Introducing Sustainability to Secondary Level Students Using Automated Tracking Solar Arrays

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Abstract

With the national push to develop STEM education programs and increase interest and performance levels of students, the need for alternative educational programs is growing. The goal of this work was to design and construct a small-scale solar array that could be used by high school students to both manually and automatically track the sun. Based on the results of both of these systems students would be introduced to the idea of creating an algorithm that could be used to optimize a system with regards to solar energy collection and thus understand the importance of STEM education. It should be noted that this experiment will be used in conjunction with a number of other small-scale projects that highlight several aspects of the zero plus energy building (more energy is converted to electric power than used) developed by the University of Tennessee at Chattanooga. For ease of demonstration, separate manual and automatic trackers were designed for the experiment. Using a standard camera tripod, the solar panels were attached to fabricated mounts to allow for omnidirectional movement. For the automated, or active tracker, an Ardunio Uno microcontroller was used in conjunction with two 180˚ servos to position the active tracker into the optimum orientation for energy collection.

Keywords

Solar Energy, Education, Zero Energy Building

Introduction

The photovoltaic industry has grown dramatically, increasing output 200 fold in a twenty year period. Even now in remote areas, solar energy is considered one of the most effective solutions for electrical power production. Coupling these facts with current environmental concerns, solar arrays are at the forefront of new development in energy production as coal and other fossil fuels are beginning to be phased out as a means to power the United States.[4]

The overall goal for this work is to provide two apparatuses that will be utilized in a number of experiments as part of a summer youth program for high school students. Ideally students will be taught engineering principles and how they can be applied with regard to energy collection using solar arrays. One of the structures will be manually adjusted to find the optimal angle for energy production while the other will be automated through a microcontroller.

The need for a lightweight and portable apparatus, as well as a desire for students to be able to conduct experiments quickly, drove the design to be as simple as possible. The two structures were designed to support the weight of not only the panel but also the brackets that housed the panel and all additional components. The manual tracker (one-axis) mode will allow the user to physically move and adjust the position of the panel. The active tracker (two-axis) structure will include a Maximum Power Point Tracking (MPPT) device that can sense the maximum sunlight around the solar panel for optimal power generation.[3] Both the apparatuses can be seen below in Figures 1 and 2.

Figure 1: Front and rear view of the manual tracker

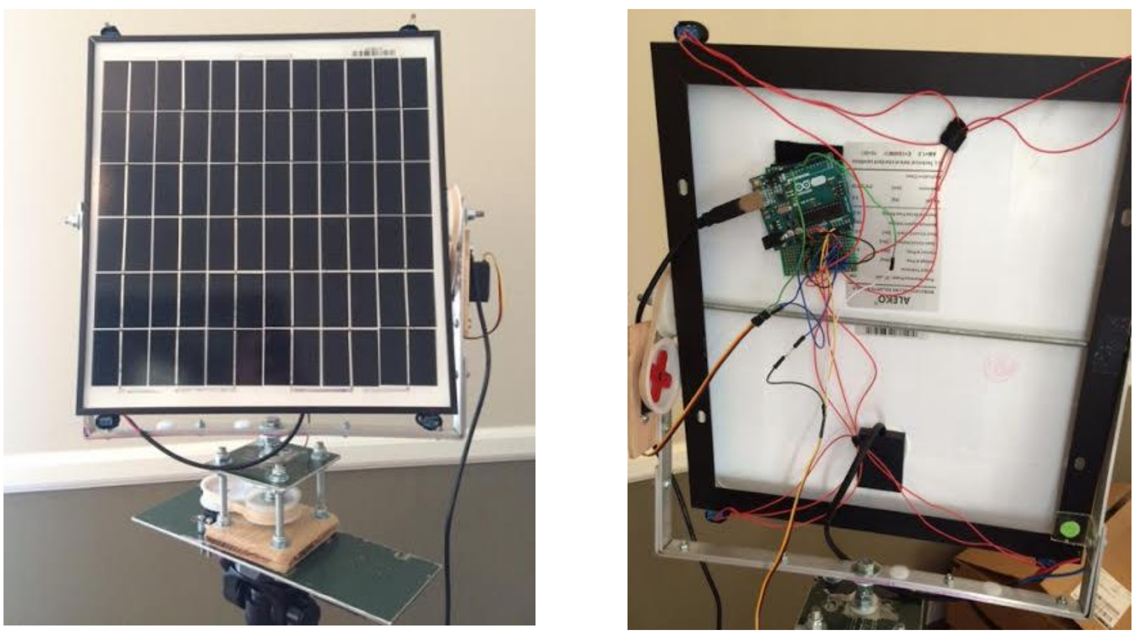

Figure 2: Front and rear view of the active tracker

The simple three step logic implemented for the two-axis tracker consists of a comparative inequality and functions as follows:

1. If the average value of the top sensors is less than the average value of the bottom sensors, and the difference between the average values is greater than the sensitivity margin, then the servo will decrement toward the top sensor and vice versa.

