OPTIMAL ENERGY MANAGEMENT OF HYBRID PHOTOVOLTAIC AND BATTERY ENERGY STORAGE SYSTEM FOR FTKE'S SOLAR LABORATORY

MUHAMMAD AKMAL BIN ABD AZIZ

BACHELOR DEGREE OF ELECTRICAL ENGINEERING WITH HONOUR
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MUHAMMAD AKMAL BIN ABD AZIZ

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DECLARATION

I declare that this thesis entitled "Optimal Energy Management Of Hybrid Photovoltaic And Battery Energy Storage System For FTKE's Solar Laboratory is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature	:	
Name	:	MUHAMMAD AKMAL BIN ABD AZIZ
Date	:	20/6/2024

APPROVAL

I hereby declare that I have checked this report entitled " Optimal Energy Management Of Hybrid Photovoltaic And Battery Energy Storage System For FTKE's Solar Laboratory ", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Mechatronics Engineering with Honours

Signature	:	
Supervisor Name	:	ASSOC. PROF. IR DR AIDA FAZLIANA ABDUL KADIR
Date	:	20/6/2024

DEDICATIONS

I would like to devote my thesis to my beloved parents and siblings who have given me constant support, love, motivation and pray for completing this project.

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ABSTRACT

Malaysia introduced the National Energy Transition Roadmap (NETR) to encourage the country to outline its path towards a sustainable, low-carbon energy system. Effective energy management in photovoltaic (PV) and battery energy storage systems (BESS) is essential to optimize energy use, reduce costs and reduce carbon emissions. To support the Malaysian NETR and SDG, UTeM has installed a hybrid inverter with PV and BESS at the FTKE's Solar Lab. The hybrid inverter rating is 5kW; it has a solar capacity of 4.62kW with up to 12 solar PV panels and a BESS of 10.24kWh. The hybrid inverter has unique features working modes such as general, peak-shaving, and economy modes. This study compares the energy consumption of an FTKE's building with and without a hybrid inverter PV and Battery Energy Storage System (BESS) installation. Due to the feature of the hybrid inverter integrated with the PV and BESS, this project will analyze the impact of various modes of the hybrid inverter that can contribute to energy saving and cost reduction for FTKE's building. The main loads used for this study are the fourteen units of 3kW air-conditioning connected to the hybrid inverter PV and BESS. The logging data will be taken for two months for each mode to analyze the energy performance, like energy saving, cost reduction, and emission reduction of the FTKE's building. At the end of this project, this study will suggest the optimal modes for the operator to get significant outcomes. The result from this study can also be documented in a module so that people can better understand operating the hybrid inverter PV BESS installed in the FTKE's building.

ABSTRAK

Malaysia memperkenalkan Pelan Hala Tuju Peralihan Tenaga Nasional (NETR) untuk menggalakkan negara menggariskan laluannya ke arah sistem tenaga rendah karbon yang mampan. Pengurusan tenaga yang berkesan dalam sistem storan tenaga fotovoltan (PV) dan bateri (BESS) adalah penting untuk mengoptimumkan penggunaan tenaga, mengurangkan kos dan mengurangkan pelepasan karbon. Untuk menyokong NETR dan SDG Malaysia, UTeM telah memasang penyongsang hibrid dengan PV dan BESS di Makmal Suria FTKE. Penarafan penyongsang hibrid ialah 5kW, ia mempunyai kapasiti solar 4.62kW dengan sehingga 12 panel PV solar dan BESS sebanyak 10.24kWh. Penyongsang hibrid mempunyai mod kerja ciri unik seperti mod umum, pencukuran puncak dan ekonomi. Kajian ini membandingkan penggunaan tenaga bangunan FTKE dengan dan tanpa pemasangan PV penyongsang hibrid dan Sistem Penyimpanan Tenaga Bateri (BESS). Disebabkan ciri penyongsang hibrid yang disepadukan dengan PV dan BESS, projek ini akan menganalisis kesan pelbagai mod penyongsang hibrid yang boleh menyumbang kepada penjimatan tenaga dan pengurangan kos untuk bangunan FTKE. Beban utama yang digunakan untuk kajian ini ialah empat belas unit penyaman udara 3kW yang disambungkan kepada penyongsang hibrid PV dan BESS. Data pengelogan akan diambil selama dua bulan untuk setiap mod untuk menganalisis prestasi tenaga, seperti penjimatan tenaga, pengurangan kos dan pengurangan pelepasan bangunan FTKE. Pada akhir projek ini, kajian ini akan mencadangkan mod optimum untuk pengendali mendapatkan hasil yang ketara. Hasil daripada kajian ini juga boleh didokumenkan dalam modul supaya orang ramai dapat lebih memahami pengendalian penyongsang hibrid PV BESS yang dipasang di bangunan FTKE.

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LIST OF SYMBOLS AND ABBREVIATIONS

FTKE	-	Fakulti Teknologi Kejuruteraan Elektrik
BESS	-	Battery Energy Storage System
PV	-	Photovoltaic
AC	-	Alternating Current
DC	-	Direct Current
SDG	-	Sustainable Development Goals
NETR	-	National Energy Transition Roadmap
FTKE	-	Fakulti Teknologi Kejuruteraan Elektrik

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CHAPTER 1

INTRODUCTION

1.1 Background

Renewable energy is natural energy whose sources are free and can be replaced naturally such as sunlight, wind, biomass, waves, petroleum, and water. Due to the growing global emphasis on renewable energy sources, the integration of solar photovoltaic (PV) systems and battery energy storage systems (BESS) has gained attention in the context of commercial building energy management. Sunlight is used as an energy source that is converted from light to electricity using solar PV [1]. Malaysia is a lucky country when it comes to solar energy where the climate is suitable for electricity generation. The country receives excellent solar radiation potential while having a good amount of daily sunlight therefore solar energy is plentiful, and energy can be easily obtained through solar panel technology [2]. Therefore, this solar PV system is suitable for use in homes, industrial sectors, and commercial buildings. Commercial buildings play an important role in the use of solar PV systems because they can reduce environmental impact and cost. This is because with the roof space it can provide installation for solar PV systems. In addition, this solar PV system can connect energy to the grid which can cause less dependence on the use of the grid and can meet part of the building's demand and save bill costs.

To make the solar PV system work efficiently, it needs a hybrid inverter and a battery energy storage system (BESS). A hybrid inverter is an inverter that has various modes compared to a normal inverter. This inverter can store excess solar energy into the battery and can also connect excess energy to the grid depending on the selected mode and application. One of the modes available on this inverter is peak shaving mode. This mode will operate according to the energy that has been set, when the energy used exceeds what is set, the battery will release energy to reduce the maximum energy demand. In this system, the battery will be charged and discharged according to the set settings.

1.2 Motivation

Most of the electricity produced depends on fossil fuels such as coal and natural gas. The price of coal is increasing day by day followed by the effect of fluctuating currency exchange rates has further increased the price of coal for the energy sector [3]. According to the National Energy Transition Roadmap, the energy transition from using fossil fuel energy to renewable energy. In addition, wanting to develop a country that emphasizes low-carbon development, environmental conservation, resource efficiency through green growth, 80 percent of greenhouse gas emissions come from the energy sector. By the year 2050, the country's energy wants to increase the installation target of renewable energy capacity by 70 percent compared to 2040, which is 40 percent, and wants net zero emissions. One of the renewable energies and clean energy that uses sunlight as an energy source is the solar system [4]. There are various ways to efficiently reduce power consumption and address excessive energy tariff costs. Currently, the main cause of this growing trend of solar energy use involves all areas of domestic, commercial, and industrial buildings [5]. Peak shaving is used to reduce the user's power consumption during peak hours to avoid an increase in demand. Peak shaving apps are popular because they help reduce bill costs. Battery Energy Storage Systems play an important role between renewable energy supply and responding to electricity demand. Battery systems can release stored energy during times of high energy demand.

1.3 Problem Statement

Inefficiency in the management of energy resources in commercial buildings will cause financial losses and will contribute to increased carbon emissions. Solar energy systems are built based on average load profiles without a comprehensive understanding of building load patterns [7]. The maximum demand for expensive bills is one of the reasons for the loss of money. In addition, parameter settings on the inverter also need to be considered to determine suitability in the system used. Each data taken will determine the selection of modes available on the inverter [8]. Examples of such data include peak load, peak time, average energy consumption, non-peak current load and more. This data may be used to define the parameters, settings, and specifications for an energy solar system to maximize savings, minimize carbon emissions, and save energy.

The lack of systematic module documentation on solar technology systems on commercial buildings has hindered the wider application of solar technology. In addition, the absence of comprehensive modules can pose safety risks related to PV installation. It will also cause inefficiencies in the system used and will cause a loss in cost effectiveness and maximizing energy generation [9].

1.4 Objectives

The objectives of this project are:

i. To analyze the load profile of FTKE's Solar Laboratory with and without hybrid inverter of PV and BESS system using different control modes.

ii. To develop the module of the hybrid inverter of PV and BESS system for users at Solar Laboratory FTKE, UTeM.

1.5 Scope

The project will be conducted at FTKE's Solar Laboratory, UTeM. The scope of this project is to measure and record power generation data, load consumption and to see the difference without using the system and using the hybrid PV and BESS system. Each data will be obtained through the PV Master or SEMS Portal application. In addition, the data will be taken according to the mode (General Mode, Peak Shaving Mode and Economic Mode) that has been set for every two months. Each data obtained will be analyzed in terms of load profile, energy use, energy savings, bill savings and reduction of CO_2 gas emissions.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter includes a study of the literature on the energy performance of hybrid inverter and battery energy storage systems, as well as the equipment that will be used. The literature review continues with the concept of applied to systems and technological advancements. Besides form that, the literature review focuses on the inverter's work modes and how it operates. Each element's concept and functionality must be thoroughly understood to simply analyze its performance in relation to this study.

2.2 Energy Management

Energy management is an important matter for all newly constructed buildings. It requires strategic coordination of systems for energy use and distribution in a way that optimises efficiency, cost-effectiveness, and sustainability. In addition, energy management aims to minimise waste, reduce environmental impact, conserve energy resources, and ensure a reliable energy supply. This can include a few things, including demand-side management, energy audits, and integrating renewable energy sources [5]. Energy management of a building using renewable energy and battery energy storage systems (BESS) is a strategy that strives to maximise energy use, lessen dependence on fossil fuels, and advance sustainability [6]. By using renewable energy and energy storage systems it can increase the durability of buildings by providing energy supply, contributing to environmental sustainability, and reducing energy costs for a long time because renewable energy such as solar and wind is free energy and can reduce the use of grid energy [5][6]. Currently, solar and wind energy are the most advanced renewable energy sources. Both technologies have a bright future due to significant reductions in production costs, improved reliability and enhanced scientific research. Although these renewable energy systems only occasionally work, interest in renewable energy sources, such as wind and solar energy, has grown recently as an alternative that can supply energy needs [7]. 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].

2.3 Solar Panel

The source of solar energy is the sun. Photons, the energy particles that make up sunlight, are converted into electricity using solar panels (sometimes referred to as "PV panels") so that electrical loads can be powered. The main part of a solar panel is the solar cell. PV cells are components produced from various semi-conductive devices such as Silicon, Cadmium, Gallium, Germanium, Titanium, and others. It can directly generate solar energy from sunlight. In general, PV cells are named for the semi-conductive material used to create them. They are classified according to their producing metal, properties, and applications. There are three varieties of PV cells which are first generation PV cells, second generation PV cells, and third generation PV cells. Figure 2.1 is a summary of the different PV cells [11].

Categories	First-generation PV cell	Second-generation PV cell	Third-generation PV cell
Raw materials	Polysilicon and Monocrystalline silicon	Amorphous silicon, CdTe, CIGS	Organic material, Inorganic substances
Cost comparison	Higher than the other two	Lower than the other two	Lower than 1st but higher than 2nd generation
Innovation	Oldest and common	Latest than 1st generation	Very recent and not used commercially yet
Efficiency	Lab-based 24.7% Module-based 22.7%	Lab-based 18.4% Module-based 13.4%	Lab and module-based efficiency is higher than 30%
Advantages	1. It has high conversion efficiency.	1. It has a higher absorption co-efficient. 2. Lower cost compared with silicon-based solar cells.	1. Raw material is available and easy to find. 2. Fabrication process is easier than the other two.
Disadvantages	1. Fabrication is very complex. 2. Cost is very high.	1. Raw material is not available everywhere. 2. Environment pollution can occur during fabrication.	1. It uses liquid electrolytes which need to maintain low temperature. 2. Higher cost for using Ru (dye) and Pt (electrode)

Figure 2.1: Summary of different PV cells [11]

To model a single solar cell as a current source coupled with a single diode and two resistors is possible. To build a photovoltaic (PV) module is to connect several solar cells in parallel and in series. When photons particles fused with negatively charged silicon of the cell, electrons freed off and move to the positively charged silicon. Hence direct current is produced as electron moves from positive to negative silicon and so on [12]. Figure 2.2 shows a model photovoltaic (PV) module. [12].

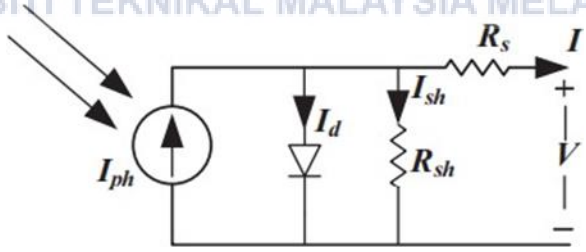

Figure 2.2: Single diode model of a solar cell[12]

The output current of the PV cell can be simplified and expressed as in Equation (1) [12].

$$I = I_{ph} - I_0\left\{\exp\left[\frac{q(V + R_s I)}{nkT}\right] - 1\right\} - \frac{V + R_s I}{R_{sh}}$$

(1)

where I is the output current, Iph is the light generation current, Io is the reverse saturation current of the cell, V is the output voltage, q is the electron charge, 1.6 x 1023 (C), T is the cell temperature in Celsius, k is Boltzamann's constant, 1.38 x 1019 (J/k), Rsh is the shunt resistance and RsI is the series resistance. n represents the ideality factor where it ranges from 1 to 2, it is for a non-ideal diode where it is a defect from an ideal diode [13]. The amount of incoming radiation affects the output produced by the PV module. The photocurrent will increase, and the open circuit voltage will decrease with increasing light intensity. Any solar cell has a loss of efficiency when the temperature increases and is not evenly distributed throughout the cell [11]. Photovoltaic (PV) systems consist of various solar panels, inverters, and loads that are electrical or mechanical components. One or more solar panels paired with an inverter and a load form a photovoltaic (PV) system.

2.4 Inverter

The main function of the Inverter is to convert direct current (DC) to alternating current (AC) [14]. Based on its function and use, photovoltaic systems are divided into two, namely grid-connected PV systems and stand-alone PV systems. On this system, it can operate directly connected to the load or can be connected to the utility grid. Solar inverters maximized the generated power from solar panels by detecting the maximum power point tracking (MPPT) under different environmental conditions and converting DC to AC power at an appropriate voltage and frequency. To store surplus energy from solar in the battery system or known as battery energy storage system (BESS) it requires a hybrid inverter for later consumption consumers [9]. Figure 2.3 shows the connection for grid system and stand-alone system and the solar power system [15].

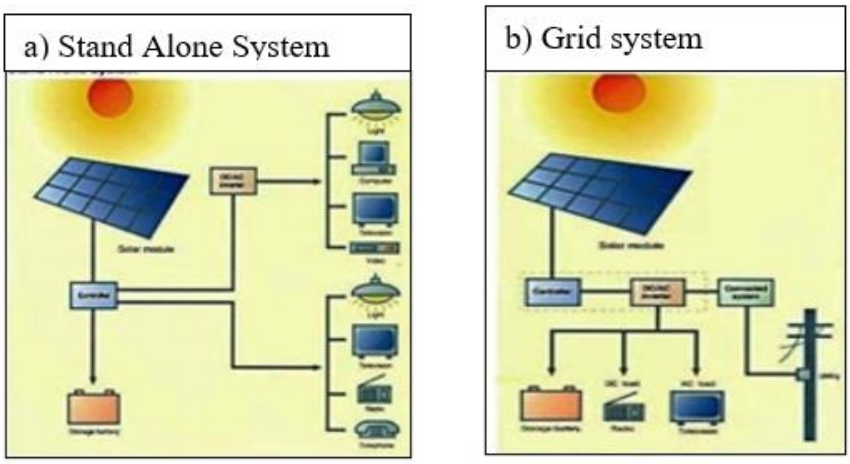

Figure 2.3: The connection for grid system and stand-alone system and the solar power system [15]

2.4.1 Hybrid Inveter

A hybrid inverter is a type of inverter used in a grid-connected microgrid system with a hybrid photovoltaic (PV) and battery energy storage system (BESS). Its purpose is to control the flow of power between the main grid, the battery storage, and the photovoltaic system. Hybrid inverters allow the combination of renewable energy sources, such as solar energy from PV systems, as well as excess energy storage in battery systems. It also enables the system to work in both grid and off-grid connection modes to increase the flexibility and reliability of the power supply. The hybrid inverter can dynamically transition between multiple power sources, such as solar, battery, and grid power, in hybrid mode to optimize energy output and consumption [11]. Figure 2.4 shows a diagram solar power system with hybrid inverter and battery energy storage [16].

