Modelling and Sizing a Grid-connected PV-Battery System Using DIgSILENT for Powering UTeM Main Campus

Khaldon Ahmed Qaid*, Wei Hown Tee*, Chin Kim Gan*‡, Pi Hua Tan**

* Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka

**AFRY Malaysia Sdn. Bhd., Kuala Lumpur, Malaysia

(khaldon603@gmail.com, weihowntee@gmail.com, ckgan@utem.edu.my, tan.pi-hua@afry.com)

‡ Corresponding Author; Chin Kim Gan, Faculty of Electrical Engineering, Universiti Teknikal Malaysia Melaka, Jalan Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Tel: +60 62701310, ckgan@utem.edu.my.

Received: 26.03.2023 Accepted:29.05.2023

Abstract- Universities encounter challenges stemming from the escalating electrical bills attributed to the substantial energy consumption of their expansive buildings. This serves as a clear impetus for universities to transition to renewable energy technologies, which offer the advantages of cost-effective operation and minimal environmental footprint. This paper presents the design of a grid-connected photovoltaic (PV) system with battery storage to fulfil the electricity consumption needs of Universiti Teknikal Malaysia Melaka (UTeM) main campus. The objective is to reduce grid dependency, lower electricity costs, and minimize carbon dioxide (CO_2) emissions. The system was modelled and simulated using DIgSILENT software. Load demand and energy consumption data were extracted from the Tenaga Nasional Berhad (TNB) electricity bill, while the PV profile and irradiance data were obtained from the UTeM solar laboratory. Based on the findings, it has been determined that a 12 MWp PV system, coupled with a 25.8 MWh battery, represents the optimal solution for satisfying the total electricity demand of UTeM's main campus. The installation of this system is projected to result in estimated monthly electricity bill savings of MYR 422,611 for UTeM. Furthermore, the proposed system offers a significant environmental benefit by potentially reducing CO_2 emissions by up to 1,507,520 kg per month. The findings of this study can inform decision-makers in implementing a cost-effective and environmentally friendly energy solution for UTeM's main campus.

Keywords University microgrid, grid-connected, DIgSILENT, solar PV, battery.

Nomenclature

ADEC	Average Daily Energy Consumed
FiT	Feed-in Tariff
ICPT	Imbalance Cost Pass-Through Tariff
KWTBB	Renewable Energy Fund
PSHs	Peak Sun Hours
PR	Performance Ratio
PV	Photovoltaic
QDS	Quasi Dynamic Simulation
SST	Sales and Services Tax
TNB	Tenaga Nasional Berhad
UTeM	Universiti Teknikal Malaysia Melaka

1. Introduction

Public universities in Malaysia have recently faced a decline in funding. Specifically, the budget allocated to higher education institutions in Malaysia witnessed a decrease from MYR 15.78 billion in 2015 to MYR 13.37 billion in 2016. However, there has been a slight increase in the subsequent years, with the budget rising to MYR 14.50 billion in 2022 [1][2]. Consequently, the Ministry of Education in Malaysia has urged educational institutions to prioritize energy conservation efforts [3]. Moreover, administrators at local universities in Malaysia are expressing concern over the substantial monthly electricity bills arising from inefficient use of energy. These universities are currently incurring an annual energy cost exceeding 10 million ringgits, which is increasingly becoming a significant financial burden [4]. In addition to the budget cuts, there is a notable drive in Malaysia to foster environmental consciousness and encourage the adoption of practices aimed at reducing carbon emissions. This emphasis on environmental consciousness is further motivated by the fact that Malaysia's carbon emissions reached approximately 253,270 kt in 2019. Consequently, there is an urgent need to implement and adopt more eco-friendly methods to effectively tackle environmental challenges and mitigate the adverse impact of carbon emissions on the environment [5][6]. To achieve sustainable green energy growth and reduce carbon emissions by up to 45% by 2030, Malaysia has identified and formulated several strategic plans [7][8]. Concurrently, Malaysia recognizes solar PV systems as a primary energy source due to their lower operational costs and the abundant solar irradiance available in the country [9]. This proposal suggests that solar energy has This proposal highlights that solar energy possesses the potential to offer an affordable and sustainable power source, making it a promising solution to meet the energy requirements of the country [10]. Studies have been carried out by researchers for integrating solar PV with battery bank systems into the grid to reduce the load demand peak [11] and to reduce customer electricity bills [12]. Solar PV-battery systems, including both grid-connected and off-grid systems, are widely recognized as the most easily installed and accessible type of renewable energy system for providing universities with sustainable energy solutions.

UTeM is a technical public university located in Melaka, Malaysia. In recent years, the expansion of buildings and the growth of educational activities at UTeM have led to an increased total demand for energy supply. Consequently, this has led to a rise in the monthly electricity bills for the university. UTeM is currently incurring a monthly electricity bill of over MYR 600,000 [13]. This substantial amount represents a significant portion of the university's overall expenses, and it is anticipated to further increase in the near future. Given the rise in electricity costs and the limitation of government support, UTeM is compelled to seek a solution to effectively reduce its electricity bills. One of the proposed solutions involves minimizing energy costs by reducing reliance on the main power grid and instead prioritizing the utilization of renewable energy sources [14]. Furthermore, the university has set ambitious goals to significantly decrease its overall energy consumption and strive towards meeting up to 100% of the campus' energy needs through the utilization of on-site renewable energy resources.

Several universities have conducted numerous studies to assess the feasibility of implementing microgrids powered by solar PV systems to electrify their campuses. A comprehensive review was conducted, referencing microgrid installations on university campuses worldwide [15]. For instance, a stochastic modelling approach using kernel density distributions was applied to real data obtained from a 34kWp on-grid PV system installed at the campus of the Federal University of Goias in Brazil [16]. In Nigeria [17], a hybrid off-grid PV-diesel system was designed specifically for a postgraduate hall of residence located at the University of Ibadan in Ibadan, Oyo State. In Saudi Arabia [18], a technical evaluation was performed to assess the effectiveness of a 7.0 kW hybrid PV/Wind on-grid power system. The system was installed on the rooftop of the engineering building at the Islamic University of Madinah. In Turkey [19], a research study was conducted to evaluate the feasibility of implementing a solar PV system with the aim of reducing peak power consumption at Bahcesehir University's finance campus. The study considered both the technical and financial aspects of the implementation. At Okinawa Institute of Science and Technology in Japan [20], a virtual environment was created utilizing Internet of Things technology for DC-based PV-battery microgrid systems within the campus. Furthermore, an experimental study was conducted on the Tagajo campus of Tohoku Gakuin University, where a hybrid microgrid system was installed and examined [21]. In Indonesia [22], Semarang State University employed a combination of deep learning techniques and unmanned aerial vehicle-based aerial photography to forecast the solar energy potential of rooftops. This assessment also accounted for the subsequent reduction in CO_2 emissions.

