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FEASIBILITY ASSESSMENT OF A SUSTAINABLE BUILDING APPLIED PHOTOVOLTAIC (BAPV) SYSTEM WITH SOLAR TRACKING FEATURES BASED ON TECHNO-ECONOMIC CRITERIA: MALAYSIA CASE STUDY

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ABSTRACT
In line with the increase attention regarding building applied photovoltaic system, the research in enhancing its performance is also critical to be explored, one of them is the utilization of solar tracking system. The goal of this paper is to analyze the feasibility of using a tracking system for increasing the PV output power and analyzing the energy sustainability aspects on a building applied photovoltaic system. A feasibility study considering three scenarios of PV capacities and propose two options in either renewing or reusing the PV panels to extend its life time. Based on the results, the tracking system contributes to the improvement of 18% in the energy generation. On the technical aspects, renewing the PV panels with a large capacity of up to 30 kW-peak is the most feasible option to meet the electricity demand on the building. In the meantime, the reuse option with large capacity is the best with the net present value is about USD 24,639.22 or 34% more than the option of renewal the PV panels. In summary, reusing the panel is beneficial from the economic and environment standpoints as it represents sustainable development of power generation. Since the realistic feasibility cases and analyses used, the novelty in terms of the approach is beneficial for the future investigations on adding a tracking system, keeping or replacing the PV system for sustainable aspect while improving its output power.
Keywords : *Single-Axis Solar Tracking System, Fixed Solar System, BAPV, Techno-Economic Analyses*

1. Introduction

Solar energy is categorized as a non-depletable source as it can be harvested directly from the Sun and is widely available over the world. This fact is also in line with the massively technology development of solar energy harvesting especially photovoltaics, to improve the efficiency in harvesting energy and keeping the lower price of energy density compared to other energy conversion technologies. Even though the solar energy harvester is one of the oldest technologies, it is still in hype until now and becomes essential for the future energy prospects in the world.

Building-integrated photovoltaics (BIPV) can be associated with the installation of photovoltaic cells to the parts of building materials, including its façade, roof, windows with the intention of solar energy harvesting that can be used to achieve zero-net building (ZEB) (Gholami et al., 2019). Meanwhile, Building applied photovoltaic system (BAPV) is defined as the application of PV to be attached into a building without affecting the building structure or material (Elnosh et al., 2018). Rooftop PV installations are the most common BIPV/BAPV applications for harvesting solar energy and supplying electricity to the buildings. BIPV is applied when the rooftop material or the façade is replaced directly with solar films, while BAPV is applied when the separated solar panel is attached on the rooftop. In Malaysia, either BAPV panels are usually installed in a fixed-mount configuration tilted between 00 to 15º towards the South related to optimizing the energy yield (Rivai et al., 2020).

Although various PV technologies have been widely used for building applications, their efficiencies are still a major drawback. NREL's recently developed a solar cell technology that can achieve an efficiency of about 47%, but it is still in the research and development stage (Geisz et al., 2020). The highest efficiency of the commercial PV panel is about 22.8% for monocrystalline and 16% for polycrystalline without any modifications to control the panel's temperature (*Solar Panel Efficiency - Pick the Most Efficient Solar Panels*, 2024). Therefore, this issue is crucial for its applications in BIPV/BAPV systems.

A solar tracking system is essential to improve the efficiency of solar harvesting by inclining the panel to the optimum tilt angle heading to the sun. Various technologies in solar tracking have improved the efficiency of PV harvesting from 10% to 30% for single-axis and 40% to 60% for double-axis compared to fixed mounted PV panels (Amelia et al., 2020). However, another review of solar tracking technologies also revealed that the improvement in solar harvesting efficiency depends on the weather conditions at the time (Mohamad et al., 2021). The study mentioned that the solar harvesting efficiency could reach up to 24.91% in cloudy conditions. Yet, on a sunny day, the tracker can improve the solar harvesting to up to 82.12% compared to fixed mounted PV panels (Lee et al., 2013; Mohamad et al., 2021).

Most of the technologies to enhance the solar tracking systems are related to its tracking technologies, experimental design (Chong et al., 2019; Mahendran et al., 2013), and its automation systems (Sarkar et al., 2021; Sharma et al., 2017; Sidek et al., 2017; Svetozarevic et al., 2016). Imran et al. (2020) proposed a customized solar tracking for single and bifacial technologies for agrivoltaics applications. Based on photosynthetically active radiation (PAR), the study developed an algorithm to change the orientation of the tracker, hence the excess PAR can be benefit for crops needs. Jamroen et al. (2021) developed a dual-axis solar tracker based on the reading of UV sensor. The ultraviolet (UV) spectrum sensor was claimed to be more effective approximately 11% more than the general light dependence resistor (LDR) sensor in defining the sunlight intensity that is absorbed by the PV panels. Reza and Mondol (2021) developed a single axis tracking PV equipped with a water-cooling system. The proposed solar tracker achieved higher fill factor of up to 18% higher than the conventional single axis without cooling system. A real-time performance analysis was conducted for a large scale BAPV system with the capacity of 425 kW (Alazazmeh et al., 2022). The economic and environmental performances were also analyzed with the annual capacity factor is determined to be 21.85%. The impact of cleaning and soil texture in the area was investigated through a real-time analysis for a BAPV system (Vaziri Rad et al., 2020). The annual average daily deposition rate of dust was measured as 0.122 gm/ m2/day with the power losses recorder of 24-39% compared to the clean PV panel. All the existing literature were focused on the technical aspects such as power factor, efficiency and fill factor of the supply.

However, since many research have pointed the technologies and their technical performance, yet only a few studies focused to the broader aspects such as economic and environmental impact, the existing studies must start to focus on the comprehensive analyses and seek for alternatives to gain sustainability of the BAPV by considering reuse, reduce and recycle aspects on the panels, controller and electricity installations.

This study aims to perform a comprehensive feasibility analysis of BAPV application for a university building in Malaysia considering the application of PV tracker technology to improve the existing PV rooftop system. This study is close to reality due to real-time data for solar harvesting and the load profile of electricity consumption used for the related building assessments. It also applies several realistic scenarios that can be investigated to search for the optimum solution based on the technical and economic criteria. Some significant points to be achieved by this study can be elaborated as; Applicable feasibility assessment of PV tracker system for BAPV using real-time data collection and long-period data interval (throughout one year) to represent real-time analyses; comprehensive investigation based on logical scenarios used for current condition in the university building based on the technical and economic criteria; propose an option and recommendation of reusable the existing PV panels with economic viability assessment considering degradation in PV generation per year; and generate optimal solutions from the proposed scenarios to be implemented in real conditions of the building and future requirements of the electricity load.

The systematic of this study is presented as follows. Section 2 presents the literature review while Section 3 presents the Methodology of this study consisting the descriptions of the

BAPV system in one of the university buildings in Malaysia. It also explains the load profile patterns, real-time monitoring, experimental setup, and assessment criteria. Results and analysis are presented in Section 4, including experiment analysis, energy analysis, and economic analysis. Finally, discussions of the findings are presented in Section 5.

2. Literature review

Malaysia can be categorized as a good place to apply solar harvesting systems. It is located on the equatorial side, which makes most of the area pouring sunlight throughout the year. The climate and weather temperature of Malaysia, which is suitable for PV installation, has triggered initiatives from the government to expand the utilization of PV panels for green electricity generators in public and residential buildings. It also started more studies on solar harvester and solar tracking systems considering Malaysia's climate conditions. Whereas the results revealed that most of the areas in Malaysia are favorable for PV installation and PV tracker developments (Abdulmula et al., 2019; Ahmad et al., 2013; Ghazali M & Abdul Rahman, 2012; Khatib et al., 2015; Lee & Rahim, 2013; Lee et al., 2013; Mahendran et al., 2013; Mohammad et al., 2020).

Even though a significant number of literature can be found for the application of PV applications in the Malaysia climate conditions, most of them are related to the PV tracker developments and technologies (Abdulmula et al., 2019; Ghazali M & Abdul Rahman, 2012), comparison between the technologies (Lee & Rahim, 2013; Lee et al., 2013; Mahendran et al., 2013) and effectivity measurement and optimal direction of sunlight (Ahmad et al., 2013; Khatib et al., 2015). On the other hand, the potential of BAPV implementation can also be found in a significant amount of literature numbers. Yatim et al. proposed techno-economic analysis for BAPV building with net metering in Malaysia (Yatim et al., 2017). The study implemented a grid-connected PV system on the rooftop with considering tariffs mechanism in 2011. The study found that the payback period can be reached after 10-15 years at the current economic conditions. Another study by Kumar et al. investigated the energy loss of large-scale BAPV applications for a University in Malaysia (Kumar et al., 2021). The study found that a quite significant rate of energy loss occurred of up to -14.8% in the conversion stage of the solar harvesting system. Sarkar et al. developed and analyzed a BAPV-based residential grid-connected system in Malaysia (Sarkar et al., 2021). Naveed et al. evaluated the performance of a 6.575 kW-peak BAPV system with three PV technologies for university building applications in Malaysia (Akhter et al., 2020).

