Chapter 18
Performance Analysis on an Arduino-Based Low-Cost Active Dual-Axis Solar Tracking System

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18.1 Introduction

Renewable energy has rapidly become a highly important subject area due to world problems nowadays, such as global warming which affects climate change. Somehow, it is difficult to recover from the exponential growth of the world population; thus, this reflects the increased use of electricity. On the other hand, this project is also made to meet the electricity demand somewhere far from the source, for example, on a remote agricultural farm. Modern farms are now also equipped with a variety of automated electrical appliances that require batteries to operate. Drones are one example of a farming tool used as a fertiliser sprayer. To have an efficient electric generator system within this area is considered valuable and practical.

Researchers have undertaken many efforts to improve the efficiency of solar panels. Vast research on the improvement of solar cells by using various types of advanced cells (Mohammad and Karim 2013; Rotar et al. 2018). There are three common PV solar cell types in the market, i.e., mono-crystal silicon solar PV (monocrystalline solar cell), poly-crystal silicon solar PV (polycrystalline solar cell) and thin film solar cell (TFSC). Mono-crystalline, the highest purity silicon solar PV

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cell produced from single-crystal silicon. It also performs better in hot temperatures and low light (Rotar et al. 2018).

There are many studies that have investigated the effectiveness of single-axis solar trackers. The researcher Bawa and Patil (2013) developed a single-axis solar tracker using a hybrid approach. They used a buck converter device to capture the power generated from the panel, and then the fuzzy system will evaluate the maximum power point tracking. Sabran and Fajardo (2018) developed a single-axis sun tracker inspired by the sunflower. To track the sun, they manipulate the light received and use circadian clock calculation. These two works as an input to the controller to instruct the motor to rotate accordingly to the sun position. It goes the same for Kuttybay et al. (2020), where they developed a hybrid tracking system using a light-dependent resistor (LDR), a photosensor, and astronomical calculations of the sun's position in the sky.

The dual-axis solar tracker also implements the same concept as single axis, except the panel can orient in both angles, azimuth, and altitude. Thus, the aim is to make sure the PV is accurately orientated perpendicular to the sun. Studies have shown that the dual-axis PV tracker can yield excellent electric power compared to static PV installation. The study showed that the system they built could yield a minimum of 20% (Sabran and Fajardo 2018) up to 60% (Kuttybay et al. 2020) more than the statics PV installation. Most past studies have only been researched for about one to five days. Only one study by Morón et al. (2017) was found to have conducted a continuous complete study for up to 5 months. The parameters they get from the system they build are voltage, current, light resistance, and temperature. Rotar et al. (2018) found that the PV panel efficiency would decrease if the temperature increased. Next, they calculated the efficient percentage between the tracker PV and the static PV. These percentages reflect the results of their study.

The main purpose of this study was to develop and compare the power gained by two solar harvesting systems, the dual-axis PV panel tracker and fixed PV. Both systems were designed and assembled using on-the-market-ready equipment. Detailed equipment and assembly processes are explained in the methodology section. The remainder of this paper consists of a study of the result and conclusions.

18.2 Methodology

This section covers all the details regarding the design and development of the dual-axis solar tracker and the static PV panel. The exact material name, quantity needed, and cost for this study are shown in Table 18.1. Material listed in this table was for the two system builds, the solar tracker, and the fixed PV. The total material cost for this study is 170.37 USD.

The solar panel chosen was a monocrystalline cell with a 420 mm × 190 mm × 3 mm dimension. The chosen panel has a rated maximum power (P_{max}) of 20 W, maximum power current of 1.4 A and maximum power voltage of 14 V. Two DC servo motors with metal gear were used in this study. The purpose of these motors

Table 18.1 Material cost (seller website: https://my.cytron.io/)

No.	Item name	Quantity	Unit cost (USD)	Total cost (USD
1	20 W 12 V/5 V DC solar panel (monocrystalline cell)	2 pcs	14.22	28.44
2	RC servo motor (metal gear)	2 pcs	18.97	37.94
3	Arduino Uno Rev3-main board	1 pc	25.84	25.84
4	Light dependent resistor (LDR)	4 pcs	0.12	0.48
5	100 A solar charge controller 12 V/24 V with dual USB port	2 pcs	15.00	30.00
6	Sealed lead acid battery 12 V 7.0 Ah	2 pcs	14.22	28.44
7	Acrylic sheet/Perspex A2 size 3 mm casting grade A	2 pcs	5.93	11.86
8	Plastic box (120 × 80 × 40mm) grey	1 pc	2.37	2.37
9	Other electric and electronic components	1 pc	5.00	5.00
Grand total				170.37

is to rotate the panel in both directions, the latitude and azimuth angle. The chosen controller was the Arduino Uno. Four photoresistor or light dependent resistor (LDR) has a maximum voltage of 150-V DC and a maximum wattage of 90 mW. The light resistance is between 5 and 10 KΩ.

