Single-axis solar tracking system referring to date and time

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Abstract. This article is about designing and building a single-axis solar tracking system referring to the sun position database. The objectives are as follows: 1. to design and build a solar tracking system, and, 2. to compare the power produced from the solar tracking system with that from the stationary solar panel. The angle of the solar panel from the solar tracking system is positioned at a constant altitude angle, 15 degrees, facing south, and the moving part was the azimuth, which follows the position of the sun. Latitude and longitude coordinates are identified by an Arduino UNO R3 microcontroller board for processing data, reading coordinates of the sun's angle degrees from the SD card module, and commanding the servo motor to rotate to adjust the angle of the solar panel in a position perpendicular to the sun. Results from the experiment were collected in October 2020 from 9 AM to 4 PM. The system changed the angle degree every 30 minutes. It is found that the solar tracking system can easily be created and controlled, and can also accurately follow the sun's position all day long. Moreover, it can generate more electric power than that generated by the stationary solar panel by up to 15%. The system is applicable and can generate more electric power than other tracking systems, although the results were collected during the rainy season when the weather was generally cloudy and rainy throughout the month.

1. Introduction

Generating electricity from solar energy continues to increase in Thailand every year. In 2018, cumulative installed capacity was 2,962.44 megawatts. Solar power generation system can be divided into 2 groups as follows: 1. on-grid solar power generation system, and 2. off-grid solar power generation system. From the conclusion of the measurement of solar radiation intensity data by the Department of Alternative Energy Development and Efficiency in 2020, the mean was 4.807 kWh/m^2-day. Moreover, according to the solar radiation intensity data statistics in Thailand during 2016-2020, it is found that the daily solar radiation intensity per month is low (especially in October 2020) in the rainy season (from mid-May to mid-October). The mean of daily solar radiation intensity per month is 13.364, which is extremely low [1-3]. However, solar radiation intensity is the important variable for making the electricity generating with solar cells more efficient.

Implementing solar cells to generate electricity to get the most efficiency is based on various factors, for example, the most suitable solar panel installation in Thailand with angle of inclination in Bangkok area is 15 degrees facing south [4]. However, the popular controllable factor to enable the solar panel to generate more electric power in each day is controlling solar panels to obtain the highest solar intensity at different times of the day, which is mostly use light dependent resistors (LDR) instead of a light intensity sensor. The researchers studied the light intensity measurement system to compare the power generation efficiency of the day and found that light dependent resistors (LDR) work well when the sky is clear as it is able to measure the light intensity effectively. One to four light dependent resistors or more will be installed in the different positions and angles of the solar panel [5-9]. However, using the light dependent resistors (LDR) when the sky is cloudy is not efficient since the intensity of the sun's rays when hitting the clouds is reflected back into the atmosphere and pass through the clouds before hitting the ground. There are different proportions for different periods and the time that the weather changes. In the rainy season, most of the sky is covered by the clouds, especially cumulus and cumulonimbus clouds, which are low level clouds and are important factors for the relationship of clouds and the sun's rays [10-12]. Because of this reason, the light intensity received by the light dependent resistors in the cloudy sky will cause errors and will directly lead to the system control unit. When the system receives the data from the light dependent resistors, the motor will adjust its direction in that position. For the image processing method, which is used instead of the light dependent resistors to detect the brightest point to track the position of the sun, it works well when the sky is clear. However, when it is cloudy, the tracking system will have less efficiency [13]. Therefore, we will have to use a suitable sun tracking system in designing and building a solar tracking system to be the most efficient at different times of the year [14-15].

From the problems stated above, the researchers, therefore, designed and constructed a single-axis solar tracking system by referring to www.timeanddate.com and www.suncalc.org for the position of the rising and setting of the sun at different times in a day. This is to enhance the sun tracking system to generate electric power in the rainy season, or on cloudy days, so that the solar panels can generate maximum power. Arduino board is used in the circuit control system and all the equipment to process the data derived from SD card module of the sun’s degree of arc in each period. Moreover, the Arduino board is also used to activate the servo motor to rotate the solar panel at specified time.

2. The structure and algorithms design

2.1. The structure of the single-axis solar tracking system referring to date and time

Structural design of the single-axis solar tracking system to be used with 40-watt and 2.7-kilogram monocrystalline solar panel can rotate 180-degree in horizontal axis. The solar panel specifications are shown in table 1. Moreover, it is designed with a rectangular base to make it durable in windy weather. The servo motor, which controls the direction of solar cells, is positioned in the middle so that the solar panel can move freely and accurately at the specified angle. Figure 1 show the single-axis solar tracking system whose main components are: 1) solar panel, 2) LCD display, 3) servo motor for controlling the rotation of the spur gear, 4) Arduino board and 5) battery.