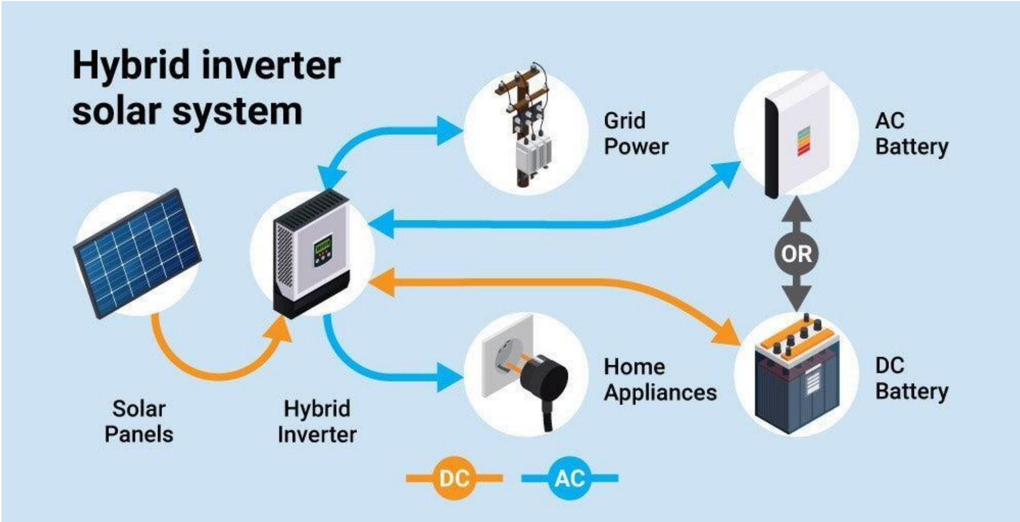

Figure 2.4: Solar power system with hybrid inverter and battery energy storage [16].

2.4.1.1 Advantages of Hybrid Inverter

Hybrid Inverter offers many advantages compared to normal inverter. It incorporates energy storage in the form of a battery, this hybrid inverter offers continuous energy. The saved energy will be utilized in accordance with the mode selected. This system can operate in a variety of modes. It is also possible to save cost by employing a hybrid inverter. This is because the energy generated is free and comes from the sun. Furthermore, because the system is less reliant on grid energy, it can minimize the cost of our electrical bills. Finally, because of solar router installed within the inverter, it can allow the user the flexibility to manage and monitor energy usage using smart controller or an application [11].

2.5 Battery Energy Storage System (BESS)

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 [17]. 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 [18]. 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.[19].

2.5.1 Battery Energy Storage System (BESS) Technology

BESS has a variety type of technologies based on its structure such as based on Lead-Acid, Lithium-ion, Sodium sulfur battery, Vanadium Redox flow or Sodium Nickel Chloride. However, the most used for BESS is Lithium-ion batteries, this is because when considered with performance, calendar life and cycle life and cost, it is cheaper and worthwhile in the long run and can be used in a wide variety of applications [20].

2.6 Peak load shaving

Peak shaving is the process of reducing electricity use to avoid peak demand too high. Peak demand charges are the costliest portion of the power bill [21]. Peak demand is when energy customers have the most electricity. These unexpected jumps in electricity consumption can put a strain on the system, potentially leading to power outages and blackouts if supply cannot keep up [22]. Reducing peak demand allows utilities to better match supply and demand, optimize the use of existing infrastructure, and reduce the need for costly infrastructure expansions [23]. Energy storage technologies, such as battery energy storage systems, can be important in peak shaving. Energy consumers can store energy in this battery system for use during off-peak hours. Then, this stored energy can be delivered to the load during times of high demand, thus reducing the peak demand that the grid has to supply [24].

2.7 Cost Saving

Hybrid inverters provide significant cost savings via a variety of methods. Combining solar power and grid electricity can lower electricity expenses by up to 50% [25][26]. Maximizing the usage of solar energy has the potential to minimize grid energy consumption and boost long-term cost savings. Excess solar energy can be stored in batteries for use during peak hours or outages, significantly reducing grid electricity use and costs. In regions with net metering, excess solar energy can be sold back to the grid, generating additional revenue. Furthermore, by minimizing peak demand, hybrid inverters help prevent costly infrastructure changes, which may result in cheaper electricity rates. Increased reliance on self-generated solar power also shields homeowners against future rises in grid electricity costs. Overall, a hybrid inverter is a valuable investment that reduces energy costs and promotes sustainability [27].

2.8 Summary

To provide a complete review of relevant literature for my research, I created a table summarizing data from multiple publications. This table contains important information such as publication titles and study results. Examining this table will allow me to gain a better knowledge of the current state of research in my subject, as well as discover any gaps in my own work.

Table 2.1: Journal Summary

No.	Title	Findings
1	A predictive and adaptive control strategy to optimize the management of integrated energy systems in buildings	Enhancing energy cost optimisation, boosting the use of on-site renewable energy sources like solar photovoltaics, and enhancing the energy system's flexibility and resilience by making the best use of energy storage
2	Efficiency Comparison of Data Analysis for Inverter System	There are many factors that can affect the efficiency of the inverter so, analysis can help in finding ways to enhance system performance as an entire system.
3	A review on hybrid photovoltaic – Battery energy storage system: Status, challenges, and future directions	Hybrid photovoltaic (PV) and battery energy storage systems (BESS) are attracting global interest due to the benefits of PV in generating clean, renewable energy and the advantages of BESS in cost-effectiveness, performance, response time, and lifecycle
4	Forecasting Cost Saving Through Solar System Installation	To raise awareness by analyzing solar energy generation and potential cost saving.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the methodology used in this project to obtain data on the energy performance of hybrid inverter and battery energy storage systems in FTKE's buildings in UTeM. This project starts by studying and researching the previous data energy performance of hybrid inverter and battery energy storage systems. Data was taken in Inverter Room Solar Lab inside Solar PV System and Smart Grid Laboratory. The data that will be taken are current, voltage, battery discharge and power of both load and sources. This data is used for determining load profile for different modes in the inverter, energy saved and the cost savings of the system. The data is obtained digitally through a smart inverter where the inverter is built in Wi-Fi to transmit the data through the cloud and finally to the application where the user can view the data. Moreover, a smart meter is also installed in the distribution box to measure total power of the load by measuring current and power throughout the analysis. Therefore, in this research to investigate the energy performance of hybrid inverter and battery energy storage systems in FTKE's buildings in UTeM, this chapter will give information data that be taken with the calculation and be described on the graph.

3.2 Research Design

This project is carried out in the FTKE Laboratory at UTeM. Each data will be taken according to a specific time interval that is different. There are several tools used to obtain energy data performance, namely smart meters, solar routers and PV Master and SEMS Portal applications. The smart meter will be installed in the distribution box. Solar routers have Wi-Fi to send data to the cloud for applications. PV Master is used to select the modes available on the hybrid inverter and to make settings while the SEMS Portal application is used to monitor stored data such as battery performance, load usage, PV generated and battery charge and discharge time. To achieve the objectives in investigative analysis of energy performance of hybrid inverter and battery energy storage system, it requires a flowchart in Figure 3.1.

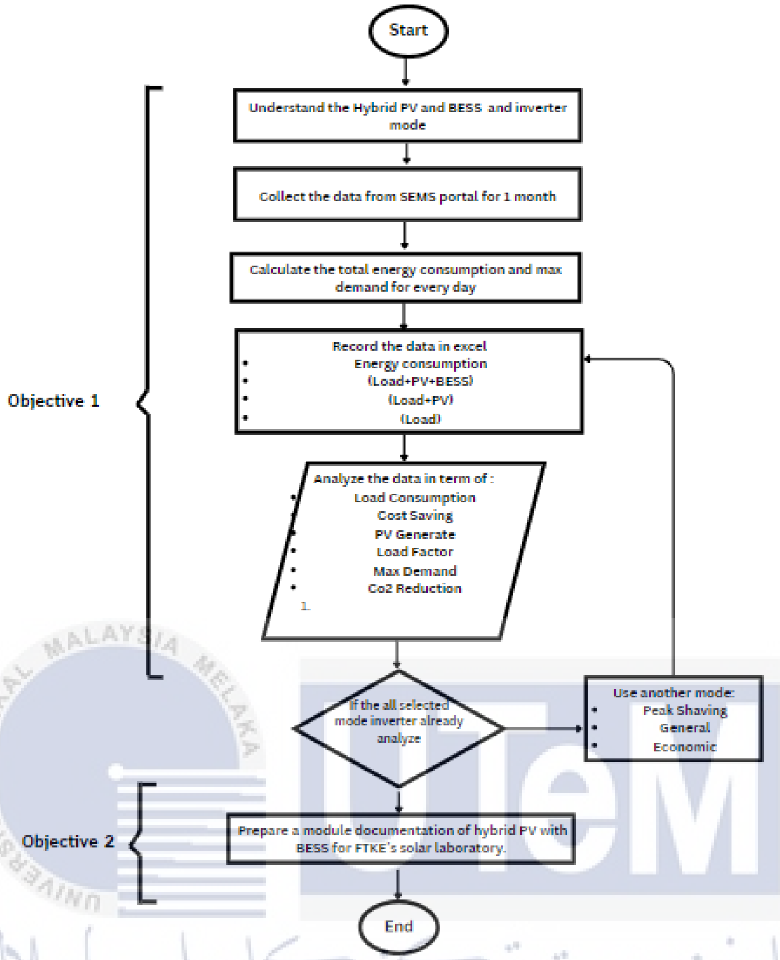

Figure 3.1: Flow chart of the methodology

This flowchart shows hoe to run the final year project. Each objective has been placed to be achieved. The first objective is to analyze the data load profile of each inverter mode without using and using PV and BESS. Data will be taken every day for one month for each type of mode that has been set. Then will be recorded in Microsoft Excel to plot the load profile and analyze it. Data to be analyzed such as load usage, PV generated, Max Demand, cost savings and load factor. Next, the same method will be repeated for each mode that will be selected, namely General Mode, Shaving Peak Mode and Economy Mode. After all the data is obtained, the second objective will be carried out, which is to create a documentation module for hybrid PV with BESS for FTKE's solar laboratory.

3.2.1 Experimental Setup

To study the energy performance of hybrid inverter and battery energy storage systems. The main components in this system are solar panels, hybrid inverters, and battery storage. There are many different models available in the market, hence the right selection is necessary to create an efficient and budget-friendly solar energy system. Applications are also used to select energy management and monitoring.

3.2.1.1 Solar Panel

The solar panels model used for this system is SunPower SPR-P19-385-COM, the has the capability to produce up to 385W for 1 panel. The number of modules used for this setup is 12 panels, total output for 12 panel is 4.62kW of total power capacity. Below, Figure 3.2 shows the technical data of the solar panel and Figure 3.3 shows the solar panel technical data.

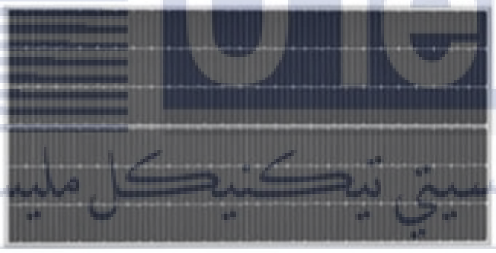

Figure 3.2: Solar panel model SunPower SPR-P19-385-COM

Electrical Data						
Model	SPR-P19-410-COM	SPR-P19-405-COM	SPR-P19-400-COM	SPR-P19-395-COM	SPR-P19-390-COM	SPR-P19-385-COM
Nominal Power (Pnom)[4]	410 W	405 W	400 W	395 W	390 W	385 W
Power Tolerance	+5/−0%	+5/−0%	+5/−0%	+5/−0%	+5/−0%	+5/−0%
Efficiency	19.9%	19.6%	19.4%	19.2%	18.9%	18.7%
Rated Voltage (Vmpp)	45.7 V	45.3 V	44.8 V	44.4 V	44.1 V	43.8 V
Rated Current (Impp)	8.98 A	8.94 A	8.93 A	8.90 A	8.85 A	8.80 A
Open-Circuit Voltage (Voc)	54.5 V	54.0 V	53.6 V	53.4 V	52.9 V	52.5 V
Short-Circuit Current (Isc)	9.55 A	9.53 A	9.50 A	9.47 A	9.45 A	9.44 A
Maximum System Voltage	1000 V IEC					
Maximum Series Fuse	18 A					
Power Temp. Coef.	−0.36% / ° C					
Voltage Temp. Coef.	−0.29% / ° C					
Current Temp. Coef.	0.05% / ° C					

Figure 3.3: Solar panel technical data

3.2.1.2 Hybrid Inverter

A hybrid inverter works like a regular inverter, but it allows for an uninterruptible power supply (UPS) that supplies power consistently to the load. In addition, this hybrid inverter has 5 types of modes that can be selected according to the user's needs. The mode in inverter is general mode, peak shaving mode, backup mode, off-grid mode, and economic mode. The solar router is embedded in the inverter. A solar router is a type of technology installed in an inverter that gives users the flexibility to control, optimize and manage the energy produced. Inverter model GoodWe GW5K-ET which is a 3phase inverter is use for this project. The power output for inverter supports up to 5000W of AC power. Figure 3.4 shows the inverter installed.

Inverter mode:

1. **General mode:** PV generated power will supply load first then charge battery, if their surplus power will export to grid.

2. **Peak Shaving mode:** Battery will discharge energy when the load power usage exceeds power import set by inverter.

3. **Backup mode:** If PV generated is more than load, PV will supply load first and charge battery, if PV generated less than load, PV and battery will supply the load.

4. **Off grid mode:** same as backup mode. But this mode is when we do not want use supply form grid.

5. **Economic mode:** Battery charge/discharge time and power can be flexible set on application.

Figure 3.4: GoodWe GW5K-ET inverter

3.2.1.3 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 10.24kWh with usable energy of 9.22kWh which is Li-Ion battery. Figure3.5 shows the battery model used for the setup.

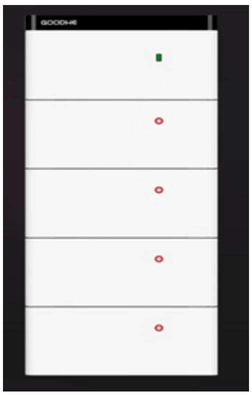

Figure 3.5: Lynx Home S series LX S10-H

3.2.1.4 Electrical Load

The electrical load connected to the solar energy system is 14 units of ceiling exposed aircond. The model is York with a 3.0 hp ceiling type. Figure 3.6 below shows the aircond used as loads of the solar energy system in Solar PV system and Smart Grid Laboratory. Table 3.1 shows the specification of the model.

Figure 3.6: Aircond 3hp ceiling exposed

Table 3.1: Airconditioner model specification

Data	**York aircond (YCE30CB)**
Cooling (Btu/Hr)	30,000
Horsepower (HP)	3.0
Total Power (W)	3.238W
Total Current (A)	13.6A
Power Source	220-240v, 1 phase, 50hz
Dimension	235x1.553x680
Weight	56
Refrigerant	R22

3.2.1.5 Smart Meter

The smart meter was installed in the distribution box of the connected load which are the 16 units of air conditioner. The data collected was the voltage, current and power passing through the distribution box. Figure 3.7 shows the distribution box of the load along with the smart meter installed.

Figure 3.7: Smart Meter

3.2.1.6 Application PV Master

The PV Master app is a configuration tool for GoodWe's battery energy storage inverter products. It can configure the storage inverter locally through a direct Wi-Fi connection. The solar go application can monitor energy performance in the selected mode. Several features can be used in the application namely energy mode, energy consumption monitoring, energy generated and battery performance. In addition, in this application is a place to select the mode available on the inverter and a place to make the settings provided. Figure 3.8 shows the application that needs to be downloaded at mobile phone. Besides that, Figure 3.9 below shows the application used where it shows the interface used to select modes and Figure 3.10 shows the interface for energy monitoring.

Figure 3.8: Application Solar Go

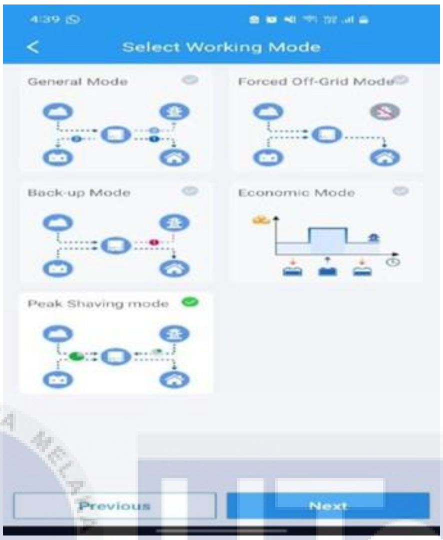

Figure 3.9: Interface for work modes

Figure 3.10: Interface for energy monitoring

3.2.1.7 Goodwe SEMS Portal

The SEMS portal is a website that serves as a monitoring platform for all power plants. The SEMS site allows you to manage organizations and users, add power plants, and view operational statistics and alarm information for power plants. In this scenario, our plant is the solar energy system at the FTKE Laboratory, UTeM. Figure 3.11 shows the logo for SEMS Portal that can be downloaded at mobile phone or open at website. Figure 3.12 shows the interface used to collect data and observe its load profile, PV energy profile and battery charge and discharge pattern and battery SOC for 1 day. Besides that, it displays current situation data. Figure 3.13 shows the generation monthly report that shows numerous amounts of data such energy consumption per day, PV energy generated, self-consumption ratio and energy from PV and battery.

