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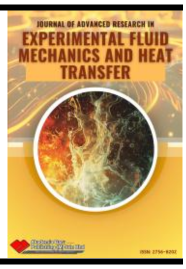

Efficiency Assessments of a Dual-Axis Solar Tracker for Energy Harvesting in Malaysia

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ABSTRACT

To ensure countries' food security and enhance agricultural sustainability, indoor farming is among the methods that can be implemented. However, to support the indoor farming system a vast amount of electricity is needed. Supplying power to agricultural activities using an optimized renewable energy system will increase the system's reliability in the long term. A dual-axis tracker system is developed to become the alternative power supply of an indoor farm. The tracker system performance under Malaysia's weather conditions was investigated and analysed over a day. The developed system has shown its ability to provide adequate power to the load. Besides that, the tracker power output was found to be dependent on solar radiation. The tracker system also has good efficiency of 16.75%.

Keywords:
Photovoltaic; MPPT; dual-axis; solar tracker; indoor farming

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1. Introduction

An alternative measure such as indoor farming has been considered to deal with inconsistent and low food supplies from conventional agriculture. Farmers and the agriculture industry are urged to strengthen their adaptive capacity to provide more dependable food sources due to climate change [1]. As the demand for food supply continues to increase, urban farming methods such as indoor farming, vertical farming, and rooftop greenhouse have been highly adopted [2,3]. Advantages of urban farming methods include lower carbon footprint, more efficient use of farming inputs, and year-round crop output compared to conventional outdoor farming methods. Implementing indoor farms needed a vast amount of electricity to maintain an ideal growth environment which is considered as the biggest disadvantage of the system [4,5]. Artificial lighting, automatic equipment, heating, cooling, and ventilation all require a lot of electricity to run indoor farms. Fossil fuels sources such as coal, natural gas, and oils are the sources that share more than half of electricity production [6]. While energy can be derived from multiple sources, most of the current energy supply continues

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to depend on fossil fuels [7]. The environment has been negatively impacted by the emissions of greenhouse gases from the burning of fossil fuels, instigating global warming, melting glaciers, and rising sea levels [8-10]. To reduce future damage to the environment, increasing the use of renewable energy sources is critical. Alternative energy sources such as wind, hydro, biomass, wave, solar, and geothermal have become more popular in recent years [11]. Based on recent energy usage trends, the conversion of primary energy sources from fossil fuels to renewable energy sources is expected to continue and accelerate. The convenience of solar photovoltaic (PV) panels and solar thermal collectors establishes solar energy as the most accessible type of renewable energy. PV technology has undergone significant commercialization and cost reductions, yet its performance remains highly dependent on Global Horizontal Irradiance (GHI) [12].

Solar PV panels with solar energy on agricultural land have been used as a cost-cutting method to reduce the power supply from the grid and lower the danger of farmers' revenue loss [13]. Due to the numerous advantages of this method, a significant number of studies have been conducted on the possibility of utilizing solar PV for energy generation while growing crops [14-17]. Solar energy technologies are being presented as a shift in agricultural methods for a more sustainable agriculture system [18]. Thus, upgrading solar PV with the capacity to track the sun for maximum solar energy absorption may help to improve its dependability and performance. Solar tracker systems have recently gained popularity among researchers as one of the more promising solar systems [19,20]. A solar tracker is a solar energy harvesting system that directs the solar panel in the direction of the sun to reduce the angle of incidence to increase the amount of solar energy generation. This makes solar trackers attractive to utilize in indoor farming systems, where maximum solar energy absorption can be used to produce more electricity.

The dual-axis solar tracker is the most studied system. The typical setup of the tracker system is to attach an actuator to the PV panel. Often Maximum Power Point Tracker (MPPT) is introduced to ensure the loads receive maximum current [21-23]. The tracking mechanism of the solar tracker plays a vital role in producing the maximum overall power output by the tracking system. In single-axis solar tracking systems with astronomical calculations tracking mechanisms, this system would perform better compared to fixed PV systems as reported by Kuttybay *et al.,* [24]. The analytical investigation showed that the tracking system managed to increase its efficiency by 57.4% as compared to the fixed PV system. Saymbetov *et al.,* [25] found that an adaptive algorithm dual-axis tacker with mini-PV and mini tracker installation generates 66-69% more energy compared to the typical dual-axis tracker, due to the improvement in solar energy absorption.