Based on the literature presented, there are some gaps in the application of BAPV in Malaysia and generally in other countries. Most of the studies considered PV panels the major power source for the building. However, the rooftop installation is only the way BAPV application can be found in the literature. On the other hand, the significant improvement of a tracking system has not been approached for real implementation, such as the BAPV system. Most of the studies found in the literature of PV tracker technologies only used the system for comparison and measured at a certain time of solar harvesting. As the best as authors' knowledge, two related studies that have implemented solar tracker systems for BAPV use. The first study implemented (Maximum Light Detection) MLD based solar tracker for telecommunication towers in Malaysia (Abdulmula et al., 2019). Using the solar tracker method, another study implemented a smart photovoltaic blinds system for windows material in BIPV (Kang et al., 2019). The significant gap that is tried to be filled by this study is implementing a solar tracker system to be installed in the BAPV in a university building in Malaysia. However, this study focuses not only on assessing the tracking system and its improvement to the BAPV, but also on investigating the feasibility of sustainability actions from the current PV installation in the building into by adding the PV tracker on a large scale. As mentioned in the literature, the implementation of solar tracker might not be economically attractive, still for larger-scale applications such as BAPV, the PV tracker technology could be viable and profitable (Hafez et al., 2018). The literature review was conducted through a qualitative analysis starting from an analysis of the contents, classifications of the keywords and screening the abstract and the conclusion of the papers. Moreover, the analyzed paper was synthesized and classified based on its significant. Data analyses was conducted to define the gap between the collected studies and this study (Lau & Kuziemsky, 2016).

The novelty highlighted by this study is in line with the fact that no related study has been found which focuses on the realistic feasibility assessment and sustainable scenario in the building applied photovoltaic system (BAPV) applying solar tracker system as an option. Therefore, this study is beneficial for future investigations on adding a tracking system, reusing or replacing the existing PV system especially for non-commercial buildings.

3. Research Methods

The methodology of this research starts with the brief explanation about the building applied photovoltaic system which is installed in a university in Malaysia. The electrical component is explained including the installation of the solar tracker. Moreover, the load profile of the case study is presented following electricity consumption and climate conditions. The real-time monitoring system is presented with the explanation of hardware and software features with the data collection procedures. The experimental setup is elaborated with the scenario built for the measurements. Lastly, the assessment criteria are comprehensively explained from the energy and the economic aspects.

3.1 Building-Applied Photovoltaic System

UM Power Energy Dedicated Advanced Centre (UMPEDAC) is located in the Research and Development (R&D) building of Universiti Malaya, Kuala Lumpur, with a geographical coordinate of N 3º 7' 2.3", E 101º 40' 0.427". Since it has a low range of latitude (< 20º), it harnesses more sunlight intensity in a day around 12 hours. Fig. 1 depicts the R&D building and the level used by UMPEDAC where the feasibility study is conducted. The building has more sunny days where the dry season starts from March to August and continues with a wet season from September to February (Ghazali M & Abdul Rahman, 2012). The photovoltaic-based power generation system is placed at several points i.e., level 3, parking area ground level, and the rooftop of the building.

Fig. 1. Case study of BAPV at the R&D building in the Universiti Malaya

The details of the electrical component system, the load profile as the case study, and the energy monitoring system built for the building are presented in the following sub-sections. Also, the experimental setup for the feasibility study and the assessment criteria are explained.

3.2 Electrical component system

UMPEDAC occupies most of the building levels at the R&D, yet this feasibility study focuses on the BAPV application for the level 4 of the building used for laboratories and office. The fixed mounted photovoltaic system is installed at level 3 of the building with the capacity of about 12.24 kW-peak, and other photovoltaic systems are installed on a parking area at a ground level rooftop of the building at the capacity of 6.06 kW-peak and 12 kW-peak, respectively.

With a total of panels, it could generate electricity of about 82.26 kWh per day and 30.02 MWh per year. The photovoltaic panels are connected to the grid-tied inverters that support the electricity supply from the national grid to the building and reduce the monthly electrical bill. The details of the current fixed mounted solar panel that have been installed in the R&D building are presented in Table 1.

Table 1 - Current fixed mounted solar panel capacity in R&D building

Places	Maximum Power (W-peak)	Numbers	Total power (kW-peak)	Inverter installed (kW)	Installation year
Parking area	303	20	6.06	6	2018
Level 3	303	10	3.03	3	2018
	125	44	5.5	2 and 4	2012
	250	10	2.5	3	2013
	305	4	1.22	2	2018
Rooftop	250	16	4	4	2013
	250	16	4	4	2013
	100	40	4	4	2013
Total			30.31		

For the feasibility study of the tracking system along with the scenario of replacing or renewing the existing photovoltaic panels, a prototype of solar tracking system has been installed at the level 3 of the building. Two photovoltaic panel with a capacity of 305 W-peak is mounted in the tracking rack, which is moved by a linear motor. The proposed configuration to analyze the feasibility of tracking solar systems along with the options to replace or renew the existing fixed mounted PV panel is depicted in Fig. 2. The testing system has two PV panels mounted in the tracking system, and another mounted at a fixed tilt angle. Each of them is connected to a grid-tied inverter, and the power flow is monitored using a wireless power meter. The power flow data is transmitted to the monitoring system through a network operation center (NOC). The tracking system moves in a vertical direction single axis. The proposed solar tracker has an active movement that determines the position of the sun path in the sky during the day with the sensors. It is a horizontal single-axis tracker (HSAT) with one degree of freedom that acts as an axis of rotation (Burduhos et al., 2011) and the angular stroke of 90 degree with one axis which is categorized as single axis TYPE I (Moldovan et al., 2023; Visa et al., 2009). It implements two parameters i.e., sensor and time to control the solar tracker movements. The system detects light from irradiance sensors mounted on the frame, while for the time, it uses two approaches i.e., active and inactive periods to trigger the tracking system yet saving the power consumption from the parasitic load.

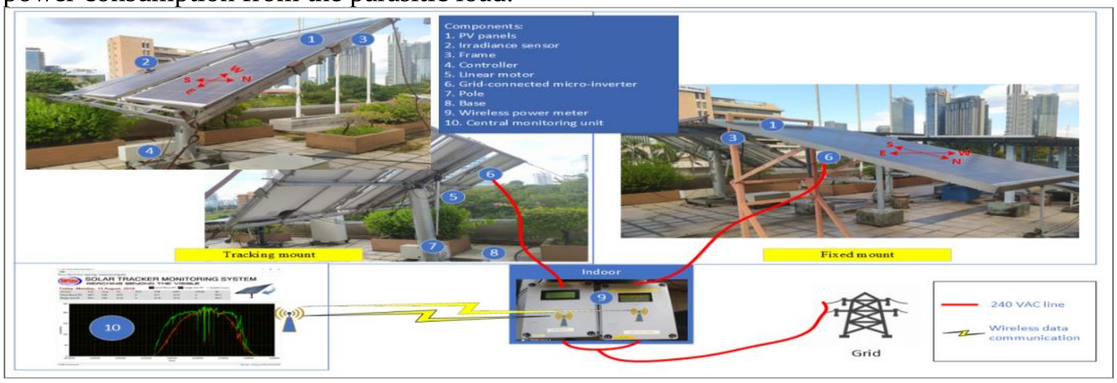


Fig. 2. Single-axis tracking system and fixed mounted PV components

The proposed solar tracker has several components such as PV panels, irradiance sensors, frame, controller, linear motor, grid-connected micro inverter, pole, base, and wireless power meter.

A single-axis control mechanism is applied to move the PV panel to tracking the highest intensity of sunlight real-time. Fig. 2 also shows a control unit of the proposed solar tracker with several involved components i.e., irradiance sensors (east and west), controller, LCD, RTC, motor driver, and linear motor. The controller reads the voltage from irradiance sensors, and converts it to the irradiance value. Moreover, it also reads the digital value of the time from the real-time clock (RTC) and displays it through liquid-crystal display (LCD). Finally, based on the readings from the sensors and the RTC, it controls the movement of the linear motor.

The control algorithm for the tracking system is depicted in Fig. 3. At the first stage, the current time was read through the RTC module and detected whether the periodic time is active or inactive. If it was in an active period (7 a.m. to 6 p.m.), then the irradiance sensors (including east and west) were read, in the inactive period (< 7 p.m. or > 6 p.m.), the solar tracker would be in the standby position (about 45º of elevation towards sunrise). During the active period, these irradiance sensors continuously measure the sun radiation. The linear motor moves based on the sensor's measurements with the error tolerance of about 20 W/m2 to avoid the linear motor running continuously and save the power consumption from the motor.

As comparison, the fix mounted solar panel is placed close to the tracking system to make sure each of the panels gets a closely similar amount of sunlight intensity. The fixed mounted solar panel is tilted in a favorable angle of about 15º facing south of the earth similar to those are installed in level 3 and the parking area.

