings of the study, it is concluded that the utilization of the Dual-Axis Solar Tracker statistically increases the effectiveness of solar panels in harnessing energy generation.

Keywords: *Dual-axis solar tracker, Effectiveness, Static Solar Panel System*

INTRODUCTION

Students of today can be the ones to spearhead change and work toward universal access to clean and affordable energy for all. Studies in solar energy are relevant to address a significant problem in the modern world which is access to efficient renewable energy. Renewable energy impacts jobs, housing, food supplies, and climate change. The world could not function without energy, and access to inexpensive and clean energy is now more important than ever. Even with the advancements made by humanity in the development of sustainable energy sources like solar and wind power, energy still accounts for around 60% of the world's emissions of greenhouse gases, one of the primary factors in climate change (UNEP). Renewable energy is vital to the country's low-carbon sustainability emissions development strategy and is vital to addressing the challenges of energy security, climate change, and access to energy (Uy, 2022). The Philippines is subject to price changes and supply constraints due to its reliance on imported coal and oil (Brahim, 2014). The development and optimal use of the country's renewable energy resources are central to the Philippines' sustainable energy agenda. Renewable energy is an essential part of the country's low-emissions development strategy. It is vital to address climate change challenges, energy security, and access to energy. This research used electronic components to fabricate a dual-axis solar tracker to increase the effectiveness of solar panels. In order to create a more effective way of harnessing solar energy using solar panels, the researchers applied robotics fundamentals to create the solar tracker, a system that positions a body at an angle relative to the sun. Solar trackers could generate more electricity than their stationary counterparts. This is due to its feature, which increases its direct exposure to solar rays (SPW, 2016). Solar trackers generate more electricity in approximately the same amount of space needed for the static panel system, making them ideal for optimizing land usage (McHale, 2015). If the trackers are installed in an environment with ideal conditions, they added value to the solar panel system and boost energy production. In terms of sustainability, the usage of solar trackers decreased reliance on the local grid and increase reliance on renewable energy as an alternative source for electricity generation (Gregus, 2021). Many studies have explored aspects of solar panels and the use of solar trackers (del Rosario, 2014). The present study explored creating a dual-axis solar tracker by utilizing micro servos instead of direct current (D.C.) motors for the solar tracker's movement, computer systems and microprocessors to control solar tracking systems to follow the sun's location, and introduces a power efficient method to minimize the power consumption of the dual-axis solar tracker. This study created a model of a dual-axis solar tracker that is not dependent on the electrical grid. Furthermore, it used batteries to store solar energy and use the energy to power up the dual-axis solar tracker. Thus, considering the foregoing claims, this study was conducted to utilize a dual-axis solar tracker to increase the effectiveness of solar panels.