Besides that, the number of tracking axes of the solar tracker system also impacts the overall efficiency of the system. Jamroen *et al.,* [26], carried out a comparative analysis of a dual-axis tracker with a fixed PV system. The dual-axis system can provide a higher power output with Light Dependent Resistor (LDR) as a sensor to track the sun, compared to a fixed PV system. This finding aligned with Saeedi and Reza [27], where an LDR-based tracker with Wheatstone bridge circuit function achieved 48% higher efficiency compared to a fixed PV system. However, both studies found that the overall efficiency of the system deteriorates with cloudy weather conditions due to a dip in power generated.

Furthermore, the solar tracker system has been tested to explore the impact of actual weather conditions on the PV system. Gonul *et al.,* [28] assessed the solar tracker system's performance in three Turkish provinces based on monthly electricity generation. The authors discovered that the tracking system produces more power during the summer than it does during the winter. Jamroen *et al.,* [29] use one day's weather in Bangkok, Thailand to evaluate the performance of a dual-axis tracker system. The results showed that the PV system performed better, particularly at the start and end of the day, due to the system tracking ability.

In this paper, a functional prototype of a dual-axis solar tracker system is developed and examined based on the power output supply required by the load utilized for indoor farming. A simple tracking mechanism is developed to track the sun's trajectory for better PV performance. An experiment was conducted to evaluate the tracker system's performance under Malaysian weather conditions. The PV tracker system's performance and load power are discussed. Finally, the tracker system's power output is tested to ensure it meets load requirements.

2. Methodology

2.1 Dual-Axis Solar Tracker Electronic Control Unit

Trackers' electronic control units have different algorithms, structures, and purposes. Figure 1 below depicts the schematic diagram of the dual-axis solar tracking system, which includes a closed-loop algorithm. The central component of the device is the Arduino microcontroller, which contains the tracker's algorithm. The system is powered by a 12-volt battery. Furthermore, the DS1307 component is defined by its built-in real-time clock, which displays the date, month, and local time. The system also uses the MPU6050 gyro meter to adjust the solar tracker's tilt and horizontal angles.