Figure 3.11: Application SEMS Portal

Figure 3.12: Interface GoodWe SEMS Portal website

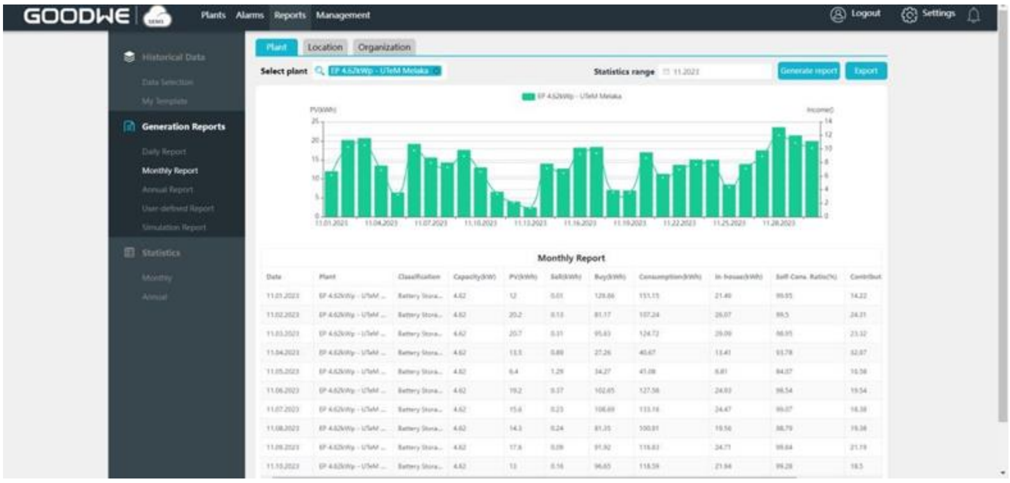

Figure 3.13: Data generation report of a month

3.2.1.8 Parameter setting for General Mode

In general mode, the system uses PV energy to supply the load. If the PV power has excess energy, it will charge the battery. The battery is only charged using energy from solar. and if there is excess energy will be exported to the grid. In addition, when the PV energy is insufficient for the load demand, the battery will be discharged. Insufficient energy will be supported from grid energy. At night, the PV is not working, the battery will be discharged to supply energy to the load and the grid will supply energy if the battery power is insufficient.

3.2.1.9 Parameter setting for Peak Shaving Mode

The system uses only PV energy to supply the load and the battery energy storage system can be set when and under what conditions to discharge. The battery is set to charge and discharge at a certain value of the peak value or also known as "import power limit" and the time period can also be set in the parameter settings. If the load is higher than the import power limit value then the battery will be discharged within the specified time period and if the load is below that, then the battery will not be discharged. The battery is charged when there is excess PV energy or by the grid when the load is low. The parameter set for the peak shaving mode is the time period starting from 12.00 am to 11.59 pm and the import power limit is set at 5kW. This parameter will repeat every day. The time period is set due to the unpredictable load spikes that occur throughout the day in the system used. Power import limits are set so that batteries can discharge energy to reduce consumption from grid energy and reduce peak demand.

3.2.1.10 Parameter setting for Economic Mode

In economy mode, also known as peak shaving application, used mostly to minimize peak demand. This is usually used to reduce costs in areas where peak demand rates are high. Battery discharge can be configured using time or power thresholds based on the user's power consumption profile and applied during peak demand. Currently, PV electricity is used to further minimize peak demand. During off-peak hours, the battery is charged using solar PV panels or the power grid.

3.2.1.11 Module Documentation

This documentation module is intended to be used as a guide to Hybrid PV and battery energy storage systems for solar lab FTKE's. This module will make it easier for system owners to understand more clearly and easily. This is to reveal the technology of this system in the commercial building sector that wants bill savings, energy efficiency and carbon gas reduction.

3.3 Gantt Chart

A Gantt chart is used to show the project timeline and report progress for Analysis of Hybrid Inverter and Battery Energy Storage System Performance in FKE Building. The time set for each activity is expressed in weeks, and each task has a dependency relationship. The total time required is from the first week to the 14th week. Table 3.2 is a Gantt chart illustrating the timeline of the project and the evolution of the research report.

Table 3.2: Gantt Chart

Activity / Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research about project title	■	■												
Project work planning		■	■											
Literature Review			■	■	■	■	■							
Methodology						■	■	■	■					
Collect selected data for result							■	■	■	■				
Analyze Data Collection										■	■	■		
Seminar Presentation												■		
Report Progress												■	■	■

3.4 Limitations of proposed methodology

A hybrid inverter has five separate modes. The mode observed in the hybrid inverter cannot be analyzed in this investigation because the load consumption exceeds solar production. Increasing solar energy capacity requires a large investment. As a result, only three modes are viable for investigation. In addition, each parameter is carefully set based on monthly load usage.

3.5 Summary

In summary, this chapter suggests the methodology needed to conduct this research. The presented flowchart shows the workflow, allowing smooth progress by following the chart. A flowchart guides the process flow from the beginning of the process to the end, and it includes objectives, technical data and information or data acquisition. In addition, there are several procedures that need to be done to achieve the objectives while conducting research. Every data taken needs to be analyzed, presented and calculated to get the difference in how the inverter works. Finally, create a documentation module to create a clear and easy-to-understand guide for users.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

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 CO2 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 and CO2 reduction.

4.2 Case study

Several case studies have been carried-out to achieve the objective of analyzing the load profile of buildings with and without hybrid PV inverters and BESS using the difference in control modes. The case studies have a total of 3 consisting of different inverter control modes and load profile types. Such case studies are listed below:

i. Peak Shaving Mode

ii. General Mode

iii. Economic Mode

4.2.1 Case study 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 500W, 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 500W. The battery will be charged using energy from PV production as well as energy from the grid.

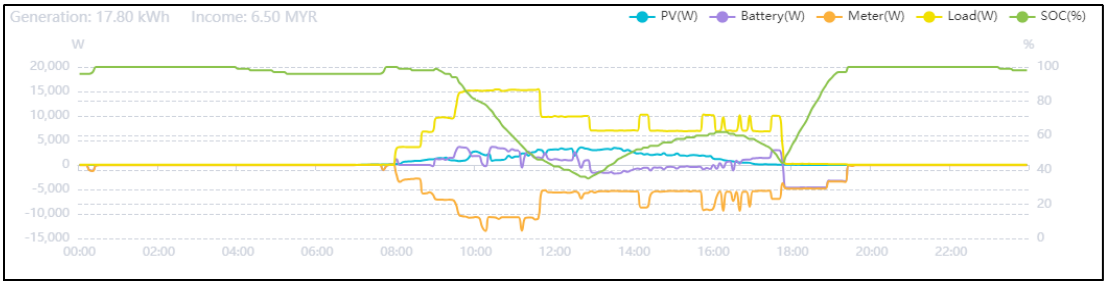

Figure 4.1: Load profile in weekdays

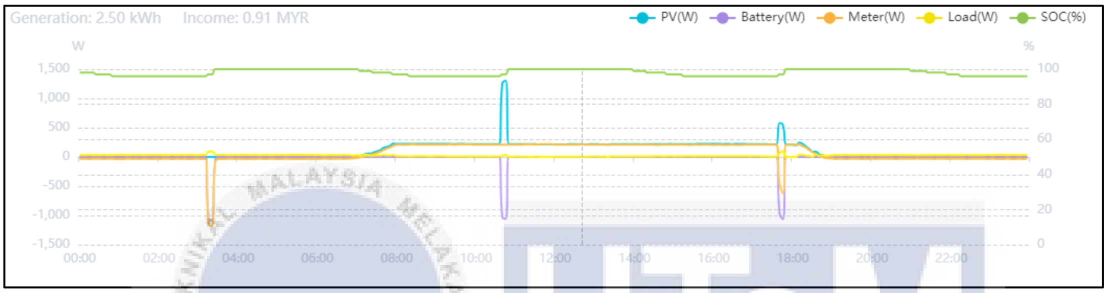

Figure 4.2:Load profile in weekends

Based on Figures 4.1 and 4.2 shows a sample of a 2-days load profile during weekdays and weekends. From that figures, the energy consumption used is more on weekdays compared to weekends. Lower energy consumption during weekend due to no research activity on weekends. The load profile also shows the usage time of the battery charged and discharged according to the current load demand.

4.2.1.1 Energy Consumption

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 October 2023 to November 2023. The bar chart in Figure 4.3 nd 4.4 shows the energy consumptions information.

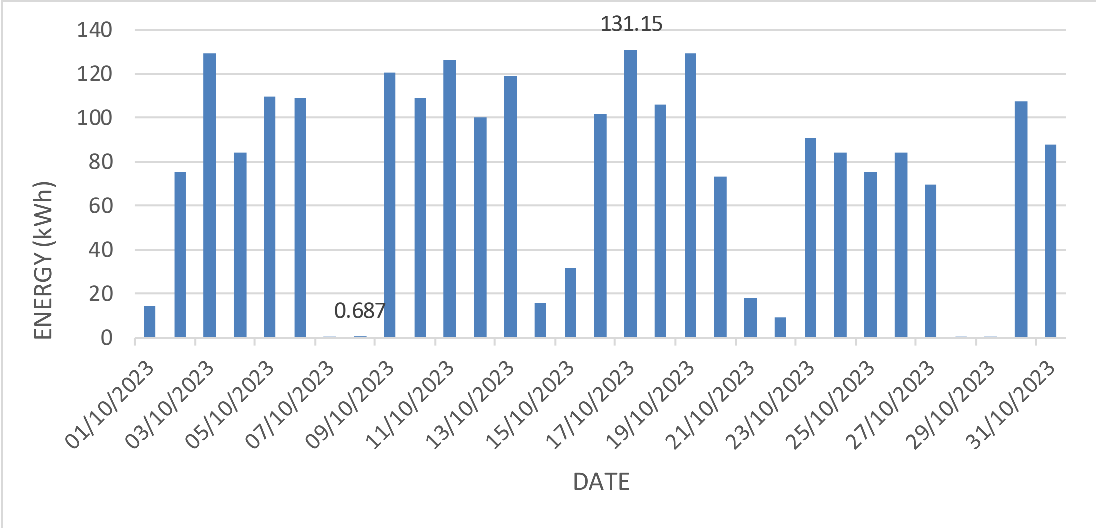

Figure 4.3: Energy consumption in October 2023

Based on Figure 4.3, it shows the data represented in a graph where the bar shows the energy consumption for a period of 31 days in October 2023. The highest energy consumption was 131.15 kWh where it occurred on 17 October 2023 while the lowest energy consumption was 0.687 kWh where it occurred on 8 October 2023 .

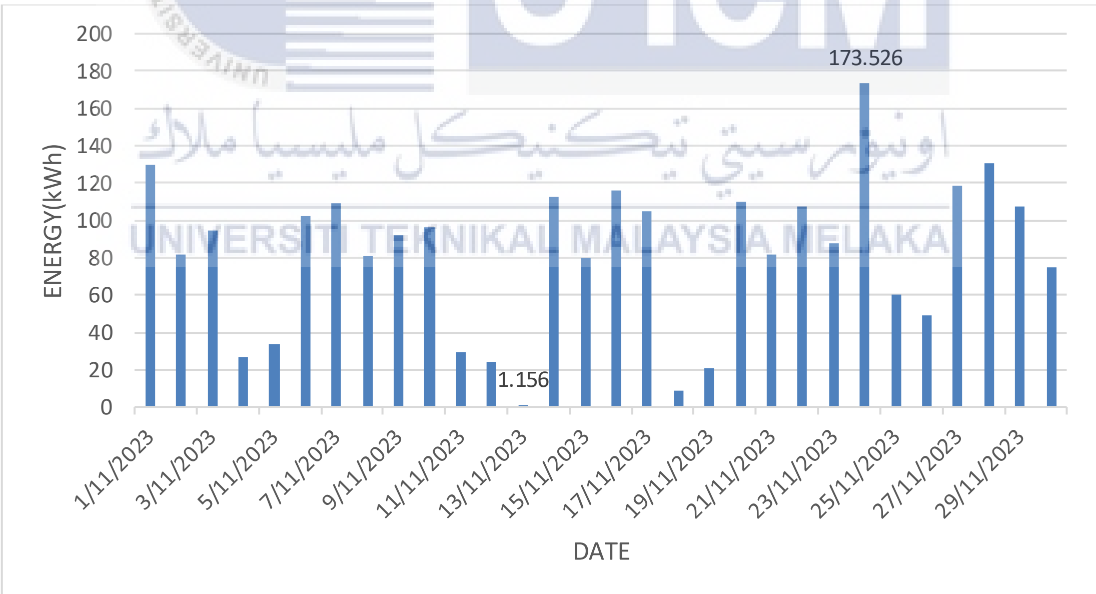

Figure 4.4: Energy consumption in November 2023

Based on Figure 4.4, it shows the data represented in a graph shows the energy consumption for a period of 30 days in November 2023. The highest energy consumption was 173.526 kWh where it occurred on 24 November 2023 while the lowest energy consumption was 1.156 kWh where it occurred on 13 November 2023.

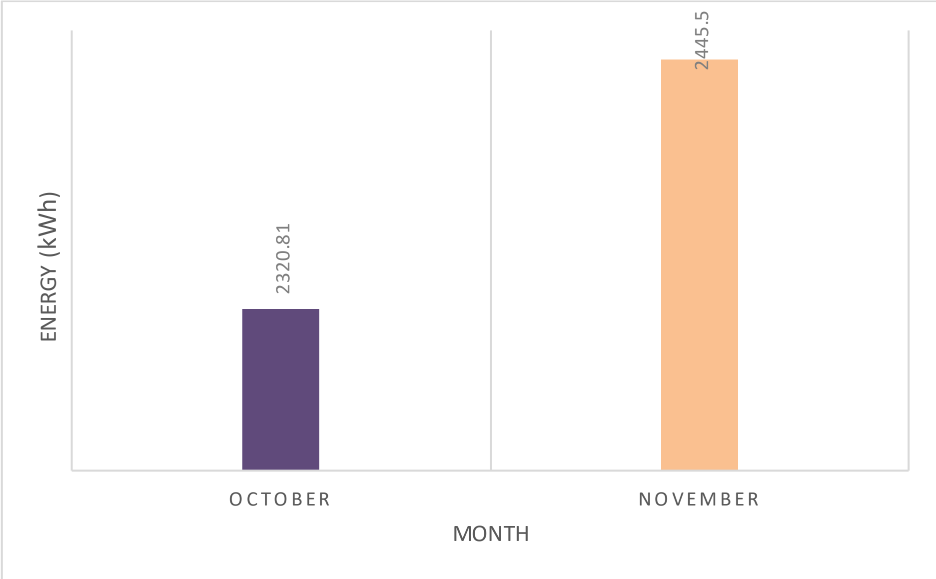

Figure 4.5: Total consumption per month

Based on Figure 4.5, the graph shows the total consumption for 2 different months where November has more energy usage compared to October which is 2445.5 kWh and 2320.81 kWh per month respectively.

4.2.1.2 Maximum Demand

Maximum Demand (MD) is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is very RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month. The Table 4.1 and Figure 4.6 show the MD data for the Solar Laboratory in the months of October 2023 and Table 4.2 and Figure 4.7 for November 2023.