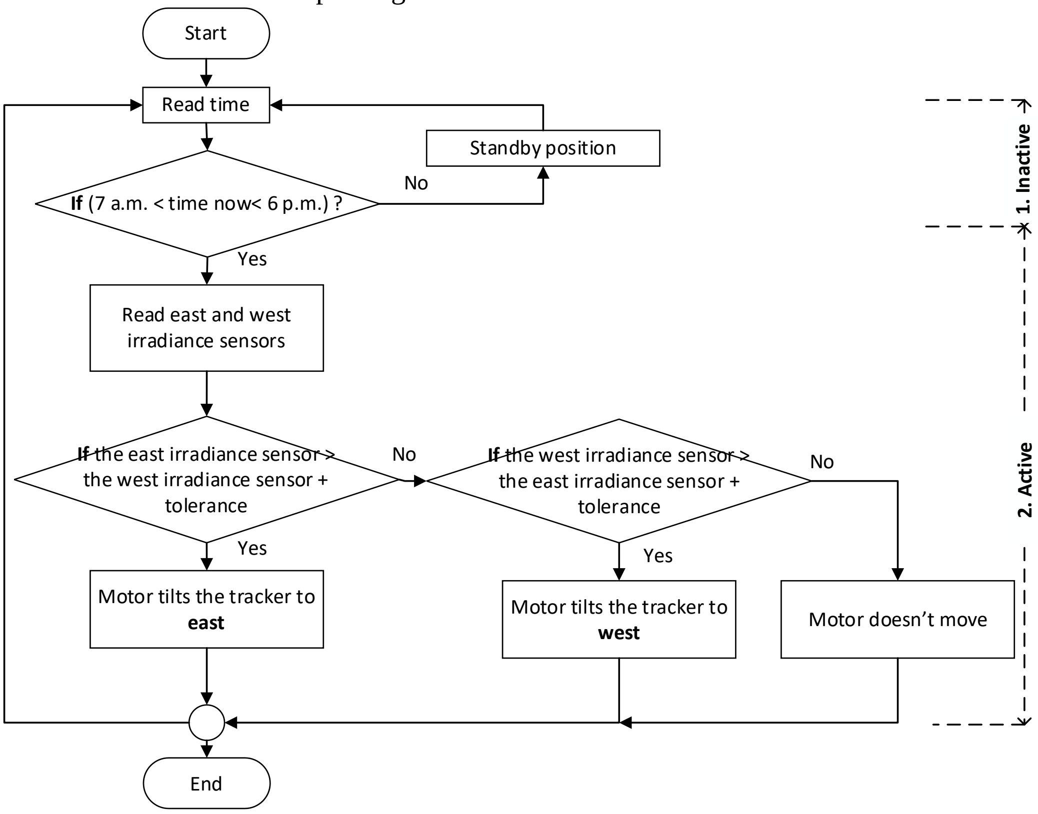


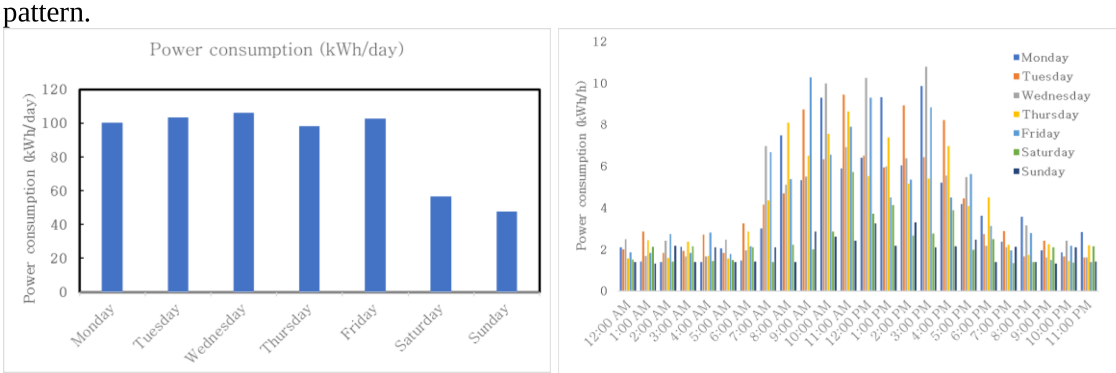
Fig. 3. Flowchart of closed-loop control of single-axis solar tracker

3.3 Load profile

The BAPV system considers the load profile from the laboratory buildings at UMPEDAC, Malaysia. The case study is one of the 22 levels (level 4) in the building powered by the PV system depicted in Fig. 1. UMPEDAC has laboratories and offices that is placed at level 4 in the R&D building including five laboratories, three office rooms and two meeting rooms. Since the activities are mostly at noon, electricity is mainly used for computers, electronic devices, air conditioning, lighting, and lab activities.

The load profile for electricity consumption at level 4 is depicted in Fig. 4. The hourly load profile (4.b) is used to improve the analyses accuracy of the BAPV system. It is based on the real-time measurement of the UMPEDAC laboratories and offices throughout a year. Using a PM5111 power meter manufactured by Scheider, the data was collected through Personal Computer (PC) connected to the PM5111 and RS485 communication. On the PC, a software was developed to retrieve data from the PM5111 and stored in a database locally. The data was stored at one-minute intervals and then converted into hourly period as shown in Figure 4.

Therefore, the feasibility study would be more accurate based on the condition of the real load pattern.



(a) (b)

Fig. 4. Load profile of electricity consumption at level 4 a) daily and b) hourly

3.4 Real-time monitoring system

The monitoring system for collecting real-time data consists of wireless communication devices and a graphical user interface (GUI) developed using Visual Basic .Net. Wireless communication is used to transfer the data from the power meter installed at the inverter to the monitoring system at the network operations center (NOC). Specifications of the wireless communication system can be found in Appendix Table A.3. Since a high-intensity data transfer is used to send the data every second to the monitoring system, the protocol has to be built as simple as possible to avoid data congestions and save the computational time.

In the GUI, shown in Fig. 5, four main features can be accessed by users, i.e., power monitoring, data log, configuration, and database. The power monitoring feature displays the current value of all parameters i.e., voltage, current, reactive power, active power, apparent power, active energy, reactive energy, and frequency. It also plots the power generation data hourly in a day. The data log feature displays overall parameters all the time, while the configuration feature is used to set the serial communication i.e., COM port, baud rate, data bit, flow control, and parity and the database storage location. Lastly, the database feature saves the collected data from the tracking system and fixed mounted system into excel every day, as shown in Fig. 6.