The solar charger is used to control the power collected from the solar panel. The chosen solar charger is a dual MOSFET reverse current protection system with low heat production. The battery voltage is 12 V and has a USB output to a load of 5 V with three maximum amperes. The power collected is then stored in a battery. The seal lead acid (SLA) rechargeable battery was used as this is a typical general-purpose battery.

System Operation

The LDRs act as the sensor to capture the position of the sun. The Arduino then processes the signal from these LDR and evaluates it to instruct the motors to change the panel direction towards the sun.

The process begins with the solar tracker in initial mode. All the LDR can act as a sensor that measures the sun's strength when the sun rises. All four LDRs were placed on one acrylic plate, and there is a separator between the LDRs. The four regions are representing the North, South, East, and West. The LDRs were named LDR1 for North, LDR2 for South, LDR3 for East and LDR4 for West.

If the light intensity of all LDRs is the same, it is likely at noon since the sun is on top of the solar tracker so the LDR can get the same light intensity. If the light intensity is the same at LDR1 and LDR3, the solar tracker would be in the exact location between North and East as the other LDRs with the same light intensity. LDR1 and LDR2 can detect the strength of the sun during the first operation. If the resistance of LDR1 is greater than LDR2, the data is sent to the Arduino, which processes it and instructs the servo motor controller. The motor controller then instructs the servo motor to move the direction of the solar panel to the north. The same process will occur if the amplitude of LDR2 is higher than LDR1, and the servo motor will shift the solar panel to the South.

After that, the Arduino will receive LDR3 and LDR4 results. If the intensity of LDR3 is greater than LDR4, the panel will be on the East side, and if the intensity of LDR4 is greater than LDR3, the solar panel will be on the Westside. Finally, suppose the day turns into night, and the LDR does not get any lighter intensity. In that case, the solar tracker will return to its initial position, facing an upward direction perpendicular to the sky.

Experimental Setup

The experiment was designed to run for 14 consecutive days, and the parameters to be collected are the hourly voltage, ampere, and power value. The daily data collection is made from 8 a.m. until 6 p.m. Therefore, there were 11 data observations and collection made daily.

Both systems, the solar tracker and fixed PV, were placed at the same testing site. The test site is in an open park and is not covered by any shadow at all. This is to ensure that the PV can receive direct and continuous sunlight. Study materials are not changed or removed until the last day of the test.

18.3 Results and Discussion

The daily average performance result of both systems for 14 days is shown in Table 18.2. Three comparison analyses were made, the voltage, the current and the power. These comparison was based on the overall 14 days data obtained. The details hourly analysis also was made but it just only for a day data analysis. The discussion then summarized by evaluating the tracker efficiency.

Voltage Generated by the PV Panels

The voltage data for both systems is then plotted for ease of discussion as shown in Fig. 18.1. Volt DA for the dual-axis tracker and Volt Fix for the fixed solar panel. Figure 18.1 shows that the solar tracker outperforms the fixed PV system for all days. The highest voltage recorded was 10.07 V by the solar tracker system and the lowest was 6.65 V by the fixed PV system. Even though the solar PV selected is designed to generate a maximum of 14 V, the maximum average voltage acquired is only 10.07 V. The weather condition during the experiment were cloudy and rainy. This 10.07 V was only achieved on day one of the experiment while the rest remain below this value.