2. If the average value of the left sensors is less than the average value of the right sensors, and the difference between the average values is greater than the sensitivity margin, then the servo will decrement toward the left sensor, and vice versa.
3. However, when the values are equal and less than the sensitivity threshold, the servo will stop and hold position. Each iteration of the loop is delayed 100 ms.

This algorithm ensures that as the Sun's position changes throughout the day the active tracker will follow, keeping the rays normal to the panel.

Methodology

The procedure for this experiment can be broken down into two main tests. The first test will be to determine the optimum angle for power generation of the fixed array. The other test will be to determine the overall power generation over the course of a day. In this test, the fixed array, at its optimum angle, will be compared to the active tracker. The full procedure is dictated by the setup of the two apparatuses, data collection and analysis. Parameters that will affect each test are: the angle of the fixed array, the load generation circuit used for each apparatus, the weather on the particular day, and the instruments used to collect data for analysis.

In order to demonstrate the effectiveness of the automatic tracker, versus a fixed solar panel, tests were initially completed on the manual tracker to provide a baseline. One-axis trackers, when positioned in the Northern Hemisphere, perform best when facing due south, based on a yearly average[1,2]

Next, three five-hour day tests were completed using both the manual and automatic tracker. As stated previously, the one-axis or manual tracker was set at 40 degrees facing true south for the entirety of the test. Each half hour, beginning at 10:00 AM EST, the active tracker was plugged in and activated to locate the optimum position with respect to the sun.

Results

The manual tracker was placed due south and the optimum angle was determined by measuring the power output while moving the tracker in 2^o increments from 20^o to 75^o. The data plotted in figure 3 represents average values taken over ten days of testing during the month of February at approximately 12:00 pm. The optimum angle from this testing was found to be 40^o. This was deemed the best average setting for the manual tracker and was therefore fixed for all additional testing.

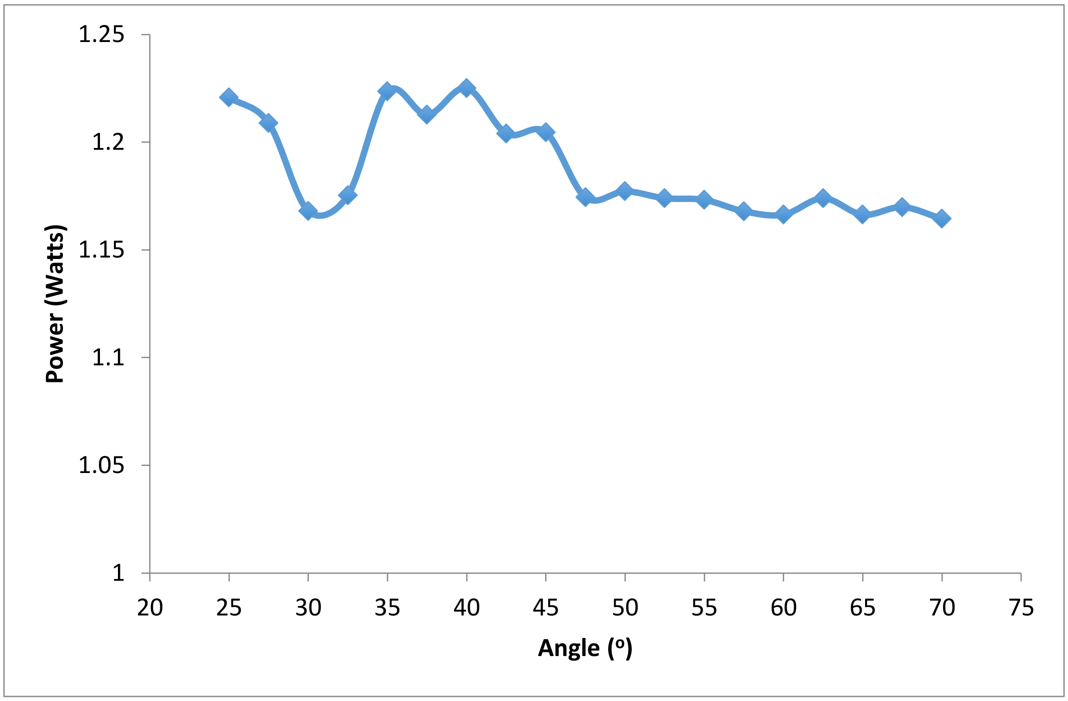

Figure 3: Manual Tracker Power vs Horizontal Angle

From both of the apparatuses, the data from the five-hour day tests was compiled. Table 1 provides the average data taken from these tests including power output and panel direction.