Numerous investigations have been carried out in Malaysia to explore the financial and environmental advantages of various campus microgrids. These studies have primarily focused on the sizing and design of different components within microgrid systems. For instance, Khan et al. [23] have developed a grid-connected microgrid for Universiti Kuala Lumpur. This microgrid incorporates PV panels and battery storage to fulfil the campus's electricity requirements while reducing dependence on the main power grid. Jefry and Zambri [24] developed a demand response program integrated with PV energy to effectively reduce the energy consumption of the highest-consuming buildings at Universiti Tun Hussein Onn. In [25], a preliminary investigation was conducted to evaluate the power potential of PV panels at the campus of the International Islamic University Malaysia. In [26], a feasibility study was carried out to examine the viability of utilizing small-scale PV panels for lighting purposes at the Universiti Teknologi MARA, Sarawak campus. The study considered factors such as operation and maintenance costs to assess the feasibility of the project. In [27], Krishna et al. proposed a comprehensive design for on-grid PV panels intending to reduce electricity consumption at Taylor's University Malaysia campus. The study presented in [28] assesses the financial and ecological aspects of implementing PV panels with a capacity of 1 MW for electrifying the campus of Universiti Malaysia Pahang. In [29] a thorough evaluation was conducted to assess the performance of grid-connected PV panels installed on the campus of Monash University in Malaysia. Tan and Chow [30] conducted a comparative analysis between the Feed-in Tariff (FiT) and net metering schemes to reduce the overall electricity consumption at UCSI University Malaysia campus. The comparison focused on the installation of PV panels to achieve this goal. In [31], Yassim et al. conducted a feasibility study using HOMER to determine the optimal size and cost-effective configurations for an on-grid PV system that can effectively power the UTeM main campus. Optimal battery energy storage system sizing in the DIgSILENT programming language was developed in [32] to reduce power losses in the tested system with optimal operation costs. The aforementioned studies focused on the design and implementation of microgrids within university campuses, aiming to assess their effectiveness in meeting electricity requirements. These investigations considered various factors, including energy efficiency, cost-effectiveness, and ecological impact, to evaluate the overall performance of the microgrid systems.

This paper aims to utilize DIgSILENT software to model and size an on-grid PV system integrated with a battery bank. The objective is to provide the main campus of UTeM with a reliable and fully renewable energy source. By accurately simulating the system, the study intends to determine the optimal configuration and sizing of the PV system and battery, ensuring efficient energy generation, storage, and utilization within the campus. The primary objective of this scheme is twofold: to reduce the electrical bill of the university and to minimize the level of CO_2 emissions in the city. By implementing the proposed system, the university aims to achieve significant cost savings in its electricity expenditure while simultaneously making a positive impact on the environment by reducing carbon dioxide emissions. The proposed method was implemented by utilizing solar irradiance data obtained from the PV laboratory station, as well as the monthly energy consumption data gathered from the university's electricity bill. These inputs were crucial in accurately modelling and simulating the performance of the PV system, allowing for an informed analysis of the system's energy generation and consumption patterns. It is important to note that this study did not consider losses and FiT costs in its analysis. The rest of the paper is structured as follows: Section 2 provides a brief overview of UTeM's location, load profile, and solar resources, as well as the basic mathematical models. Section 3 elaborates on the proposed methodology and system configuration, accompanied by the case study description. The findings and discussions are presented in Section 4. Section 5 includes the concluding remarks of the research.

2. Assessment and Analysis

2.1. Load Demand

The initial stage of the proposed method entails formulating a mathematical model to accurately calculate the load demand. Typically, the load demand and energy consumption of the UTeM main campus can be obtained by monitoring the main energy meter and reviewing the utility bills. The average daily energy consumed (ADEC) can be calculated by equation (1).

$$ADEC = \frac{Energy\ consuming\ in\ month}{number\ of\ days} \quad (1)$$

In January 2018, the total energy consumption of the UTeM main campus amounted to 1,412.975 MWh, with the highest peak demand of 4.653 MW occurring on January 4th of that year [13]. Fig. 1 shows the energy consumption data recorded every 30 minutes by UTeM's main energy measuring device on January 4th, 2018. Thus, the total energy consumed in MWh can be calculated by equation (2).

$$L_E = \frac{1}{2}\sum_{i=1}^{n=48} L_{Pi} \quad (2)$$

Where L_E is the total load energy consumed MWh for one day. L_{Pi} is the load profile in time i for the same day.

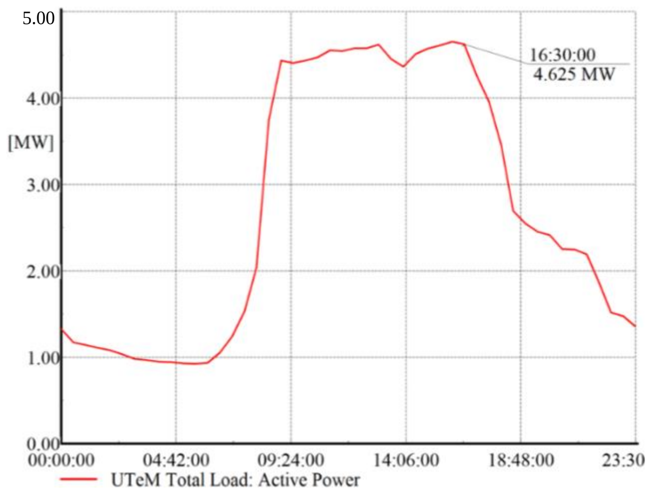

Fig. 1. UTeM load profile.

As illustrated in Fig. 1, the energy demand exhibits a peak during the daytime, aligning with the operational hours of UTeM from 8:00 to 17:00. During this time, the load represents approximately 70% of the total daily energy demand. Conversely, during the night hours, the load requirement decreases, constituting only 30% of the daily energy demand.

2.2. Solar PV System Calculation

The main campus of UTeM is situated in Durian Tunggal, Alor Gajah District, within the state of Melaka. Its geographical coordinates are approximately 2.313965°N latitude and 102.319872°E longitude. Melaka is renowned for its warm and humid climate, characterized by high temperatures and humidity levels ranging between 80% and 90%. Throughout the year, temperatures on the campus exhibit a range of 22°C to 33°C, with a median daily temperature of 26.5°C. The monthly solar irradiance in Melaka is estimated to range between 400-600 MJ/m2, with higher radiation during the northeast monsoon season and lower radiation during the southwest monsoon season. In this study, the irradiance levels were recorded at intervals of 30 minutes using the UTeM solar laboratory station. Daytime in Melaka typically begins at 07:30 and lasts until 19:30, aligning with the standard sunrise and sunset timings for the city [33]. Fig. 2 presents the solar PV profile for a sunny day, demonstrating the variation of solar power generation during the day. The research objective is to design a PV system capable of generating enough energy to meet the daily energy requirements of UTeM. Thus, the maximum energy output from the PV panels to satisfy the campus's peak demand and energy consumption can be mathematically expressed as shown in equation (3) [34].

