Self-sustaining and externally-powered fixed, single, and dual-axis solar trackers

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ABSTRACT

Power output from a small solar panel can be affected by its power consumption when it consumes power from the solar panel. There has been a lack of proper research and experiment in the use of small solar panel with tracking systems. Its significance was detailed in this paper where the voltage output are compared with those which were externally powered. The solar trackers and a microcontroller have been designed and fabricated for this research. Due to the use of the tracking system (single axis and dual axis), the power consumption varies from one to another and its effect on the voltage output. Several experiments have been conducted and it was concluded that small solar panels are not efficient enough to utilize with tracking capabilities due to an increase in power consumption. The externally powered system was found to generate 18% more output compared to a self-sustaining system and that the increase in average power consumptions compared to a fixed panel were 31.7% and 82.5% for single-axis and dual-axis tracker respectively. A concrete evidence was made that utilizing solar tracking capabilities for low power rated solar panel is unfeasible.

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1. INTRODUCTION

When the solar panel is directly facing the sun, the highest power output is obtained [1-3] and to generate reliable output, the solar panel must face the sun at all times. A 35% increase in output has been achieved by utilizing dual-axis against a fixed panel setup [2]. One research achieved near 50% output gain [3]. Even a single axis tracker can be used to generate 12% more output compared to a fixed angle system [4, 5]. The use of a dual-axis solar tracking method will ensure that the solar panel always faces the sun [2-11]. There are several methods of dual and single-axis tracking methods that have been done previously by others. Examples are microprocessor-based tracking [5], using webcam and computer controlled [9], GPS based tracking using astronomical equation [10, 11] or solar maps [12], RTC-based algorithm [13], simple light dependent resistor (LDR)-based tracking [14], or thermal expansion of material connected to a lever [15]. Solar panel systems may be self-sustained or powered up through external power. For a self-sustained system, the solar panel generates some power for its systems (controller and motors) while excess power is stored into a battery charger. A self-sustained method is normally used for large solar trackers because the solar panel generates sufficient output to power itself. With this powering method, the power consumption from its systems will affect how much power is required to sustain itself and still provide power for other uses. For trackers using external power source, power consumption from the controller and tracking system may be disregarded. All power outputted by the solar panel is wholly stored into the battery charger. This can be used for a small scale solar tracking system whereby its small solar panel could not generate enough power for its system let alone excess power for the battery charger. A small system may still be self-sustained but could affect the voltage and power output of the solar panel. Because of this and the power consumption of the system, some research discouraged the use of a tracking system for small solar panels [16, 17]. Many papers have concluded power consumption at 2-3% [16-20] of the increased power for standard large panel with few papers giving 0.5 to 0.6Wh as their power consumption [21-23]. Several papers have tried to reduce their system's power consumption to maximize power generation [24-26].

Theoretically, the dual-axis solar tracking system generated the highest output from the single-axis and fixed panel system, followed by the single-axis solar tracking system producing higher than fixed panel while a fixed angle solar panel generates the least output among them [27]. However, the power consumption for a dual-axis tracking system is higher than the other two. For a small scale and self-sustained solar tracking system, when there is a lack of direct sunlight, the output may be lower than single-axis and fixed panel. The tracking method for this research will be LDR-dependent as explained in [6, 7 and 10]. For the first few experiments, the solar tracking systems are self-sustained and after several experiments, they are powered from an external source. The 3 voltages from the dual-axis, single axis, and the fixed panel are then compared between the self-sustained and externally powered to determine whether self-sustained is feasible or not for use in small solar tracking systems as stated by [12, 13]. The power consumption from all the solar tracking systems will also be measured by calculating current as measured with the voltage required to operate the system. The readings from this will be used to determine the increase in power consumption between the fixed panel, single-axis tracking and also dual-axis solar tracking systems.

There have been no conclusive results from other papers where small solar panel output is affected when the systems are self-sustained. The solar tracking systems on which others have presented have medium to large panels [2, 6, 14, 28-30] which are capable of generating power outputs of more than 30 watts for medium size solar panel and above 200W for large size solar panel. Small solar panels, in this case, output less than 30 watts. In this paper, the main objective is to compare the voltage outputs between 3 small solar tracking systems which are likely to be affected by the power consumption of its system. It has been found that power consumption indeed increases 2-3 times of fixed solar panel and that externally powered solar tracker generated over 10% more output compared to self-sustained trackers [31].