Background

Electric power generation accounts for the second highest share of greenhouse gas emissions: carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The greenhouse gas emissions from electricity generation are attributed to the electricity sector. Approximately 60% of our electricity is generated by the combustion of fossil fuels like coal, oil, and natural gas, as stated by the U.S. Energy Information Administration (2019). Therefore, the Philippines' reliance on fossil fuels compromises its energy security (Lea, 2020). Renewable energy is in development. Denmark produced 43% of its energy from renewables, and it is working towards achieving 70% by 2020. At more than 25% now and 30% soon, Germany is going for 40% to 45% clean energy by 2025, 55% to 60% by 2035, and a possible 80% by 2050 (Ahuja, 2009). In the Philippines, renewable energy supplied 26.44% of total electricity in 2013 and 19,903 gigawatt-hours (GWh) of electrical energy out of a total demand of 75,266 gigawatt-hours (Membrere, 2013). The Philippine government has aimed to increase renewable energy contributions to 50% of its total electricity generating capacity (France-Presse, 2011) to 15.3 gigawatts (G.W.) by 2030 (Rhodium, n.d). The approach would enhance the country's objective of reducing carbon emissions by 70% by 2030. From the data given, it can be observed that in the Philippines, currently, the large-scale use of photovoltaic cells is not economically competitive in the market for electricity generation. Solar energy is the conversion of renewable energy from photons into electricity, either directly through photovoltaics, indirectly through concentrated solar power, or through a mix of the two. Several mechanisms have been put in place in order to derive maximum energy from solar power. An example of this is solar tracker which is a system that positions a body at an angle relative to the sun and is commonly used. More sunlight strikes the solar panel, and less light is reflected. Hence, more energy is collected by maintaining the panel perpendicular to the sun. Solar tracking employs complex devices to determine the sun's position in relation to the item being aligned. To track the sun, computers will be used to execute complex algorithms that allow the system to monitor the sun and sensors that provide information about the sun's location. A solar panel with a basic circuit board can also track the sun without the need for a computer (Encyclopedia Britannica, n.d.). Various solar tracking systems differ in their cost, functionality, and complexity (Jyoti, 2017). Solar tracking systems are typically classified into two categories, depending on the controlling mechanisms that drive the photovoltaic panels. These categories are active tracking systems and passive tracking systems. Both are considered essential methods for obtaining tracking efficiency. Active tracking systems utilize motors and gears to guide the panels in the sun's direction; thus, they must be provided with energy for their actuators to move. While passive tracking systems utilize compressed gas fluid with a low boiling point that boils with heat generated from the sun, these are the systems that do not need any external source of energy (Rooij, 2022). This study is centered on using the active tracking system, specifically the dual-axis tracking system. The dual-axis tracking device follows the sun to collect more solar energy. Using dual-axis trackers, maximum energy collection can be achieved due to its total freedom of movement (north-south and east-west). The tracker can face the sun's rays throughout the day (Chang, 2016).

Objectives

The general objective of this study was to design and create a Dual-Axis Solar Tracker that can increase the effectiveness of the solar panels more than the static version of the system can harvest.

Specifically, this project aimed to:

1. develop a dual-axis solar tracker that is self-sufficient having the characteristics of:
    a. an off-grid powered model that is not reliant on the electrical grid; and
    b. has the capacity to store power in lithium-ion batteries;
2. determine the amount of power that the solar panels can store in the lithium-ion batteries in terms of the batteries':
    a. voltage; and
    b. milliamps per hour harnessed;
3. determine the significant difference between the static and dual-axis systems in terms of the batteries':
    a. voltage; and
    b. milliamps per hour harnessed

METHODS

Research Design

Applied Experimental Research was used as the research design of the study. This study relied on experiments and examine the electrical signals generated from the solar tracker system. Therefore, an applied experimental research design is the best way to examine the effectiveness of the application of solar trackers to the power output of solar panels.

Population and Sampling

The respondents of this study consisted of the members of this research paper. The respondents have the needed technical skills to acquire and record the necessary data for the study. This means that the respondents could measure the voltage and the milliamps per hour of the lithium-ion batteries.

Instrumentation

This study utilized a multimeter and the state of charge of the batteries for its capacity to measure voltage and milliamps per hour of the lithium-ion batteries. The voltmeter method (where the state of charge can be computed based on the outputted voltage of the batteries) was used in order to compute the state of charge of the batteries and their percentage.

Data Collection

The researchers started the data collection by placing the solar panel systems for seven days directly under the sun where there was no shade. Then, the voltage and milliamps per hour of the lithium-ion batteries was measured. The milliamps per hour of the batteries were determined using the charge/discharge rate of the ICR3000 lithium-ion batteries. In addition, the data that was collected was the voltage and the milliamps per hour harnessed by the lithium-ion batteries of the dual-axis solar tracker and the static solar panel system in a span of 11 hours for 7 days.

The system architecture shows the conceptual model that defines the structure, behavior, and views of the Dual-Axis Solar Tracker. It is a formal description and representation of a system, organized in a way that supports reasoning about the structures and behaviors of the system. The researchers divided the procedure into four steps to produce the system—the Flowchart, Code, Schematic, and Chassis. Figure 2 shows the system architecture flowchart of the Dual-Axis Solar Tracker.