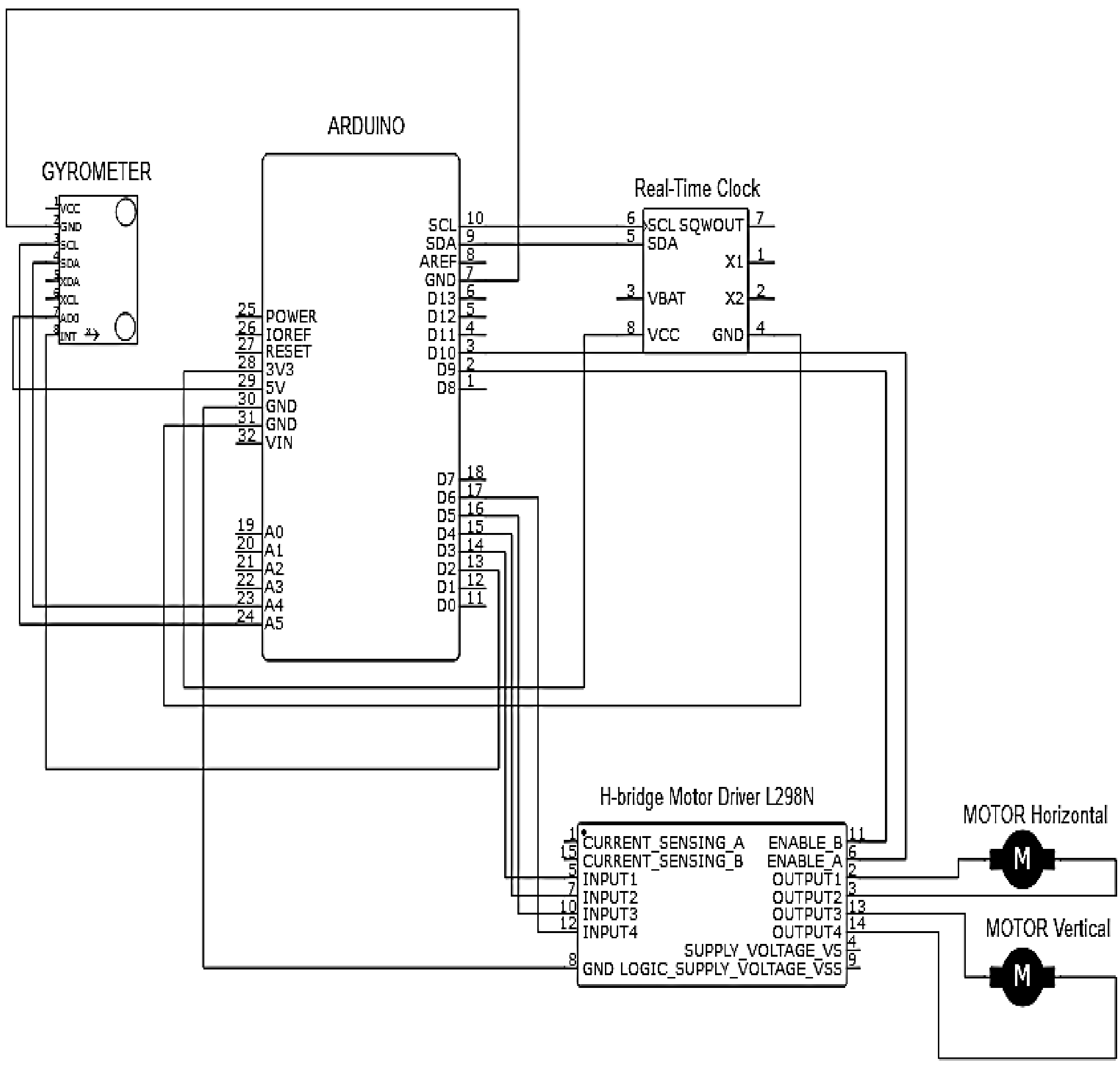

Fig. 1. Schematic diagram of dual-axis solar tracker control unit

2.2 Solar Tracking System Algorithm

The proposed tracking mechanism is based on astronomical calculations of the Sun's path relative to the Earth in the horizontal coordinate system as shown in Eq. (1) below [30].

$$\delta = sin^{-1}\left(\sin(23.45°)\sin\left(\frac{360}{365}(d-81)\right)\right) \tag{1}$$

The declination angle (δ) is the angular position of the sun at solar noon (when it is on the local meridian) with respect to the equator, north positive; -23.45° < δ ≤ 23.45°, and d is the ordinal number of the current day of the year, so for January 1, d = 1. The equation assumes a perfect circle for the sun's orbit and uses a factor of 360/365 to translate day numbers to orbital positions. 360 represents the overall angle of the circle and 365 represents the number of days in a year. The 81 days symbolize the spring equinox from January 1st. The elevation angle of the Sun α is calculated from Eq. (2).

$$\alpha = sin^{-1}(\sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos\,(15°(LST-12))) \tag{2}$$

where φ is the latitude of the sun tracker system's location and LST is the local solar time. Finally, the formula for the azimuth angle, γ is shown in Eq. (3).

$$\gamma = sin^{-1}\left(\frac{\sin(\delta)\sin(\varphi)+\cos(\delta)\cos(\varphi)\cos\,(15°(LST-12))}{\cos(\alpha)}\right) \tag{3}$$

The tracking mechanism of the proposed dual-axis solar tracker system is illustrated in Figure 2. Once the system is turned on, the Arduino utilizes the DS1307 real-time clock (RTC) to obtain the current date and time. If the system is powered up before sunrise, it will remain in idle mode. When dawn arrives, the system reads the tilt and horizontal angles of the solar panel. The system rotates the solar panel's tilt and horizontal angles when the time to move the panel arrives. The angles are measured by using the gyro meter MPU6050. After the desired position is reached the system will enter idle mode after a delay. The whole tracking mechanism is repeated until it is sunset time. The proposed tracking mechanism is focused on a schedule-based tracking method. The system moves the solar panel at tilt and horizontal angles every three hours based on the angle input by the user. This simple tracking mechanism is utilized to reduce the power consumption to move the solar panel and to improve the solar energy harvest by the PV panel with minimum movement.