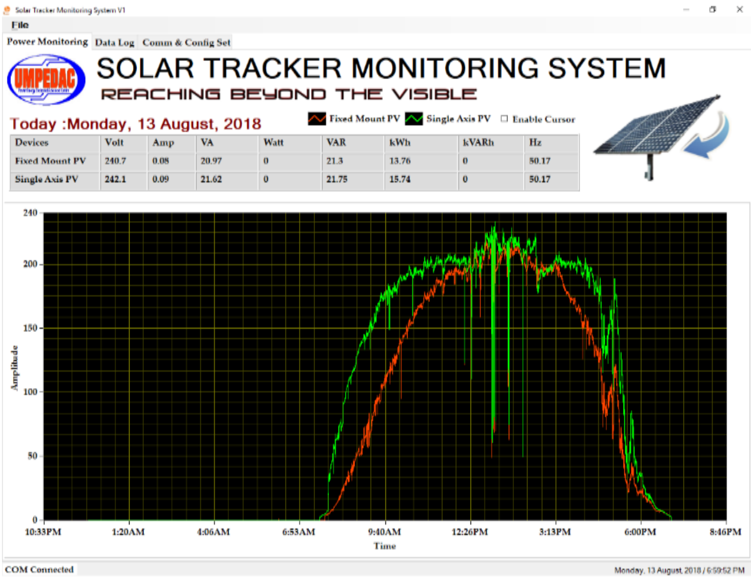


Fig. 5. Graphical user interface of the proposed system

	Time	Volt1	Amp1	VA1	Watt1	VAR1	kWh1	kVARh1	Hz1	Volt2	Amp2	VA2	Watt2	VAR2	kWh2	kVARh2	Hz2
2	3/8/2018 19:31	0	0	0	0	0	0	0	0	241.4	0.08	21.62	0	21.7	0	0	50.17
3	3/8/2018 19:31	0	0	0	0	0	0	0	0	241.4	0.08	21.62	0	21.7	3.99	0	50.17
4	3/8/2018 19:31	240.7	0.08	20.97	0	21.38	0	0	50.17	241.4	0.08	21.62	0	21.7	3.99	0	50.17
5	3/8/2018 19:31	240.7	0.08	20.97	0	21.38	3.56	0	50.17	241.4	0.08	21.62	0	21.7	3.99	0	50.17
6	3/8/2018 19:31	240.7	0.08	20.97	0	21.38	3.56	0	50.17	241.6	0.08	21.62	0	21.7	3.99	0	50.13
7	3/8/2018 19:31	240.7	0.08	20.97	0	21.38	3.56	0	50.17	241.6	0.08	21.62	0	21.7	3.99	0	50.13
8	3/8/2018 19:31	240.8	0.08	20.97	0	21.5	3.56	0	50.2	241.6	0.08	21.62	0	21.7	3.99	0	50.13
9	3/8/2018 19:32	240.8	0.08	20.97	0	21.5	3.56	0	50.2	241.6	0.08	21.62	0	21.7	3.99	0	50.13
10	3/8/2018 19:32	240.8	0.08	20.97	0	21.5	3.56	0	50.2	241.6	0.08	21.62	0	21.68	3.99	0	50.13
11	3/8/2018 19:32	240.8	0.08	20.97	0	21.5	3.56	0	50.2	241.6	0.08	21.62	0	21.68	3.99	0	50.13
12	3/8/2018 19:32	240.8	0.08	20.97	0	21.41	3.56	0	50.17	241.6	0.08	21.62	0	21.68	3.99	0	50.13
13	3/8/2018 19:32	240.8	0.08	20.97	0	21.41	3.56	0	50.17	241.6	0.08	21.62	0	21.68	3.99	0	50.13
14	3/8/2018 19:32	240.8	0.08	20.97	0	21.41	3.56	0	50.17	241.6	0.08	21.62	0	21.74	3.99	0	50.17
15	3/8/2018 19:32	240.8	0.08	20.97	0	21.41	3.56	0	50.17	241.6	0.08	21.62	0	21.74	3.99	0	50.17
16	3/8/2018 19:32	240.8	0.08	20.97	0	21.49	3.56	0	50.2	241.6	0.08	21.62	0	21.74	3.99	0	50.17
17	3/8/2018 19:32	240.8	0.08	20.97	0	21.49	3.56	0	50.2	241.6	0.08	21.62	0	21.74	3.99	0	50.17
18	3/8/2018 19:32	240.8	0.08	20.97	0	21.49	3.56	0	50.2	241.6	0.08	21.62	0	21.79	3.99	0	50.17
19	3/8/2018 19:32	240.8	0.08	20.97	0	21.49	3.56	0	50.2	241.6	0.08	21.62	0	21.79	3.99	0	50.17
20	3/8/2018 19:32	240.9	0.08	20.97	0	21.51	3.56	0	50.19	241.6	0.08	21.62	0	21.79	3.99	0	50.17
21	3/8/2018 19:32	240.9	0.08	20.97	0	21.51	3.56	0	50.19	241.6	0.08	21.62	0	21.79	3.99	0	50.17
22	3/8/2018 19:32	240.9	0.08	20.97	0	21.51	3.56	0	50.19	241.6	0.09	21.62	0	21.8	3.99	0	50.13
23	3/8/2018 19:32	240.9	0.08	20.97	0	21.51	3.56	0	50.19	241.6	0.09	21.62	0	21.8	3.99	0	50.13
24	3/8/2018 19:32	240.9	0.08	20.97	0	21.43	3.56	0	50.17	241.6	0.09	21.62	0	21.8	3.99	0	50.13
25	3/8/2018 19:32	240.9	0.08	20.97	0	21.43	3.56	0	50.17	241.6	0.09	21.62	0	21.8	3.99	0	50.13
26	3/8/2018 19:32	240.9	0.08	20.97	0	21.43	3.56	0	50.17	241.6	0.08	21.62	0	21.7	3.99	0	50.13
27	3/8/2018 19:32	240.9	0.08	20.97	0	21.43	3.56	0	50.17	241.6	0.08	21.62	0	21.7	3.99	0	50.13
28	3/8/2018 19:32	240.8	0.08	20.97	0	21.53	3.56	0	50.19	241.6	0.08	21.62	0	21.7	3.99	0	50.13

Fig. 6. Data collection for feasibility analysis from the monitoring system

3.5 Experimental setup

Malaysia has a huge potential for solar irradiation throughout the year. With this condition, average solar radiation in Malaysia can reach up to 4000-5000 Wh/m^2 daily and around 1.3 MWh/m^2 per year (Erixno & Rahim, 2020; Mohammad et al., 2020). Malaysia has also two types of seasons affected by monsoon wind; southwest monsoon, which brings dryness from May to September, and northeast monsoon, which brings rainfall from November to March. Between the two big seasons, there are two inter monsoonal periods held from March to April (first) and from October to November (second).

As depicted in Fig. 7, sunshine starts earlier at about 6 a.m., from January to March (Quarter 1), and reaches the maximum intensity of about 11 a.m. – 12 p.m. with a total active hour of almost 12 hours. The solar irradiance conditions from April to September are slightly similar, with the maximum intensity held at 12 – 1 p.m. and a total active hour of 8 hours. However, for the last quarter of the year, the solar intensity is lower than other quarters where the sunshine starts at 8 a.m. and ends earlier at 4 p.m.; with a total active hour of about 6 hours.

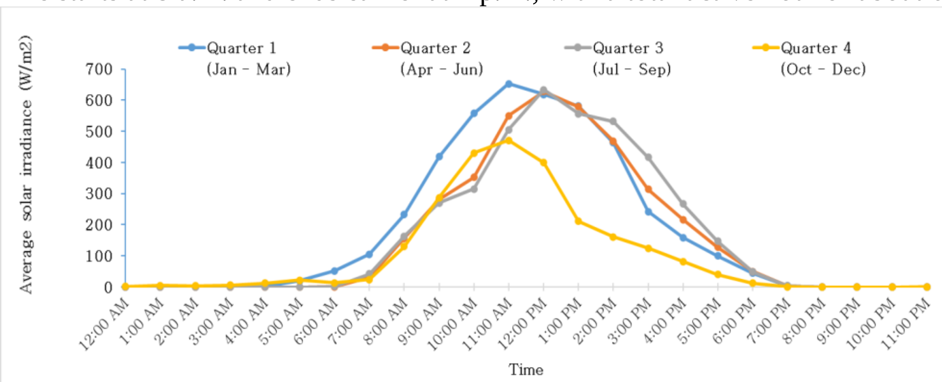


Fig. 7. Average solar irradiance hourly in quarter of a year

The solar radiation condition in Malaysia is in line with the temperature and seasonal climate throughout the year. At the first quarter season, the maximum temperature reaches 33°C and the minimum temperature approximately 27°C. The lower temperature range is held in the last quarter of the yearly season, where the maximum temperature reaches around 30°C and the minimum temperature of around 25°C. The maximum and minimum difference for quarter one and quarter four is up to 3°C. The average temperature hourly in the quarter of a year is depicted in Fig. 8.

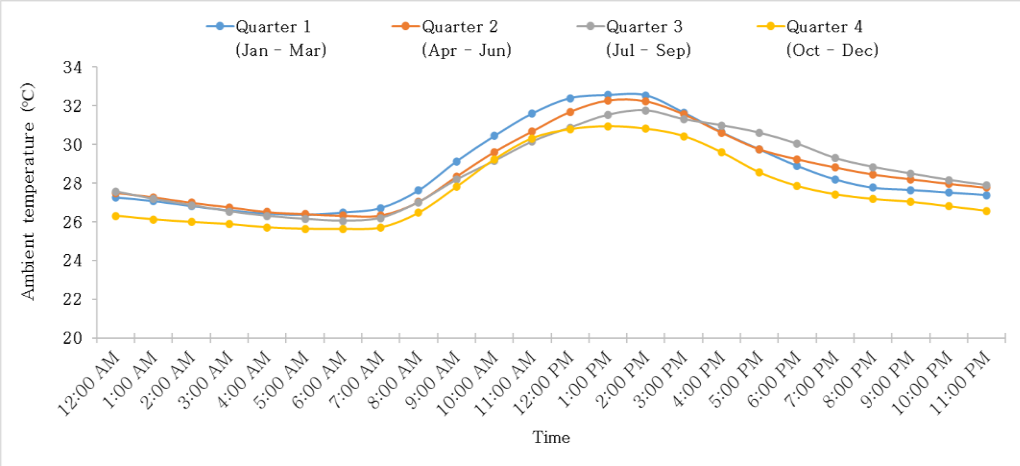


Fig. 8. Average temperature hourly in a quarter of a year

Some assumptions are taken for this feasibility study related to the tracking system, PV capacity, and the load profile. First, to enlarge the capacity of the tracking system, it is assumed that one tracking system could be installed for three PV panels based on Figure. 2. Therefore, the calculation of parasitic load from the tracking system is based on one kWp of the power generation from the PV system. Moreover, for the "reuse" scenario, it is assumed that the degradation of PV power generation is 0.5% per year for the assessment to be more reliable.

3.6 Assessment criteria

There are three alternatives of panel size considered in this study as presented in Table 2: small, medium, and large capacities. The optimum capacity is assessed based on the energy and economic criteria to satisfy the load and take profit from the excess of the PV generation if possible. Moreover, two scenarios based on technical and economic assessments are also presented: renew the panels or reuse the existing panels. Renew scenario means the PV panels and the inverter used are in a new condition along with the installation of the tracking system. As for the reuse option, the existing PV panels installed in three areas were used along with the existing inverter. Both renew and reuse options will be tested using the tracking system to distinguish between an option of renew only or reuse with tracking system. All the panels would be installed in the place similar to the renewal scenario.

Although the reuse option seems to have a higher complication in the technical aspect than the renew option, it could reduce the investment cost and increase the sustainability of the power supply generation. Moreover, it also could make the system more valuable and sustainable with a shorter payback period. However, since the PV panels have been years used, the performance might not be as good as the renew option. Therefore, this study considers the degradation issue in existing PV panels of 0.5% per year since the installation made (Erixno & Rahim, 2020). The economic analysis also assumes that the existing PV panels will be replaced 25 years after the installation year and that the specification of the new panels would follow the renew scenario.