Table 4.1:Max demand data in October 2023

Date	Max Demand(kW)	Date	Max Demand(kW)
1/10/2023	5.615	17/10/2023	14.928
2/10/2023	11.496	18/10/2023	12.264
3/10/2023	15.8605	19/10/2023	15.0193
4/10/2023	14.3493	20/10/2023	8.63883
5/10/2023	16.5878	21/10/2023	3.71683
6/10/2023	14.4958	22/10/2023	5.61983
7/10/2023	0.429667	23/10/2023	12.589

8/10/2023	0.033	24/10/2023	11.3528
9/10/2023	14.375	25/10/2023	12.2443
10/10/2023	13.8733	26/10/2023	11.024
11/10/2023	15.6027	27/10/2023	11.2313
12/10/2023	11.7603	28/10/2023	0.242167
13/10/2023	13.2637	29/10/2023	0.034
14/10/2023	5.98467	30/10/2023	12.4
15/10/2023	5.16033	31/10/2023	11.3865
16/10/2023	13.3125		

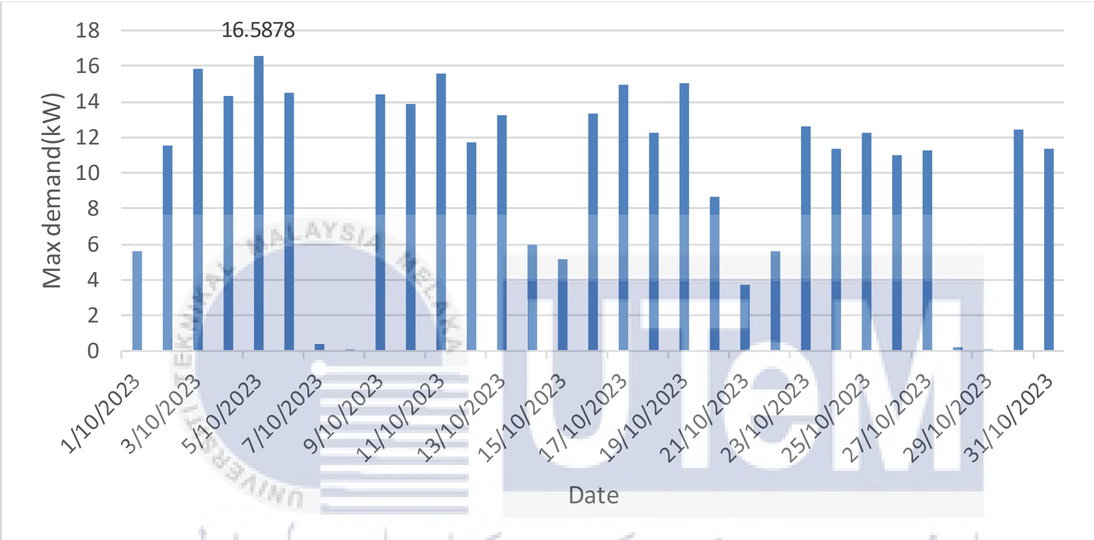

Figure 4.6: Daily Max Demand October 2023

Figure 4.6 and Table 4.1 represented the maximum demand value kW in the month of October,2023. The highest demand is 16.5878 kW (5 October 2023) while the lowest demand is 0.033 kW (8 October 2023). Therefore, the bill for MD charged for this month is RM502.61.

Table 4.2:Max demand data in November 2023

Date	**Max Demand(kW)**	**Date**	**Max Demand(kW)**
1/11/2023	14.7037	16/11/2023	12.9813
2/11/2023	11.4057	17/11/2023	14.0637
3/11/2023	12.0613	18/11/2023	2.46617
4/11/2023	4.98967	19/11/2023	6.2455

5/11/2023	5.11517	20/11/2023	15.9727
6/11/2023	12.6717	21/11/2023	11.0373
7/11/2023	11.9625	22/11/2023	12.4078
8/11/2023	9.95633	23/11/2023	8.59717
9/11/2023	12.908	24/11/2023	20.1437
10/11/2023	13.8917	25/11/2023	5.1525
11/11/2023	5.059	26/11/2023	9.36533
12/11/2023	4.983	27/11/2023	15.072
13/11/2023	0.033	28/11/2023	14.2045
14/11/2023	18.6533	29/11/2023	8.9605
15/11/2023	11.4622	30/11/2023	10.8532
16/12/2023	13.0903		

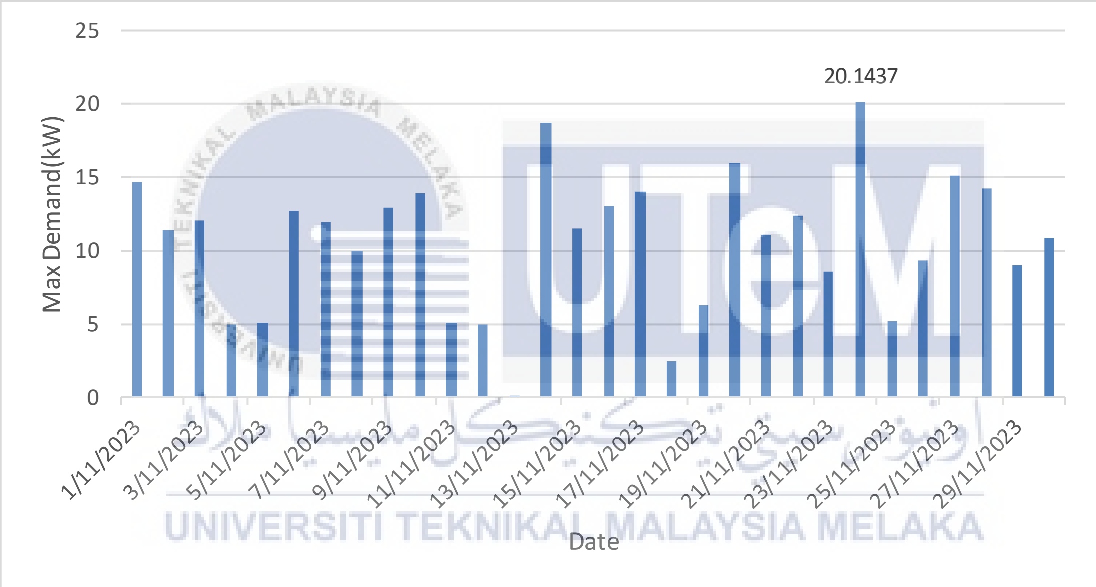

Figure 4.7: Daily Max Demand November 2023

Figure 4.7 and Table 4.2 represented in a graph represents the maximum demand value kW in the month of November 2023. The highest demand is 20.1437 kW(25 November 2023) while the lowest demand is 0.033 kW (13 November 2023). Therefore, the total bill for MD charged on this month is RM610.35.

4.2.1.3 Consumption for Load, Load with PV and Load with PV and BESS

In this section, a comparison of energy consumption, max demand, cost and load factor will be discussed by considering 3 conditions of resources and loads, which are; a) using a hybrid inverter of PV and BESS system, b) load with PV system and, c) Load only in period of 2 months (October and November,2023).

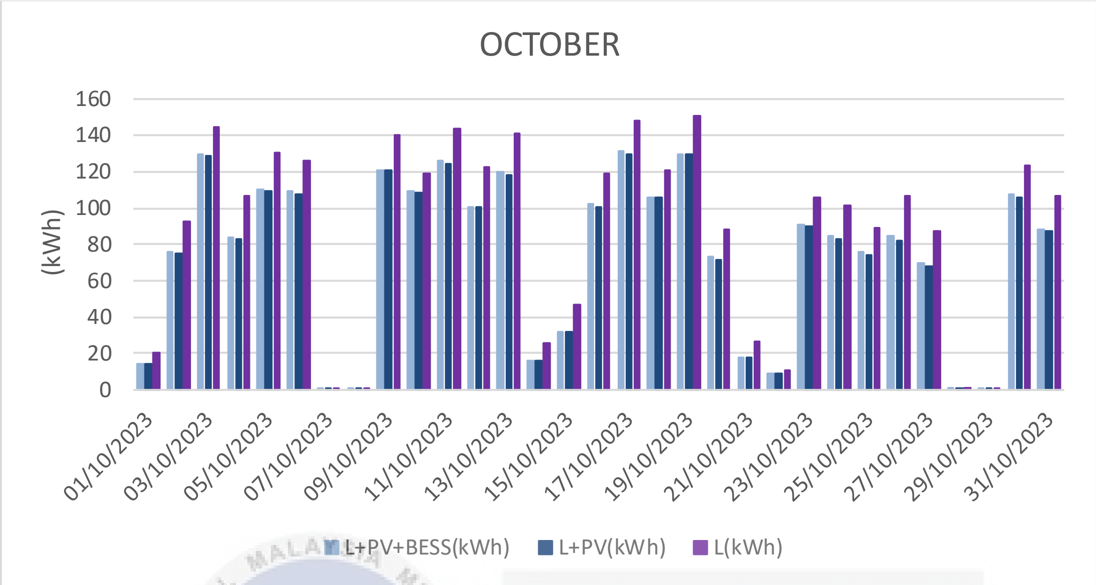

Figure 4.8: Daily energy consumption October 2023

Based on Figure 4.8, it shows the daily energy consumption for 1 month. The light blue chart shows the data of Load with hybrid inverter of PV and BESS systems, while the blue chart indicate the Load with PV system, while the purple chart shows the only Load in the system.

Table 4.3: The difference between the comparison 3 conditions of resources and loads energy consumption in October 2023

	Condition 1: Load with hybrid inverter of PV and BESS	Condition 2: Load with PV	Condition 3: Load
ENERGY (kWh)	2320.811	2295.516	2746.156
MD (kW)	16.5878	16.6927	18.9075
Bill (RM)	1349.706355	1343.65215	1575.24419
LOAD FACTOR	0.194320441	0.19099467	0.201724477
PV Generation = 465.8kWh			
CO2 Reduction : 425.345 * 0.758 = 322.41kg CO2			

Table 4.3 shows the 3 conditions of resources and loads connected in October 2023 with energy consumption (kWh), MD(kW), bill (RM) and Load Factor. Bases on Table 4.3, Condition 3 consumes the highest energy, 2746.156kWh, followed by Condition 1 and 2, 2320.811kWh and 295.516kWh, respectively. PV production in October 2023 was 465.8 kWh. Condition 1 and 3 were chosen for comparative purposes in terms of energy savings and consumption reduction. The findings from this study shows that

i. Energy usage reduced to 425,345kWh or 15.5% savings.
ii. Max demand decreased from 18.9075kW to 16.5878kW, giving in a 2.32kW reduction.
iii. The total bill can be saving by RM225.54, or 12.3% saving cost.
iv. The CO2 reduction is 322.41 kgCO2

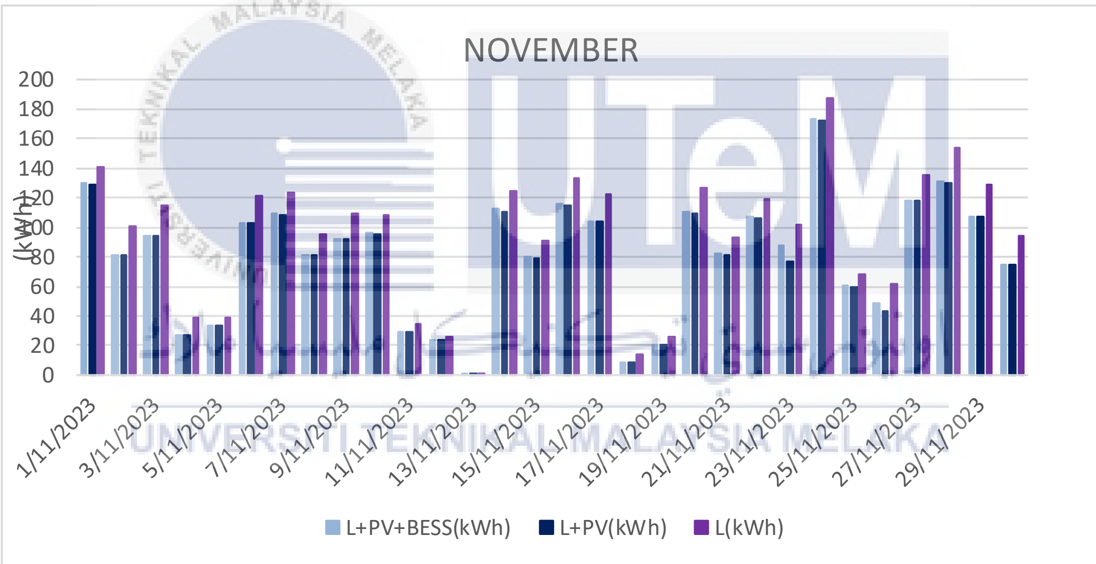

Figure 4.9: Daily energy consumption November 2023

Based on Figure 4.9, it shows the daily energy consumption for 1 month. The light blue chart shows the data of Load with hybrid inverter of PV and BESS systems, while the blue chart indicate the Load with PV system, while the purple chart shows the only Load in the system.

Table 4.4: 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 = 419.7kWh			
CO2 Reduction : 386.636 * 0.758 = 293.07kg CO2			

Table 4.4 shows the 3 conditions of resources and loads connected in November 2023 with energy consumption (kWh), MD(kW), bill (RM) and Load Factor. Bases on Table 4.4, Condition 3 consumes the highest energy, 2832.136kWh, followed by Condition 1 and 2, 2445.5kWh and 2412.336kWh, 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 shows that

i. Energy usage reduced to 386.636kWh or 13.6% savings.
ii. Max demand decreased from 23.9492kW to 20.1437kW, giving in a 3.8kW reduction.
iii. The total bill can be saving by RM256.43, or 14.6% saving cost.
iv. The CO2 reduction is 293.07 kgCO2

4.2.2 Case study 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 500W of grid energy consumption, it discharges the battery and recharges it when the load demand is less than 500W. The configuration in this mode to charge the battery is using PV energy only.

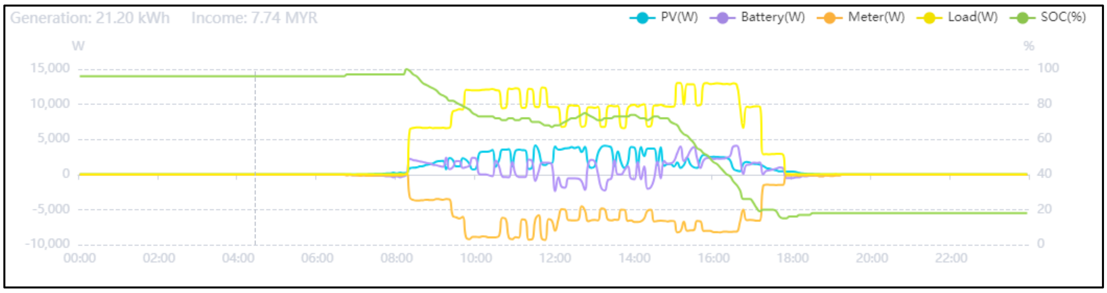

Figure 4.10: Load profile in weekdays

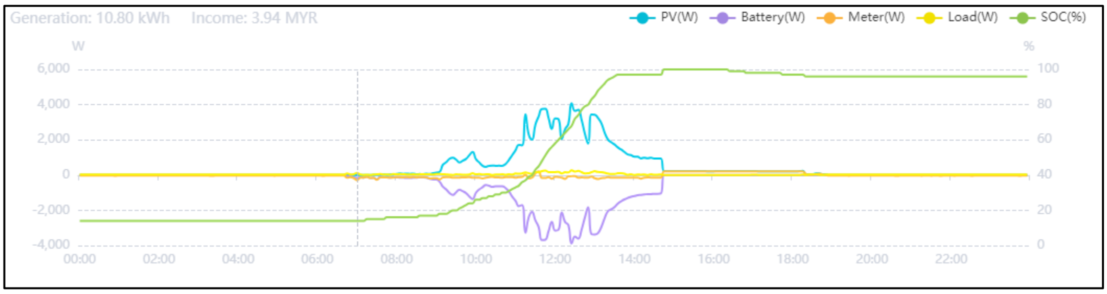

Figure 4.11: Load profile in weekends

Based on Figures 4.10 and 4.11 shows a sample of a 2-days load profile during weekdays and weekends. From that figures, the energy consumption used is more on weekdays compared to weekends. Lower energy consumption during weekend due to no research activity on weekends.The load profile also shows the usage time of the battery charged and discharged according to the current load demand. So from the load profile it can be seen that the battery will be fully charged on the weekend due to low load usage.

4.2.2.1 Energy Consumption

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 December 2023 to January 2024. The bar chart in Figure 4.12 nd 4.13 shows the energy consumptions information.

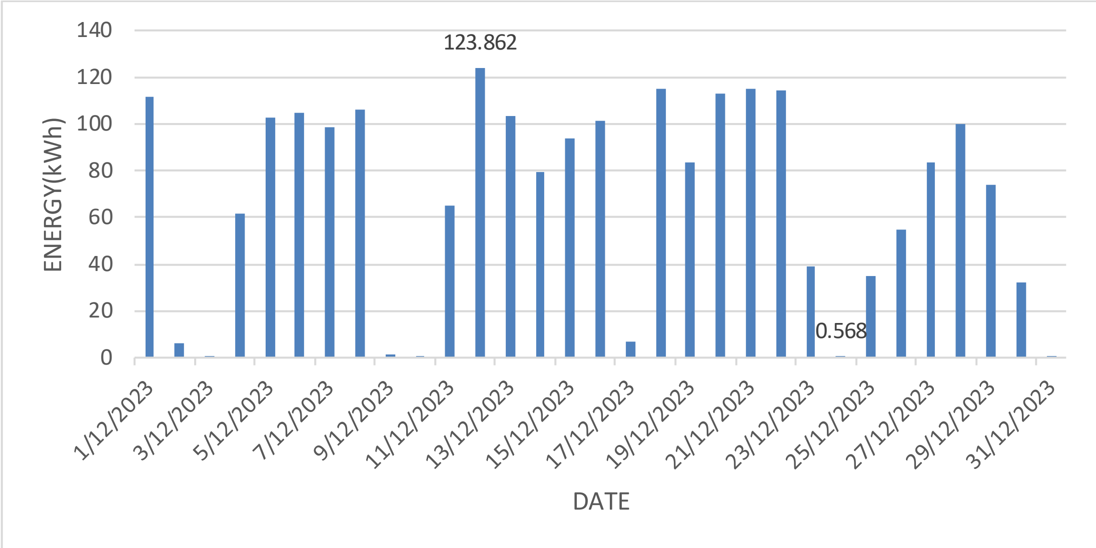

Figure 4.12: Energy consumption in December 2023

Based on Figure 4.12, it shows the data represented in a graph where the bar shows the energy consumption for a period of 31 days in December 2023. The highest energy consumption was 123.862 kWh where it occurred on 12 December 2023 while the lowest energy consumption was 0.568 kWh where it occurred on 25 December 2023.