2. RESEARCH METHOD

2.1. Controller setup

The solar panel to be used for the whole experiment is supplied by the institute which has a model name MSX01. This solar panel has a power rating of 1.01W, a voltage of 7.5V at max power, 10.3V at open circuit, current of 135mA at max power and 150mA at short circuit. Current will not be measured for this project as the current is dependent on load resistance and that load resistance will be fixed at high resistance. The voltage, on the other hand, will be measured in open circuit measurement where the resistance is very high or virtually infinite. Figure 5(a) is created according to the given power, current and voltage rating from the datasheet of the solar panel MSX01. At 0V, the circuit is short and current is at its highest of 150mA but because the voltage is 0V, power is also 0W. Increasing the voltage, the current will be fixed at 150mA while power is increasing proportionally to voltage increase up to when the voltage reaches 7V where the current starts to decrease. Max power of 1.01W can be obtained when the voltage is 7.5V and current at 135mA. From there on, current and power keep decreasing exponentially while voltage increases until 10.3V where current now becomes 0A, meaning a fully open circuit was created.

Solar panel voltage can be measured in several methods such as using sensors which are very accurate, externally measured using a multimeter or voltmeter or directly connected to the controller's analog pin. For this project, the latter method is most suitable due to less component used and automatic measuring by the controller. However, the microcontroller PIC18F4520 could only measure analog voltage up to 5V and the solar panel to be used can generate voltage up to 10.3V. Because of this, the solar panel will firstly be connected to a voltage divider circuit as in Figure 1(a) to reduce the max voltage to 5V as required by the microcontroller range. From this, the controller will calculate the value to determine the actual voltage value. The calculation follows (1) as shown. The voltage divider circuit ensures that the controller can read voltage readings up to a max of 15V for extra safety precaution.

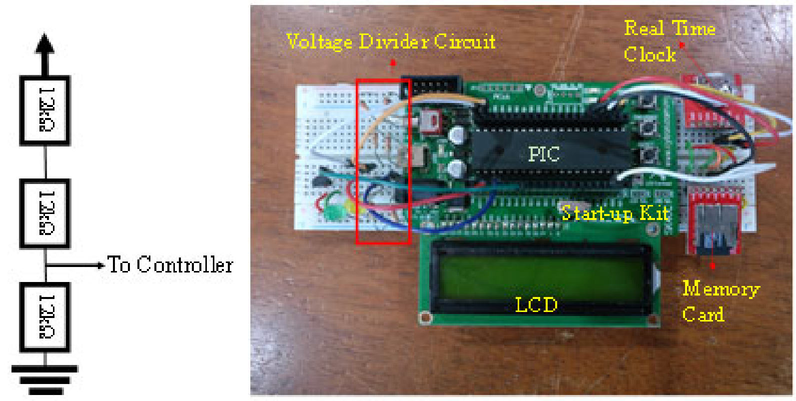


Figure 1(a). Voltage divider circuit, and Figure 1(b). Hardware controller circuit

$$\frac{R_3}{(R_1)+(R_2)+(R_3)} \times Voltage_{Panel} = Voltage_{Controller} \quad (1)$$

Power is the product between voltage generated by the solar panel and current flowing through a load. Normally, the current is determined by load resistance and the load is fixed to a specified resistance value. As a result, power from a solar panel is generally proportional to the generated voltage. The solar panel will firstly be connected to a voltage divider circuit as in Figure 1(a) to reduce the max voltage to 5V as required by the microcontroller range. Aside from the voltage divider circuit, the controller also consists of a real-time clock module and a memory card module. The controller will measure the open-circuit voltage of the solar panel every 10 seconds in real-time to ensure accurate reading as possible. The voltage read by the controller will then be recorded into the memory card and also every 10 seconds. The clock module DS3234 is used to measure the time of voltage measurement, accurate to the seconds. Figure 1(b) shows the hardware connection of the microcontroller to the voltage divider circuit as well as the memory card and a real-time clock. The controller has a set of operations in 10 seconds which are to rotate the solar panel, storing data to a memory card and idle/standby state in general. The 3 solar trackers will have slightly different operations to cater to its use. Figure 2 illustrates the sequence of operation for the 3 solar trackers. From this, the controller will calculate the value to determine the actual voltage value. The calculation follows (1) as shown. The voltage divider circuit ensures that the controller can read voltage readings up to a max of 15V for extra safety precaution.