Table 2 - Scenarios applied for feasibility analysis

Scenarios	Small capacity (12 kWp)	Medium capacity (21 kWp)	Large capacity (30 kWp)
Renew existing panel	case 1	case 2	case 3
Reuse panels	case 4	case 5	case 6

a. Energy

The technical performance of solar tracking systems can be analyzed from several criteria. This study applies significant criteria that directly affect the PV system's solar harvesting and supply performance. Hourly solar harvesting is the major criteria used to analyze and to sizing the PV system based on its feasibility in serving the loads. Since there are two options for installing the PV system, the hourly solar harvesting is calculated based on the real-time monitoring of the device throughout the year. This analysis will improve the accuracy of the sizing and feasibility rate of the proposed design, either using existing PV panels or replacing them with new panels. Moreover, based on the data collected, the annual analysis includes export-import energy flow with the grid since the configuration used is grid-connected.

Another parameter that can be used for analyzing the energy performance is parasitic load. Parasitic load is associated with the tracking system's power consumption, including motor and controller. The issue of the parasitic load is one of the concerns when developing solar tracking systems as it is related to the motion of the tracking. Therefore, this study also provides an analysis of the percentage of parasitic load annually compared to the power generated by the tracker. Based on the literature, the range of parasitic load for dual-axis solar tracker varies from 0.15- 0.35% of the power generation of the PV system (Tan et al., 2019).

b. Economic

Economic analysis is also significant in assessing the tracking system's related to the enhancement of the existing PV system installed in the building. Several economic criteria are applied for the analysis, including energy cost, profit gain, net present value (NPV), and payback period of the system. Energy unit per cost $(kWh/year)$ relates to the comparison between the cost of the system (C_s) and the power generation of the system (W) that can be calculated from Equations (1-4) (Ramadhani et al., 2019; Ramadhani et al., 2021). The sum of energy units generated and the cost related to the power generation is calculated annually below

$$C_s = C_{iv} + C_m \tag{1}$$

Where,

$$C_{iv} = C_{init} * CRF \tag{2}$$

$$\text{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3}$$

$$i = \frac{i_0 - f}{1 - f} \tag{4}$$

C_{iv} refers to the investment cost as a multiple of the initial cost purchased for the system (C_{init}) and the capital recovery factor (CRF) during the lifespan. The cost of recovery factor is calculated based on the lifetime of each PV system components and the tracker for n numbers of the components lifetimes. The real interest rate i is calculated based on the nominal interest rate (i_0) and the inflation rate (*f*). C_m describes the maintenance cost of the system; hence the energy unit per cost can be calculated as (Ramadhani et al., 2017)

$$\text{COE} = \frac{C_s}{\text{W}} \tag{5}$$

Moreover, NPV refers to the current value of all components calculated at the present. The calculation includes the total initial and installation costs (C_{init}), maintenance cost (C_m), replacement cost (C_{rep}), operational cost (C_{op}) and salvage value (C_{sv}) (Moradi et al., 2013). Therefore, the NPV can be calculated as

$$\text{NPV} = \sum_{y=1}^{M} \left\{ \frac{\lambda^y}{1+f} \left[C_{cons}(y) - C_m - C_{rep} - C_{op} \right] \right\} + C_s - C_{init} \tag{6}$$

$$Where: \lambda = \frac{1}{1 + \frac{i-f}{1+f}}$$

From the NPV and net gain in power generation, the payback period (PP) of the BAPV system (NPC_{BAPV}) can be calculated considering the cash flow of the electricity consumption annually (CF). The cash flow is calculated based on the annual power generation (W_{annual}) and the cost of electricity when the system imported the power from the national grid (C_{import}) as

$$\text{PP} = \frac{NPV_{BAPV}}{\text{CF}} \tag{7}$$

$$CF = \sum W_{annual} C_{import} \tag{8}$$

All the costs calculated are based on the experimental components tested in this study. To upscaling the size, some modifications in the cost per energy generation are needed. Table 3 presents the economic details of the system components.

Table 3 - Detailed cost of the tracking system

Components	C_in (USD)	Capacity (kW)	C_in/cap (USD/kW)	C_m (%)	C_rep (USD/kW)	Lifetime (Years)
PV Panel	77.62	0.3	258.74	1.5	125.41	25
Linear motor	204	0.06	3,400	-	3,400	5
Controller	62.4	1	62.4	-	62.4	10
Inverter	371.68	3	124.23	-	124.23	10
Bracket	600	6 m2	100/m2	0.05	-	-

The national grid price applied in Malaysia considers fluctuations based on monthly power consumption, as presented in Table 4. The tariffs for buying and selling electricity has been regulated by the government through Sustainable Energy Development Authority (SEDA) Malaysia (SEDA, 2023). Based on the regulation, Malaysia Government has adopted NEM (Nett energy metering) where the energy produce by the PV system will be delivered to the consumer first, then the excess of electricity generated after the consumption can be delivered to the grid. Moreover, the flat tariffs adopted by TNB is named FiT (Fit-in-Tariffs) where the tariff rate is fixed for the imported and exported of electricity.

Since the building applies commercial tariffs appointed by Tenaga Nasional Berhad (TNB) Malaysia, it includes normal consumption rates and maximum demand (MD) penalty. The penalty charge is applied for such commercial buildings (C1) when the power consumption reaches the maximum demand during the peak load period. The minimum monthly charge for this type of building is around RM600 or $144 per month.

Table 4 - Commercial tariffs (import/export) from Tenaga Nasional Berhad (TNB) per 1 January 2014* (accessed on 14 March 2022)

Tariffs C1 – Medium voltage general commercial tariffs	
For each kilowatt of maximum demand per month	$7.27/kW
For all kWh	$0.088/kWh

* All the prices applied is converted from MYR with a rate of 0.24 USD

4. Results and Discussions

4.1. Experimental analysis

The photovoltaics with a solar tracking system has been built since 2017 and has run simultaneously. The prototype system included one PV panel with a capacity of 305 Wp with one-panel frame and the linear motor as the driver. The capacity of one frame is for three PV panels, hence the capacity of one PV system with tracking is around one kWp. The control system for tracking the sun radiation has been proven its performance with high response and effective movement. The tracking system operation can be seen in Fig. 9. The control programming avoids overreacting of the tracking system to move. It uses two conditions that the tracker can execute the movement, the time, and the closed-loop sensor for detecting solar radiation. The detailed parasitic load due to motor consumption is analyzed in the next section.

Fig. 9. Single-axis solar tracker facing (a) the sunset (b) the sunrise (c) straight up

The prototype system-generated electricity of about 7.8 kWh per day, while compared to the fixed PV system, the PV with tracking has improved the electricity generation of approximately 11.19% and 11.41% at quarter 1 and 4 where are mostly at a wet season, respectively, while for quarter 2 and 3 at dry season, the improvements on the electricity generation are about 14.95% and 25.32%. The effect of the tracking system is significant during the dry season when it is held from April to September. By totally using the tracking system, the monthly power generation has been increased about 18% on average compared to the fixed system. The generation of electricity in the seasonal period can be seen in Fig. 12, and the total energy generation per quarter is presented in Table 5.

Table 5 - Average of quarterly electricity generation for fixed mounted and tracker mounted PV panel.

Quarter	Average of Fixed mounted-1 kWp of PV (Wh/d)	Average of Tracker-1 kWp of PV (Wh/d)
Qtr1 (Jan - Mar)	3,065.94	3,408.38
Qtr2 (Apr – Jun)	2,988.22	3,435.06
Qtr3 (Jul – Sep)	2,444.05	3,063.79
Qtr4 (Oct – Dec)	2,217.75	2,470.42

The monitoring system performs an excellent condition to capture the data from the tracking system as it has been run since 2017 without any critical problems. To analyze the real-time performance of the tracking system, the power generation data was taken every second with a short interval time. The data was transmitted from the tracking system to the NOC for every second with the packet loss of about 6.9%.

The experimental test was performed to calculate the parasitic load from the motor and the tracking controller. Parasitic load relates to the effectiveness of the controller to track the sunlight, the lower the value, the better the controller performance. Since the movement algorithm was proposed based on two conditions with threshold, the motor rotation could be reduced. Based on data presented in Table 6, generally, the motor and the controller consumed about 2-3% from the daily generation. The parasitic load depends on the sunlight intensity, while at the brighter sunlight, the parasitic load could be covered by the total generation from the PV panels around 2%. Meanwhile, the tracker works few times at the cloudy as the threshold was not achieved, yet the total PV generation is quite low and the parasitic percentage rises about 1%.

Table 6 - Parasitic load measurement for tracked mounted PV panel.