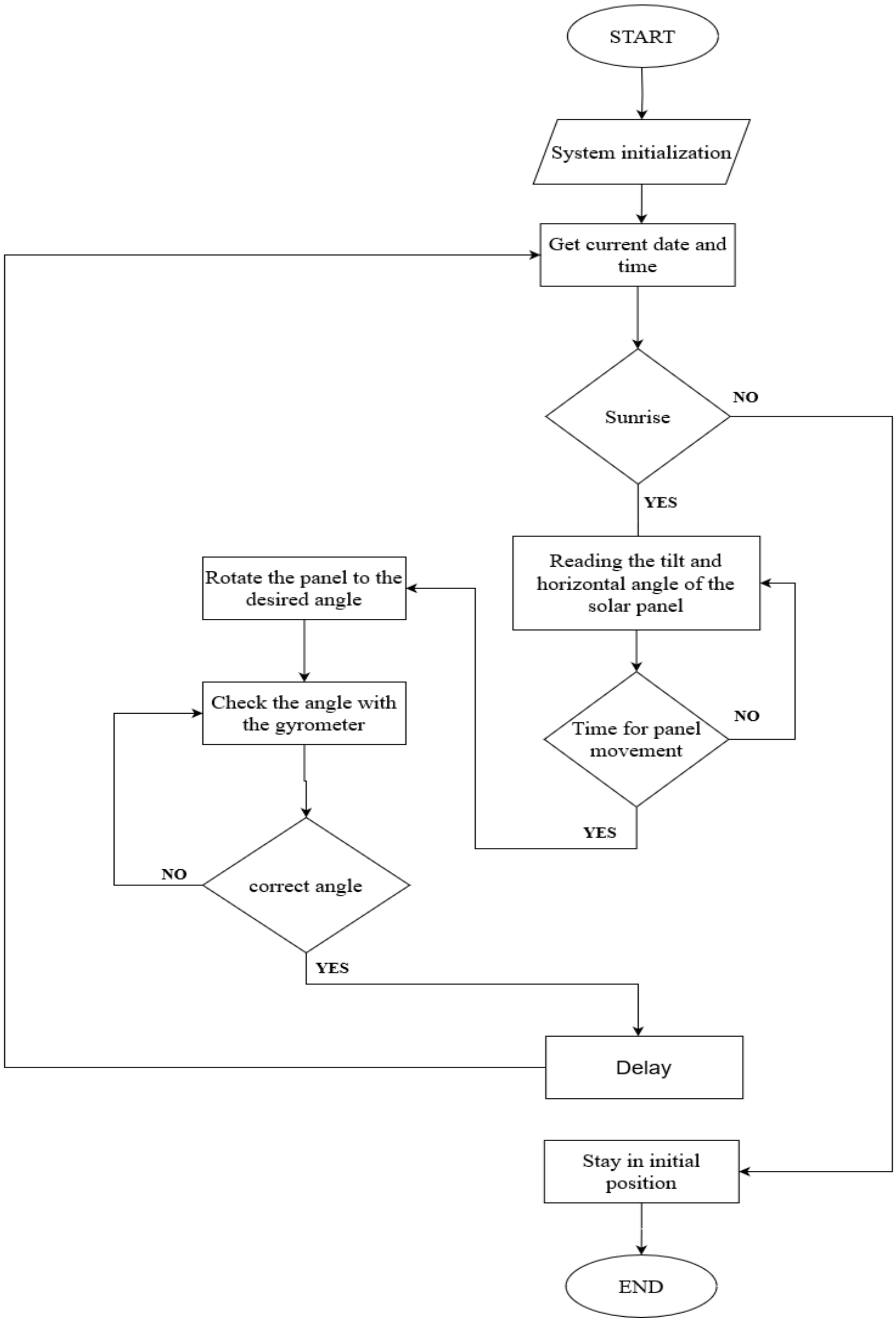

Fig. 2. Flowchart of the tracking mechanism

2.3 Load Specification

2.3.1 Load requirement

The tracker system was developed to supply power for lighting usage in indoor farming. High adjustability, energy saving, and have been widely used in indoor plant cultivation are the advantages of using LEDs as the main artificial light source for plant growth [31]. The amount of light required for optimal indoor plant growth varies according to the type of plant. According to Pereira *et al.,* [32] the usage of artificial light for 16 to 20 h/day could improve productivity across different plant species.

Figure 3 depicts the designed LED setup for the indoor cultivation idea. Figure 3 shows the LED setup in the indoor farming area. The LED has a length of 4.2 m and 14.4 W of power per meter.