$$PV_{size} = \frac{L_E}{PSH_S \ X \ PR\ \%} \quad (3)$$

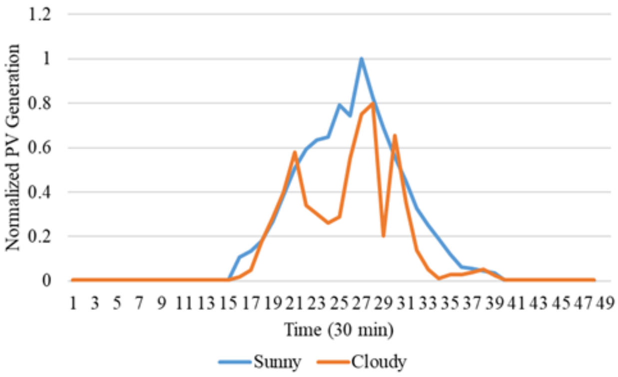

Fig. 2. UTeM PV system profile.

where PV_{size} is the solar PV system power size in MW. Peak sun hours (PSHs) play a critical role in determining the maximum solar irradiation received by a solar array within a day. In Melaka City, the PSHs are approximately 4.8 hours [35]. Assuming a performance ratio (PR) of 80% for the PV panels, the maximum power generation of the PV panel array in megawatts (MW) can be calculated using the peak watt (Wp) value [36]. Furthermore, the study considers the influence of efficiency and variability in solar energy production throughout the day [37]. The total energy generated by the PV panels, measured in MWh, is calculated using equation (4).

$$PV_E = \frac{1}{2}\sum_{i=1}^{n=48} PV_{Pi} \quad (4)$$

Where PV_E is the solar PV energy in MWh and PV_i is the solar PV profile in time i for 24-hour recorded every 30 minutes.

2.3. The Battery Bank Sizing

To ensure continuous power supply from the PV panel system even during adverse weather conditions and at night, it is essential to store energy in rechargeable battery banks during peak sunlight hours. Batteries are widely preferred for their durability, cost-effectiveness, accessibility, and compatibility with PV systems, making them the most used option. The study quantifies the energy capacity of the battery in MWh, considering multiple factors including total load, efficiency, discharge depth, nominal voltage, and required autonomy days. Autonomy days play a critical role as they determine the number of consecutive cloudy days for which the battery must store sufficient energy to meet the total load. Typically, a standard of three days is considered for autonomy days, ensuring that the battery can sustain the total load during prolonged periods of cloudy weather. It is recommended to oversize the battery energy capacity from 1.5 to 3 times to ensure sufficient energy storage and mitigate the risk of under sizing [38]. The study utilizes a mathematical model represented by equations (6) and (7) to accurately determine the optimal size of the battery storage based on the specific load demand and characteristics of the PV system [39]. The battery profile is expressed as equation (5).

$$Bat_{p(i)} = PV_{P(i)} - L_{P(i)} \quad i \in \{1,2,\ldots,n\} \quad (5)$$

where $Bat_{P(i)}$ is the battery profile, $PV_{P(i)}$ is the PV array profile and $PL_{(i)}$ is the load profile. The battery profile is obtained by subtracting the load profile from the PV profile, ensuring that any surplus energy generated by the PV panels during peak hours is effectively stored in the battery. This stored energy can then be discharged during the night or periods of limited sunlight, such as cloudy weather, to ensure a continuous and reliable power supply. The battery stored energy and size can be represented as

$$Bat_E = \sum_{i=1}^{n=48} \left| Bat_{p(i)} \right| \quad (6)$$

$$Bat_S = Max(Bat_{p(i)}) \quad (7)$$

where Bat_E is the battery energy in MWh, Bat_{Pi} is the battery profile and Bat_S is the battery size in MW which equals the maximum of the battery profile. This ensures that both the energy stored in the battery and the size of the battery system are accurately represented and optimized for efficient operation.

2.4. TNB Tariff Rates for Electricity in Universities

Educational institutions and universities in Malaysia are classified as commercial buildings due to their operational and functional nature. According to the pricing provided by TNB, the current rates for the medium voltage general commercial tariff (Tariff C1) in Malaysia are MYR 30.3 per kW for the maximum monthly demand and MYR 0.365 per kWh for the total energy consumed. Additionally, a monthly minimum charge of MYR 600 is applicable [40]. The Imbalance Cost Pass-Through Tariff Rebate (ICPT) offers a discount of MYR 0.20/kWh for each energy consumed [41]. Furthermore, the electricity bill includes a charge for the Renewable Energy Fund (KWTBB), which contributes to supporting the FiT mechanism. UTeM falls under the C1 Tariff category and is eligible for the rebate. The calculations also include the Malaysian Sales and Services Tax (SST). The following equations outline the calculations for determining the electricity bill for UTeM.

$$Charge = (kWh \text{ x } 0.365) + (kW \text{ x } 30.3) \quad (8)$$

$$ICPT = kWh \text{ x } 0.0152 \quad (9)$$

$$KWTBB = Charge \text{ x } 1.6\% \quad (10)$$

$$Bill = (Charge - ICPT) \text{ x } SST + KWTBB \quad (11)$$

2.5. CO_2 Emission Calculation

In this study, a CO_2 emission rate of 0.741 kg/kWh on average is used [35]. The reduction in CO_2 emissions is defined by equation (12).

$$CO_2 = PV_{kWh} \text{ x } Rate_{CO2} \quad (12)$$

where PV_{kWh} refers to the electricity generated by the PV panels, while $Rate_{CO2}$ represents the quantity of CO_2 emitted per kWh produced by these PV panels, measured in kilograms [42].

3. Proposed System Configuration and Case Study Description

The proposed system, illustrated in Fig. 3, comprises a PV panel, battery bank, and UTeM load connected to the main grid. The network was modelled and simulated using the DIgSILENT software and its built-in Quasi Dynamic Simulation (QDS) tool. Table 1 presents the configuration of the proposed network elements, including PV panels and batteries, as well as the simulation of six different cases representing various weather conditions and days using the QDS tool. For each case, simulations were conducted for a duration of 24-hour to analyze the distribution of power throughout the day. The technical data utilized in the simulations was obtained from the TNB electrical bill and UTeM solar laboratory. Fig. 4 illustrates the flowchart outlining the step-by-step procedure for implementing the proposed technique. The simulation process in DIgSILENT can be summarized as follows. Initially, the load demand for a single day was determined by utilizing the electricity bill data, as represented by equation (1). This calculation allowed for a comprehensive understanding of the overall energy consumption pattern. Subsequently, the load profile and PV profile were collected for various scenarios, encompassing both weekend and workday load profiles, as well as sunny or cloudy PV profiles. The load profile was derived using equation (2), while the PV profile was established based on equation (4).

After obtaining the load and PV profiles, the necessary sizes of the PV panels and battery bank were calculated. Equations (3, 6, and 7) were employed to determine the optimal PV size, considering the maximum load demand and solar irradiance levels. Similarly, the battery size was determined by considering the PV size and desired storage capacity. In cases where the PV energy generation aligned with the load demand, any surplus energy was utilized to generate a battery profile, as dictated by equation (5), allowing for a comprehensive understanding of the charging and discharging patterns of the battery. Upon collecting and calculating all the required input data, the proposed UTeM networked system was modelled in DIgSILENT, incorporating the load demand, PV size, and battery size. Subsequently, a load flow simulation was executed within DIgSILENT to ensure the system operated within desired voltage and power limits. Following this, the QDS simulation was conducted, considering the time series behaviour of the system and accounting for the variation in load and PV profiles throughout the day. The QDS yielded detailed results pertaining to power generation, energy flows, and other pertinent parameters. Finally, the obtained results from the QDS simulation were extracted and analyzed, encompassing aspects such as energy consumption, PV generation, and battery utilization. By following this comprehensive simulation process in DIgSILENT, it was possible to gain valuable insights into the performance and optimization of the proposed UTeM networked system.