Various the Sun intensities	Solar irradiation (kWh/m^2/d)	PV generation (kWh/d)	Parasitic load (% of PV gen.)
High	3.97	3.68	2.2%
Medium	2.78	3.08	1.9%
Low	1.81	1.52	3.3%

4.2 Energy Analysis

Based on the prototype system measurements, this study analyses six possible improvement scenarios described in Table 4 along with the scenario of improving the PV system with a solar tracking or keep using the fixed mounted configuration. Therefore, all the analyses will generate 12 results representing each case in this study. Fig. 10 depicts the yearly energy generation of the PV system without and with a tracker for renewing and reuse scenarios at different capacities. It can be seen that the highest energy generation is achieved by case 3 with the renewing scenario in large capacity. The total energy generation of about 33. 855 MWh per year. The reuse scenario with similar capacity achieved a lower energy generation of about 3% than the renew scenario. It is due to the consideration of PV degradation adopted by this study; hence the average replenishment of the electricity generation is 0.3-0.5% per year. For medium and small capacities, the performance reduction of the reuse option occurred approximately 3.3% and 2.8% compared to renew panels. The tracker mounted PV improves the yearly energy generation by about 15% compared to fixed mounted PV for each case.

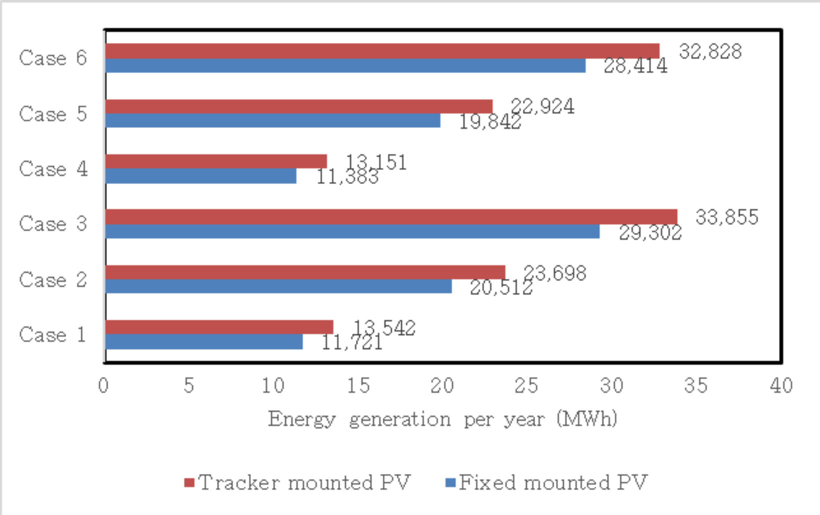


Fig. 10. Yearly energy generation for each scenario

Moreover, yearly imported electricity from the grid is also essential to analyze the performance of each scenario, as depicted in Fig. 11. The highest electricity rate imported from the grid occurred in case 4 "reuse-small" scenario. Both renewing and reuse scenarios have exported electricity to the grid for the large capacity option. The reduction of imported electricity between fixed mounted and tracker mounted PV is around 10.4% for case 1, while the reduction occurred of about 43.2% and 163.5% for cases 2 and 3, respectively. For the reuse scenarios, the reductions of imported electricity were achieved of about 9.9%, 37.8%, and 251.2% for cases 4, 5, and 6, respectively. From the results, it can be analyzed that the renew scenario has a higher reduction of imported electricity from the grid for small and medium capacities. As for the large capacity, the renew scenario has a higher percentage of electricity exported compared to the reuse scenario especially for the tracker mounted PV. It can be concluded if the capacity is enlarged than 30 kWp, the building can start to export to the grid more than approximately 11% from its self-consumption.

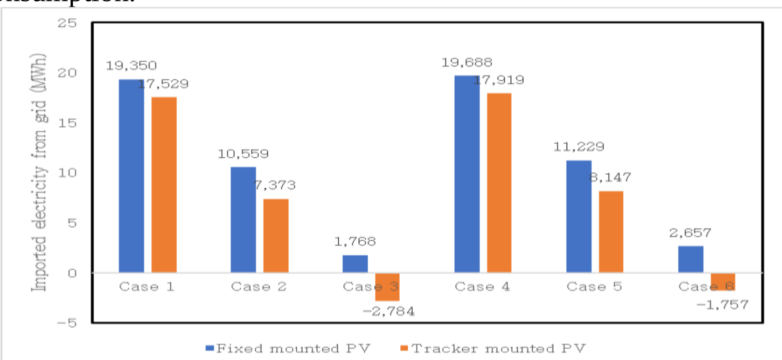


Fig. 11. Yearly imported electricity from the grid for each scenario

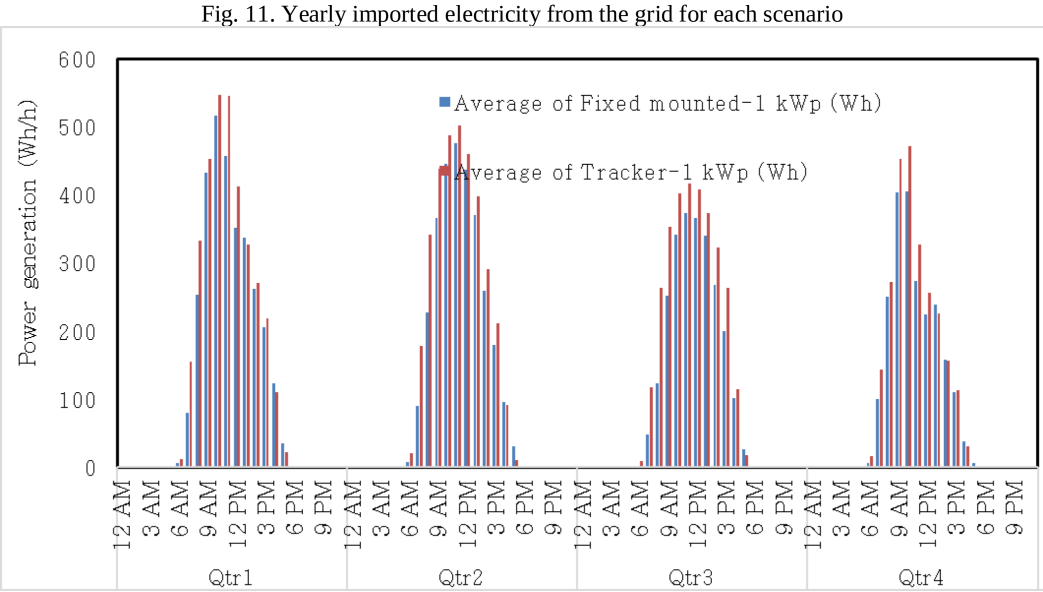


Fig. 12. Electricity generation from fixed mounted and tracked mounted PV panels quarterly over

4.3. Economic analysis

The economic calculation for each scenario was taken from the energy generated by the PV system and the cost purchased for the initial investment, maintenance, operation, and the imported electricity from the grid. The cash flow between the cost earned by using the tracking PV system compared to the electricity consumption from the grid. The cost purchased for all the expenses from the investment and operation is calculated into net present value (NPV). The higher the NPV the better the system in terms of investment. The high amount of NPV indicates that the system will be profitable in the future with higher cash flow earned compared to the money that was invested to the system.

Based on the results, case 1 depicted in Fig. 13 generates the lowest NPV approximately USD 6,683.58 compared to other cases. From the figure, it can be seen the earned cost from the PV generation is about USD 3,126.60 per year on average. Meanwhile, the average operational cost is USD 2,042.59 per year due to the capacity of the PV system that is lower than the power consumed by the building. Therefore, the PV capacity only could cover less than a half capacity of power consumption for this scenario.

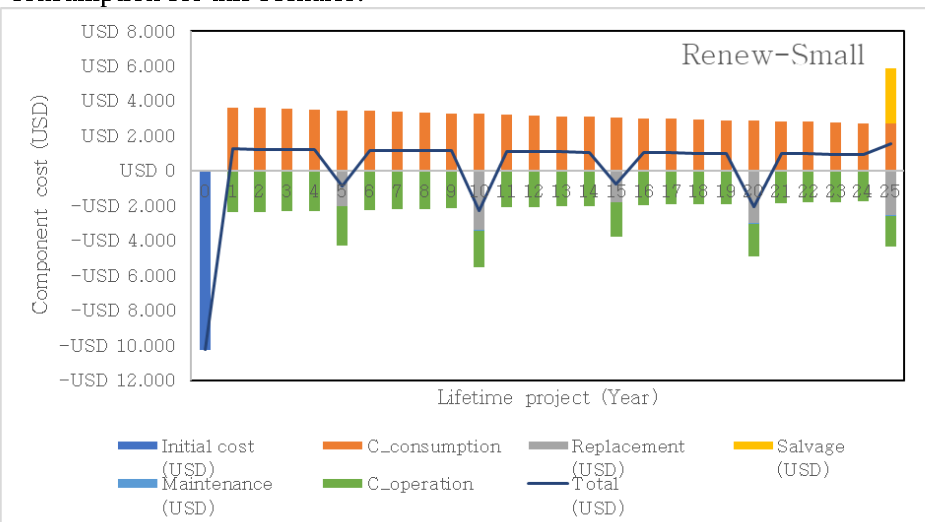


Fig. 13. Cash flow for case 1 "Renew option with small capacity"

The cash flow results for scenario two can be seen in Fig. 14, where the average cost of operation is about USD 1,262.86 or reduced by about 38% compared to the operational cost of case one due to the increase in the electricity coverage from the PV system. For case three which is depicted in Fig. 15, the cash flow is more promising than the previous two cases. The operational cost can be reduced significantly as the capacity of the PV system is almost similar to the electricity consumption of the building. The operational cost from the case is about USD 487.61 per year on average, while the limiting cost from the previous case is about 61% or more than a half of the operational cost for case two. It can be analyzed that the higher the capacity of the tracked PV system, the lower the operational cost. With a capacity of about 30 kWp, the PV system is capable to reducing the grid consumption of the building for the particular rooms level and generating surplus energy exported to the grid.