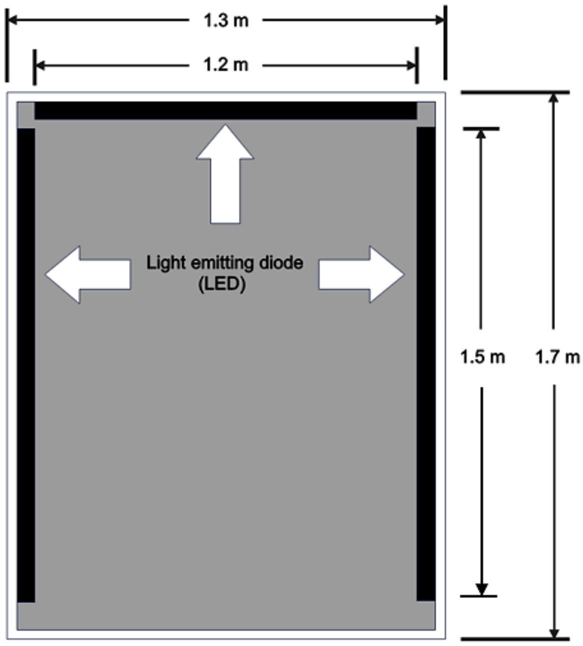

Fig. 3. LED setup in the indoor farming area [33]

2.3.2 PV system and battery

In this experiment the solar tracker system used a PV panel model SW50M-32 and a 12 V, 50Ah battery is used to store the power generated by the PV system. The battery capacity is 600Wh. The specifications of the PV panel are shown in Table 1.

Table 1
PV panel specification

Solar PV module model	SW50M-32
Maximum power at standard testing condition (Wp)	50W
Maximum power voltage (Vmp)	16V
Maximum power current (Imp)	3.13
Open circuit voltage (Voc)	19.2
Short circuit current (Isc)	3.33
Dimension (mm)	670 x 480 x 25

2.4 Experimental Setup

The solar tracker system overall experimental setup is as illustrated in Figure 4. The solar PV tracker systems and MPPT charge controller were stationed at the G3 building, Universiti Teknologi Malaysia (UTM) in Kuala Lumpur, Malaysia with coordinates of Latitude: 3.1667° N, Longitude: 101.7167° E. Other equipment, such as an LED light and a battery, were moved indoors to avoid weather-related issues. The experiment ran from 9:00 am to 4:00 pm The tracker system was placed outside of the G3 building in a sun-exposed area to completely maximize the solar energy harvested, as illustrated in Figure 5. Figure 6 shows the LED load and battery stationed indoors.

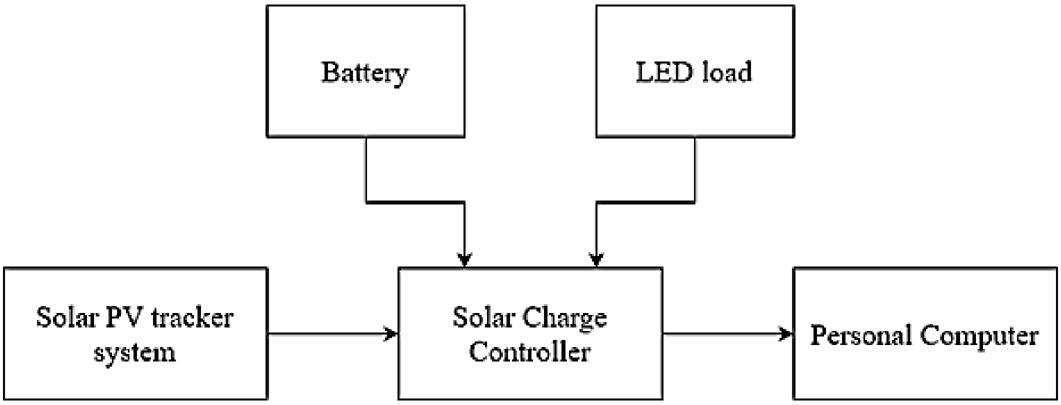

Fig. 4. Overall experimental arrangement of the solar tracker PV system

Fig. 5. Solar tracker position outside G3 building UTM

Fig. 6. LED load and battery inside G3 building

2.5 Data Collection and System Efficiency

The solar tracker system voltage, current, and power were measured using the MPPT charge controller. The MPPT also was used to monitor the battery state of charge and load power output. A data logger is utilized to record the measurement data every 1 min in an Excel file. The data logger is created using Node-RED. The data logger is deployed by connecting the MPPT to a personal computer using a USB to-serial connection.