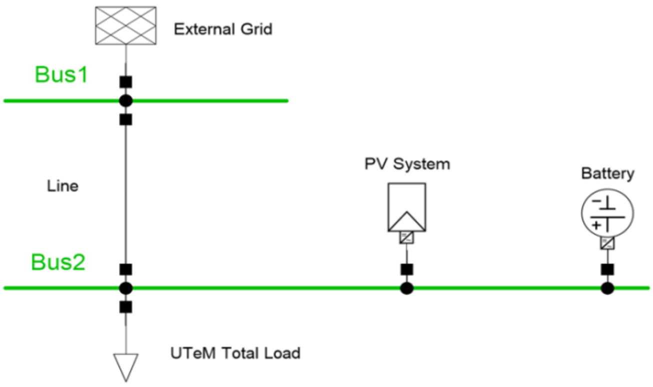

Fig. 3. Single-line illustration of the proposed grid.

Table 1. Simulation scenarios, load profile and PV profile condition of each case

Case	Grid	PV	Battery	Load profile condition	PV profile condition
Base case	Yes	No	No	Workday	-
1	Yes	Yes	No	Workday	Sunlit day
2	Yes	Yes	Yes	Workday	Sunlit day
3	Yes	Yes	Yes	Weekend	Sunlit day
4	Yes	Yes	Yes	Workday	Cloudy day
5	Yes	Yes	Yes	Weekend	Cloudy day

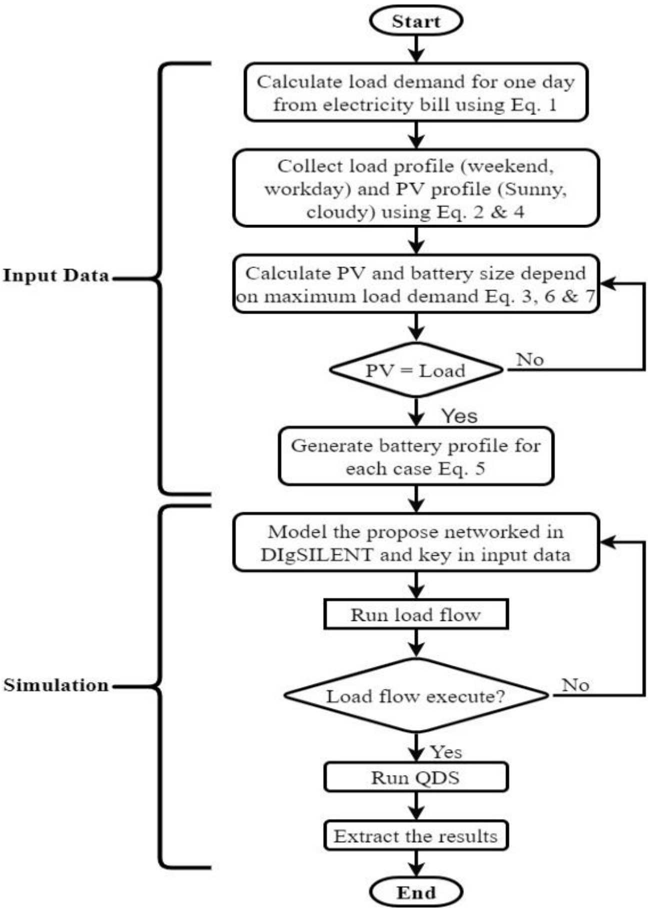

Fig. 4. Implementation step for the proposed technique.

4. Result and Discussion

A comprehensive design and modelling of PV panels with a battery system were carried out specifically for the UTeM main campus to achieve the goals of minimizing electricity bills and reducing CO_2 emissions. To simulate various scenarios, the QDS tool was employed to run six cases. These cases involved diverse configurations of network components, including the grid, PV panels, and battery. The purpose of these simulations was to accurately model the behaviour and performance of the system under different conditions and evaluate its effectiveness in meeting the objectives. Additionally, variations in days, including both workdays and weekends, as well as different weather conditions such as cloudy and sunny, were considered. The base case involved simulating the system's performance before the installation of the PV panels, serving as a reference point for comparison. The first three cases were specifically designed to demonstrate the influence of the system's maximum load, PV array, and battery power on monthly bill savings and CO_2 emissions reduction. The remaining three cases involved the utilization of different load and PV profiles to further examine the system's performance. The subsequent sections provide a more detailed discussion of the results for each case.

4.1. Results of DIgSILENT Simulation

- Base Case

In this case, the entire load of UTeM's main campus was supplied solely by power from the main grid. The load profile used in this case corresponds to a workday, specifically January 4th, 2018. The load was divided into two sections based on time. The first section encompassed the university's working hours from 7:30 to 19:30. During this time, various appliances, computers, and air conditioners were in operation, resulting in a load peak of 4.653 MW at 16:00. The second section represented the night-time period from 19:30 to 7:30, during which the energy consumption was reduced. Only corridor lamps, streetlights, and a few appliances were operational during this time, as shown in Fig. 5. Table 2 provides an overview of the energy consumption for this case. The total load was recorded as 4.6 MWp, with a total energy usage of 65.1 MWh supplied entirely by the main grid.

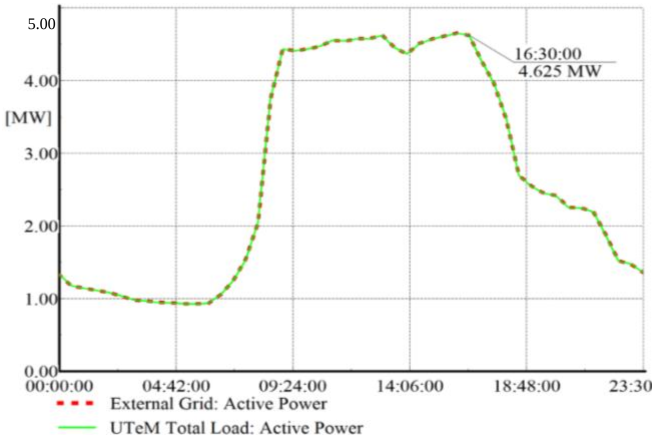

Fig. 5. Time series simulation result for the base case.