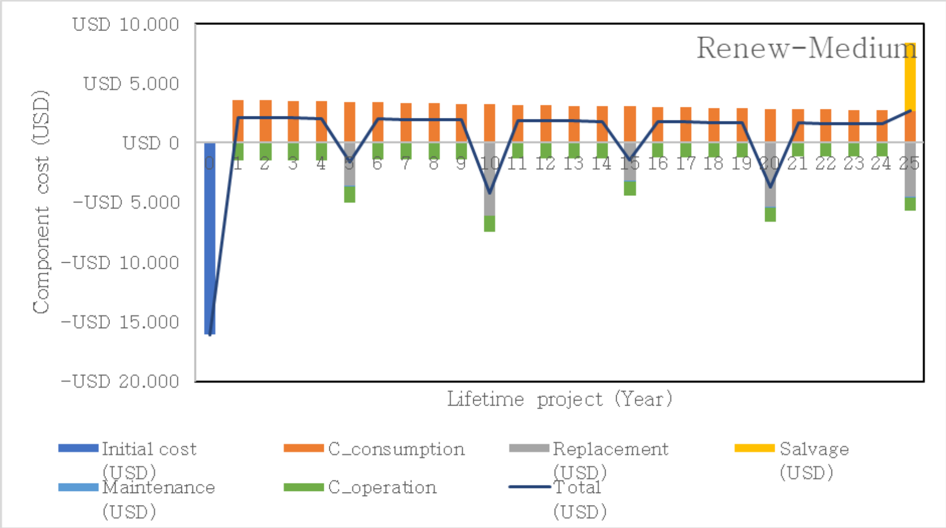


Fig. 14. Cash flow for case 2 "Renew option with medium capacity"

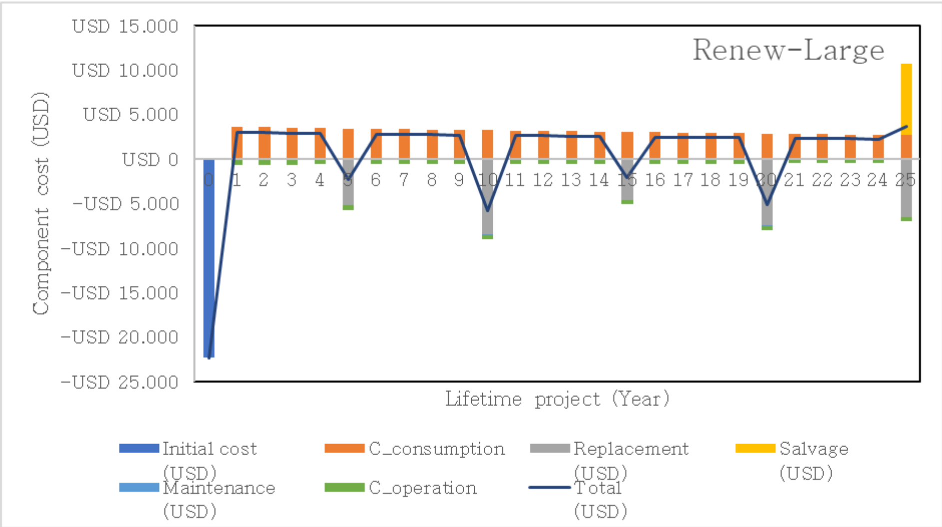


Fig. 15. Cash flow for case 3 "Renew option with large capacity."

As for the reuse scenarios, the calculation of NPV considered the time of replacement which is more frequent than the renew scenarios. As the reuse scenarios consider different lifetimes for each solar panel, as shown in Table 1. The replacement costs for each of components, especially for solar panels follow the current lifetime and is replaced after reaching 25 years of the current lifetime. The cash flow for the reuse scenario with small capacity is depicted in 16. Interesting results can be analyzed and compared for the operational cost and the NPV for case four and case one. The average operational cost for case four is USD 2,073.04 per year, slightly higher than case one. However, the total NPV for case four is approximately USD 9,250.40, which also is higher than case one. These results show a contradictory analysis for either using renew or reuse scenario, where case one has lower operational cost as it uses a new type of PV from the beginning of the scenario; hence the PV generation is optimum. On the other hand, case four when using old PVs, it must consider power degradation by about 0.5% per year calculated from the first year until the current utilization time. This makes the PV generation is not as high as the renew scenario. However, case four still has a higher NPV which means this option is more profitable than case one because the investment cost is not significantly expensive compared to the performance degradation in case four. Therefore, the overall cost of case four is still higher than case one.

Fig. 16. Cash flow for case 4 "Reuse option with small capacity"

From Fig. 17 and Fig. 18, it can be seen that the total costs for cases five and six are more flexible than case two and case three as the replacement costs are almost distributed every year of operation. The average operational cost for case five is approximately USD 1,321.98, while case six is about USD 565.65 per year. Both scenarios have higher operational costs compared to case two and case three. However, case five and case six still have higher NPV of about USD 15,525.82 and USD 24,639.22, respectively. The increase in the NPV is about 24% and 34% for each case, respectively. Therefore, it can be analyzed that the reuse scenario could be more profitable than the renew scenario even though it has higher operational costs due to the depletion in the energy generation as the lifetime reduced. The total NPV for each case is depicted in Fig. 19.

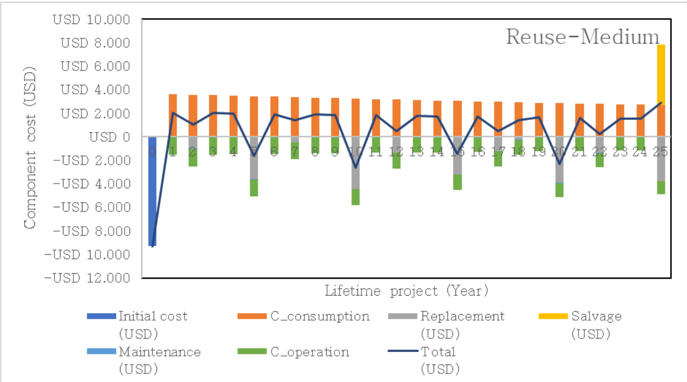


Fig. 17. Cash flow for case 5 "Reuse option with medium capacity."

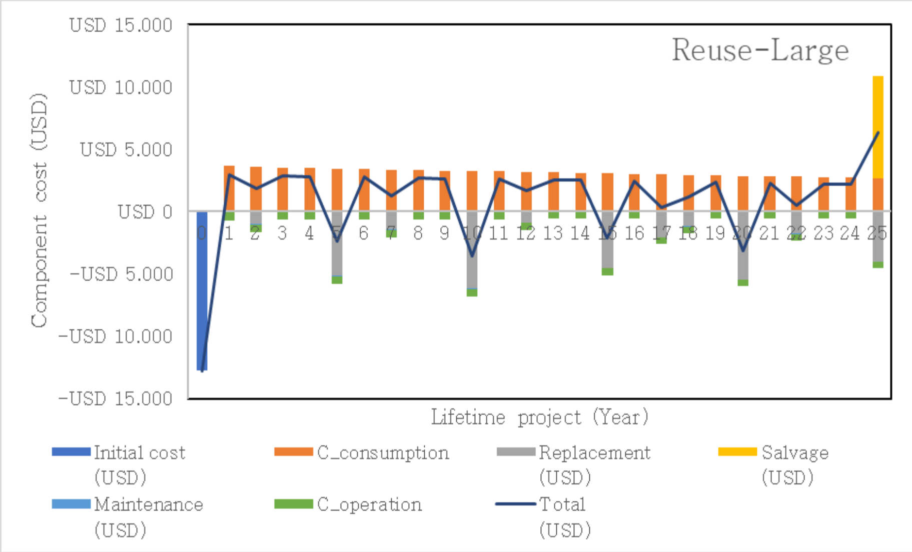


Fig. 18. Cash flow for case 6 "Reuse option with large capacity."