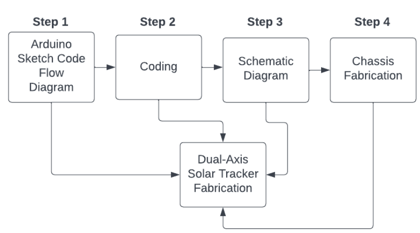

Figure 2. System Architecture flowchart

Step 1: System Flow Diagram. Figure 3 in page 19 shows the flowchart to separate the processes and steps for tracking the position of the greatest light. The program will read the resistance value of the light-dependent resistors and store it in variables to be used for the next steps. There are two major tests that the data gathered must pass through before creating a movement in the hardware. Using the formulas: elevation = (average top - average bottom) and azimuth = (average right - average left), the program will compute the azimuth and elevation values of the system. Knowing that there is a portion of greater focus on sunlight, the process will move the system leftwards. The program starts by deciding whether the average top is greater than the average bottom.

If the first major decision of the system returns True, then the system proceeds to the minor decisions of the elevation movement. After this process, the system will repeat the loop starting from the first process, which is reading the

analog values from the light-dependent sensors. The next decision tests whether the average left is less than the average right. If the boolean logic returns True, this defines that there is no significant amount of sunlight present between the left and right portions of the system.

Figure 3. System flow diagram for tracking the position of greatest light.

Step 2: Coding. Using the open-source Arduino Software (IDE), the codes were made to program the Arduino board and control the position of the dual-axis solar tracker.

Step 3. Schematic. Figure 3 represents the elements of a system using a diagram of the components used in the electronic circuit. It also shows how the researchers wired the individual components in the system.

Starting from the power supply, connect the 5v pin to the positive rail of the breadboard. Then, connect the ground pin to the negative power rail of the breadboard.

The servo has three pins—the VCC, ground, and signal. Connect the ground pins to the negative rail of the breadboard. Then the VCC pins to the positive rail of the breadboard. For the horizontal servo, connect the signal pin to the digital pin number 9 of the Arduino, and for the vertical servo, connect the signal pin to the digital pin number 10.

For the wirings of the light-dependent resistors, ground the 1kΩ resistors to the negative rail of the breadboard. Connect the VCC to one pin of the light-dependent resistors and connect the light-dependent resistors to the 1kΩ resistors. Connect the analog pins between the connection of the 1kΩ resistor and the light-dependent resistor. This voltage divider turns a large voltage into a smaller one making it possible to input an analog signal to the Arduino. From the code, the top left LDR is connected to the A0 analog pin, the top right LDR is connected to the A2 analog pin, the bottom left LDR is connected to the A1 analog pin, and the bottom right LDR is connected to the A3 analog pin.

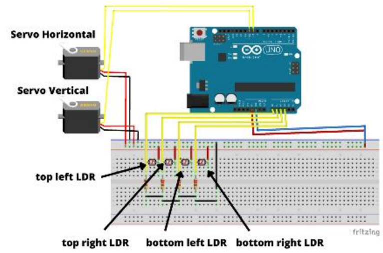

Figure 4. Wirings of dual-axis solar tracker

Step 4: Chassis Fabrication. This study used Solidworks Premium 2021 to fabricate the 3d designs and Ultimaker Cura version 4.9.1 as the slicer for 3d files.
Using the BIQU B1 3D printer, the pan-tilt servo motor, which includes the base, head, arm, support, and solar panel holder, which comprises of base and LDR separator, was fabricated.

Data Analysis

After the data were gathered, the researchers tabulated, evaluated, and analyzed the state of charge of the lithium-ion batteries that were harvested by the dual-axis solar tracker and static solar panel system using mean and standard deviation. T-test was used to determine the significant difference in the effectivity between the Dual-Axis Solar Tracker and the Static Solar Panel System.

RESULTS and DISCUSSION

Table I. Voltage output of the batteries that harvested solar power from the dual-axis solar panel system and the batteries that harvested solar power from the static solar panel system. The voltage output was measured using a multimeter.

Table 1 Average voltage outputs of dual-axis solar tracker and static solar panel.