- Case 1

In this case, the PV panel was connected to the UTeM system without a battery bank. Fig. 6 illustrates the time series simulation for 24-hour, demonstrating the energy supply from the PV panels to the UTeM load between 7:30 and 19:30, depending on the level of solar irradiance. Between 10:00 and 15:00, the PV panels generated sufficient power to meet the campus's energy demand, resulting in an additional 25.8 MWh of surplus energy exported to the grid. At 13:00, the solar PV system reached its peak power output of 12.0 MWp, allowing for a maximum power export of 7.4 MWp to the grid. Meanwhile, the load at 16:00 was approximately 4.6 MWp. During the night-time period, the load was solely supplied by the grid, as the PV panels do not generate electricity in the absence of sunlight. The results showed that during the irradiance peak in the daytime, the PV panels exported 25.8 MWh of surplus power to the grid. This surplus power can contribute to reducing UTeM's electricity bills by allowing the university to sell the excess energy back to the main grid. Table 2 presents a summary of the power (MWp) and energy (MWh/day) for the network components, including the UTeM load and the solar PV panels. It is worth noting that the solar PV energy generation matched the load energy consumption, which amounted to 57.6 MWh. This indicates that the solar PV system successfully provided enough energy to meet the demand of UTeM's load during the specified period.

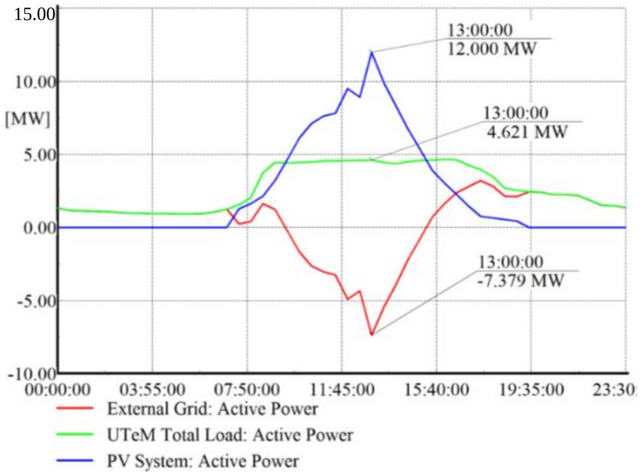

Fig. 6. Time series simulation result for Case 1.

➢ Case 2

In this case, the main campus network of UTeM was connected to a PV system with a battery bank. The PV system supplied power to the UTeM campus from 7:30 to 19:30, with the peak irradiance observed between 12:00 and 13:00. The load fluctuated between 4.0 MW and 4.5 MW from 9:30 to 15:30, and the surplus generation during this time was utilized to charge the battery. The battery reached its peak power output of 7.379 MWp when the solar PV panels produced their maximum output of 12.0 MWp at 13:00. The stored power in the battery was subsequently utilized to supply the UTeM load during the evening period. Significantly, there was no energy import from the grid throughout the entire day, resulting in a substantial reduction in power consumption and the associated electricity bill. Table 2 provides a summary of the power and energy values (in MWp and MWh/day) for the UTeM load, PV panels, and battery bank. The results in Fig. 7 demonstrate that the PV system successfully met all of the campus's energy requirements during the day and also stored an additional 25.8 MWh of energy in the battery storage for later use during the evening hours. The solar PV energy output matched the energy consumption of the load, which was 57.6 MWh, illustrating the system's capability to fulfil the campus's energy requirements while simultaneously reducing CO_2 emissions.

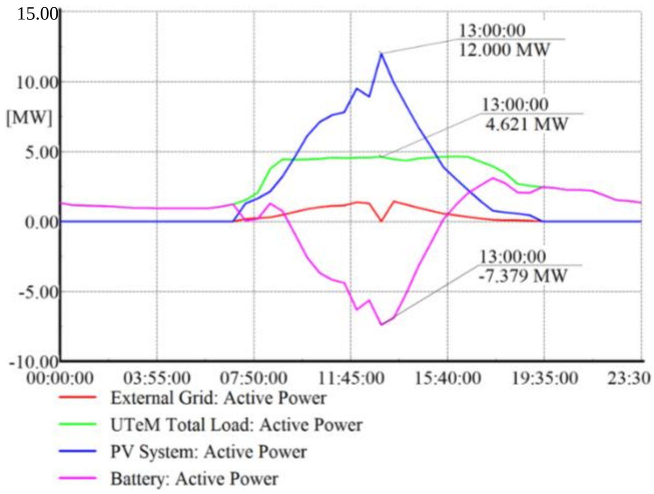

Fig. 7. Time series simulation result for Case 2.

➢ Case 3

This case expands on the power components of Case 2, incorporating a distinct load profile for January 21st, 2018, which corresponds to a weekend. Despite the reduced load demand, the PV profile remains consistent with a sunny day, similar to the base case. With minimal usage for lights and appliances, the load remained relatively constant throughout the day, reaching a peak of 1.2 MWp at 13:00. As shown in Fig. 8, the QDS findings indicate that the solar photovoltaic system's maximum power output reached 12 MWp, significantly exceeding the demand throughout the 24-hour period. During the daylight hours (7:30 to 19:30), the PV system effectively supplied energy to the campus while simultaneously charging the battery during the peak PV hours from 10:00 to 15:00. The power output during this time reached a maximum of 7.3 MWp. During the night-time period, the battery efficiently supplied power to the load, ensuring a continuous supply of electricity. Additionally, any excess power stored in the battery during the day was reserved for use on the following day, further optimizing the system's performance and enhancing its overall efficiency. During the period from 8:00 to 17:00, the PV system had surplus power that exceeded the campus's demand. This excess power was exported to the main grid, with a peak export of 3.3MWp occurring at 13:00. By selling this excess energy to the grid, UTeM has the opportunity to benefit from discounts or have the value of the exported power deducted from its electricity bill. This arrangement allows UTeM to optimize its energy usage and potentially reduce overall electricity costs. Table 2 provides a comprehensive overview of the daily power and energy consumption for the UTeM load, solar PV system, and battery bank. It is important to note that the sizes of the PV and battery components were consistent and maintained identical values throughout all cases. As a result, their energy values remained unchanged across the different scenarios. This demonstrates the stable and consistent performance of the PV and battery system, irrespective of variations in load profiles or weather conditions.

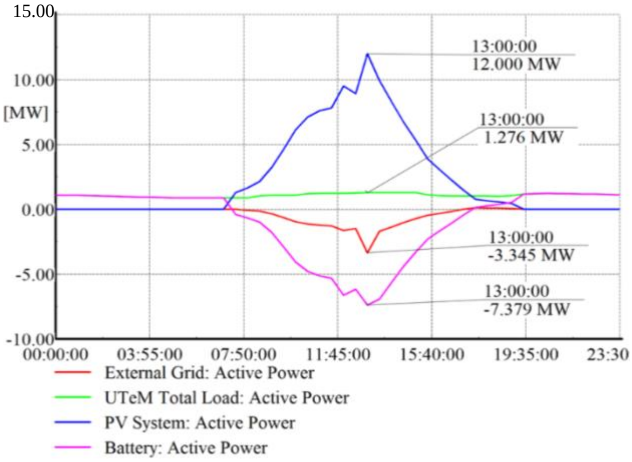

Fig. 8. Time series simulation result for Case 3.