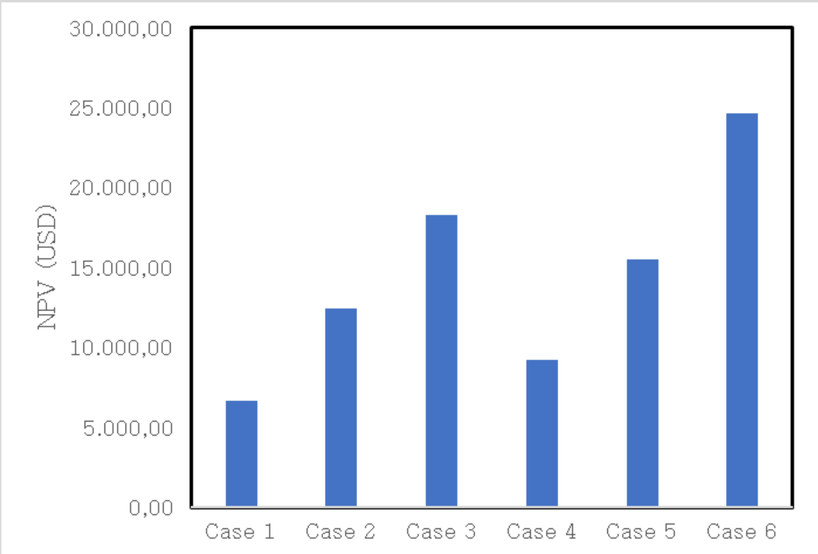


Fig. 19. Total NPV for each case

Besides the NPV, the economic analysis also includes calculating the energy cost for each scenario. The calculation is simpler than the NPV, where it summarizes the total initial and maintenance costs for each case divided by the total energy generation per year. The interesting results generated from each scenario which is depicted in Fig. 20. It can be seen that the energy cost value for the renewing scenario is lower than the energy cost for reuse scenarios at the same capacity. The lowest energy cost is generated from case three, while the highest is from case four. The reductions of energy costs for case three compared to cases two and one are about 5% and 12%, respectively. Meanwhile, energy cost reductions for case six compared to case five and case four are about 4% and 5%, respectively. The highest energy cost reduction occurred by comparing case two and case four, where both have the same capacity with different used scenarios. The energy cost from the comparison between case two and case four is about 28%, while case 3 and case 6 is about 27%. At the end, the reuse scenarios can achieve shorter payback period compared to renew scenarios. The reuse scenarios have the average payback period of 8 years, which is faster 30% faster than the renew scenarios which have longer payback period of about 12-13 years.

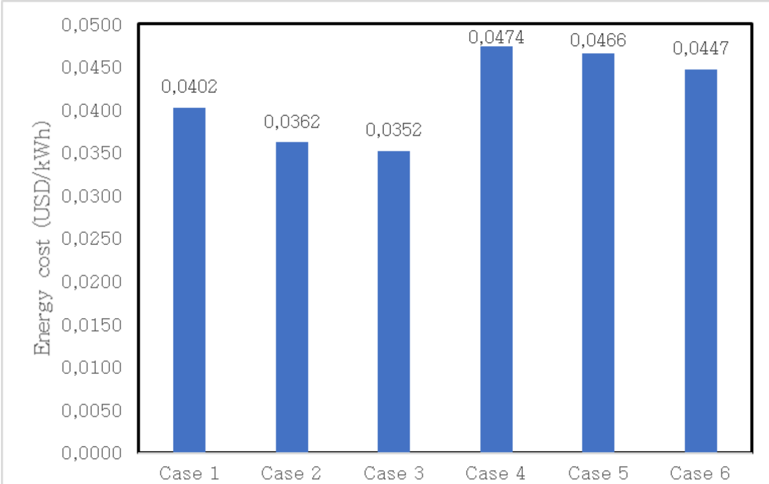


Fig. 20. The energy cost for each case

It is fascinating to analyze that the NPV value is contradicted with the energy cost value for the case of renew and reuse. From the economic perspective, the difference happens due to the capital recovery factor (CRF) for the reuse scenario, which is more than half of the CRF of the renewing scenario. CRF is the ratio of the constant annuity to the present value of receiving the annuity for a given length of time. As the reuse scenario has limitations in terms of lifetime, it increases the system's investment cost and lowers its energy cost. However, the energy cost analysis only considers the costs during the first year of use without considering the overall cost as presented in the NPV. Therefore, the energy cost analysis only depends on the general cost and general power generation of the system. NPV is preferably used for more accurate analysis as it considers more parameters than the energy cost. Another analysis could be taken for the renew and reuse scenarios at different capacities, where it is analyzed that the higher the capacity, the lower the energy cost. Both renew and reuse scenarios show a similar pattern of energy cost reduction as the capacity increases.

4.4. Discussions

From the technical and economic analyses results, the scenario proposed has successfully shown the expected distinguishes to decide either renew all the PV panels or reuse the existing PV panel with the capacity decided to achieve energy coverage for the building. From the energy analysis, generally the tracker system has contributed to the improvement of energy harvesting approximately 15% compared to the fix mounted PV panel. Meanwhile, the renew scenarios give the better performance in terms of energy generation and reduce its imported electricity from the grid. The renew scenarios have improved its energy generation 2.8%-3.3% depending on the installation capacity. On the other hand, reuse scenarios have limitations in generating power as optimal as the renew cases due to power degradation from the PV panels. It can be analyzed that the large capacity option is suitable to cover the energy demand of the building in this study more than half of the power consumption. This study suggested that the installed capacity more than 30kWp can cover the building level while exporting the excess to the grid of about 11% of its self-consumption.

It is interesting to analyze the economic aspect from the proposed scenarios in this study. From the economic results, the reuse scenario gives the better NPV than the renew scenarios of about 38%, 24% and 34%, for the small, medium and large capacities, respectively as the investment cost are distributed every year. It also can be analyzed that there are conflicting results between the NPV and the energy cost for either renew or reuse scenarios since the energy cost also considers the generated power where the reuse scenarios must face the degradation of the panels faster than the renew scenarios. However, another indicator in the payback period proved that the reuse scenarios still attractive with the payback faster of about 30% than the renew scenario. It is because the capital cost can be distributed through several years and lessen the economic load from the capital aspect.

All the energy cost presented is in line with the current market survey of PV systems, where is about 3.5 cents – 5 cents per kWh as the data presented by the U.S Department of Energy (NREL). Based on Malaysia case study, the energy cost of the PV generation is still promising which is lower approximately more than 50% compared to the grid cost (8.8 cents/kWh) without considering the peak load charge at a certain time in a month.

From the perspective of technical and economic criteria, it could be said that if the consideration is towards the improvement of the energy generation, then the option to renew all the panels with new components with large capacity is the best. Meanwhile, from the perspective of economic evaluability, the option to reuse the existing panel and gradually replace it after reaching the maximum lifetime is the best choice. In contrast, it is not only valuable from the economic but also for the environment. Sustainable development is one of Malaysia's energy plans to obtain renewable and clean energy generation from sustainable energy resources and life cycle.

From this study, several future directions could be proposed regarding the tracking mechanism and the options for extending the PV capacities. The improvement of the solar tracking mechanism is interesting to study as Malaysia has potential solar energy harvesting throughout the year (Abdulmula et al., 2019; Ghazali M & Abdul Rahman, 2012; Mahendran et al., 2013). Also, by using a more accurate control system, it is expected to optimize the tracker's movement and save more energy to supply the building instead of wasting into the parasitic load for the motor and the controller (Tan et al., 2019).

Regarding the technology, the improvement of the axis and the algorithms have also been investigated not only to make sure the visibility from the economic and infrastructure of the solar tracking system as per analyzed in (Gholami et al., 2019; Weerasinghe et al., 2021). Even though the comprehensive analyses is still scarce, in the future, the technological development should also consider any other criteria when developing a solar tracking system (Singh et al., 2021).

In the application, sustainable development of BAPV through reusing the old PV panels and enhance them with solar tracker-based mounting is attractive to increase its efficiency and reduce the carbon footprint from the manufacturing phase and make the panel lifetime longer than the conventional fixed mounted system as proven by several studies (Antonanzas et al., 2019; Jayathissa et al., 2016; Tırmıkçı & Yavuz, 2019). At the end, solar panel applications for building applied photovoltaic (BAPV) is promising to be executed. With the development of photovoltaic cell technologies, BAPV has been transforming not only using rooftop PV panels but also for any other parts of the building such as skylight, rainscreens, curtain walls, and shading devices with profitable economic viability (Weerasinghe et al., 2021)

5. Conclusion

With the significance of energy generation potential, Malaysia is one of the suitable places in the world to expand the utilization of building applied with photovoltaic systems (BAPV). This study tried to propose several scenarios to optimize the utilization of PV systems installed in one level of R&D building occupied for laboratory and office. Several scenarios are proposed based on the option to renew all the PV panels or reuse the existing panels with different capacity sizes. This study can analyze the opportunity in terms of each case's technical and economic aspects. Based on the scenario studied, installation of solar tracking system did the improvement in increasing the energy harvesting from the PV system of about 18% compared to the existing fixed mounted BAPV. From the technical aspects, the option to renew all the panels with an additional tracking system with large capacity is the best. In contrast, from the economic value, the option to reuse the existing panels with additional solar tracker is the best way. The decision made for utilizing the existing panels is viable from the economic aspect and also good for the environment as the life cycle of the BAPV can be improved any longer. This research has a potential future development to analyze BAPV with bigger capacities with different technologies of solar tracker to analyze the impact of the tracker not only for enhancing the technical aspects but also for the economical view and environmental perspective regarding the Net Zero Emission path in Malaysia.

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