Voltage Output	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Mean
Static Solar Panel System	3.55 V	3.54 V	3.46 V	3.57 V	3.55 V	3.60 V	3.54 V	3.54V
Dual-Axis Solar Tracker	3.61 V	3.60 V	3.54 V	3.68 V	3.62 V	3.65 V	3.61 V	3.62V

Table 1 above indicates that in seven (7) days of data gathering, the voltage output of the batteries that harvested solar power from the Dual-Axis Solar Tracker generated an average of 3.62 volts, while the batteries that harvested solar power from the static solar panel system generated 3.54 volts. It further shows that the Dual-Axis Solar Tracker has generated a greater amount of voltage compared to the Static Solar Panel System with a difference of 0.08 volts and by a factor of 2.2%. The Dual-Axis Solar Tracker System outputs a greater voltage than the Static Solar Panel System. This indicates that more amperage (in milliamps) is stored in the batteries of the Dual-Axis Solar Panel System than in the Static Solar Panel System. The proportion between the voltage and amperage of an ICR3000 can be seen in figure 6 on page 24. Moreover, figure 6 shows that the graph between voltage and amperage is not linear. This could further explain how a difference of 0.08 could create about a greater number of milliamps per hour.

Table II. Milliamps per hour generated by the dual-axis solar tracker system and the static solar panel system. The milliamp per hour is a measure of a battery's capacity for supplying current. It was measured by measuring the voltage of the battery and solving the state of charge of the ICR 3600 lithium-ion battery.

Table 2. Average of current outputs of dual-axis solar tracker and static solar panel.

Milliamps per hour Harnessed	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Mean
Static Solar Panel System	2400 mAh	2400 mAh	1125 mAh	2850 mAh	2400 mAh	3000 mAh	2400 mAh	2367.86 mAh
Dual-Axis Solar Tracker	3000 mAh	3000 mAh	2400 mAh	4425 mAh	3000 mAh	4050 mAh	3000 mAh	3267.86 mAh

Table 2 above indicates that in seven (7) days of data gathering, the current output of the dual-axis solar tracker generated an average of 3267.86 milliamps per hour, while the static solar panel system generated 2367.86 milliamps per hour. This implies a 38% increase in the current output of the Dual-Axis Solar Tracker compared to the Static Solar Panel System.

This result proved what Altenergy posited, that a dual-axis tracker can increase energy production by up to 40% because of the angle at which it enables the solar panel to face the sun. Hypothetically, if an appliance that uses 10 watts of power is connected to the battery of a static solar panel, it would take about 8.76 hours until the said appliance would stop functioning. Comparing the same conditions with the dual-axis solar tracker, it would take about 12.09 hours until the said appliance would stop functioning.

Table III. T-test on the effectivity of the Dual-Axis Solar Tracker in terms of milliamps per hour.

t-Test: Two Independent Means

Table 3. T-Test on the effectivity of the Dual-Axis Solar Tracker System and the Static Solar Panel System in terms of voltage.

N=7

Voltage Output	Mean	SD	p-value	t-value	Result	Decision
Static Solar Panel System	3.54	0.0001			Significant	Reject Ho_2
Dual-Axis Solar Tracker	3.62	0.0001	0.004622	3.0969		

**Significant at a = 0.05

The results revealed that the computed value of P is 0.004622, which is less than the 0.05 level of significance; therefore, Ho_1 which stated that "there is no significant difference in the effectivity of the Static Solar Panel System and the Dual-Axis Solar Tracker System in terms of the voltage stored in the lithium-ion batteries." is rejected. This implies that there is a significant difference in the effectivity of the Static Solar Panel System and the Dual-Axis Solar Tracker System in terms of voltage output. Therefore, the utilization of a Dual-Axis Solar Tracker System is more effective in terms of voltage output than the Static Solar Panel System since there is a significant difference in the t-test done.

With the T-test done, the significant difference shows that the voltage data that were gathered are not due to chance or sampling error. On a bright sunny day, the Dual-Axis Solar Tracker System will always generate more voltage than the Static Solar Panel System.