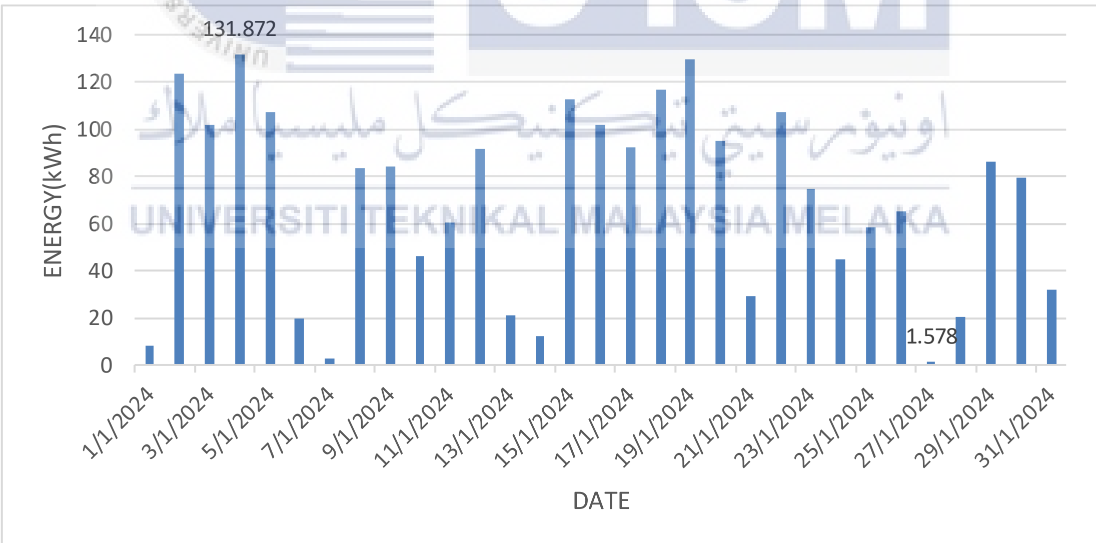

Figure 4.13: Energy consumption in January 2024

Based on Figure 4.13, it shows the data represented in a graph shows the energy consumption for a period of 31 days in January. The highest energy consumption was 131.872 kWh where it occurred on 5 January 2024 while the lowest energy consumption was 1.578 kWh where it occurred on 27 January 2024.

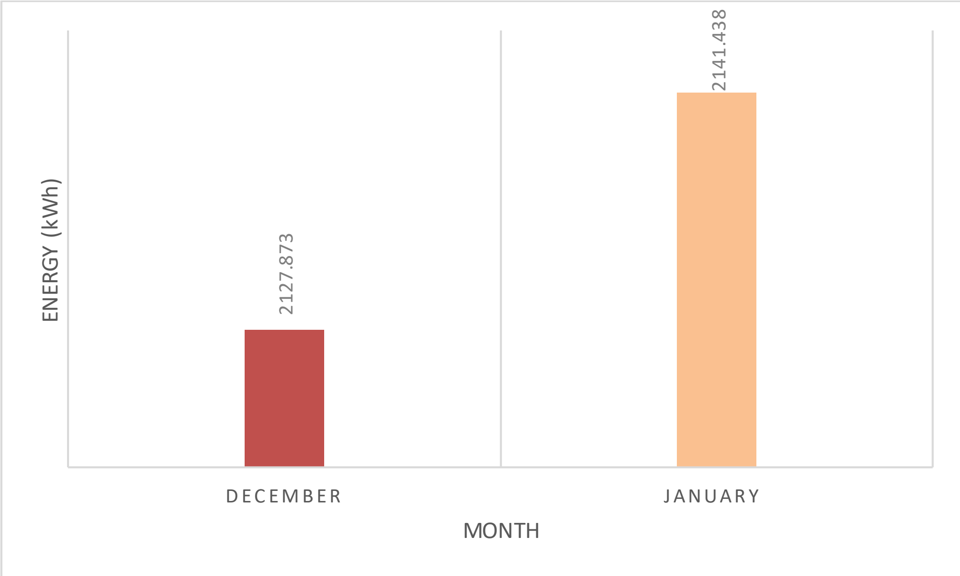

Figure 4.14: Total consumption per month

Based on Figure 4.14, the graph shows the total consumption for 2 different months where January has more energy usage compared to December which is 2141.498 kWh and 2127.873 kWh per month respectively.

4.2.2.2 Maximum Demand

Maximum Demand (MD) is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is very RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month. The Table 4.5 and Figure 4.15 show the MD data for the Solar Laboratory in the months of December 2023 and Table 4.6 and Figure 4.16 for January 2024.

Table 4.5: Max demand data in December 2023

Date	**Max Demand(kW)**	**Date**	**Max Demand(kW)**
1/12/2023	15.3308	17/12/2023	2.25
2/12/2023	1.341	18/12/2023	14.6937
3/12/2023	0.036	19/12/2023	10.6077
4/12/2023	8.18	20/12/2023	14.2458
5/12/2023	15.4	21/12/2023	12.2032
6/12/2023	13.4158	22/12/2023	15.199

7/12/2023	12.3342	23/12/2023	7.3325
8/12/2023	14.5833	24/12/2023	0.033
9/12/2023	0.159667	25/12/2023	7.06233
10/12/2023	0.033	26/12/2023	8.30617
11/12/2023	9.01983	27/12/2023	9.961
12/12/2023	15.264	28/12/2023	10.8288
13/12/2023	13.4585	29/12/2023	7.36567
14/12/2023	9.818	30/12/2023	5.3608
15/12/2023	13.1365	31/12/2023	0.034
16/12/2023	13.0903		

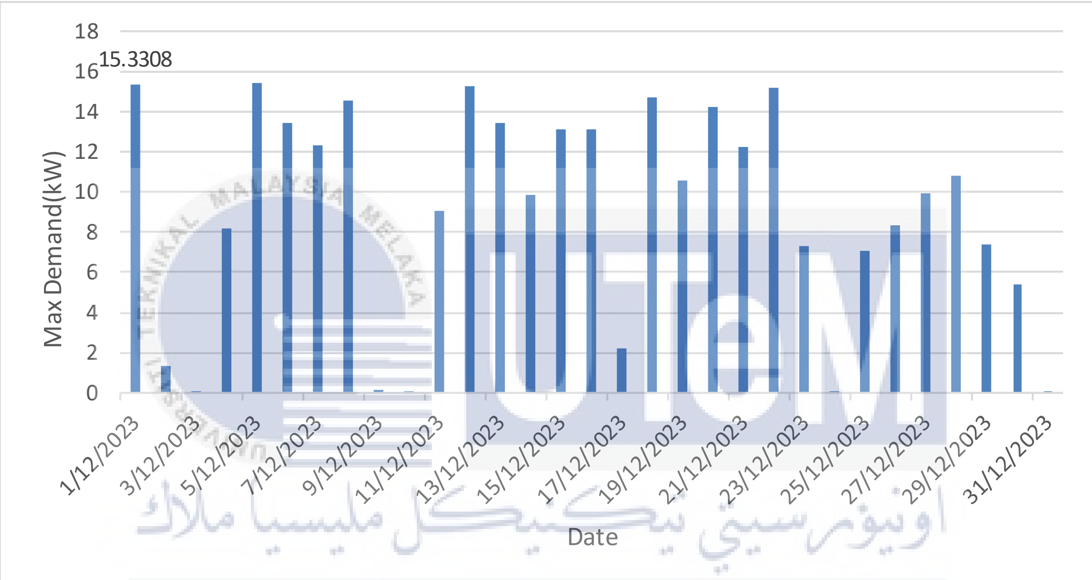

Figure 4.15: Daily Max Demand December 2023

Figure 4.15 and Table 4.5 represented the maximum demand value kW in the month of December 2023. The highest demand is 15.3308 kW (1 December 2023) while the lowest demand is 0.033 kW (10 December 2023). Therefore, the bill for MD charged for this month is RM464.52.

Table 4.6: Max demand data in January 2024

Date	**Max Demand(kW)**	**Date**	**Max Demand(kW)**
1/1/2024	3	16/1/2024	14.3355
2/1/2024	12.2973	17/1/2024	9.9586
3/1/2024	12.9303	18/1/2024	10.561
4/1/2024	15.47	19/1/2024	11.025
5/1/2024	12.264	20/1/2024	11.4803

6/1/2024	5.432	21/1/2024	5.44183
7/1/2024	0.187	22/1/2024	13.3972
8/1/2024	11.2082	23/1/2024	10.6607
9/1/2024	11.259	24/1/2024	9.29867
10/1/2024	7.516	25/1/2024	10.3278
11/1/2024	9	26/1/2024	7.8425
12/1/2024	14.1083	27/1/2024	0.19
13/1/2024	2.903	28/1/2024	5.0315
14/1/2024	1.83633	29/1/2024	8.92183
15/1/2024	16		

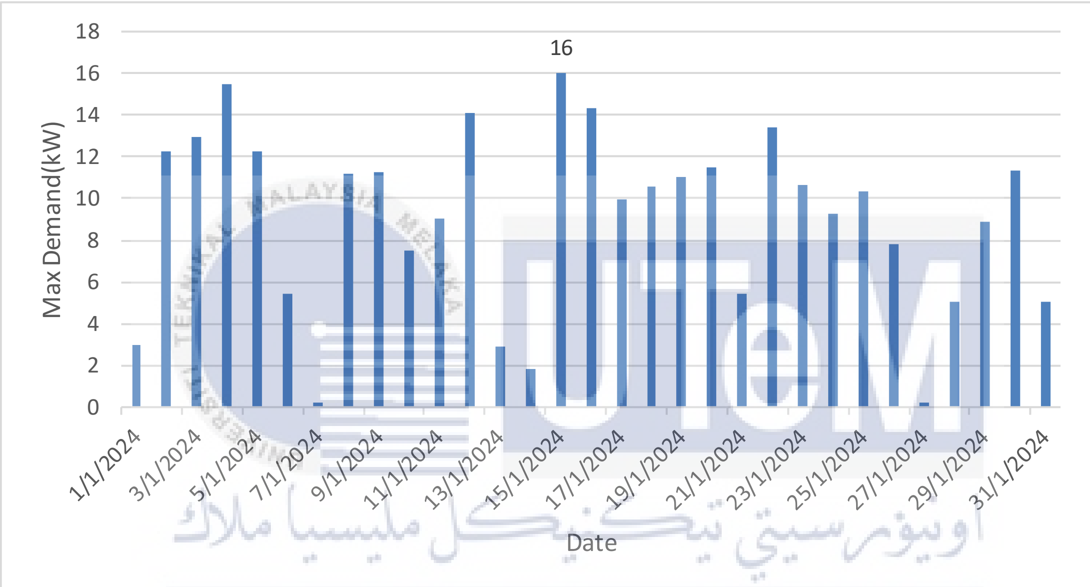

Figure 4.16: Daily Max Demand January 2024

Figure 4.16 and Table 4.6 represented in a graph represents the maximum demand value kW in the month of January 2024. The highest demand is 16 kW(15 January 2024) while the lowest demand is 0.187 kW (7 January 2024). Therefore, the total bill for MD charged on this month is RM484.8.

4.2.2.3 Consumption for Load, Load with PV and Load with PV and BESS

In this section, a comparison of energy consumption, max demand, cost and load factor will be discussed by considering 3 conditions of resources and loads, which are; a) using a hybrid inverter of PV and BESS system, b) load with PV system and, c) Load only in period of 2 months (December 2023 and January 2024).

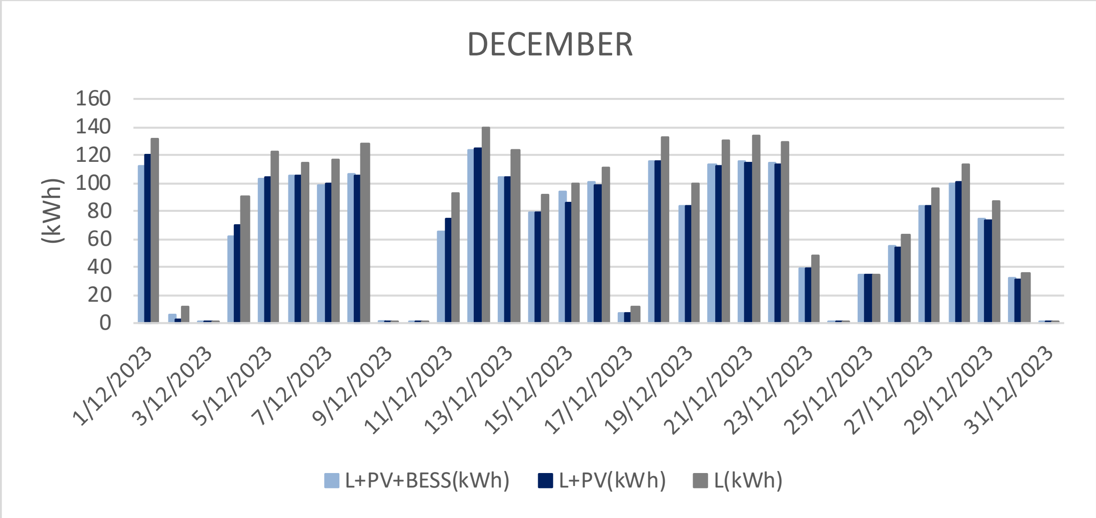

Figure 4.17: Daily energy consumption December 2023

Based on Figure 4.8, it shows the daily energy consumption for 1 month. The light blue chart shows the data of Load with hybrid inverter of PV and BESS systems, while the blue chart indicate the Load with PV system, while the grey chart shows the only Load in the system.

Table 4.7: The difference between the comparison 3 conditions of resources and loads energy consumption in December 2023

	Condition 1: Load with hybrid inverter of PV and BESS	Condition 2: Load with PV	Condition 3: Load
ENERGY (kWh)	2127.873	2134.55	2492.796
MD (kW)	15.3308	17.381	18.1074
Bill (RM)	1241.196885	1305.75505	1458.52476
LOAD FACTOR	0.192773969	0.170568597	0.191204517
PV Generation = 396.1kWh			
CO2 Reduction : 364.923 * 0.758 = 276.61kg CO2			

Table 4.7 shows the 3 conditions of resources and loads connected in December 2023 with energy consumption (kWh), MD(kW), bill (RM) and Load Factor. Bases on Table 4.7, Condition 3 consumes the highest energy, 2492.796kWh, followed by Condition 1 and 2, 2127.873kWh and 2134.55kWh, respectively. PV production in December 2023 was 396.1 kWh. Condition 1 and 3 were chosen for comparative purposes in terms of energy savings and consumption reduction. The findings from this study shows that

i. Energy usage reduced to 364.923kWh or 14.6% savings.

ii. Max demand decreased from 18.1074kW to 15.3308kW, giving in a 2.78kW reduction.

iii. The total bill can be saving by RM217.33, or 14.9% saving cost.

iv. The CO2 reduction is 276.61 kgCO2

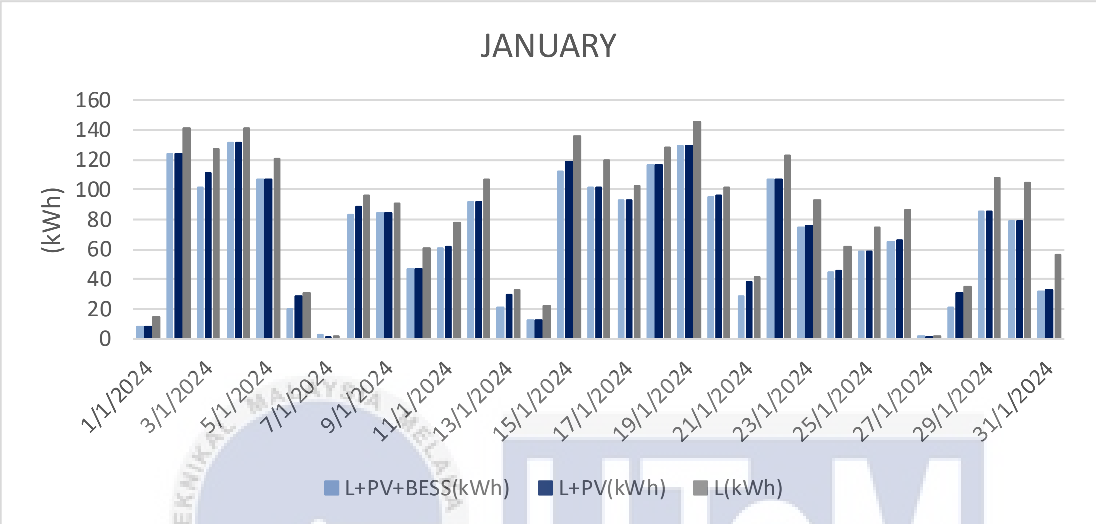

Figure 4.18: Daily energy consumption January 2024

Based on Figure 4.18, it shows the daily energy consumption for 1 month. The light blue chart shows the data of Load with hybrid inverter of PV and BESS systems, while the blue chart indicate the Load with PV system, while the grey chart shows the only Load in the system.