PV module efficiency depends on the solar radiation received by the solar cells. The calculation is based on the maximum output power the PV module is calculated from Eq. (4) [34].

$$P_{PV\,max} = V_m\ X\ I_m \tag{4}$$

where V_m and I_m are the voltage and current at maximum power point. The PV panel electric efficiency is calculated as follows using Eq. (5).

$$\eta_e = \frac{P_{PV\,max}}{G_s A_{PV}} \tag{5}$$

where G_s is the solar radiation (W/m^2) on the surface of the panel and A_{PV} is the PV module area. The average rise in efficiency of the PV system can be determined using the following Eq. (6) [35].

$$\eta_{avg} = \frac{\Sigma(P_2 - P_1)}{\Sigma P_1} \times 100\% \tag{6}$$

where η_{avg} is photovoltaic panel efficiency, P_1 is the output power of the static PV module (W) and P_2 is the output power of the dual-axis solar tracker PV module (W).

3. Results and Discussion

The PV panel power which represents the tracker system power and solar radiation data for seven hours (420 minutes) is shown in Figure 7. Starting from 0 to 120 minutes the PV panel power steadily increases as the solar radiation also increases. The PV panel power increased from 10 W to 30 W during this period. Then from 150 to 360 minutes, the PV panel power and solar radiation show peaks and valleys. This is due to the intermittent cloudy weather conditions during the experiment. It is observed that when solar radiation is peak the PV panel power also peak. Moreover, the PV power panel significantly drops from 360 to 420 minutes along with the solar radiation. The drop in power is because the weather conditions got very cloudy during this period. These results establish the relationship between PV panel power and solar radiation. In addition, the tracker system seems to generate sufficient power with respect to solar radiation but weather conditions play a crucial role in generating PV panel power.

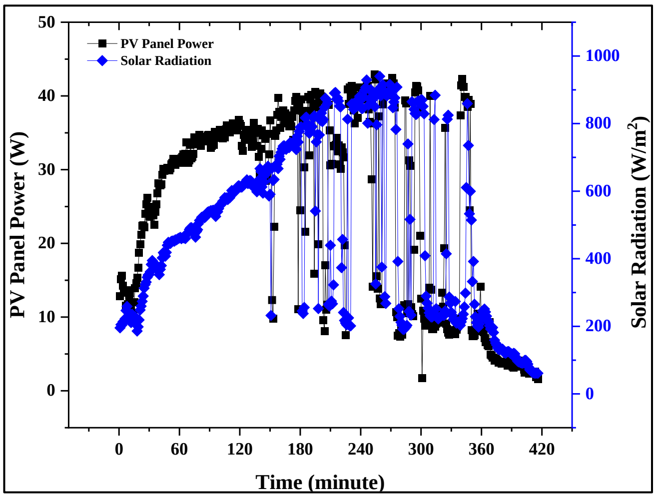

Fig. 7. PV panel power and solar radiation

Furthermore, the comparison between dual-axis and fixed-panel PV systems for 1 hour experiment period is shown in Figure 8. In Figure 8, the result indicates that the dual-axis system generated much higher solar power compared to the fixed panel system. The dual-axis system generated the highest power at 46.6 W. Meanwhile, the fixed PV system generated the highest power at 27.4 W. The average rise in efficiency of the dual-axis system is 48.49% higher as calculated using Eq. (6) compared to the fixed panel system. Moreover, the dual-axis also performs better with respect to solar radiation. The dual-axis generates high power when the solar radiation is high. The fixed PV system continues to generate low power even though the solar radiation is high. The experimental results show that the tracking system with an angle on the horizontal and vertical axis can follow the sun's trajectory more effectively than a fixed flat-plate system, leading to improved solar power generation performance.

