Scientific Research Publishing

Journal of Power and Energy Engineering, 2025, 13(8), 277-292
https://www.scirp.org/journal/jpee
ISSN Online: 2327-5901
ISSN Print: 2327-588X

Energy Management Analysis of Hybrid Photovoltaic and Battery Energy Storage System

Aida Fazliana Abdul Kadir[1*], Muhamad Akmal Abd Aziz[1], Mohamad Fani Sulaima[1], Subiyanto Subiyanto[2], Zulkifli Ab Rahman[3]

[1]Faculty of Electrical Technology & Engineering, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[2]Department of Electrical Engineering, Universitas Negeri Semarang, Semarang, Indonesia
[3]Transafe Consult Sdn Bhd, Shah Alam, Malaysia
Email: *fazliana@utem.edu.my

How to cite this paper: Kadir, A.F.A., Aziz, M.A.A., Sulaima, M.F., Subiyanto, S. and Rahman, Z.A. (2025) Energy Management Analysis of Hybrid Photovoltaic and Battery Energy Storage System. *Journal of Power and Energy Engineering*, **13**, 277-292.
https://doi.org/10.4236/jpee.2025.138015

Received: July 27, 2025
Accepted: August 24, 2025
Published: August 27, 2025

Abstract

Malaysia's National Energy Transition Roadmap (NETR) aims to accelerate the shift towards a sustainable, low-carbon energy system. The effective integration of photovoltaic (PV) systems and battery energy storage systems (BESS) is crucial for optimizing energy usage, reducing costs, and lowering carbon emissions. To support these goals, Universiti Teknikal Malaysia Melaka (UTeM) has deployed a 5 kW hybrid inverter integrated with a 4.62 kW PV array (12 panels) and a 10.24 kWh BESS at the FTKE Solar Laboratory. The hybrid inverter operates in three modes—general, peak-shaving, and economy—to enable flexible energy management. This study compared the energy consumption of an FTKE building with and without the hybrid inverter PV-BESS system, where fourteen 3 kW air-conditioning units served as the primary loads. Over two months of testing in each mode, results showed that the General mode achieved the highest energy savings of 441.94 kWh, while the Peak-Shaving mode provided the greatest cost reduction of RM 256.43. These findings indicate that operational mode selection can significantly influence energy and cost performance, with implications for supporting Malaysia's NETR objectives through improved energy efficiency and reduced carbon emissions.

Keywords

Photovoltaic, Peak Shaving, Energy, Battery Energy Storage System (BESS), Hybrid Inverter, Energy Management

1. Introduction

Renewable energy is energy derived naturally from sources that can be replenished, such as sunlight, wind, biomass, waves, petroleum, and water. As the world increasingly focuses on renewable energy, the use of solar photovoltaic (PV) systems together with battery energy storage systems (BESS) has become more prominent in commercial building energy systems. Solar PV systems generate electricity directly from sunlight [1]. Malaysia is fortunate to have abundant solar energy due to its favorable climate for electricity generation. The country benefits from strong solar radiation and plenty of sunshine throughout the year [2]. As a result, solar PV systems are well-suited for homes, industries, and commercial buildings. Commercial buildings, in particular, gain significant advantages from solar PV systems as they help lower costs while reducing environmental impact.

Commercial buildings often have large rooftop spaces suitable for installing solar PV systems. These systems can be connected to the grid, reduce reliance on grid electricity, supply part of the building's energy demand, and lower overall energy costs. For the solar PV system to operate efficiently, both a hybrid inverter and a battery energy storage system (BESS) are required. Unlike a standard inverter, a hybrid inverter offers multiple operating modes. It can store surplus energy from the solar panels in the battery and also export excess power to the grid, depending on the selected mode and application. One useful feature is the peak shaving mode, which activates when energy consumption exceeds a preset limit. In this mode, the battery discharges to bring consumption back within the limit, reducing peak demand and associated charges. The battery automatically charges and discharges based on the configured settings.

Most electricity production relies on fossil fuels such as coal and natural gas. The price of coal is rising steadily, exacerbated by fluctuating currency exchange rates, further driving up costs for the energy sector [3]. According to the National Energy Transition Roadmap, the goal is to transition from fossil fuel energy to renewable energy. In line with developing a low-carbon economy, environmental conservation, and resource efficiency through green growth, it is noted that 80 percent of greenhouse gas emissions come from the energy sector. By 2050, the country aims to increase the target for renewable energy capacity installation to 70 percent, up from 40 percent in 2040, and achieve net zero emissions. One key renewable and clean energy source is solar power, which harnesses sunlight [4]. There are various strategies to efficiently reduce power consumption and tackle high energy tariff costs. The rising trend in solar energy adoption is driven by its application across domestic, commercial, and industrial buildings [5]. Peak shaving is employed to lower power consumption during peak hours, thereby avoiding demand surges and reducing energy bills. Battery Energy Storage Systems (BESS) play a crucial role in balancing renewable energy supply and electricity demand, as they can release stored energy during periods of high demand. Most electricity generation still depends on fossil fuels such as coal and natural gas. Coal prices have been steadily increasing, and fluctuating currency exchange rates have further raised costs for the energy sector [3]. According to the National Energy Transition