Table 1. Specification of solar panel.

Specification	Values
Maximum power (P_{max})	40 W
Open circuit voltage (V_{oc})	21.5 V
Short circuit current (I_{sc})	2.38 A
Maximum power voltage (V_{mp})	18 V
Maximum power current (I_{mp})	2.22 A
Dimensions	664 x 408 x 18 mm

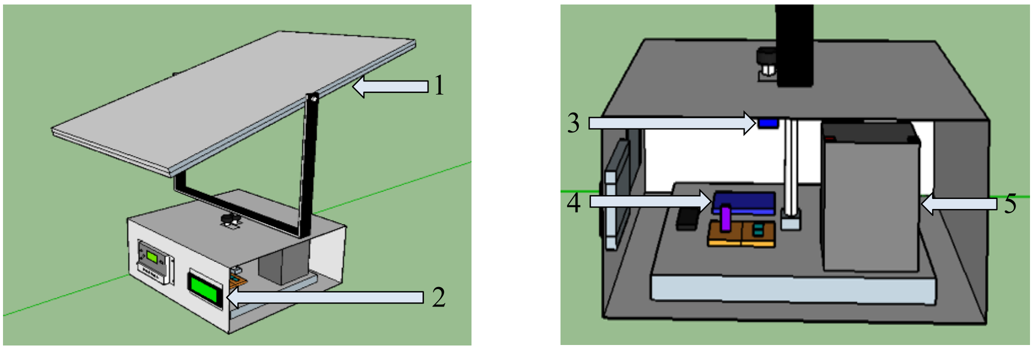


Figure 1. The design (a) Structure of a single-axis solar tracking system. (b) Control box.

2.2. Algorithms of the single-axis solar tracking system referring to date and time

Algorithms of the single-axis solar tracking system can be explained as follows: Arduino board reads the date; (d), time; (t), and the azimuth angle data; (ψ) from an .csv file in the SD card module, but azimuth angle in the file must be minus 90 degrees because the servo motor can rotate 180 degrees. After that, the Arduino board commands the servo motor to rotate to adjust the angle of the solar panel towards the sun in the set direction for 30 minutes. When it reached the specified time, the Arduino board would read the azimuth angle data of the next period and command the servo motor to run continually. When it finished rotating in the set period, the system commands the servo motor to move towards the default arcdegree at 9 AM of the following day until Day 31 based on the system program details shown in figure 2 and circuit's connection of single-axis solar tracking system shown in figure 3.

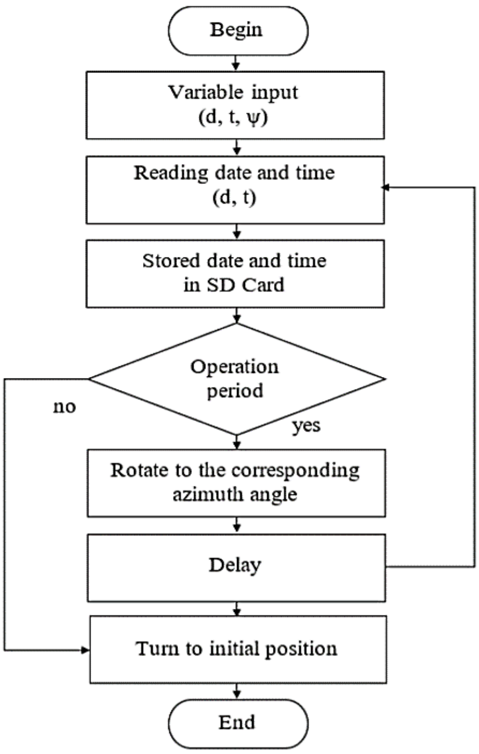


Figure 2. Algorithm for a single-axis solar tracking system.