Table 1: Averaged Values from Hourly Tests

Type of Tracker	Active									
Time of Day	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30
Direction (°)	97	112	117	117	128	178	179	184	187	189
Angle (°)	50	50	53	44	42	39	38	43	42	43
Voltage (V)	19.525	21.500	21.375	21.750	21.850	21.650	21.500	21.350	21.250	21.075
Amperage (A)	0.0589	0.0606	0.0607	0.0610	0.0615	0.0602	0.0597	0.0589	0.0586	0.0581
Power (W)	1.14904625	1.3029	1.2974625	1.32729375	1.343775	1.3022475	1.28355	1.2564475	1.24471875	1.2244575
Type of Tracker	Fixed									
Time of Day	10:00	10:30	11:00	11:30	12:00	12:30	1:00	1:30	2:00	2:30
Direction (°)	180	180	180	180	180	180	180	180	180	180
Angle (°)	40	40	40	40	40	40	40	40	40	40
Voltage (V)	18.88	18.92	18.90	18.90	19.08	18.85	18.83	18.63	18.63	18.58
Amperage (A)	0.0554	0.0572	0.0571	0.0575	0.0589	0.0582	0.0577	0.0568	0.0564	0.0560
Power (W)	1.045675	1.08099225	1.07919	1.0872225	1.1235175	1.09707	1.08667313	1.05743438	1.04951875	1.03927125

Examining the results from the active tracker show that the average angle over the five hour period was approximately 44.4^{o}, matching closely that of the fixed panel. However the direction changes significantly as the panel follows the sun as it moves from east to west throughout the day.

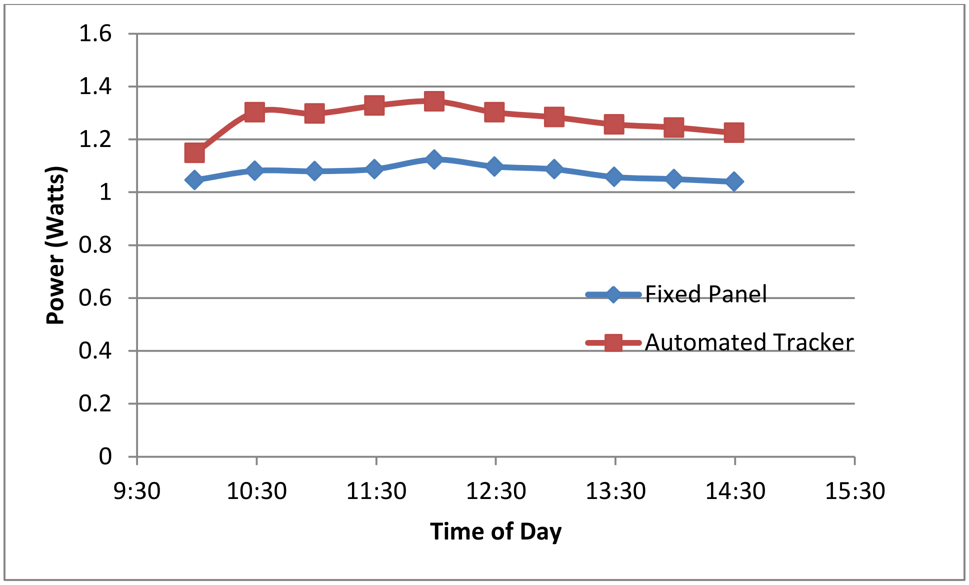

Figure 4: Active and Fixed Tracker Power Output

Figure 4 provides the power output of the solar panels for both the fixed panel and active tracker with respect to the time of day. The first observation is that the fixed panel experienced an average maximum power of 1.12 watts, which is 9% lower than the original optimal angle tests. A possible cause of this loss could be attributed to partial cloud cover on the day this test was taken. However the most probable factor is due to the fact that these tests were taken in mid March, after Daylight Savings Time was observed, when the azimuth of the Sun was slightly altered from the original optimal angle tests taken in February. This change in azimuth can account for the power loss due to the fact that as the sun rises higher in the sky a larger angle is needed in order for more rays to strike the photovoltaic cells at 90˚.[2]

The second and most important observation is the obvious increase in the power output of the automated tracker compared to the fixed panel. The average maximum power reading is 1.34 watts. This value is 10% greater than the fixed panel during the optimal angle test and almost 20% greater over the hourly test. Overall, the automated tracker's lowest average value from 10:00 AM EST to 2:30 PM EST was 1.14 watts, which is around 2% greater than the maximum the fixed panel was able to accomplish. As observed in Table 1 the cardinal direction increases throughout the day, as the azimuth of the Sun changes. This is to be expected, as the goal of the active tracker is to maximize the amount of photons hitting the photovoltaic cell at 90˚[1]. On average, the two-axis tracker was 18% better at generating power than the fixed panel when it was locked into place at 40 degrees facing true south.

Conclusions and Recommendations

The goal of this project was met and the apparatuses proved to be an effective means of demonstrating engineering principles through the use of solar panels. Specifically the quantitative results obtained from this study would help students understand the significant improvement that can be made by applying these principles. This apparatus will hopefully prove to be a valuable asset for a summer youth program focused on energy conservation and production. The next and final step in this work would be to complete the design and implementation of a tracking algorithm that would follow the sun automatically throughout the year, rather than performing a search for the best position throughout the day.

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