The mean for Volt DA is 8.624 V while the Volt Fix is 8.134 V. The solar tracker generated a higher voltage, and the difference is about 0.49 V. The percentage difference in voltage-mean-value was 5.85%. According to Cubas et al. (2015), this percentage difference could not bring significant performance to the solar tracker

Table 18.2 Two weeks averaged performance result

Day	Dual-axis solar tracker			Fixed solar panel		
	Voltage (Volt DA)	Ampere (Amp DA)	Watt (Watt DA)	Voltage (Vol Fix)	Ampere (Amp Fix)	Watt (Watt Fix)
1	10.07	0.87	9.76	9.39	0.8	8.77
2	9.94	0.83	9.11	9.32	0.75	8.24
3	8.33	0.81	7.43	7.68	0.6	6.76
4	8.96	0.73	7.63	8.37	0.66	7.08
5	9.24	0.76	8.33	8.44	0.69	7.36
6	8.16	0.66	7.65	7.96	0.65	7.41
7	7.09	0.62	5.53	6.65	0.57	5.03
8	8.16	0.65	7.22	7.85	0.64	6.94
9	9.42	0.8	8.49	8.85	0.73	7.89
10	6.92	0.59	6.49	6.68	0.58	6.26
11	9.18	0.78	8.22	8.66	0.74	7.76
12	7.54	0.65	6.92	7.3	0.62	6.72
13	8.18	0.67	7.6	7.68	0.64	7.15
14	9.55	0.83	8.9	9.04	0.78	8.3
Average	8.62	0.73	7.81	8.13	0.68	7.26

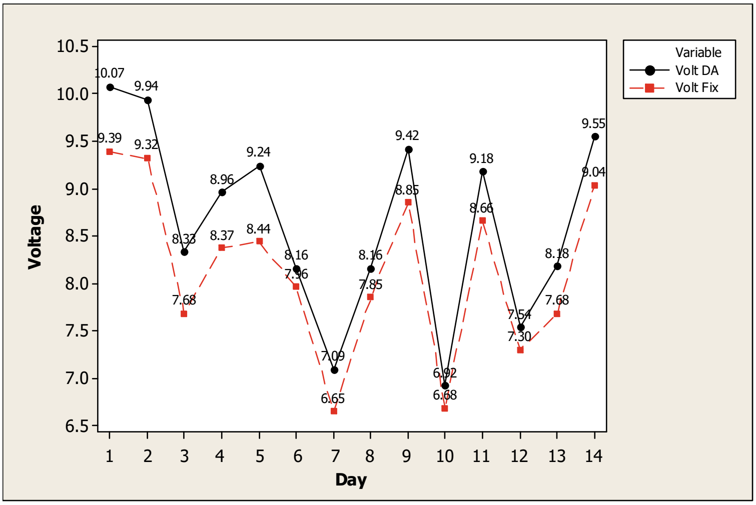

Fig. 18.1 Daily average accumulated voltage

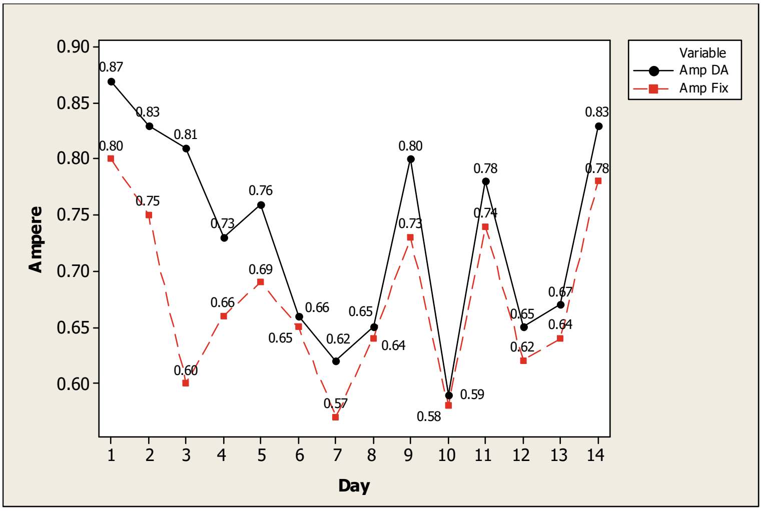

Fig. 18.2 Daily average accumulated ampere

system as the system needs another power to move the panels. This result shows the solar tracker is slightly more efficient for generating higher voltage compared to the fixed PV system. It is found that the solar tracker can generate 61.6% voltage compared to the fixed PV system, which is 58.09% only. The percentage difference between these two solar panels was 3.5%.

Electrical Current Produced by the PV Panels

Figure 18.2 shows the time series plot for averaged ampere value recorded for 14 days. The Amp DA represents the average ampere value for the solar tracker system while the Amp Fix is for the fixed PV system. The highest ampere recorded was 0.87 A on day 1 by the solar tracker system and the lowest was 0.57 A on day 7 by the fixed PV system.