➢ Case 4

In this particular case, the load profile represents a typical workday, reflecting the energy consumption pattern during business hours. On the other hand, the solar PV profile used in this scenario simulates a cloudy day, resulting in a reduced maximum generated power of only 9.6 MWp. This limited power output from the PV system was not sufficient to meet the peak load demand of 4.6MW for the campus. As a result, approximately 75% of the load demand had to be supplied by the main grid. The lower solar PV generation on a cloudy day impacted the system's ability to fully meet the energy requirements of the campus, highlighting the importance of considering varying weather conditions in the design and operation of PV systems. Due to the limited energy generation from the PV system on the cloudy day, it was not enough to fully charge the battery bank. As a result, the grid had to supply power to meet the load demand during the night-time period when the PV system was not generating electricity.

Fig. 9 presents the results obtained from the QDS simulation, showing the total power in MW and energy in MWh required by the load at different times. It is evident that the combined power and energy output from both the main grid source and the PV panels matches the load demand throughout the 24-hour period. Table 2 provides information on the maximum power output of the PV panels and battery bank for this particular case. It is noteworthy that the solar PV energy generated amounts to 39.1 MWh, which is lower than the energy consumed by the load, which is 65.1 MWh. Consequently, the shortfall of energy from the PV panels led to the import of 34.9 MWh of energy from the grid to meet the total energy demand of UTeM. In summary, this case highlights the impact of cloudy weather on the output of solar PV panels, resulting in increased dependence on the grid to meet the energy needs of the campus. The total energy demand of the campus should align with the combined energy production of the PV panels and the main grid, with the battery bank potentially not being fully charged in such conditions.

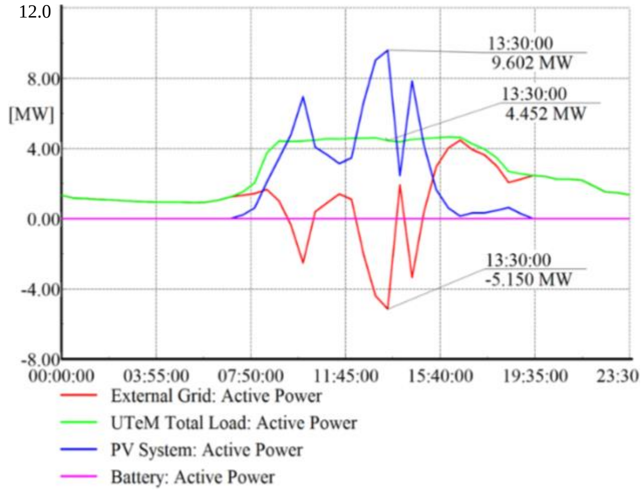

Fig. 9. Time series simulation result for Case 4.

➢ Case 5

In this specific case, the solar PV and load demand profiles demonstrate distinct energy production and consumption patterns. While the load profile represents a typical weekend day, the PV profile used in this case is based on a cloudy day, indicating lower energy production from the solar PV system. Interestingly, despite the cloudy weather, the energy produced by the solar PV system on this particular day was still sufficient to meet the load demand typically observed on a weekend day as shown in Fig. 10. Any surplus power generated was stored in the battery bank to be utilized during the night-time load. Table 2 shows that there was exported and imported energy from the grid in this case. The generated energy from the PV system was sufficient to meet the load demand with extra power exported to the grid. The solar PV system in Case 5 has a power output of 9.6 MWp, indicating the maximum power generated by the PV panels. The corresponding solar PV energy is 14.4 MWh, representing the total energy produced by the PV system. The battery in this configuration is charged with a power of -1.2 MWp and corresponding charge energy of -14.7 MWh. The battery also discharges with a power of 1.8 MWp, contributing to the discharge energy of 8.9 MWh. The grid export power in this case is -6.8 MWp, indicating that excess power is being exported back to the main grid. The corresponding grid export energy is -19.2 MWh, representing the total energy exported from the system. On the other hand, the grid import power is 0.7 MWp, signifying the amount of power being imported from the grid to meet the system's energy demand. The grid import energy is 1.2 MWh, which represents the total energy imported from the grid. The UTeM load, representing the energy consumption of the system, is 1.2 MWp in terms of power and 26.0 MWh in terms of energy.

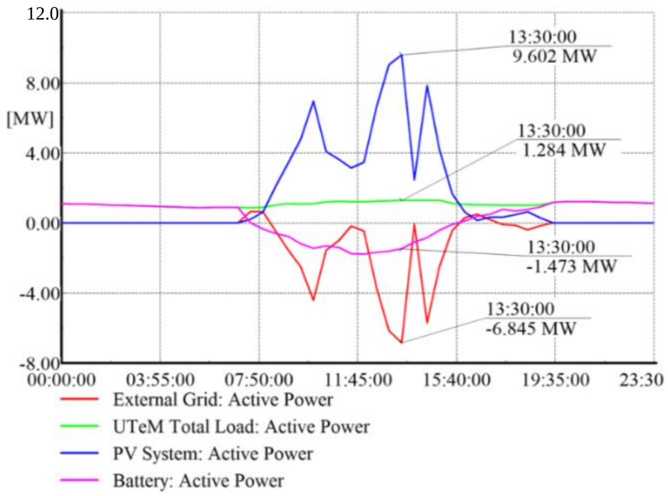

Fig. 10. Time series simulation result for Case 5.

4.2. Results of Electricity Bill and CO_2 Emission Calculations

The calculations for both the cost of electricity and the amount of CO_2 emissions are exclusively performed in the first three cases. The summary of electricity bills for various configurations is presented in Table 3. In Case 1, the monthly saving for the grid-PV configuration is MYR 43,903.72. However, in Case 2, the grid-PV-battery configuration provides a significantly higher monthly saving, which is nearly 10 times larger than the saving provided by the grid-PV configuration. From a monthly perspective, the electricity bill reduction is more significant with the grid-PV-battery configuration in Case 2, resulting in a reduction of 58.9% compared to the base case. In comparison, the grid-PV configuration in Case 1 achieves a reduction of 6.1% in the electricity bill. This significant reduction in the electricity bill with the grid-PV-battery configuration in Case 2 is primarily attributed to the utilization of a battery. The battery allows for the storage of excess energy generated during peak hours with high solar irradiance. This stored energy can then be utilized to support the load during periods when there is no solar irradiance available. The integration of PV-battery panels in Case 2 leads to the highest level of CO_2 emission avoidance, with a monthly reduction of 1,507,520.7 kg compared to the base case. This significant reduction in CO_2 emissions is attributed to the ability of the PV-battery system to generate and store renewable energy, thereby reducing the reliance on fossil fuel-based power sources. By utilizing clean and sustainable energy, the system minimizes the carbon footprint associated with electricity consumption, making it an environmentally friendly solution. The integration of battery storage enables efficient management of energy flow, ensuring optimal utilization of renewable energy and further reducing the need for conventional power generation, which results in a substantial reduction in CO_2 emissions.