Roadmap, the country aims to shift from fossil fuel–based energy to renewable energy as part of efforts to build a low-carbon economy, protect the environment, and improve resource efficiency through green growth. This transition is crucial because about 80% of greenhouse gas emissions come from the energy sector. By 2050, the target is to raise the installed renewable energy capacity to 70%, up from 40% in 2040, and achieve net-zero emissions. Solar power stands out as a major renewable and clean energy source that harnesses sunlight [4]. Several strategies can help reduce energy consumption and tackle high electricity tariff costs. The adoption of solar energy is rapidly growing across residential, commercial, and industrial buildings [5]. Peak shaving is one such strategy, used to reduce power demand during peak periods, thereby avoiding surges and lowering energy bills. Battery energy storage systems (BESS) are vital in balancing renewable energy supply and electricity demand because they can release stored energy when demand is high [6].

Poor energy management in commercial buildings often leads to financial losses and higher carbon emissions. Many solar energy systems are designed using only average load profiles, without fully understanding the building's actual load patterns [7]. As a result, high maximum demand charges become a major source of financial loss. To ensure optimal system performance, inverter parameter settings must be carefully configured to match the building's needs [8]. Key data such as peak load, peak times, average energy consumption, and non-peak current load are essential for selecting the appropriate inverter mode. Using this data allows for better parameter settings and system specifications, helping to maximize cost savings, reduce carbon emissions, and conserve energy.

The most promising renewable energy source for generating electricity is photovoltaic (PV), which is gaining popularity among power systems due to its affordability and outstanding performance. PV is widely used in practical applications such as communication systems, space technology, autonomous lighting systems, battery charging and domestic power applications [9]. Solar panels can be installed on the roof of buildings or in nearby areas and can be installed to generate clean energy from sunlight. In addition, if the building is in good condition, wind turbines can also be used to provide a continuous supply of clean electricity. This renewable energy source reduces dependence on fossil fuels and greenhouse gas emission.

However, because it depends on the weather, the production of renewable energy is intermittent. Battery energy storage system is useful in this situation. BESS makes it possible to store extra energy produced from renewable sources for later consumption. When there is a low production of renewable energy or a large demand for energy, the stored energy may be used to provide a steady and dependable power supply. Battery energy storage systems (BESS) are a valid complement to renewable energy systems. By increasing the reliability of the entire supply system, they minimize the need for emergency energy reserves [10].

2. Hybrid Inverter

This section discusses the hybrid inverter and battery energy storage system performance, detailing the components used and the system's operation once activated. It also examines the evolution of technology and concepts since their inception. Additionally, the discussion will be focusing on the various operating modes of the inverter and their functionalities. A thorough understanding of each concept and component function is essential for effectively analyzing the system's performance in the context of this research.

A hybrid inverter is a type of inverter used in grid-connected microgrid systems that combine hybrid photovoltaic (PV) and battery energy storage systems (BESS). Its purpose is to manage the flow of power between the main grid, battery storage, and the PV system. Hybrid inverters facilitate the integration of renewable energy sources, like solar energy from PV systems, and the storage of excess energy in batteries. They allow the system to operate in both grid-connected and off-grid modes, enhancing the flexibility and reliability of the power supply. In hybrid mode, the hybrid inverter can seamlessly switch between multiple power sources solar, battery, and grid power to optimize energy output and consumption [11]. A diagram solar power system with hybrid inverter and battery energy storage is shown in **Figure 1** [12].

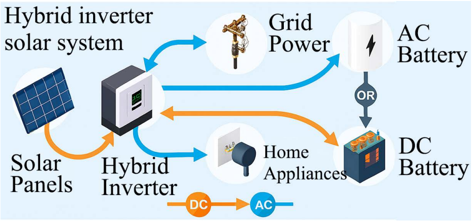

Figure 1. Solar power system with hybrid inverter and battery energy storage [12].

Battery Energy Storage System (BESS) is a system that uses batteries to store electrical energy for later use according to the user's needs. Energy storage systems provide a variety of technical options for managing power flows to build more durable energy infrastructure, save money for consumers, reduce consumption and improve energy efficiency [13]. BESS will often be used in renewable energy systems such as wind energy and solar energy. This is because renewable energy is not constant or intermittent because it depends on the weather. This battery system can link to the grid and release the stored energy to reduce the grid demand [14]. Battery energy storage systems must be appropriately kept there to release energy when needed or in the scenarios desired by the customers. This is where energy management needs to be implemented into BESS, the example such as state of charges (SOC), peak shaving, load shifting, energy arbitrage, and solar PV generation [15].

3. Methodology

The flowchart as shown in **Figure 2** presents a methodology for evaluating a hybrid photovoltaic (PV) and battery energy storage system (BESS). It begins with understanding the PV-BESS setup and inverter modes, followed by selecting an operation mode—Peak Shaving, General, or Economic—and collecting relevant data from the SEMS portal. The next steps involve calculating daily total energy consumption and maximum demand, recording energy-related data in Excel, and analyzing key parameters such as load consumption, cost savings, load factor, maximum demand, and CO_2 reduction. The process is repeated for all selected modes until complete, after which the findings from each mode are compared to determine the optimal configuration, concluding the evaluation. The next subsection discusses each component related to this project such as solar panel, hybrid inverter, BESS, electrical loads and GoodWe SEMS Portal.