Table 4.8: 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 = 445.7kWh			
CO2 Reduction : 441.94 * 0.758 = 335kg CO2			

Table 4.8 shows the 3 conditions of resources and loads connected in January 2024 with energy consumption (kWh), MD(kW), bill (RM) and Load Factor. Bases on Table 4.8, Condition 3 consumes the highest energy, 2583.378kWh, followed by Condition 1 and 2, 2141.438kWh and 2198.706kWh, 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 shows that

i. Energy usage reduced to 441.94kWh or 17% savings.
ii. Max demand decreased from 17kW to 16kW, giving in a 1kW reduction.
iii. The total bill can be saving by RM191.6, or 13% saving cost.
iv. The CO2 reduction is 335 kgCO2

4.2.3 Case study 2: Economic Mode

Economy mode is a mode that can be adjusted to the user's preferences. Users can configure the charging and discharging time of the battery. In this scenario, the battery is discharged from 11 am to 6 pm. and charge from 6.01 pm. to 10.59 a.m. The battery will be charged by PV production and the grid.

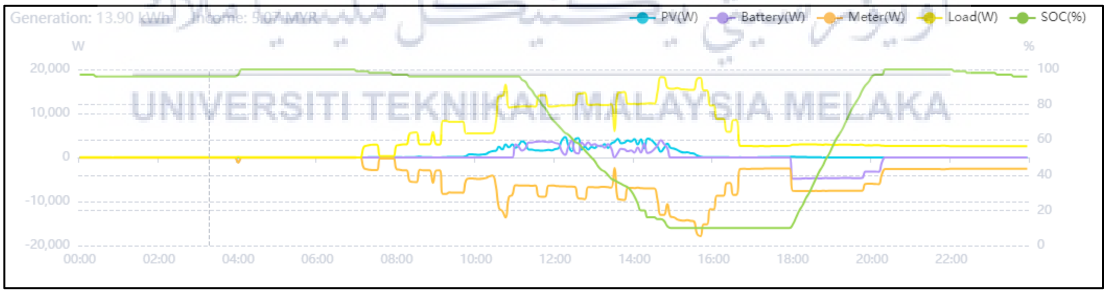

Figure 4.19: Load profile in weekdays

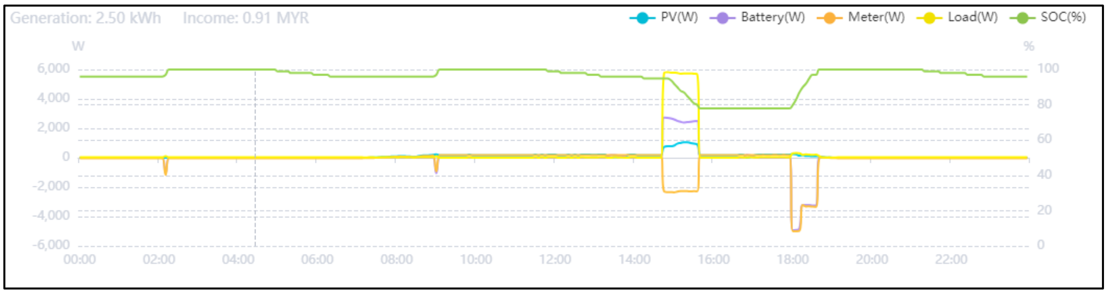

Figure 4.20: Load profile in weekends

Based on Figures 4.19 and 4.20 shows a sample of a 2-days load profile during weekdays and weekends. From that figures, the energy consumption used is more on weekdays compared to weekends. Lower energy consumption during weekend due to no research activity on weekends.The load profile also shows the usage time of the battery charged and discharged according to the current load demand. In this economy mode, the battery will be charged and discharged according to the set time, so even if the load is high or low, it will not affect the battery charge and discharge operation.

4.2.3.1 Energy Consumption

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. The bar chart in Figure 4.21 nd 4.22 shows the energy consumptions information.

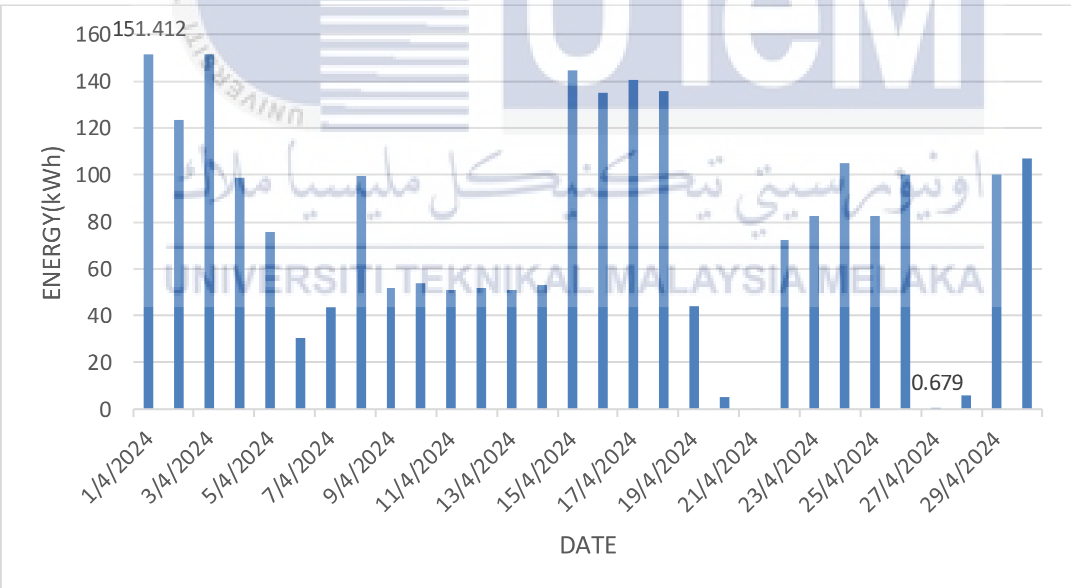

Figure 4.21: Energy consumption in April 2024

Based on Figure 4.21, it shows the data represented in a graph where the bar shows the energy consumption for a period of 30 days in April 2024. The highest energy consumption was 151.412 kWh where it occurred on 1 April 2024 while the lowest energy consumption was 0.679 kWh where it occurred on 27 April 2024.

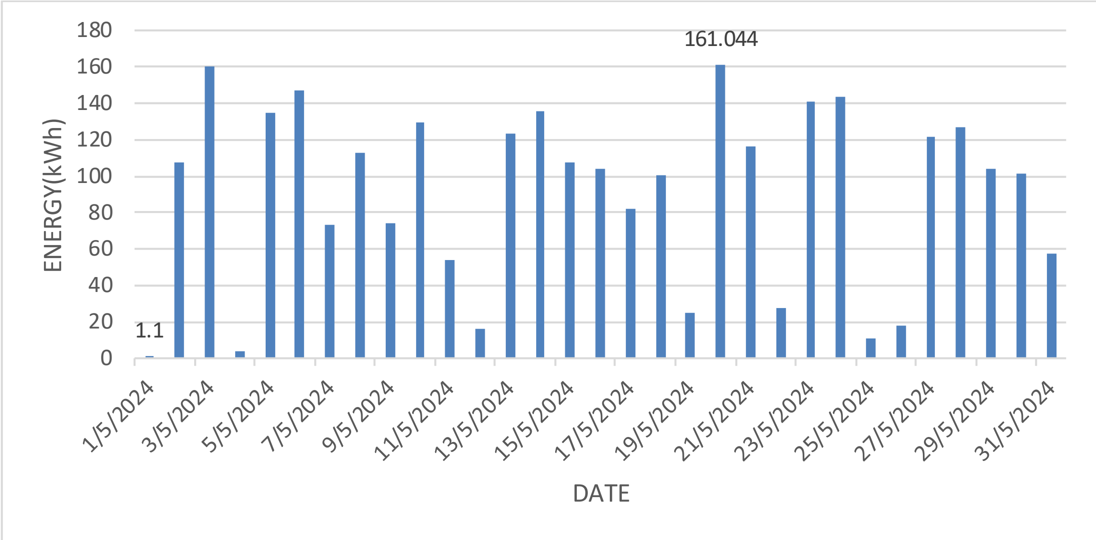

Figure 4.22: Energy consumption in May 2024

Based on Figure 4.22, it shows the data represented in a graph shows the energy consumption for a period of 31 days in May 2024. The highest energy consumption was 161.044 kWh where it occurred on 21 May 2024 while the lowest energy consumption was 1.1 kWh where it occurred on 1 May 2024.

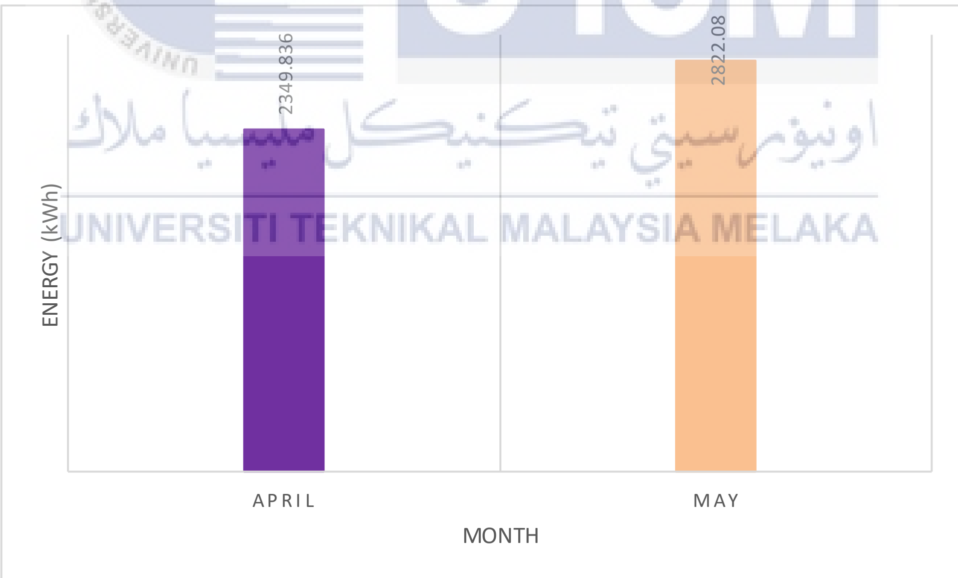

Figure 4.23: Total consumption per month

Based on Figure 4.14, the graph shows the total consumption for 2 different months where May has more energy usage compared to April which is 2822.08 kWh and 2349.836 kWh per month respectively.

4.2.3.2 Maximum Demand

Maximum Demand (MD) is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is very RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month. The Table 4.9 and Figure 4.24 show the MD data for the Solar Laboratory in the months of April 2024 and Table 4.10 and Figure 4.25 for May 2024.

Table 4.9: Max demand data in April 2024

Date	**Max Demand(kW)**	**Date**	**Max Demand(kW)**
1/4/2024	18.4462	16/4/2024	12.3778
2/4/2024	15.7997	17/4/2024	13.462
3/4/2024	19.5057	18/4/2024	12.221
4/4/2024	11.064	19/4/2024	8.94583
5/4/2024	10.4675	20/4/2024	2.28
6/4/2024	10.1037	21/4/2024	0.544
7/4/2024	9.85638	22/4/2024	10.1683
8/4/2024	14.8505	23/4/2024	11.9468
9/4/2024	7.21467	24/4/2024	13.0825
10/4/2024	7.0645	25/4/2024	12.773
11/4/2024	6.75133	26/4/2024	13.7117
12/4/2024	7.12117	27/4/2024	0.033
13/4/2024	7.18667	28/4/2024	1.72833
14/4/2024	6.99517	29/4/2024	11.9432
15/4/2024	13.8458	30/4/2024	9.43867

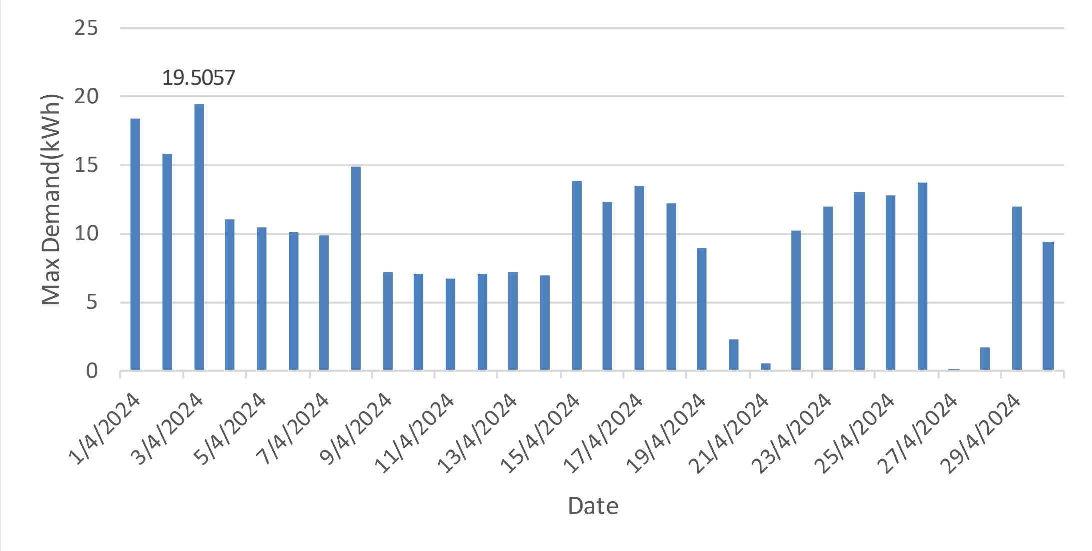

Figure 4.24: Daily Max Demand April 2024

Figure 4.24 and Table 4.9 represented the maximum demand value kW in the month of April 2024. The highest demand is 19.5057 kW (3 April 2024) while the lowest demand is 0.033 kW (27 April 2024). Therefore, the bill for MD charged for this month is RM591.

Table 4.10: Max demand data in May 2024

Date	**Max Demand(kW)**	**Date**	**Max Demand(kW)**
1/5/2024	0.596	17/5/2024	11.1967
2/5/2024	16.2063	18/5/2024	16.6542
3/5/2024	14.2948	19/5/2024	5.011
4/5/2024	0.9448	20/5/2024	15.8185
5/5/2024	19.091	21/5/2024	11.9825
6/5/2024	11.4175	22/5/2024	9.50683
7/5/2024	7.96433	23/5/2024	16.1462
8/5/2024	17.8848	24/5/2024	12.9318
9/5/2024	10.0285	25/5/2024	8
10/5/2024	20.9233	26/5/2024	5.0165
11/5/2024	12.0942	27/5/2024	11.9865
12/5/2024	5.94433	28/5/2024	14.8937
13/5/2024	16.3245	29/5/2024	14.2397
14/5/2024	16.6793	30/5/2024	12.8102
15/5/2024	14.5922	31/5/2024	11.3388
16/5/2024	19.8555		

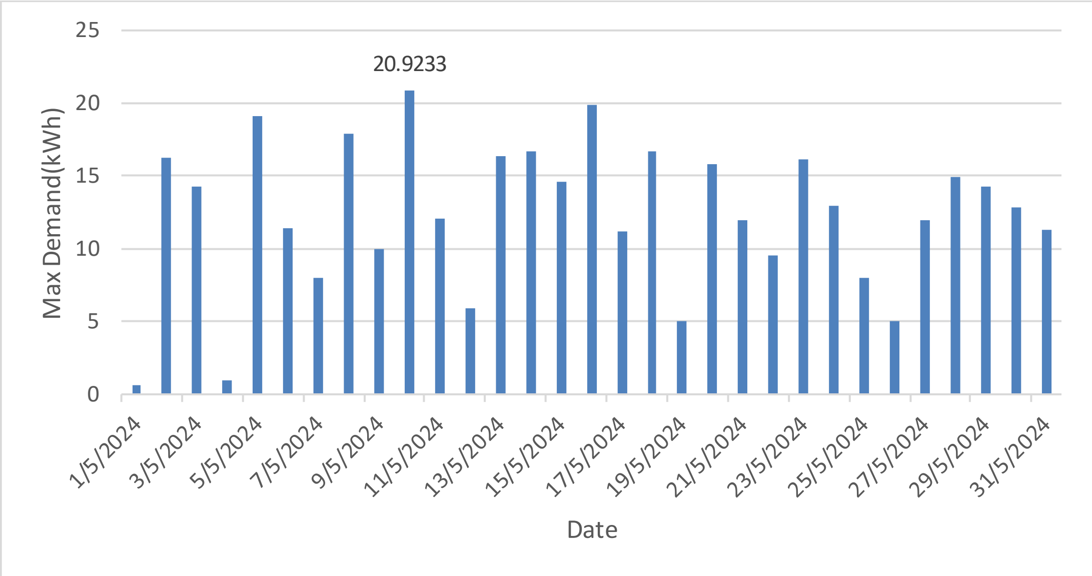

Figure 4.25: Daily Max Demand May 2024

Figure 4.25 and Table 4.10 represented in a graph represents the maximum demand value kW in the month of May 2024. The highest demand is 20.9233 (11 May 2024) while the lowest demand is 0.596 kW (1 May 2024). Therefore, the total bill for MD charged on this month is RM633.97.