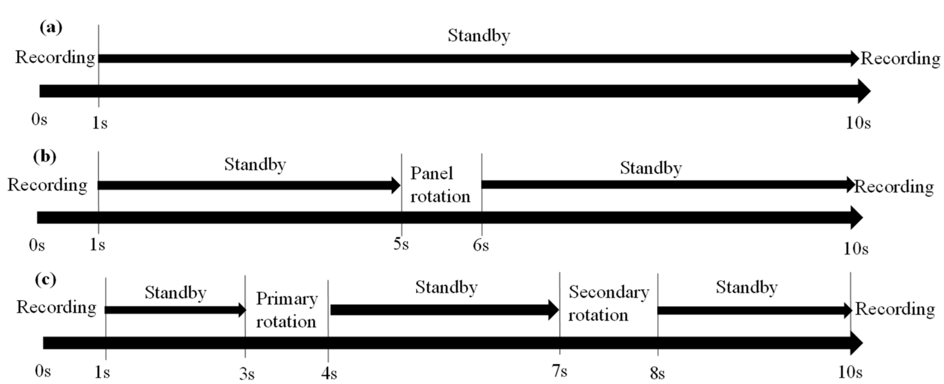


Figure 2. Sequence of operations for the 3 solar trackers

2.2. Experimental setup

For each experiment, the voltage of 3 solar trackers are to be measured, one with dual-axis tracking, another with single-axis tracking and the last fixed in one direction facing zenith. The tracking capabilities for these solar trackers are by motors and simple LED circuits as designed in [5] and [16]. These modules consume power from the controller to operate and will be included during the power consumption experiment. For the power consumption experiment, the current flowing into the controller from the source is measured at several points of time as indicated by Figure 2. The objective is to find the current when the system is rotating the solar panel, storing data to a memory card and during standby. A total of 3 current readings were expected. From here, power consumption is calculated (3) whereby the operational voltage of each component is fixed at 5V.

The initial experiment is to measure the voltage of the solar panel in which the system is self powered by its solar panel. In this setup, the voltage from the solar panel will be divided into 2 voltage channels. One channel passes through a voltage regulator then to the microcontroller for the power source and the other channel passing through the voltage divider circuit and from the voltage divider to the controller for voltage measurement. To ensure a sufficient supply of power to the controller, a rechargeable battery is connected in parallel to the microcontroller. The battery becomes a load with low resistance during charging (or when there is ample power to operate the controller) and discharges power should the solar panel not generating enough power. Figure 3 illustrates the connection of the solar panel with the controller as mentioned. For the externally powered solar tracker, a normal AC home socket will be used. The use of a voltage regulator and rechargeable battery are not needed. However, they will be replaced by the use of a typical 5V mobile adapter to change the AC voltage to a DC 5V voltage suitable for the microcontroller. Figure 4 illustrates the connection of externally power solar panel and the external power to the controller circuit.