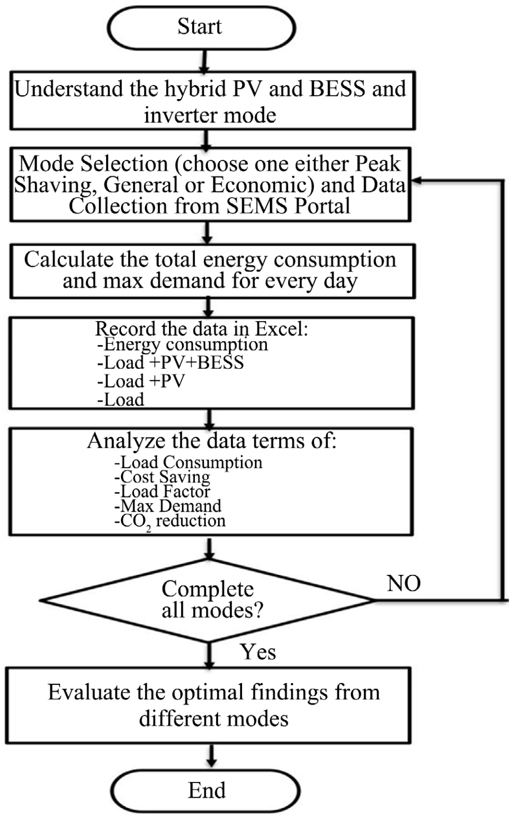

Figure 2. Flowchart of overall methodology.

3.1. Solar Panel

A solar panel is a type of device used to capture solar energy from the sun in the form of irradiation, converting that energy to electricity then transferring it to the loads or a battery system. The solar panels model used for this system is Sun Power SPR-P19-385-COM, has the capability to produce up to 385 W. The number of modules used for this setup is 12 pieces, totaling 4.62 kW of total power capacity.

3.2. Hybrid Inverter

A hybrid inverter functions similarly to a standard inverter, but it also supports an uninterruptible power supply (UPS) that continually supplies power to the load. In addition, this hybrid inverter includes five different modes that can be chosen based on the user's requirements. The inverter has five modes: general, peak shaving, backup, off-grid, and economic. The solar router is integrated into the inverter. A solar router is a sort of technology installed in an inverter that allows users to regulate, optimize, and manage the energy generated. This project makes use of the GoodWe GW5K-ET three-phase inverter type. The power output of the inverter supports up to 5000 W of AC power.

3.3. Battery Energy Storage System

Battery energy storage is a device that stores energy in the form of electricity. In this system, the stored energy comes from either renewable energy from the solar panel or electricity from the grid. The battery may be utilized at any time, according to the user's requirements. This project uses the model Lynx Home S series LX S10-H, the battery has rated energy of 10.24 kWh with usable energy of 9.22 kWh which is Li-Ion battery.

3.4. Electrical Load of Appliances

The electrical load connected to the solar energy system is 14 units of ceiling exposed air conditioner. The model is York with a 3.0 hp ceiling type air conditioner models' system used in Solar PV system and Smart Grid Laboratory. **Table 1** shows the specification of the model.

Table 1. Air conditioner model specification.

Data	York Air Cond (YCE30CB)
Cooling (Btu/Hr)	30,000
Horsepower (HP)	3.0
Total Power (W)	3.238 W
Total Current (A)	13.6 A
Power Source	220 - 240 V, 1 phase, 50 Hz
Dimension	235 × 1.553 × 680
Weight	56
Refrigerant	R22

3.5. PV Master Application

The PV Master app is a configuration tool for GoodWe battery energy storage inverter systems. It allows you to configure the storage inverter locally using a Wi-Fi connection directly. The PV Master application assists the installer in completing the installation of an energy storage system. Several functions can be employed inside the application, including energy modes, energy consumption monitoring, energy production, and battery performance.

3.6. GoodWe SEMS Portal

SEMS portal is a website that serves as a comprehensive monitoring platform for any power plant. The SEMS site allows you to manage organizations and users, add power plants, and view operational data and information for the power plant. In this scenario, our plant is the solar energy system located at FTKE laboratory. Figure 3 shows the interface used to collect data and analyze the load profile, PV energy profile, and battery pattern for one day. Figure 4 shows the generation monthly report, which shows a large amount of data such as energy consumption each, PV energy generated, self-consumption ratio, energy usage from grid etc.