Table IV. T-test on the effectivity of the Dual-Axis Solar Tracker in terms of milliamps per hour.

t-Test: Two Independent Means

Table 4 T-Test on the effectivity of the Dual-Axis Solar Tracker System and the Static Solar Panel System in terms of milliamps per hour output.
N = 7

mAh Harnessed	Mean	SD	p-value	t-value	Result	Decision
Static Solar Panel System	2367.86 mAh	602.89				Reject Ho_2
Dual-Axis Solar Tracker	3267.86 mAh	706.03	0.012392	2.56476	Significant	

**Significant at a = 0.05

The results revealed that the computed value of P is 0.012392. Since it is less than the 0.05 level of significance, Ho_2 which states that "There is no significant difference in the effectivity of the Static Solar Panel System and the Dual-Axis Solar Tracker System in terms of the milliamps per hour stored in the lithium-ion batteries." is therefore rejected. This implies that there is a significant difference in the effectivity of the Static Solar Panel System and the Dual-Axis Solar Tracker System in terms of milliamps per hour output. Therefore, the Dual-Axis Solar Tracker System is more effective in terms of milliamps per hour output than the Static Solar Panel System since there is a significant difference in the t-test done.

With the T-test done, the significant difference shows that the milliamps per hour data that were gathered are not due to chance or sampling error. On a bright sunny day, the Dual-Axis Solar Tracker System will always harness more milliamps per hour than the Static Solar Panel System.

The study utilized an applied experimental research design. The study was conducted to develop a dual-axis solar tracker that is self-sufficient having the characteristics of an off-grid powered model that is not reliant on the electrical grid; and has the capacity to store power in lithium-ion batteries. Then, determine the amount of power that the solar panels can store in the lithium-ion batteries in terms of the batteries': voltage; and milliamps per hour harnessed. And lastly, determine the significant difference between the static and dual-axis systems in terms of the batteries' voltage; and milliamps per hour harnessed. The device was created and tested at Poblacion 1, Midsayap, North Cotabato.

The Dual-Axis Solar Tracker was fabricated by first creating a working system flow diagram to track the sun's greatest light position. It was then followed by writing a code using Arduino sketches to utilize the micro servos as actuators of the system and, wiring the Arduino Uno board to the system's electrical parts. The researchers created a chassis for the Dual-Axis Solar Tracker. Additionally, the researchers connected the solar panels from the Dual-Axis Solar Tracker and the Static Solar Panel System to the lithium-ion batteries. The batteries then power the Dual-Axis Solar Tracker for about 3 minutes every hour. This function makes the Dual-Axis Solar Tracker independent from the power grid.

After the seven-day data collection, for the voltage, the Dual-Axis Solar Tracker generated an average of 3.62 volts, while the static solar panel system generated an average of 3.54 volts. For the milliamps per hour, the dual-axis solar tracker generated an average of 3267.86 milliamps per hour, while the static solar panel system generated 2367.86 milliamps per hour.

Based on the given data, facts, and the computations using the T-test, it was found that in terms of voltage, there is a significant difference between the Dual-Axis Solar Tracker and the Static Solar Panel System; therefore, the first null hypothesis which states that "there is no significant difference in the effectivity of the Static Solar Panel System and the Dual-Axis Solar Tracker System in terms of the voltage stored in the lithium-ion batteries." is rejected. Meanwhile, in terms of milliamps per hour, it was also found that there is a significant difference between the Dual-Axis Solar Tracker and the Static Solar Panel System; therefore, the second null hypothesis which states that "there is no significant difference in the effectivity of the Static Solar Panel System and the Dual-Axis Solar Tracker System in terms of the milliamps per hour stored in the lithium-ion batteries." is rejected.

CONCLUSIONS

Based on the study's findings, it is concluded that the amount of voltage and milliamps per hour generated by the Dual-Axis Solar Tracker is greater compared to the static solar panel system. Moreover, this statement is supported by the t-test that was done. The t-test shows that there is a significant difference between the voltage and milliamps per hour. Thus, the results show that on a bright sunny day, the Dual-Axis Solar Tracker System will always generate more voltage and milliamps per hour than the Static Solar Panel System. Therefore, the utilization of the Dual-Axis Solar Tracker increases the effectiveness of solar panels in improving energy generation in terms of voltage, and milliamps per hour generated.

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