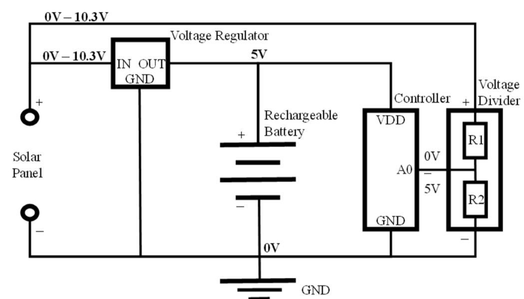


Figure 3. Solar tracker in self-sufficient power setup

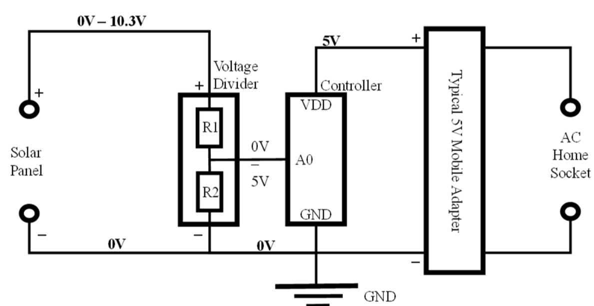


Figure 4. Solar tracker in externally-powered setup

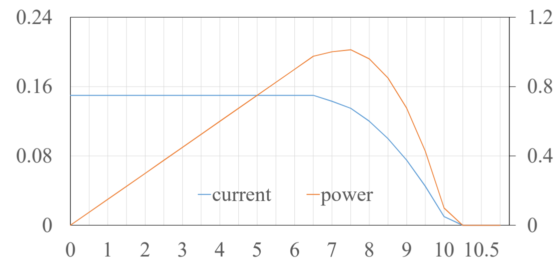
3. RESULTS AND DISCUSSION

3.1. Controller performance

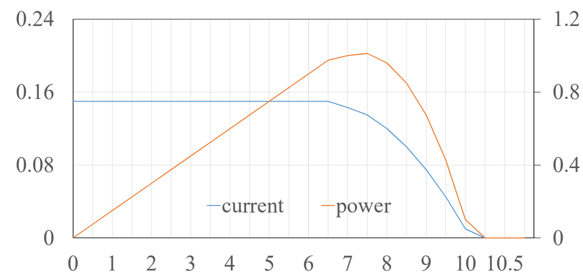
Using the above setup for the microcontroller, the voltage is very accurate with only 1.87% maximum error during the simulation. The average error was at 0.24% which was determined using (2). Figure 5 shows the voltage as measured and calculated by the microcontroller compared to the specified cell voltage and what was measured by the simulation program.

$$\% \ error = \frac{V_{display} - V_{simulation}}{V_{simulation}} \times 100 \tag{2}$$

$$power = current \times voltage \tag{3}$$



(a)



(b)

Figure 5(a). Current to voltage (I-V) and power curve of solar panel at nominal temperature. Primary y-axis (left) is current (A) and secondary y-axis (right) is power (W). Main x-axis is voltage (V). Figure 5(b). Cell voltage as calculated from simulation and microcontroller. The y and x axes are both voltage (V).

3.2. Power consumption

In power consumption experiment, several readings are taken at different operation time. Most readings taken were giving constant values of current with a very small error of 1mA. This current is then multiplied with voltage to get power under (3). The results of power consumption are as found in Table 1. The comparison of power consumption between a fixed panel with a single-axis solar tracker and a fixed panel with the dual-axis solar tracker are also shown in Table 1. From the results achieved, the average power consumption increased by 31.7% and 82.5% for single-axis and dual-axis solar tracker respectively from the fixed panel.

Table 1. Power consumption results and comparison for 3 solar trackers at different operations

Operation	Fixed panel	Single axis	Dual axis	Single axis to fixed panel	Dual axis to fixed panel
Standby	0.20W	0.25W	0.35W	25%	75%
Writing to card	0.30W	0.35W	0.45W	17%	50%
Panel rotation	0.20W	0.40W	0.55W	100%	175%
Average power consumption	0.21W	0.275W	0.38W	31.7%	82.5%

3.3. Self-sustained trackers

The next experiment is to obtain voltage results when the solar trackers are self-powered. Several experiments have been completed resulting in quite varying results depending on the weather at the time of the experiment and other various factors. The most significant results as shown in Figures 6 and 7 were 2 results when the weather was sunny and cloudy respectively. Self-powered solar trackers at sunny weathers almost output the same amount of power if the battery does not require recharging. However, due to charging, the voltage output drops by 2.5V as seen from the dual-axis tracker voltage line in Figure 6. Voltage drops for single-axis tracker and fixed panel were at 2V and 1.5V respectively.

Due to the higher power consumption of dual-axis solar tracker, the voltage drops are larger in dual-axis tracker than the other two systems causing a reduction in total output by dual-axis tracker by 18% compared to the fixed panel. A single-axis tracker only generates 0.2% more output than the fixed panel. During cloudy weather in Figure 7, several voltage drops were recorded. In this figure, the voltage drops for dual-axis tracker were also the highest among the three by almost 3V followed by a single axis tracker by 2.7V. The fixed panel has the lowest voltage drop of 1V. This caused the power generated by the fixed panel to output almost equal to dual-axis tracker but more than single-axis solar tracker. The total output compared to the fixed panel was an increase of 0.99% and -1.26% for dual-axis and single-axis tracker respectively.