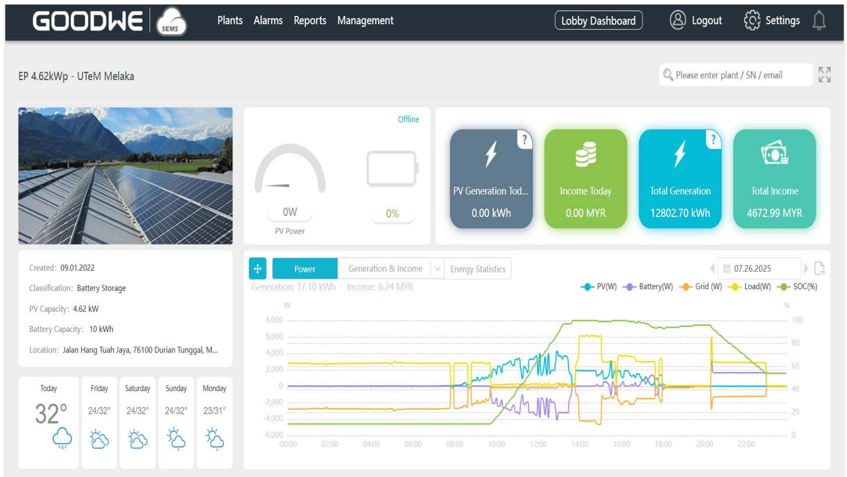

Figure 3. Interface GoodWe SEMS Portal website.

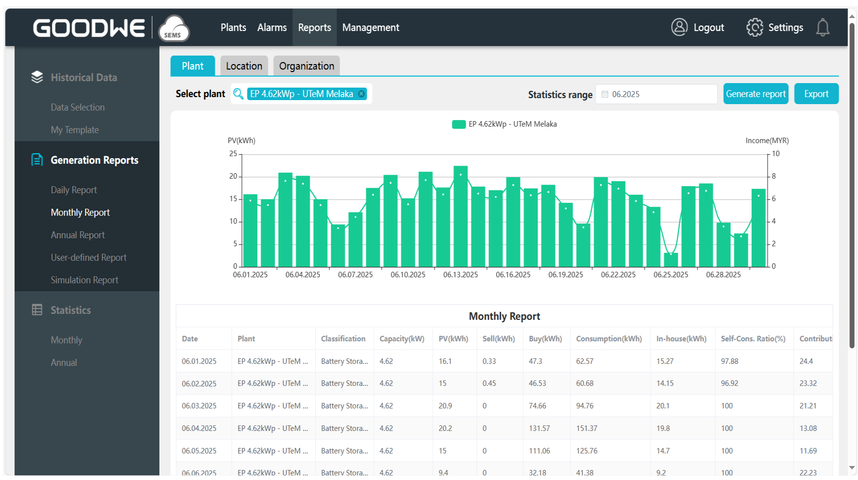

Figure 4. Data generation report of a month.

4. Result and Analysis

The main objective of this chapter is to analyze the load profile of the FTKE's Solar Laboratory with and without hybrid inverter of PV and BESS system using different control modes. There are three (3) inverter control modes considered in this study to find the opportunities for energy savings, cost savings, PV Generation, maximum demand, load factor and CO_2 reduction. The significant findings from the analysis can conclude the best option of control mode of hybrid inverter of PV and BESS to maximize the energy and cost saving.

4.1. Peak Shaving Mode

Peak shaving mode is a mode in which one of the techniques is used to reduce energy consumption from the grid at peak times. In this mode, the setting that will be used is that when the inverter detects energy consumption from the grid exceeding 500 W, battery will be discharged the energy to reduce energy consumption from the grid. The battery will be charged when the inverter detects energy consumption from a load of less than 500 W. The battery will be charged using energy from PV production as well as energy from the grid.

4.1.1. Energy Consumption

The Solar Laboratory's usage of energy is measured using a hybrid inverter for the PV and BESS systems. The data in peak shaving mode was collected for two months, from October to November of 2023.

Figure 5 illustrates the monthly energy consumption in Peak Shaving mode. The results indicate that November recorded higher energy usage compared to October, showing some seasonal variation in load demand.

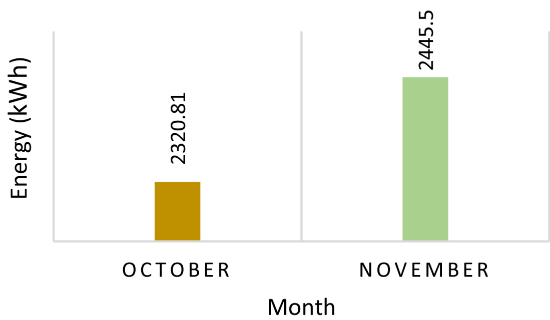

Figure 5. Monthly energy consumption comparison in Peak Shaving mode.

4.1.2. Maximum Demand

Maximum Demand (MD) is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month.

Figure 6 presents the maximum demand recorded in October and November under Peak Shaving mode. The data show that November experienced a higher maximum demand than October.

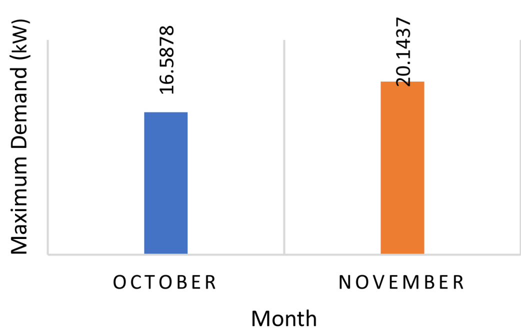

Figure 6. Maximum demand comparison for Peak Shaving mode.