4.2.3.3 Consumption for Load, Load with PV and Load with PV and BESS

In this section, a comparison of energy consumption, max demand, cost and load factor will be discussed by considering 3 conditions of resources and loads, which are; a) using a hybrid inverter of PV and BESS system, b) load with PV system and, c) Load only in period of 2 months (April 2024 and May 2024).

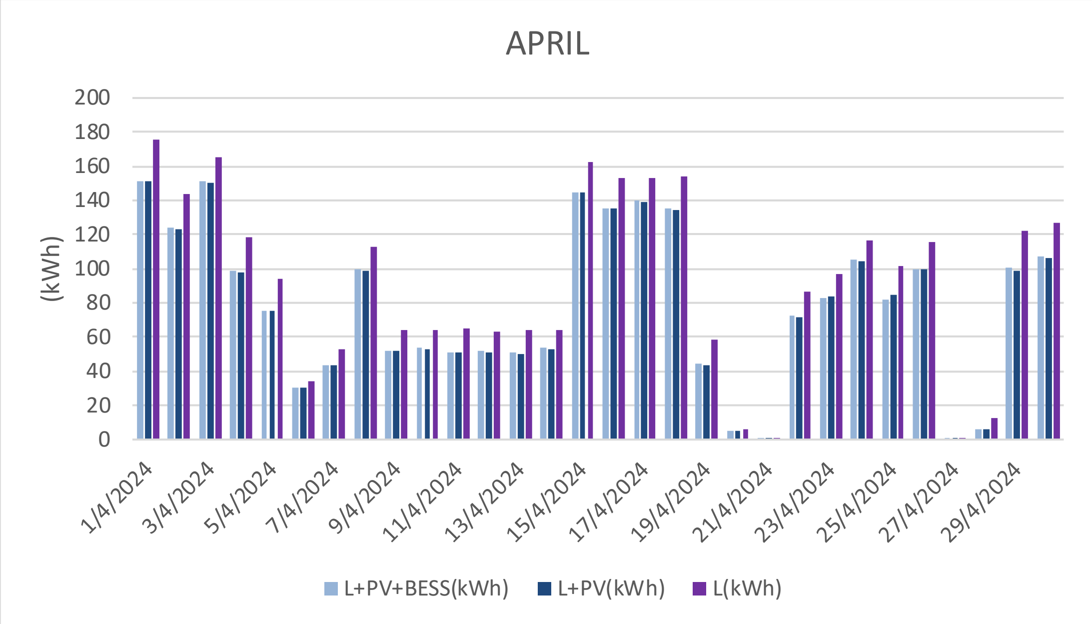

Figure 4.26: Daily energy consumption April 2024

Based on Figure 4.26, it shows the daily energy consumption for 1 month. The light blue chart shows the data of Load with hybrid inverter of PV and BESS systems, while the blue chart indicate the Load with PV system, while the purple chart shows the only Load in the system.

Table 4.11: 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: Load with PV	Condition 3: Load
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 = 423.1kWh			
CO2 Reduction : 400.117 * 0.758 = 303.29kg CO2			

Table 4.11 shows the 3 conditions of resources and loads connected in April 2024 with energy consumption (kWh), MD(kW), bill (RM) and Load Factor. Bases on Table 4.11, Condition 3 consumes the highest energy, 2749.953kWh, followed by Condition 1 and 2, 2349.836kWh and 2338.232kWh, 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 shows that

i. Energy usage reduced to 400.117kWh or 14.55% savings.
ii. Max demand decreased from 20.329kW to 19.5057kW, giving in a 0.823kW reduction
iii. The total bill can be saving by RM171, or 10.55% saving cost
iv. The CO2 reduction is 303.29 kgCO2

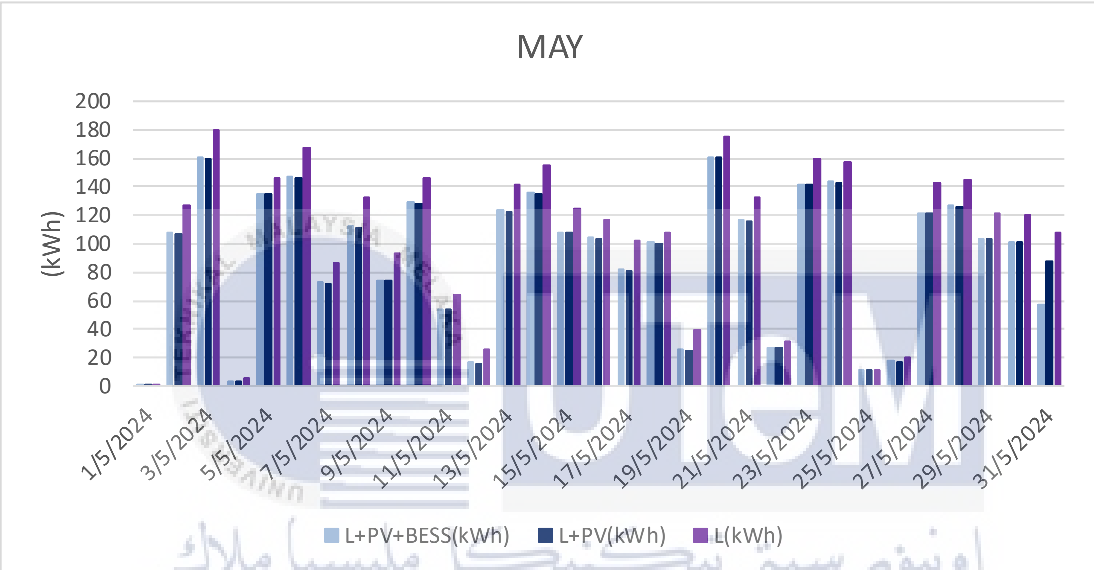

Figure 4.27: Daily energy consumption May 2024

Based on Figure 4.27, it shows the daily energy consumption for 1 month. The light blue chart shows the data of Load with hybrid inverter of PV and BESS systems, while the blue chart indicate the Load with PV system, while the purple chart shows the Load in the system.

Table 4.12: The difference between the comparison 3 conditions of resources and loads energy consumption in May 2024

	Condition 1: Load with hybrid inverter of PV and BESS	Condition 2: L with PV	Condition 3: L
ENERGY (kWh)	2822.08	2834.947	3286.638
MD (kW)	20.9233	20.9233	21.7909
Bill (RM)	1664.03519	1668.73165	1859.88714
LOAD FACTOR	0.187329702	0.18818381	0.20948079
PV Generation = 467.6kWh			
CO2 Reduction : 464.558 * 0.758 = 352.13kg CO2			

Table 4.12 shows the 3 conditions of resources and loads connected in May 2024 with energy consumption (kWh), MD(kW), bill (RM) and Load Factor. Bases on Table 4.8, Condition 3 consumes the highest energy, 3286.638kWh, followed by Condition 1 and 2, 2822.08kWh and 2834.947kWh, respectively. PV production in May 2024 was 467.6 kWh. Condition 1 and 3 were chosen for comparative purposes in terms of energy savings and consumption reduction. The findings from this study shows that

i. Energy usage reduced to 464.558kWh or 14.1% savings
ii. Max demand decreased from 21.7909kW to 20.9233kW, giving in a 0.87kW reduction
iii. The total bill can be saving by RM195.852, or 10.5% saving cost
iv. The CO2 reduction is 352.13 kgCO2

4.3 Comparison of inverter mode

This section will compare the differences in energy consumption, cost savings, maximum demand and energy savings for each mode analyzed, which is general mode economic mode and peak shaving mode. Comparisons will be limited to one month per mode. The months chosen due to energy consumption if not using hybrid PV and BESS systems are almost the same. So, the months selected for comparison are November for Peak Shaving mode, January for General mode, and April for Economic mode.

4.3.1.1 Energy Consumption

The energy usage of the laboratory is monitored using a hybrid PV inverter and a BESS system. The intelligent inverter monitors and saves all relevant data. The data to be analysed consists of the energy consumption of each inverter mode. The bar chart below displays energy usage data.

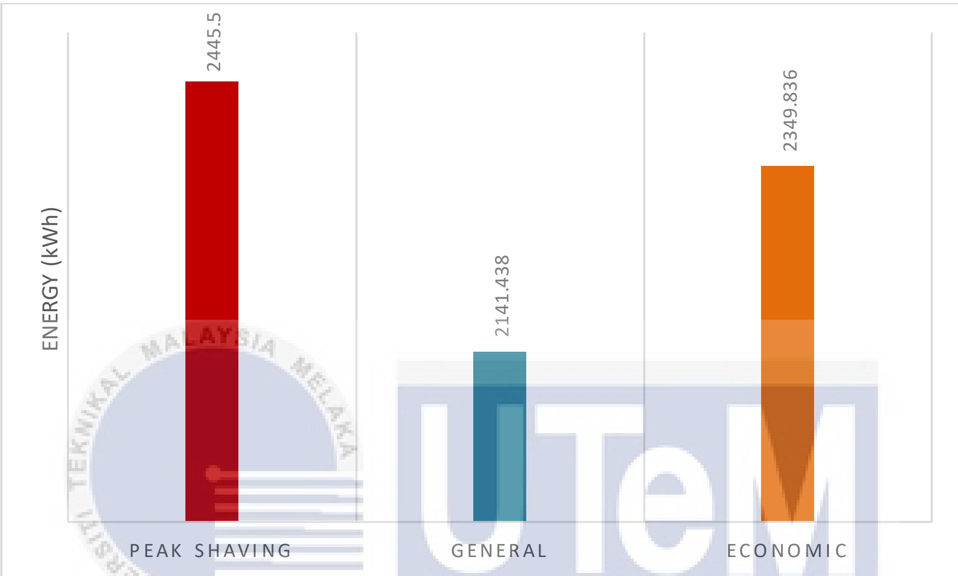

Figure 4.28: Energy consumption different mode

Based on Figure 4.28, it shows the energy consumption for different mode. Peak Shaving use the highest energy, 2445.5kWh, followed by General and Economic, 2141.438kWh and 2349.836kWh, respectively.

4.3.1.2 Cost Saving

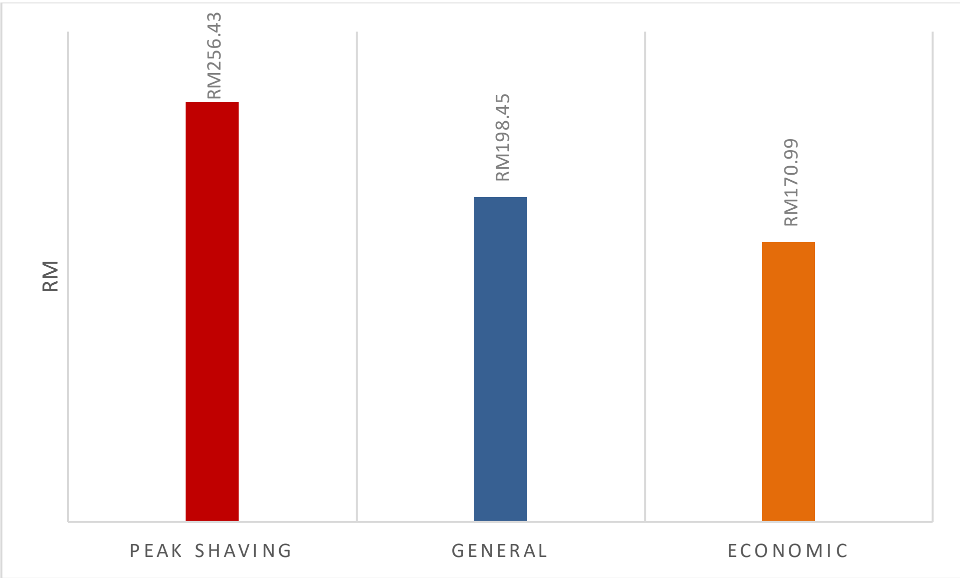

Figure 4.29: Cost saving different mode

Based on Figure 4.29, it shows the cost saving for different mode. Peak Shaving the highest saving, RM256.43, followed by General and Economic, RM198.45 and RM170.99, respectively.

4.3.1.3 Maximum Demand

Maximum demand is the peak of energy consumption for 30 consecutive minutes in kW. The charge rate is very RM 30.3/kW for C1 tariff. The selected maximum demand value will be the day with the highest peak demand for 1 month. For a comparison of the max demand when using the system and not using system and will see which mode can reduce the max demand the most.

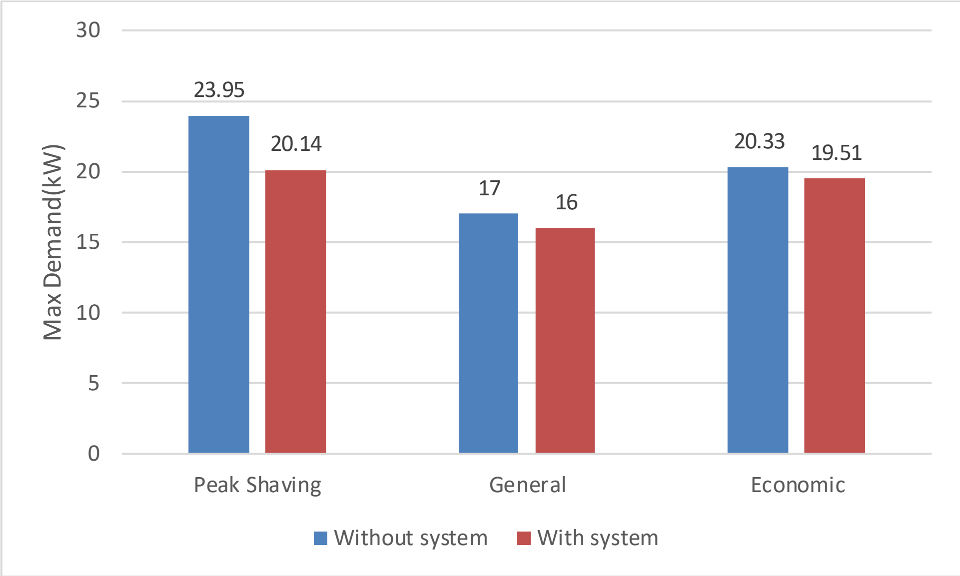

Figure 4.30: Maximum Demand comparison

Based on Figure 4.30, it shows the difference between each type of mode in the inverter if using the system and not using the system. Peak shaving mode has reduced the max demand from 23.95kW to 20.14kW which is 3.81kW or 16% reduction. General mode has reduced from 17kW to 16kW which is 1kW or 5.8% and Economic mode has reduced 20.33kW to 19.51kW which is 0.82kW or 4%.

4.3.1.4 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.

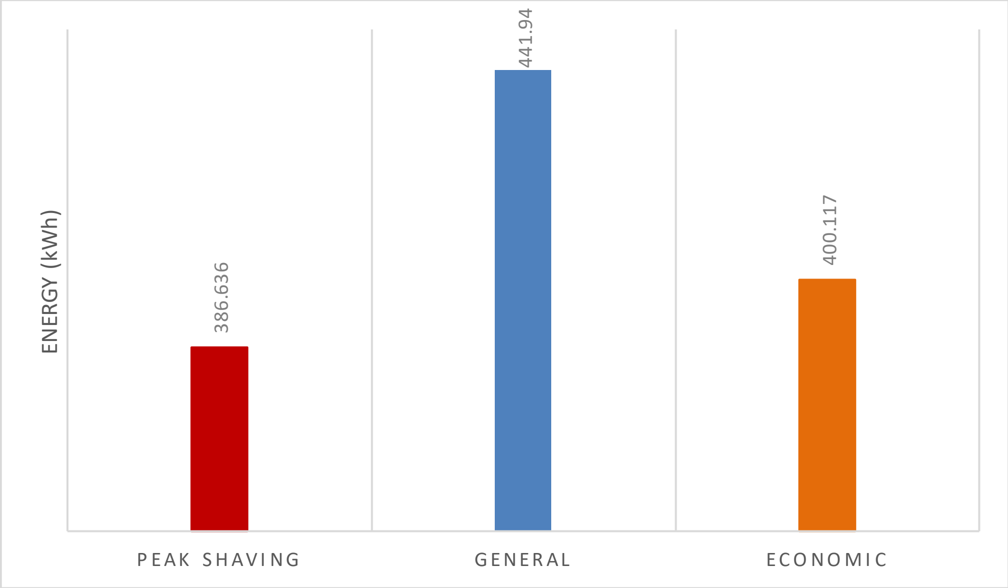

Figure 4.31: Energy saving different mode

Based on Figure 4.31, the highest energy saving is in General mode which is 441.94kWh, while Economic mode is 400.117kWh and the lowest is Peak shaving mode which is 386.636kWh. Energy saving depends on PV generation and also the frequency of energy used to charge the battery.