Table 2. Summary of power and energy results for the six cases

Case No.	Grid				PV		Battery				Load	
	Import		Export				Charge		Discharge			
	(MWp)	(MWh)	(MWp)	(MWh)	(MWp)	(MWh)	(MWp)	(MWh)	(MWp)	(MWh)	(MWp)	(MWh)
Base case	4.6	65.1	-	-	-	-	-	-	-	-	4.6	65.1
1	3	25.8	-7.4	-25.8	12.0	57.6	-	-	-	-	4.6	65.1
2	1.4	7.5	0	0	12.0	57.6	-7.4	-25.8	3.0	25.8	4.6	65.1
3	0	0	-3.3	-9.0	12.0	57.6	-7.4	-35.9	1.2	13.2	1.2	26.0
4	4.5	34.9	-5.1	-8.9	9.6	39.1	0	0	0	0	4.6	65.1
5	0.7	1.2	-6.8	-19.2	9.6	14.4	-1.2	-14.7	1.8	8.9	1.2	26.0

Table 3. Summary of electricity bill and CO_2 emission for different configurations

Case No.	Energy consumption tariff Charge (MYR)	Maximum demand charge (MYR)	Total bill (MYR)	Monthly savings (MYR)	CO_2 emission (kg)	CO_2 avoidance (kg)
Base case	515,735	140,985	716,469	0	1,507,520	0
1	506,912	118,170	672,565	43,903	597,450	910,070
2	173,119	99,990	293,858	422,611	0	1,507,520

5. Conclusion

This study highlights the potential benefits of implementing an on-grid PV panels system with a battery bank to meet the electricity demand of UTeM's main campus. The research utilized load calculations based on the TNB electricity bill and practical sizing considerations to determine the appropriate size of the PV panels system combined with the battery bank. Through the simulation and modelling conducted in DIgSILENT software using actual load and PV profiles, the study evaluated six operational scenarios to assess their suitability for different load and solar PV profiles. The results demonstrate that the installation of a 12 MWp PV array with a 25.8 MWh battery bank provides optimal performance for meeting the entire electricity demand of UTeM's main campus. The proposed system offers significant advantages, including monthly electricity bill savings of MYR 422,611 and a substantial reduction of 1,507,520 kg in CO_2 emissions. These findings provide valuable insights for decision-makers at UTeM, showcasing the potential for implementing an environmentally friendly and cost-effective energy solution for the campus. By emphasizing the potential for electricity bill savings and CO_2 emission reductions, UTeM can prioritize the adoption of clean and renewable energy sources while simultaneously achieving financial benefits. This study can serve as a guideline to inform UTeM and other institutions seeking to implement similar energy solutions, supporting their transition towards sustainability and reduced environmental impact.

Acknowledgements

The authors gratefully acknowledge Universiti Teknikal Malaysia Melaka (UTeM) for supporting this research through research grant PJP/2022/FKE/TD/S01828.

References

[1] Asia Sentinel, “Budget axe falls on Malaysian universities,” 2016. https://www.asiasentinel.com/p/malaysia-universities-massive-cuts

[2] D. Ganeson, “Budget 2022: Lukewarm allocation for higher education concerning,” The vibes, 2021. https://www.thevibes.com/articles/education/46124/budget-2022-lukewarm-allocation-for-higher-education-concerns-sector

[3] N. S. Yen, E. S. A. Shakur, and C. W. Wai, “Energy conservation opportunities in Malaysian universities,” Malaysian J. Real Estate, vol. 5, no. 1, pp. 26–35, 2010.

[4] Cenergi, “Concept note on incorporating the energy savings performance agreement model into universities,” Cenergi, 2017. https://www.cenergi-sea.com/energy-efficiency-universities.

[5] Trading Economics, “Malaysia CO2 emissions,” Trading economics, 2021. https://tradingeconomics.com/malaysia/co2-emissions

[6] World Bank, “GHG emissions,” World resources institute, 2020. https://data.worldbank.org/indicator/EN.ATM.CO2E.KT?locations=MY.

[7] Bernama, “Malaysia re-pledges to achieve 45 per cent CO2 emission by 2030,” New straits times onlines, Kuala Lumpur, 2016.

[8] M. A. M. Khan and Y. I. Go, “ Design, optimization and safety assessment of energy storage: A case study of large-scale solar in Malaysia ,” Energy Storage, vol. 3, no. 3. 2021. doi: 10.1002/est2.221.

[9] S. Mekhilef, M. Barimani, A. Safari, and Z. Salam, “Malaysia’s renewable energy policies and programs with green aspects,” Renew. Sustain. Energy Rev., vol. 40, pp. 497–504, 2014, doi: 10.1016/j.rser.2014.07.095.

[10] K. Y. Lau, M. F. M. Yousof, S. N. M. Arshad, M. Anwari, and A. H. M. Yatim, “Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions,” Energy, vol. 35, no. 8, pp. 3245–3255, 2010, doi: 10.1016/j.energy.2010.04.008.

[11] M. Shamshiri, C. K. Gan, J. Sardi, M. T. Au, and W. H. Tee, “Design of battery storage system for Malaysia low voltage distribution network with the presence of residential solar photovoltaic system,” Energies, vol. 13, no. 18, 2020, doi: 10.3390/en13184887.

[12] J. Sardi, N. Mithulananthan, M. M. Islam, and C. K. Gan, “Framework of virtual microgrids formation using community energy storage in residential networks with rooftop photovoltaic units,” J. Energy Storage, vol. 35, no. October 2020, p. 102250, 2021, doi: 10.1016/j.est.2021.102250.

[13] Tenaga Nasional Berhad, UTeM’s January electrical bill. 2018.

[14] K. A. Ibrahim, C. K. Gan, Z. Z. Abidin, M. T. Au, N. Salim, and A. N. Azmi, “A conceptual design of technical losses assessment and monitoring system for power distribution network in Universiti Teknikal Malaysia Melaka (UTeM),” J. Electr. Syst., vol. 15, no. 3, pp. 359–374, 2019.

[15] K. T. Akindeji, R. Tiako, and I. E. Davidson, “Use of renewable energy sources in university campus microgrid - A review,” in 2019 International Conference on the Domestic Use of Energy (DUE), 2019, pp. 76–83.

[16] S. Trashchenkov, S. P. Pimentel, V. Astapov, A. Annuk, and E. G. Marra, “Kernel density estimation for stochastic modeling of PV power output,” in 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), IEEE, 2018, pp. 1179–1183. doi: 10.1109/ICRERA.2018.8566995.

[17] I. M. Opedare, T. M. Adekoya, and A. E. Longe, “Optimal sizing of hybrid renewable energy system for off-grid electrification: A case study of University of Ibadan Abdusalam Abubakar post graduate hall of residence,” Int. J. Smart Grid-ijSmartGrid, vol. 4, no. 4, pp. 176–189, 2020, doi: 10.20508/ijsmartgrid.v4i4.135.g110.

[18] A. AlKassem, M. Al Ahmadi, and A. Draou, “Modeling and simulation analysis of a hybrid PV-wind renewable energy sources for a micro-grid application,” in 2021 9th International Conference on Smart Grid (icSmartGrid), 2021, pp. 103–106. doi: 10.1109/icSmartGrid52357.2021.9551215.