4.1.3. Consumption for Load, Load with PV and Load with PV and BESS

In this section, a comparison of energy consumption, maximum demand, cost, and load factor will be stated by considering 3 conditions of resources and loads: 1) using a hybrid inverter of PV and BESS system, 2) load with PV system, and 3) load only.

Table 2 shows the 3 conditions of resources and loads connected in November 2023 with energy consumption (kWh), MD (kW), bill (RM) and Load Factor. Condition 3 consumes the highest energy, 2832.136 kWh, followed by Condition 1 and 2, 2445.5 kWh and 2412.336 kWh, respectively. PV production in November 2023 was 419.7 kWh. Condition 1 and 3 were chosen for comparative purposes in terms of energy savings and consumption reduction. The findings from this study show that:

Table 2. The difference between the comparison 3 conditions of resources and loads energy consumption in November 2023.

	Condition 1: Load with hybrid inverter of PV and BESS	Condition 2: L with PV	Condition 3: L
ENERGY (kWh)	2445.5	2412.336	2832.136
MD (kW)	20.1437	20.7537	23.9492
Bill (RM)	1502.962	1509.34	1759.39
LOAD FACTOR	0.168615	0.161439	0.164244
PV Generation = 419.7 kWh			
CO_2 Reduction: 386.636 * 0.758 = 293.07 kg CO_2			

1) Energy usage reduced to 386.636 kWh or 13.6% savings.

2) Max demand decreased from 23.9492 kW to 20.1437 kW, giving in a 3.8 kW reduction.

3) The total bill can be saved by RM 256.43, or 14.6% saving cost.

4) The CO_2 reduction is 293.07 kg CO_2.

4.2. General Mode

General mode is the most basic mode available on all types of inverters, although in this case, it is used with hybrid inverters. In this mode, the PV production will go to the load first then if there is excess it will charge the battery. When the inverter detects more than 500 W of grid energy consumption, it discharges the battery and recharges it when the load demand is less than 500 W. The configuration in this mode to charge the battery is using PV energy only.

4.2.1. Energy Consumption

The Solar Laboratory's usage of energy is measured using a hybrid inverter for the PV and BESS systems. The data in peak shaving mode was collected for two months, from December 2023 to January 2024.

Figure 7 shows the monthly energy consumption under General mode. Energy usage in January was slightly higher than in December, consistent with varying building operational patterns.

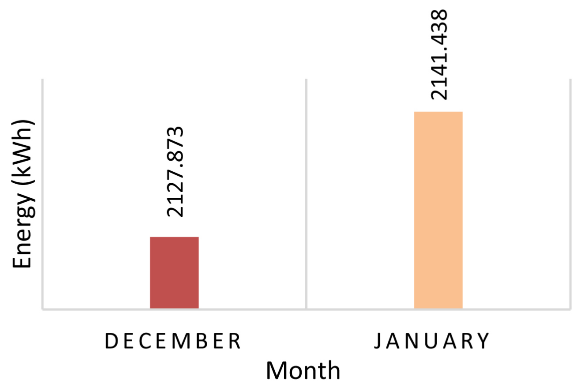

Figure 7. Monthly energy consumption comparison in General mode.

4.2.2. Maximum Demand

Maximum Demand (MD) is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month.

Figure 8 displays the maximum demand for December and January in General mode. The data indicate a small increase in maximum demand in January compared to December.

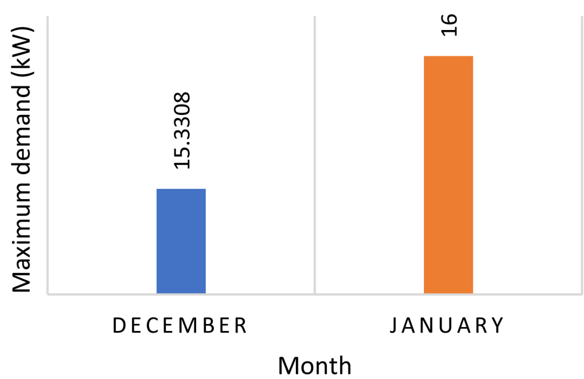

Figure 8. Maximum demand comparison for General mode.

4.2.3. Consumption for Load, Load with PV and Load with PV and BESS

In this section, a comparison of energy consumption, maximum demand, cost, and load factor will be stated by considering 3 conditions of resources and loads: 1) using a hybrid inverter of PV and BESS system, 2) load with PV system, and 3) load only.

Table 3 shows the 3 conditions of resources and loads connected in January 2024 with energy consumption (kWh), MD (kW), bill (RM) and Load Factor. Condition 3 consumes the highest energy, 2583.378 kWh, followed by Condition 1 and 2, 2141.438 kWh and 2198.706 kWh, respectively. PV production in January

2024 was 445.7 kWh. Condition 1 and 3 were chosen for comparative purposes in terms of energy savings and consumption reduction. The findings from this study show that:

Table 3. The difference between the comparison 3 conditions of resources and loads energy consumption in January 2024.