The average mean for Amp DA was 0.7321 A while 0.6750 A for Amp Fix. The difference is about 0.0571 A (7.79%). The solar tracker system was able to generate a maximum of 0.87 A and a minimum of 0.59 A during the experiment duration. The fixed PV system has a maximum of 0.80 A and a minimum is 0.57 A. Comparing the voltage (5.85%) and ampere (7.79%) percentage difference, the ampere percentage difference is higher than the voltage.

The designed solar panel can generate a maximum of 1.5 A. Using the formula output (mean ampere for 14 days) over input times 100, the solar tracker produces 48.80% of the current, while the fixed PV system produces 45.0%. A solar tracker 3.8% outperforms a fixed solar panel.

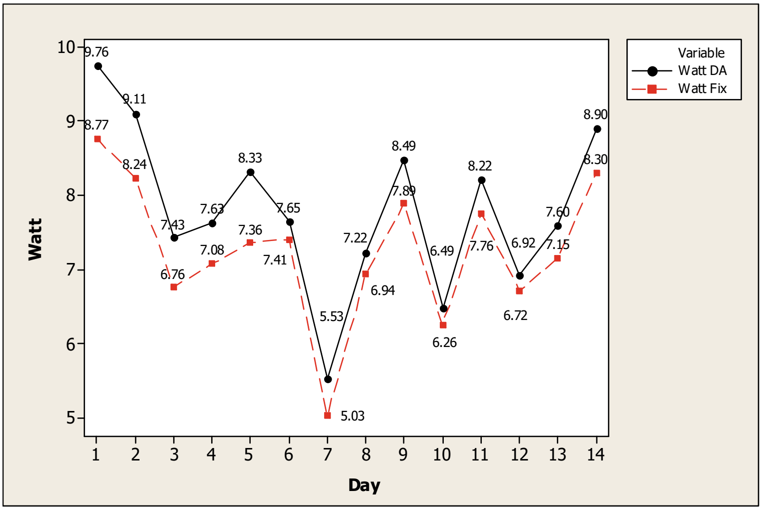

Fig. 18.3 Comparison of daily average accumulated watt

Power Comparison

The power generated by the solar panel is simply a multiplication of voltage and ampere (power = voltage × ampere). Table 18.2, in column Watt Da and Watt Fix, shows the result of power yielded for the 14 days experiment.

The daily averaged ampere for Wat DA and Watt Fix is plotted in time series for better comparison as shown in Fig. 18.3. Briefly, the Watt DA outperforms the Watt Fix for all days. There were 6 days where the power generates more than 7 watts. The lower power rate was recorded because of the weather conditions, and it seems consistent with the value recorded for voltage and ampere.

The solar panel chosen can generate a maximum power of 20 W. Evaluating the performance of this solar panel, the formula output over input times 100 is used. The average power solar tracker can generate 39.05% in these 14 days, while a fixed solar panel can generate only 36.30%. The gap is 2.75% solar tracker lead in 14 days.

Variation of Electrical Power Produced by PV Panels in One Day

The experiment on day 1 was the highest average power generated for both systems. Therefore, a further investigation was made on that day. The hourly data on day 1 are tabulated in Table 18.3. It displays the voltage, current, and power output of the solar tracker as well as the fixed solar panel. The peak performance is at midday. The same power, 17.68 W, is provided by both solar panels. At 8 a.m., relative to a fixed solar panel that begins at 2.8 V, the solar tracker voltage starts at 4.44 V. The fixed solar panel only produces 0.2 A current and 0.56 W power, whereas the solar tracker produces 0.4 A current and 1.78 W electricity. This happens because the sun’s location at 8 a.m. prevents the static solar panel from absorbing all the sunlight, as opposed to the solar tracker, which tracks the sun’s rays and directs the solar panel at it. The power difference between a solar tracker and a fixed solar panel at 8 a.m. is 1.22 W.

By absorbing the most sunlight in the morning, the solar tracker will maximise the efficiency of the solar panels. The fixed solar panel only produced 0.58 W at 6 p.m. on day one whereas the solar tracker produced 1.14 W. According to this finding, the solar tracker has a major advantage over the permanent PV system in the early morning and late in the evening since its surface will always face the sun.