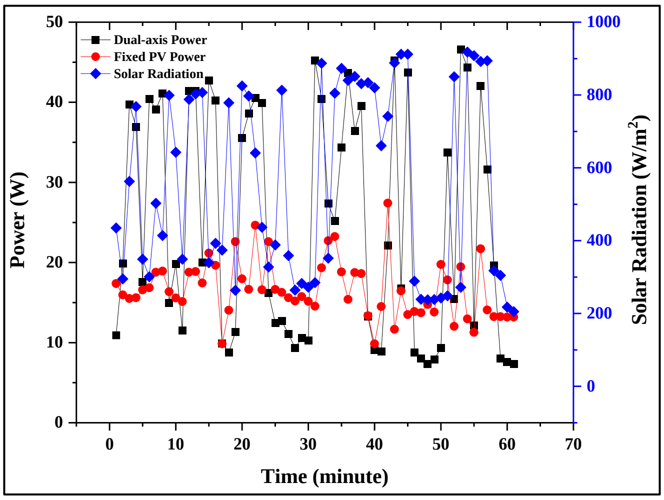

Fig. 8. Dual-axis, fixed PV power and solar radiation

For the indoor farm, an LED light with a length of 5 m was used as the load requirement. The light was switched on for the entire experiment time which is 7 hours and the LED light required about 40 W of electricity on average. The PV panel power and load power are illustrated in Figure 9. In the beginning, the PV panel power is low but steadily increases to match the LED load power. The PV panel generated a sufficient power range from 30 to 40 W range during the middle of the experiment when solar radiation was high as referred to in Figure 7 above. Moreover, the load power decreases when the PV panel power decreases. Overall observation shows that the load power is mostly higher than the PV panel power. However, the PV tracker system has generated adequate power to support the LED load as the LED continue to be switched on for 7 hours without any difficulty.

In addition, the LED was continued to turn on for 2 more hours by using the power stored in the battery during the experiment. In total, the dual-axis system managed to provide 10 hours of LED light usage. Furthermore, the PV tracker system demonstrates good performance as an alternative power supply for the indoor farm load requirement. The efficiency of the PV tracker system is 16.75% as calculated using Eq. (4) and Eq. (5). Factors such as increased PV temperature, dust accumulation, and losses from wiring and connections could interfere with the performance of the PV panel.

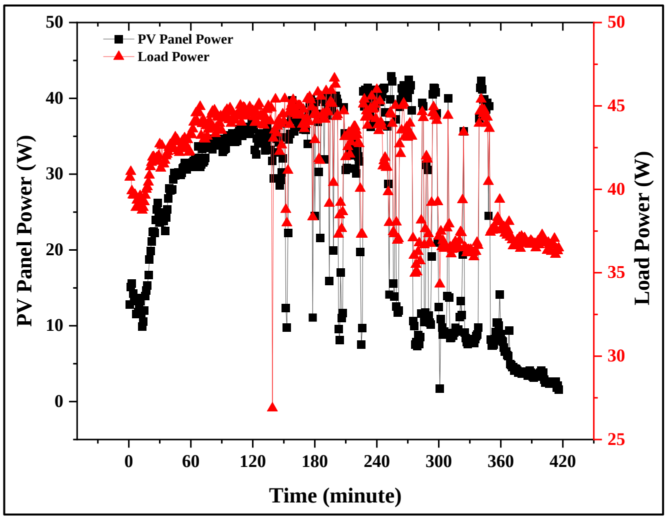

Fig. 9. Load power and PV panel power

4. Conclusions

In conclusion, this paper focused on the solar tracker system and its possible uses in indoor farming. The use of renewable energy for agricultural activities was prioritized to achieve agricultural sustainability, particularly with progressively improved agricultural practices, such as indoor farming. Solar energy, particularly solar photovoltaic, is perfect for Malaysia's hot, humid climate. A dual-axis tracker system was created to address the unreliability of solar PV systems. The tracker system was tested to ensure that it provided enough power to the LEDs used in indoor farming. Furthermore, the system was tested under actual Malaysian weather conditions. The tracker system's performance was evaluated based on solar radiation, load power, and overall power output.

The power outputs of the PV tracker system were varied, ranging from 10 to 40 W. Solar radiation is the factor that caused the variation while running the experiment. The tracker system developed was successful in providing adequate power output to the LED load for 7 hours. This suggests that the Malaysian-designed tracker technology can be used to create a completely self-sufficient indoor farm that runs solely on renewable energy. However, a bigger and better battery is needed to provide power to the LED for a longer period than 7 hours. Regardless, this study suggests that a tracker system can perform better on sunny days than on cloudy days.

Acknowledgement
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