	Condition 1: Load with hybrid inverter of PV and BESS	Condition 2: L with PV	Condition 3: L
ENERGY (kWh)	2141.438	2198.706	2583.378
MD (kW)	16	16	17
Bill (RM)	1266.42487	1287.32769	1458.03
LOAD FACTOR	0.18588872	0.1908599	0.21490713
PV Generation = 445.7 kWh			
CO_2 Reduction: 441.94 * 0.758 = 335 kg CO_2			

1) Energy usage reduced to 441.94 kWh or 17% savings.
2) Max demand decreased from 17 kW to 16 kW, giving in a 1 kW reduction.
3) The total bill can be saved by RM191.6, or 13% saving cost.
4) The CO_2 reduction is 335 kg CO_2.

4.3. Economic Mode

Economy mode is another option that can be customized to the user's preferences. Users can set the charging and discharging times of the battery. In this case, the battery is discharge from 11 a.m. to 6 p.m., and then charged from 6.01 p.m. to 10.59 a. The battery will be charged by solar production and the grid.

4.3.1. Energy Consumption

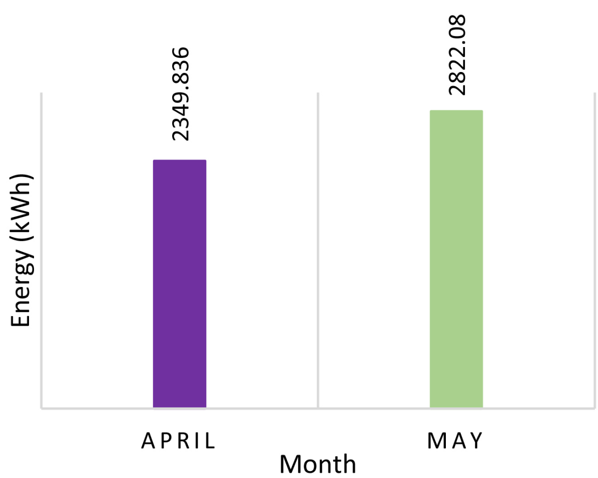

Figure 9. Monthly energy consumption comparison in Economic mode.

The energy consumption of the Solar Laboratory is measured with a hybrid inverter of PV and BESS system. The intelligent inverter monitors and records all the necessary data. The data in peak shaving mode was collected for two months, from April 2024 to May 2024.

Figure 9 illustrates the monthly energy consumption under Economic mode. The building's energy use in May was higher than in April, which may reflect seasonal cooling requirements.

4.3.2. Maximum Demand

Maximum Demand (MD) is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month.

Figure 10 shows the maximum demand for April and May under Economic mode. May recorded a higher maximum demand compared to April.

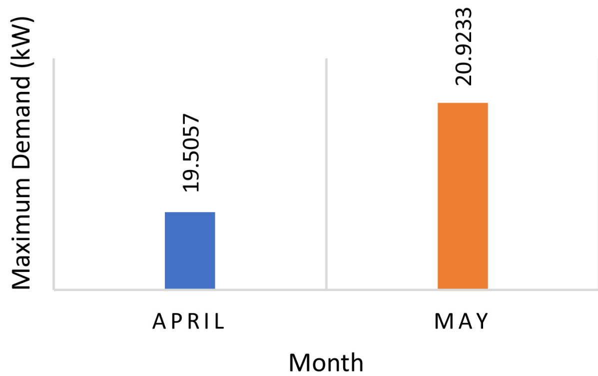

Figure 10. Maximum demand comparison for economic mode.

4.3.3. Consumption for Load, Load with PV and Load with PV and BESS

In this section, a comparison of energy consumption, maximum demand, cost, and load factor will be stated by considering 3 conditions of resources and loads: 1) using a hybrid inverter of PV and BESS system, 2) load with PV system, and 3) load only.

Table 4 shows the 3 conditions of resources and loads connected in April 2024 with energy consumption (kWh), MD (kW), bill (RM) and Load Factor. Condition 3 consumes the highest energy, 2749.953 kWh, followed by Condition 1 and 2, 2349.836 kWh and 2338.232 kWh, respectively. PV production in April 2024 was 423.1 kWh. Condition 1 and 3 were chosen for comparative purposes in terms of energy savings and consumption reduction. The findings from this study show that:

1) Energy usage reduced to 400.117 kWh or 14.55% savings.

2) Max demand decreased from 20.329 kW to 19.5057 kW, giving in a 0.823 kW reduction.

3) The total bill can be saved by RM 171, or 10.55% saving cost.

4) The CO_2 reduction is 303.29 kg CO_2.

Table 4. The difference between the comparison 3 conditions of resources and loads energy consumption in April 2024.