[19] I. Keskin and G. Soykan, “Reduction of peak power consumption by using photovoltaic panels in Turkey,” in 2017 IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), 2017, pp. 886–890. doi: 10.1109/ICRERA.2017.8191187.

[20] K. Kuwae, K. Arakaki, Y. Shimizu, and H. Kitano, “IoT based virtual environment for DC microgrid systems with energy exchange,” in 2018 International Conference on Smart Grid (icSmartGrid), IEEE, 2018, pp. 113–117. doi: 10.1109/ISGWCP.2018.8634466.

[21] G. Wu, S. Kodama, Y. Ono, and Y. Monma, “A hybrid microgrid system including renewable power generations and energy storages for supplying both the DC and AC loads,” in 2012 International Conference on Renewable Energy Research and Applications, ICRERA 2012, 2012, pp. 1–5. doi: 10.1109/ICRERA.2012.6477373.

[22] D. A. Widodo, N. Iksan, R. D. M. Putri, and A. Mulwinda, “Study of solar photovoltaic potential and carbon mitigation in university buildings,” Int. J. Renew. Energy Res., vol. 12, no. 4, pp. 2053–2060, 2022, doi: 10.20508/ijrer.v12i4.13575.g8566.

[23] M. Reyasudin Basir Khan, J. Pasupuleti, J. Al-Fattah, and M. Tahmasebi, “Optimal grid-connected PV system for a campus microgrid,” Indones. J. Electr. Eng. Comput. Sci., vol. 12, no. 3, pp. 899–906, 2018, doi: 10.11591/ijeecs.v12.i3.pp899-906.

[24] N. A. Jefry and N. A. Zambri, “Suitability of demand response program equipped with solar energy in UTHM,” Indones. J. Electr. Eng. Comput. Sci., vol. 6, no. 2, pp. 294–300, 2017, doi: 10.11591/ijeecs.v6.i2.pp294-300.

[25] G. G. Sadeq, A. N. Zafirah Sanusi, and F. Abdullah, “Solar power assessment for photovoltaic installation in Malaysia university campus,” in 2021 Third International Sustainability and Resilience Conference: Climate Change, IEEE, 2021, pp. 121–125. doi: 10.1109/IEEECONF53624.2021.9668126.

[26] N. F. B. Ibrahim, Z. Bin Abu Bakar, and W. S. B. W. Ibrahim, “The feasibility study of solar PV lighting: In Universiti Teknologi MARA Sarawak,” in 2016 IEEE Industrial Electronics and Applications Conference (IEACon), IEEE, 2016, pp. 92–96. doi: 10.1109/IEACON.2016.8067362.

[27] Y. Krishna, M. F. Fauzan, and N. B. M. N. Gan, “Design and simulation of a rooftop PV System in Taylor’s University Lakeside Campus,” J. Phys. Conf. Ser., vol. 2120, no. 1, 2021, doi: 10.1088/1742-

6596/2120/1/012035.

[28] N. Manoj Kumar, K. Sudhakar, and M. Samykano, “Techno-economic analysis of 1 MWp grid connected solar PV plant in Malaysia,” Int. J. Ambient Energy, vol. 40, no. 4, pp. 434–443, 2019, doi: 10.1080/01430750.2017.1410226.

[29] M. Z. Saleheen, A. A. Salema, S. M. Mominul Islam, C. R. Sarimuthu, and M. Z. Hasan, “A target-oriented performance assessment and model development of a grid-connected solar PV (GCPV) system for a commercial building in Malaysia,” Renew. Energy, vol. 171, pp. 371–382, 2021, doi: 10.1016/j.renene.2021.02.108.

[30] R. H. G. Tan and T. L. Chow, “A comparative study of feed in tariff and net metering for UCSI University North Wing Campus with 100 kW solar photovoltaic system,” Energy Procedia, vol. 100, pp. 86–91, 2016, doi: 10.1016/j.egypro.2016.10.136.

[31] H. M. Yassim, G. C. Kim, M. S. F. Hussin, R. Jaafar, N. A. Maidin, and M. H. A. Rahman, “Feasibility study of a grid tied PV system for Universiti Teknikal Malaysia Melaka,” ARPN J. Eng. Appl. Sci., vol. 15, no. 16, pp. 1791–1796, 2020.

[32] W. H. Tee, K. A. Qaid, C. K. Gan, and P. H. Tan, “Battery energy storage system sizing using PSO algorithm in DIgSILENT PowerFactory,” Int. J. Renew. Energy Res., vol. 12, no. 4, pp. 2142–2150, 2022, doi: 10.20508/ijrer.v12i4.13470.g8591.

[33] S. Mekhilef, A. Safari, W. E. S. Mustaffa, R. Saidur, R. Omar, and M. A. A. Younis, “Solar energy in Malaysia: Current state and prospects,” Renew. Sustain. Energy Rev., vol. 16, no. 1, pp. 386–396, 2012, doi: 10.1016/j.rser.2011.08.003.

[34] C. A. Hossain, N. Chowdhury, M. Longo, and W. Yaïci, “System and cost analysis of stand-alone solar home system applied to a developing country,” Sustain., vol. 11, no. 5, 2019, doi: 10.3390/su11051403.

[35] Sustainable energy development authority (SEDA) Malaysia, “CO2 Avoidance,” 2012. https://www.seda.gov.my/statistics-monitoring/co2-avoidance.

[36] W. X. Shen, “Optimally sizing of solar array and battery in a standalone photovoltaic system in Malaysia,” Renew. Energy, vol. 34, no. 1, pp. 348–352, 2009, doi: 10.1016/j.renene.2008.03.015.

[37] A. S. Aziz, M. F. N. Tajuddin, M. R. Adzman, M. A. M. Ramli, and S. Mekhilef, “Energy management and optimization of a PV/diesel/battery hybrid energy system using a combined dispatch strategy,” Sustain., vol. 11, no. 3, 2019, doi: 10.3390/su11030683.

[38] S. M. Najmul Hoque and B. Kumar Das, “Present status of solar home and photovoltaic micro utility systems in Bangladesh and recommendation for further expansion and upgrading for rural electrification,” J. Renew. Sustain. Energy, vol. 5, no. 4, 2013, doi: 10.1063/1.4812993.

[39] W. Ali, H. Farooq, A. U. Rehman, Q. Awais, M. Jamil, and A. Noman, “Design considerations of stand-alone solar photovoltaic systems,” in 2018 International Conference on Computing, Electronic and Electrical Engineering (ICE Cube), IEEE, 2018, pp. 1–6. doi: 10.1109/ICECUBE.2018.8610970.

[40] Tenaga Nasional Berhad, “Pricing and tariffs,” 2014. https://www.tnb.com.my/residential/pricing-tariffs.

[41] Tenaga Nasional Berhad, “Imbalance cost pass-through (ICPT),” 2023. https://www.tnb.com.my/faq/icpt-english.

[42] S. J. Kassim, K. Syakirin, and Z. Denan, “Introduction to the MyCrest Malaysian carbon reduction and environmental sustainability tool guideline.” Construction industry development board Malaysia, 2016. Available at: www.cidb.gov.my.