To calculate the percentage and determine how a solar tracker differs from a fixed solar panel, use the formula output over input times 100. At midday on day 1, both solar panels produced the same results and operated at almost full capacity. The output from both solar trackers is 97.14% of their whole 14 V capacity. Both solar panels produced 88.4% of their 20 W electricity and 86.66% of their total 1.5 A current capacity.

The solar tracker's voltage generated for the day's total average from 8 a.m. to 6 p.m. reaches 76.42% of its maximum capacity (10.7 V). The 9.39 V fixed solar panel, however, only operates at 67.07% of its full potential. The solar tracker made a difference that was roughly 9.35% greater. The complete average solar tracker current production is only 53.33% of the fixed solar panel's maximum, but it still exceeds 58% of the maximum it can accomplish. The average power output from the solar tracker is 48.8%, compared to 44.35% from the fixed solar panel. The solar tracker may provide 4.45% more power than a fixed solar panel on day one, from 8 a.m. to 6 p.m.

Table 18.3 Day 1 hourly data

Day 1	Dual-axis solar tracker			Fixed solar panel		
Time	Voltage (V)	Current (A)	Power (W)	Voltage (V)	Current (A)	Power (W)
8:00 a.m.	4.44	0.40	1.78	2.80	0.20	0.59
9:00 a.m.	7.79	0.70	5.45	6.20	0.50	3.10
10:00 a.m.	10.21	0.90	9.19	9.30	0.80	7.44
11:00 a.m.	12.31	1.00	12.31	11.90	0.90	10.71
12:00 p.m.	13.60	1.30	17.68	13.60	1.30	17.68
1:00 p.m.	13.58	1.20	16.30	13.55	1.20	16.26
2:00 p.m.	13.33	1.10	14.66	13.32	1.10	14.65
3:00 p.m.	12.34	1.00	12.34	12.34	1.00	12.34
4:00 p.m.	10.09	0.90	9.08	10.09	0.90	9.08
5:00 p.m.	9.31	0.80	7.45	7.31	0.70	5.12
6:00 p.m.	3.81	0.30	1.14	2.90	0.20	0.58
Average	10.07	0.87	9.76	9.39	0.80	8.87

18.3.1 Tracker Efficiency

The efficiency of the tracker was calculated based on the sum of the average total power generated in two weeks. The efficiency (η) is calculated by defining the difference absolute average power of the tracker ($P_{tracker}$) and the fixed panel (P_{fix}), divided by the average P_{fix} and multiply by 100. The equation is $\eta = ((P_{tracker} - P_{fix})/P_{fix}) \times 100$.

The total power generated by the tracker based on Table 18.2 was 7.81 W, while the total energy by the fixed panel was 7.26 W. Based on the formula, the efficiency of the solar tracker is 7.57%.

18.4 Conclusion

This study was about developing and comparing the performance of solar systems. Two systems were built up with similar dimensions, but one is a fixed system, and the other can track the sun. The exact size of photovoltaic (PV) panels was installed in both systems.

The automated dual-axis solar tracker system was successfully built-up using an Arduino as a controller. To locate the sun's position, the LDR was used as a sensor. Two servo motors were installed to tilt and oriented the panel according to proper latitude and azimuth angles. The fixed solar panel was also built with a 30° inclination towards the sunset direction. The total cost to build the solar tracker systems is less than 200 USD. The experiment was run for about 14 days, and hourly data was collected during that experiment duration. The data collected were the values of voltage and ampere acquired.

Both systems can work efficiently with the highest values recorded on day 1. The higher voltage acquired was 10.07 V with 0.87 A, which produce an amount of 9.76 W. The fixed solar panel also shows the highest earned value on the same day. Comparing both data, the dual-axis tracker has significantly generated 4.45% higher power generation than the fixed solar panel in a day. The efficiency of the solar tracker based on the generated power during the two weeks test period (Table 18.2) is about 7.57% better compared to the fixed panel.

Future improvement work for this area is still plentiful in many ways, such as management, control, reduction of construction costs, maintenance methods, and others. Future works are to improvise the methods or techniques for tracking the sun by integrating with other tools and techniques such as adding the pyranometer. It is also interesting to have the performance comparison of different solar trackers that may consist of different methods or techniques. For instance, to compare the performance of single or dual-axis solar trackers built with other techniques.

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