	Condition 1: Load with hybrid inverter of PV and BESS	Condition 2: L with PV	Condition 3: L
ENERGY (kWh)	2349.836	2338.232	2749.953
MD (kW)	19.5057	18.6443	20.3291
Bill (RM)	1448.71285	1418.37697	1619.70458
LOAD FACTOR	0.16731833	0.17418431	0.18787744
PV Generation = 423.1 kWh			
CO_2 Reduction: 400.117 * 0.758 = 303.29 kg CO_2			

4.4. Comparison of Inverter Mode

This section will evaluate the differences in energy consumption, cost savings, maximum demand, and energy savings for the three modes analysed: general mode, economic mode, and peak shaving mode. Comparisons will be limited to a single month per mode. If hybrid PV and BESS systems are not used, the months chosen are nearly identical in terms of energy usage. So, the months chosen for comparison are: November for Peak Shaving mode, January for General mode, and April for Economic mode.

4.4.1. Energy Consumption

Figure 11 compares energy consumption across the three inverter modes. Peak Shaving mode resulted in the highest consumption, followed by Economic mode, while General mode achieved the lowest.

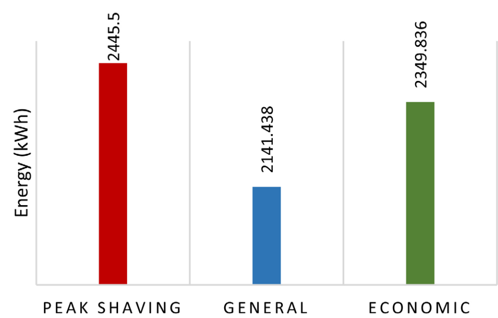

Figure 11. Comparison of energy consumption across inverter modes.

4.4.2. Cost Saving

Figure 12 presents the cost savings for each inverter mode. Among the modes, Peak Shaving provided the greatest cost savings, while Economic mode offered the least.

4.4.3. Maximum Demand

Figure 13 shows the reduction in maximum demand for each inverter mode compared to operation without the hybrid system. Peak Shaving mode achieved the largest reduction, while Economic mode resulted in the smallest decrease.

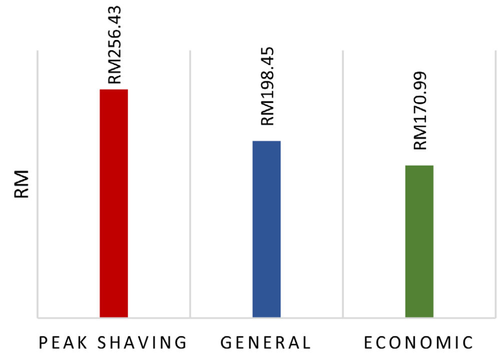

Figure 12. Comparison of cost savings across inverter modes.

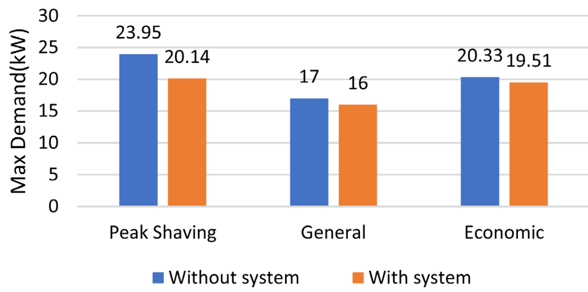

Figure 13. Comparison of maximum demand reduction across inverter modes.

4.4.4. Energy Saving

Energy savings are obtained from the reduction of energy consumption when using hybrid PV and BESS systems. So, in this section we will see which mode has more reduction in terms of energy.

Figure 14 compares energy savings for the three modes. General mode achieved the highest energy savings, followed by Economic mode, while Peak Shaving mode provided the lowest savings.

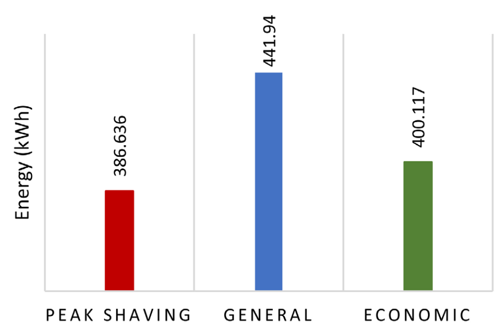

Figure 14. Comparison of energy savings across inverter modes.

5. Conclusions

This project demonstrates the optimal energy management of a hybrid photovoltaic (PV) and battery energy storage system (BESS) inverter installed at the FTKE Solar Laboratory. Three inverter control modes—Peak Shaving, General, and Economic—were evaluated based on load profile, energy savings, cost savings, maximum demand, and CO_2 emission reduction. Energy consumption was analyzed for each mode with and without the hybrid inverter system.

The objectives of this project were successfully achieved, yielding significant findings. Energy savings resulted from the reduction in grid energy consumption when using the hybrid inverter PV-BESS system. The highest energy saving was achieved in General mode (441.94 kWh), followed by Economic mode (400.12 kWh), while the lowest saving was recorded in Peak Shaving mode (386.64 kWh). The results indicate that energy savings depend on PV generation and the frequency of battery charging.