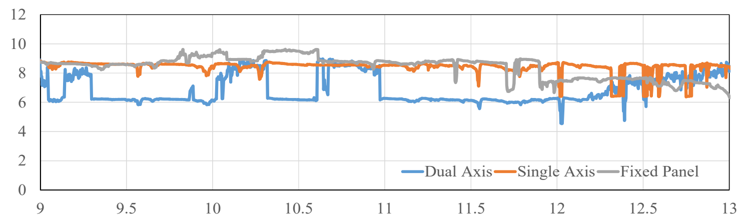


Figure 6. Solar trackers in self-sustained setup during sunny weather

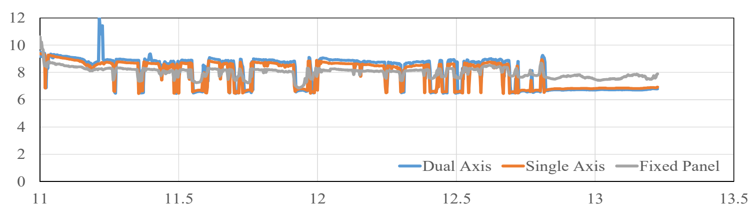


Figure 7. Solar trackers in self-sustained setup during cloudy weather

3.4. Externally-powered trackers

The final experiment is to obtain voltage results when the solar trackers are powered by an external source where no battery is required for this experiment. In this experiment, much stable voltage lines were achieved as shown in Figures 8 and 9 because there are less significant voltage drops as opposed to a self sustained setup of Figures 6 and 7. The voltage drops experienced in this experiment were only caused by cloud cover as seen in Figure 8. In Figure 8, the weather was sunny with a clear sky. Dual-axis and single axis solar trackers also output almost the same amount of power albeit a bit high for dual-axis solar trackers. The fixed panel generated the same output with the two trackers when the sun is perpendicular to the solar panel and the solar panel is fixed to zenith but outputs lower power before and after noon time. The total output generated at sunny weather was an increase of 9.44% for both single and dual-axis trackers compared to fixed panel. During cloudy weather as in Figure 9, dual-axis generates the most amount of power most of the time even when the solar panels are shaded by clouds and almost linear throughout the experiment between 8V and 9V. Single-axis solar tracker produced a bit larger variation of voltage between 6.7V and 8.5V while fixed panel produced voltages between 6V and 8.2V. Total output generated during cloudy weather was an increase of 10.14% and 5.19% for dual-axis and single-axis respectively compared to fixed panel.

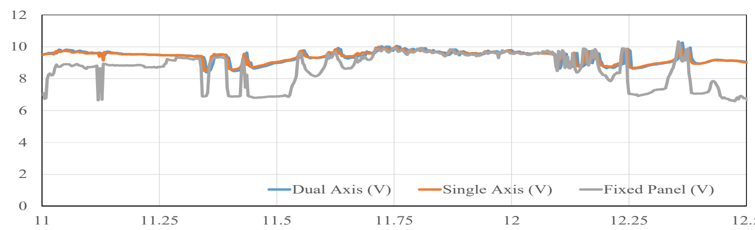


Figure 8. Solar trackers in externally-powered setup during sunny weather

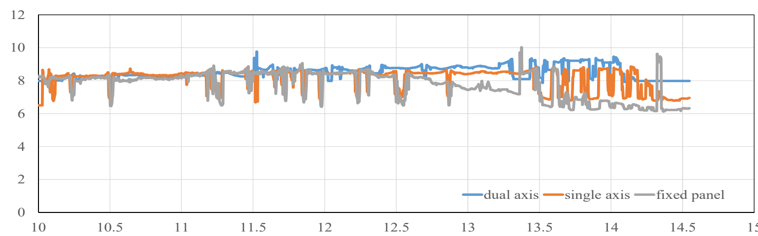


Figure 9. Solar trackers in externally powered setup during cloudy weather

4. CONCLUSION

Prototype solar tracking systems have been fabricated to compare their voltage outputs when they are self-powered or externally powered. A microcontroller was also designed to automatically measure the voltage outputs from the solar trackers. It has been observed that dual-axis solar tracker in self-sustaining power setup generates less output in general of 18% maximum reduction against fixed panel while single axis tracker generates an almost equivalent amount of output to fixed panel. For externally power setup, the output for both dual and single-axis solar tracker is more stable and higher than the fixed panel with 10% and 5% increase respectively. From these observations, it can be concluded that externally power solar trackers generated 18% more output than self-sustaining solar trackers. Power output generation from a self sustaining power setup suffers from increasing power consumption for the tracking system. In summary, a small-sized dual-axis solar tracker consumes more power than generating it with 82.5% increase power consumption for a 10% increase in output generation. For a single-axis tracker, the power consumption increases by 31.7% for a 5% to 9% increase in output generation. In conclusion, it is unfeasible to utilized solar tracking capabilities on low power rated solar panel.

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