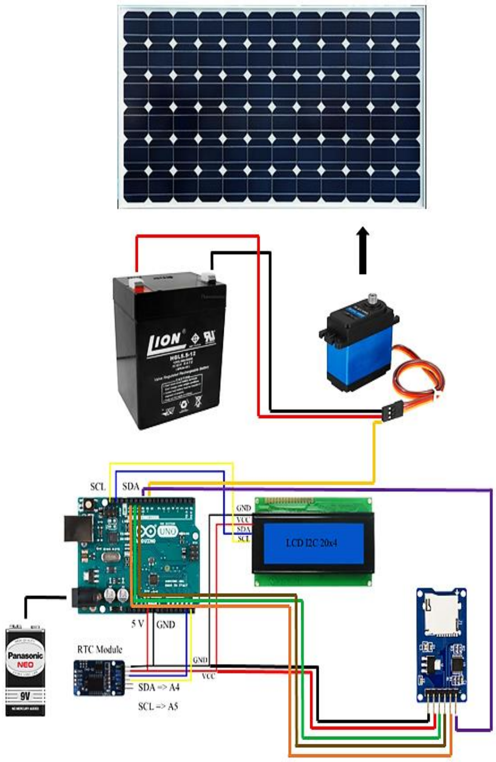
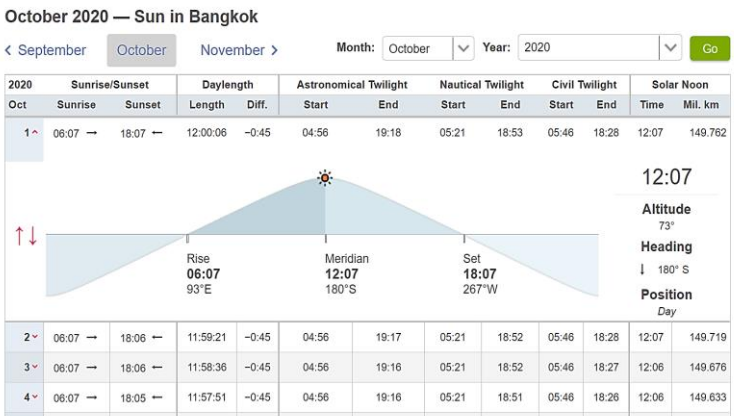


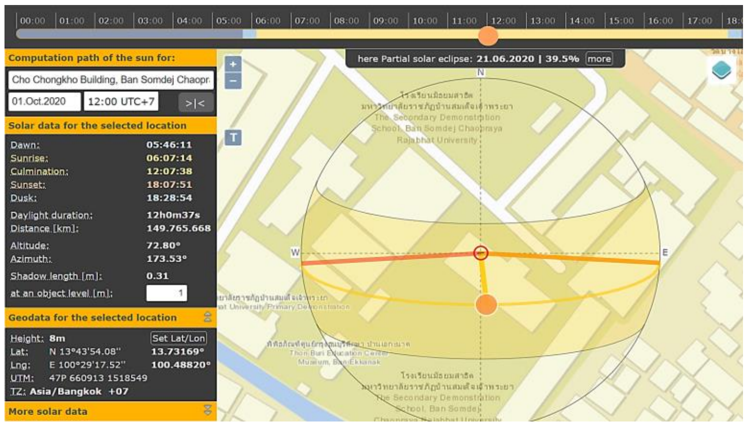
Figure 3. Device and circuit's connection of single-axis solar tracking system.

3. Experiments

To evaluate the electric power generated between single-axis solar tracking system referring to date, time and stationary solar panel, the researchers stored the azimuth angle of the date and time used in the experiment from www.timeanddate.com and www.suncalc.org in October 2020 as shown in figure 4 in the SD card module. In this way, the Arduino board could read and command the servo motor to rotate in the set direction, which was to rotate every 30 minutes from 9 AM to 4 PM. The researchers also measured the current and voltage with a multimeter every 30 minutes. The area used for the experiment was 13 Floor of Building 24 in Bansomdejchaopraya Rajabhat University, which is an open space and does not have any shadows that obscure the position of the solar panels at all times. In order to find the latitude and longitude of the experiment area, the researchers used Google Maps program to find the geographic coordinates to compare with the coordinates of the website and location data of the sun to receive the right coordinates.



(a)



(b)

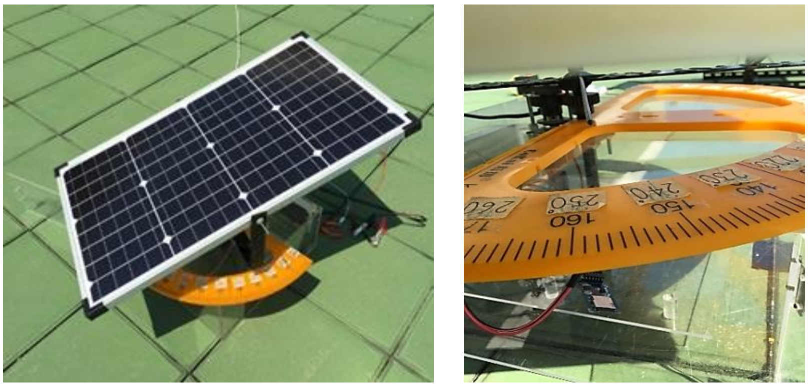
Figure 4. Date and time, and degree of arc data from (a) www.timeanddate.com [16] and (b) www.suncalc.org [17].