Overall, the hybrid PV-BESS inverter significantly reduces energy consumption and costs while supporting sustainable energy management. Optimal results can be achieved by selecting the inverter mode based on PV generation availability and load profiles, ensuring flexible and efficient operation tailored to user needs. For commercial buildings, building managers can select the General mode to maximize energy savings, the Peak Shaving mode to reduce costs under high-demand tariffs, or the Economic mode to balance both objectives according to their utility tariff structure and sustainability goals. However, these findings are based on a single building with a load profile dominated by air-conditioning in one climate location. As such, the results may vary for buildings with different load characteristics, occupancy patterns, or in regions with differing solar resources and tariff structures.

Acknowledgements

The authors would like to express their sincere gratitude to **Universiti Teknikal Malaysia Melaka (UTeM)** for providing the financial support and research facilities that made this project possible. The resources and guidance provided have been invaluable in ensuring the successful completion of this study. This work directly supports the aspirations of the **United Nations Sustainable Development Goals (SDGs)**, particularly **SDG 7 (Affordable and Clean Energy)** through the promotion of renewable energy integration, **SDG 11 (Sustainable Cities and Communities)** by fostering energy-efficient infrastructure, and **SDG 13 (Climate Action)** through the reduction of carbon emissions and advancement of sustainable energy practices.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Syafii, Z., Juliandri, D. and Akbar, Y. (2018) Design of PV System for Electricity Peak-Shaving: A Case Study of Faculty of Engineering, Andalas University. 2018 *International Conference on Computing, Power and Communication Technologies* (*GUCON*), Greater Noida, 28-29 September 2018, 294-298. https://doi.org/10.1109/gucon.2018.8675096

[2] Koons, E. (2023) Solar Energy in Malaysia: A Bright Future or Dim Prospect?

https://energytracker.asia/solar-energy-in-malaysia/

[3] Department for Energy Security and Net Zero (2023) Energy Trends. https://assets.publishing.service.gov.uk/media/6581bceffc07f300128d44d7/Energy_Trends_December_2023.pdf

[4] Ministry of Economy (2023) National Energy Transition Roadmap. https://ekonomi.gov.my/sites/default/files/2023-08/National%20Energy%20Transition%20Roadmap.pdf

[5] U.S. Department of Energy. Reducing Electricity Use and Costs. https://www.energy.gov/energysaver/reducing-electricity-use-and-costs

[6] Bereczki, B., Hartmann, B. and Kertesz, S. (2019) Industrial Application of Battery Energy Storage Systems: Peak Shaving. 2019 7*th International Youth Conference on Energy* (*IYCE*), Bled, 3-6 July 2019, 1-5. https://doi.org/10.1109/iyce45807.2019.8991594

[7] Paracha, Z.J. and Doulai, P. (1998) Load Management Techniques and Methods in Electric Power System. *Proceedings of EMPD* '98. 1998 *International Conference on Energy Management and Power Delivery* (*Cat. No.*98*EX*137), Singapore, 5 March 1998, 213-217. https://doi.org/10.1109/empd.1998.705514

[8] Sawangsri, W., Kongcharoen, J. and Boonnam, N. (2019) Efficiency Comparison of Data Analysis for Inverter System. 2019 23*rd International Computer Science and Engineering Conference* (*ICSEC*), Phuket, 30 October-1 November 2019, 182-185. https://doi.org/10.1109/icsec47112.2019.8974746

[9] Business Norway (2023) Solar Power Is Revolutionising Commercial Buildings. https://businessnorway.com/articles/solar-power-across-walls-and-roofs-the-future-of-commercial-buildings

[10] Brandi, S., Gallo, A. and Capozzoli, A. (2022) A Predictive and Adaptive Control Strategy to Optimize the Management of Integrated Energy Systems in Buildings. *Energy Reports*, **8**, 1550-1567. https://doi.org/10.1016/j.egyr.2021.12.058

[11] Li, X., Li, H., Fang, B., Wang, L., Li, Y. and Dong, L. (2023) Energy Management Strategy of Battery Energy Storage Station (BESS) for Power Grid Frequency Regulation Considering Battery SOX. *Energy Reports*, **9**, 283-292. https://doi.org/10.1016/j.egyr.2023.04.318

[12] Bai, W., Abedi, M.R. and Lee, K.Y. (2016) Distributed Generation System Control Strategies with PV and Fuel Cell in Microgrid Operation. *Control Engineering Practice*, **53**, 184-193. https://doi.org/10.1016/j.conengprac.2016.02.002

[13] Shi, H. and Chen, Q. (2021) Building Energy Management Decision-Making in the Real World: A Comparative Study of HVAC Cooling Strategies. *Journal of Building Engineering*, **33**, Article ID: 101869. https://doi.org/10.1016/j.jobe.2020.101869

[14] Güğül, G.N. (2023) Optimum Hybrid Renewable Energy System Design for on and off Grid Buildings: Hotel, Education and Animal Hospital Building Case. *Solar Energy*, **253**, 414-427. https://doi.org/10.1016/j.solener.2022.12.044

[15] EEPowers (2020) An Introduction to Inverters for Photovoltaic (PV) Applications. https://eepower.com/technical-articles/an-introduction-to-inverters-for-photovoltaic-pv-applications/#