4. Results and discussion

The results are divided into 2 parts: the percentage of arcdegree accuracy when moved by solar cell system's servo motor, and the amount of electric power generated by the single-axis solar tracking system referring to date, time and stationary solar panel.

4.1. The percentage of arcdegree accuracy when moved by solar cell system's servo motor

The solar cell structure is durable and can take the weight load of the solar cell well. The operation control system is kept in an acrylic box, which is lightweight and easy to be moved as shown in figure 5(a). The test to find the percentage of arcdegree accuracy when moved by the solar cell system's servo motor was done 10 times and the azimuth angle was chosen on 1st October 2020. The experiment was done continuously from the first arcdegree (at 9 AM) to the last (at 4 PM); this would count as one round. The test simulation was done on-site and real-time prior to the collection date as shown in figure 5(b). The researchers find that using the servo motor to move the solar panels of the system has an error at 1.07% for the whole system as shown in table 2.



(a) (b)

Figure 5. The field experiment (a) Position of single-axis solar tracking system referring to date and time. (b) The arcdegree that the servo motor can rotate at 2.30 PM.

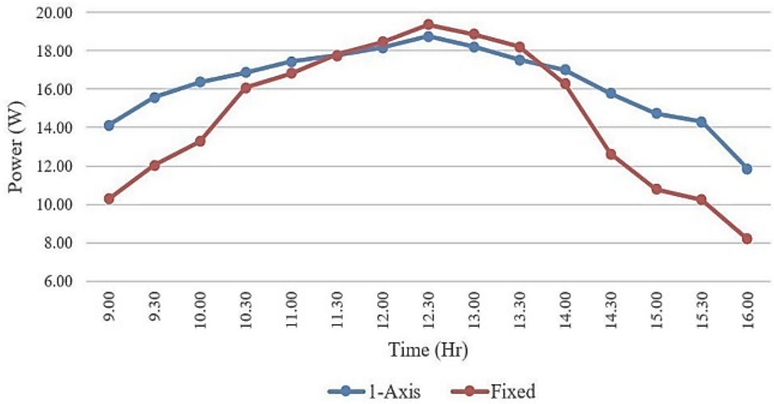
Table 2. The test result of finding the azimuth angle accuracy as of 1st October 2020.

Time (Hr)	System's angle data (°)	Rotatable angle data (°)	Error percentage (%)
9.00	17	17.20	1.18
9.30	21	21.10	0.48
10.00	26	26.40	1.54
10.30	34	34.20	0.59
11.00	45	45.40	0.89
11.30	61	62.00	1.64
12.00	84	84.90	1.07
12.30	109	110.20	1.10
13.00	129	130.40	1.09
13.30	142	144.00	1.41
14.00	151	152.00	0.66
14.30	157	159.00	1.27
15.00	161	163.60	1.61
15.30	165	166.30	0.79
16.00	168	169.20	0.71
Total mean			1.07

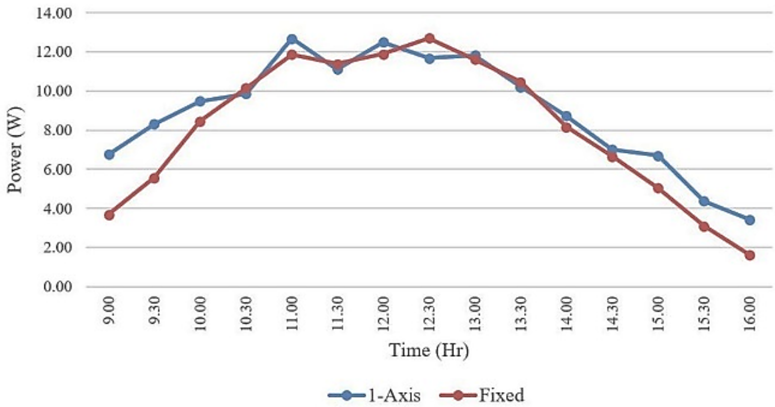
This system uses more components than that in the stationary solar panel. The components and their cost are as follows: one 40-watt monocrystalline solar panel at $36, one Arduino board at $5, one SD card module at $1, one SD card at $2, one LCD display at $2, one RTC module at $1, one servo motor at $8, gear and rod at $8, and two bearings at $4, which make the overall cost of the solar tracking system at $67. The installation and maintenance are also small due to the system being only the prototype.

4.2. The amount of electric power generated by single-axis solar tracking system referring to date, time and stationary solar panel

It is found that the average amount of electric power of single-axis solar tracking system was 12.72 watts and that of the stationary solar panel was 11.05 watts. It can be said that the single-axis solar tracking system has average electric power 15% higher than the other. For sunny days and cloudy days, the single-axis solar tracking system generated an average amount electric power more than that of the stationary solar panels at 11% and 10%, respectively as shown in figure 6. This system can generate more electric power even on cloudy days.



(a)



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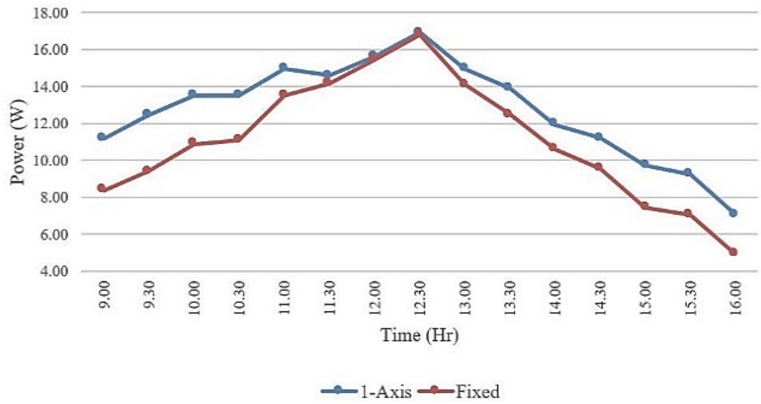

(c)

Figure 6. Electric power generated for (a) sunny days, (b) cloudy days and (c) October 2020.

The single-axis solar tracking system is a small-size prototype so it is suitable for domestic use or low-voltage equipment in remote areas. This system is also suitable to install on flat surfaces as opposed to inclined surfaces. Due to its lightweight structure, the system is easily portable. However, it is not advised to use the system during natural disasters, especially those related to storms due to its low stability.

The advantages of this system are its low cost and that it is easy to use. The components used in the system can easily be found in the market and the cost is low. In addition, it can also be used as a study approach and developed into a larger system. However, to design and build a larger system, its main parameters must be studied further, for instance, the motor that controls the overall system structure. Since these parameters depend on the size and number of solar panels, it requires more cost as a result.

Besides building a larger system to generate more electric power which requires more expense, the size and number of solar cells can be increased instead to increase the surface area receiving the sunlight, thus the intensity, as the price of solar panels tend to decrease in the future.

5. Conclusion

Single-axis solar tracking system referring to date and time is durable and lightweight, which is easily portable. Moreover, the servo motor that forces the solar panel to move at different times is accurately implemented throughout the experiment. The error is 1.07%, which is extremely low. Moreover, the servo motor consumes very little energy and is cheap in price [18]. It is also found that the single-axis solar tracking system generates 15% more electric power because of the solar tracking system referring to date and time works well on a cloudy day or in the rainy season [19]. The overall cost for the solar tracking system is at $67 as it is a small prototype. In conclusion, the solar cell system can adjust the direction of the solar panel to get more sunray almost all day long, except for 11.30 AM – 1 PM, the single-axis solar tracking system referring to date and time can generate electric power at almost the same amount as that of the stationary solar panel. The solar tracking system referring to date and time can collect the date; (d), time; (t), and the azimuth angle data; (ψ) for many years depending on memory card storage size. Using the arcdegree of the sun at different times from www.timeanddate.com and www.suncalc.org as a solar panel direction indicator is practical, even in the rainy season. Therefore, in the rainy season or on cloudy days, the single-axis solar tracking system referring to date and time should be used, or the sun tracking system should be adjusted to rotate twice a day to reduce motor power consumption during unnecessary periods.

The researchers intend for future studies to focus on developing a larger solar tracking system with adjustable solar panels to receive the highest light intensity for whole day in all weather conditions. Furthermore, the researchers intend to re-design the system to use lower-cost components and to improve the tracking system to the highest efficiency to connect with internet of things (IoT) to display important information and to remotely control the system.

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