4.4 Summary

In summary, this chapter proposes the results of the project obtained and the discussion is made based on the data. Decisions represent objective requirements to be achieved. The results of the load profile were obtained for 6 months, that is, for each mode in the inverter, data was taken for 2 months, and the analysis was made according to the scope of the study discussed. Each case study produces different results and is discussed. Each inverter mode provides different energy consumption for each time according to the load usage. PV generation plays a very important role in achieving savings, peak demand reduction and carbon reduction. Peak Shaving Mode is suitable for cost savings and to reduce the maximum demand. This mode has reduced costs by 15%, which is RM256.43 and reduced the maximum demand by 16%, the highest compared to other inverter modes. General mode suitable for energy saving. It has reduced energy consumption by 17%. For economic mode, it is suitable if the use of load is well controlled so that the time to charge the battery is not the same when using a lot of loads. CO2 reduction depends on reducing the most energy.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project represents the optimal energy management of a hybrid PV and BESS inverter system for the FTKE solar laboratory. Three control modes of the inverter are considered: peak shaving, general, and economic. Each mode type has been analyzed in terms of load profile, energy savings, cost savings, maximum demand, and CO2 emission reduction. Then, the energy consumption has been analyzed with and without the hybrid inverter PV and BESS system for each mode type on the inverter. The first objective of this project was successfully attained with significant findings. Energy savings are obtained from the reduction of energy consumption when using the hybrid inverter PV and BESS systems. The highest energy saving is in General mode, 441.94kWh, while Economic mode is 400.117kWh, and the lowest is Peak shaving mode, which is 386.636kWh. From the analysis, it can be concluded that the energy saving of the hybrid inverter of PV and BESS systems depends on PV generation and the frequency of energy used to charge the battery.

This project also successfully achieved the second objective, which is to develop a user-friendly module. This module is designed to assist staff and students in effectively implementing the hybrid inverter PV and BESS system in the FTKE Solar laboratory. Its user-friendly interface and clear instructions make it accessible to all, ensuring that the benefits of the hybrid system can be fully realized.

In conclusion, the PV and BESS system hybrid inverter installed in the FTKE Solar Laboratory can significantly impact energy consumption and savings. This project can overcome this problem by analyzing the load profile for each type of mode selected as a study. Each mode on the inverter plays a role according to the user's wishes. Therefore, to prove optimal energy management, the modes available on the inverter should be selected according to the suitability of PV generation and load.

5.2 Future Works

For the future works, some improvements can be suggested, namely the PV solar energy system can be upgraded for a larger capacity, thus more loads can be reduced especially the maximum demand of the FTKE building. Also, if the air conditioning load is reduced, or changed to another lower load, then the battery can be used optimally, especially in general mode.

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APPENDICES

APPENDIX A MODULE HYBRID INVERTER FTKE

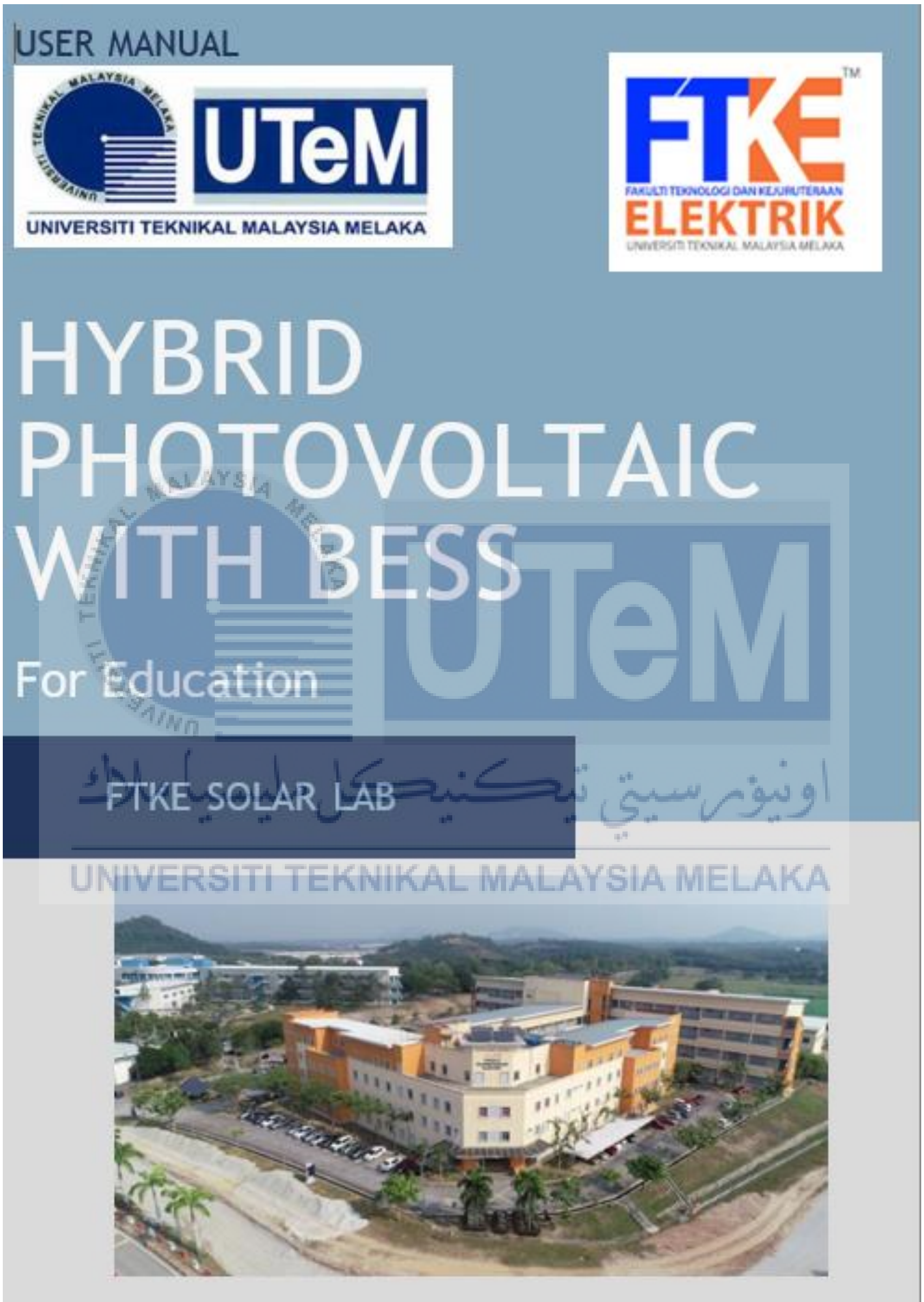
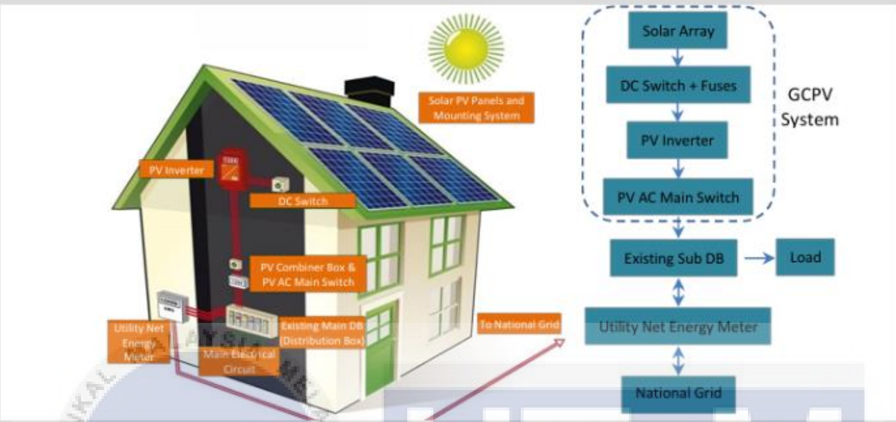


TABLE OF CONTENT

INTRODUCTION

Solar electric system will allow your Home/office/plant to generate part of its own electricity from sunlight for at least 25 years and above. In addition, with a solar system it can protect yourself from current and future electricity price increases, it also can saving significant CO2 emissions that help reduce global warming and climate change.

HYBRID PV SYSTEM INTRODUCTION



1. The Solar Photovoltaic (PV) Panels are usually fitted on the roof. The number of panels will depend on the nominal size of your system . PV solar convert sunlight to Direct Current electricity.
2. The inverter converts the DC electricity to Alternative Current (AC) electricity which is compatible with the electricity supplied to your house from the National Grid (TNB). Most inverters have a digital readout so you can monitor information such as the amount of solar electricity produced.
3. Protection switch; DC Switch are located between PV panels and Inverter and PV AC Main Switch to disconnect system from the grid.
4. Hybrid system is connected to Utility Net Energy Meter (TNB) which interconnected at Existing Sub Distribution Box (Sub DB). All generated electricity is consume first and excess will store/distributed to other loads or export to the grid.

PRODUCT FEATURES

GoodWe GW5K-ET

Our 3-Phase ET is a bidirectional inverter which can convert solar energy to AC energy and compatible with both on-grid and off-grid PV systems.

Work mode depends on PV energy and user's preference.

Control the flow of energy intelligently:

- In the daytime, inverter generated power will support load first, and then charge the battery, if there're still exceed power, export to the grid.
- At night, inverter will discharge energy from the battery to support the load. If the battery is insufficient to support load, battery and grid will support load together. When battery power drop down to the max allowed discharge value, the load will be supported by grid.
- If the grid connection lost, inverter will discharge the battery to support the backup load until the battery power drop down to the max allowed discharge value.

ADVANTAGES PRODUCT

App Control
- Check the status at anytime & anywhere using app (SEMS Portal)

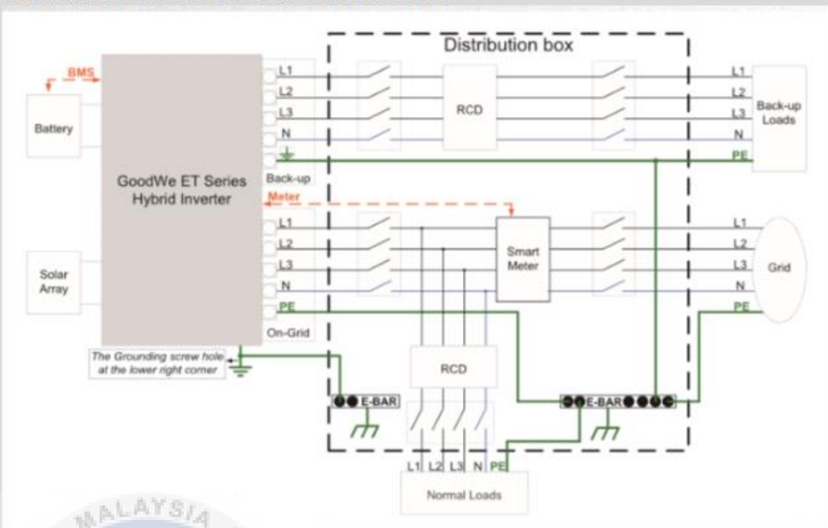
Uninterrupted Power Supply When Grid is Off
- Automatically switch to UPS within 10ms when grid is off

Anti-Reverse Current Function
- Limit the power export to grid

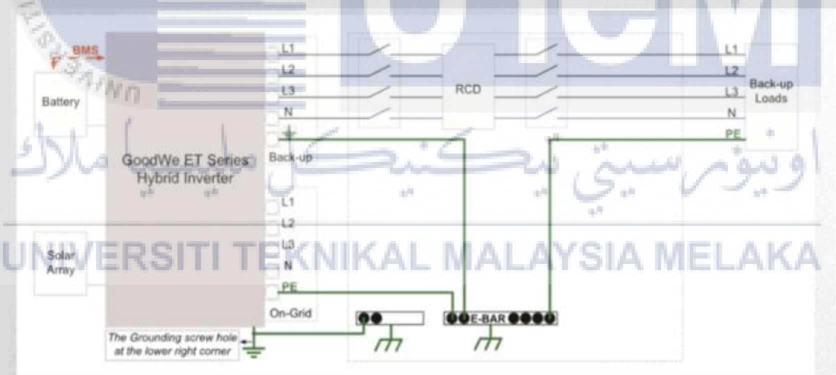
BMS
- Can work with BYD,PYLON high voltage (180-600V) lithium batteries

ET SYSTEM BLOCK DIAGRAM

STANDARD BLOCK DIARGAM



SPECIAL DIRAGRAM FOR OFF-GRID MODE



APPLICATION USED

- Can install the application on the mobile phone or open it on the website.
- This application can be used to monitor the system and collect data on a daily, monthly and yearly.

Mobile application that communicates with the inverter via Bluetooth, WIFi, 4G, or GPRS.

- Check the operating data, software version, alarms, etc.
- Set safety country, grid parameters, power limit, communication parameters, etc.
- Set charging mode of the charger.
- Equipment maintenance.
- To change the types of inverter mode.

SEMS Portal

- Interface Sems portal using mobile phone
- Shows the latest running data and total data from starting installed the system.
- Can choose to view data for today, day, month and year

Solar Go

- Need to be close to the inverter to connect to the communication.
- Can know the selected mode option and change the mode.

INVERTER MODE

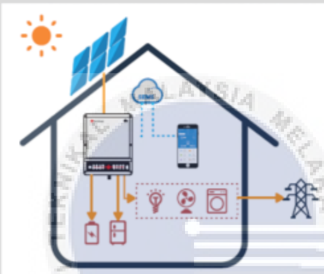
1. General mode : PV generated power will supply load first then charge battery, if there surplus power will export to grid.

2. Peak Shaving mode : Battery will discharge energy when the load power usage exceeds power import set by inverter.

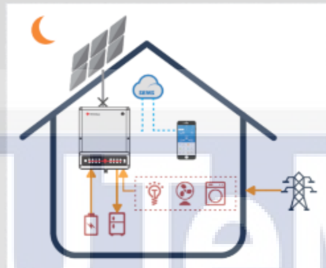
3.Backup mode : PV > load, PV will supply load first and charge battery if PV < load, PV and battery will supply the load.

4.Off grid mode : When grid fails, inverter will automatically switched to back-up mode.

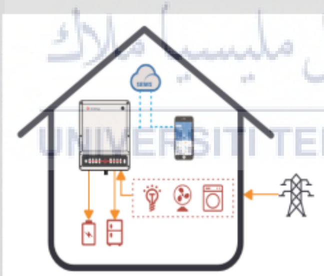
5. Economic mode : Battery charge/discharge time and power can be flexible set on application.



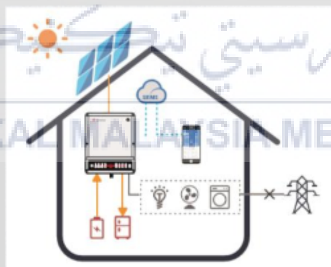
General Mode



General Mode at night



Economic Mode



Off Grid / Backup Mode

INTERFACE AT SEMS PORTAL

1

First page after login the sems portal website and select the plant to see the data.

2

The plant shows data:

- Energy flow
- Devices detail
- PV Generate
- Battery charge & discharge
- Energy from Grid
- Load Consumption
- SOC%

3

The devices detail of hybrid inverter.

HOW TO GET THE GENERATION REPORT

Daily Report

4

The data for power consumption daily and running data

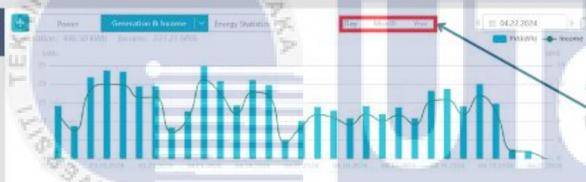
Click this to get the data in Excel

5

The data for power consumption daily in Excel.
Recorded data is in every 5 minutes

- PV(W)= PV generation
- SOC%= State of charge
- Battery= Value charge & discharge
- Meter= Energy use from grid
- Load= Total load consumption

6



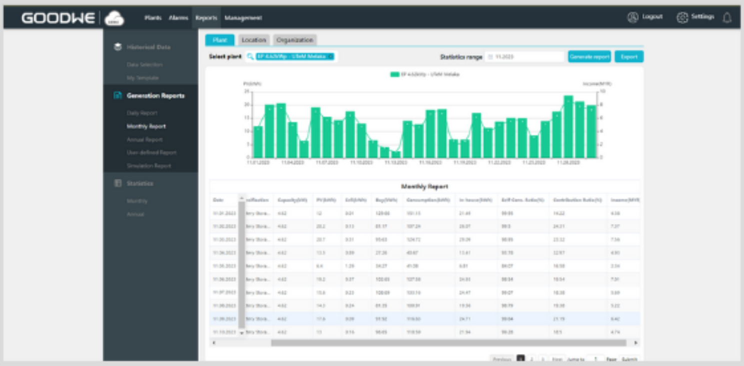
The data for generation & income.

Click this to change data for Day,Month and Year

7

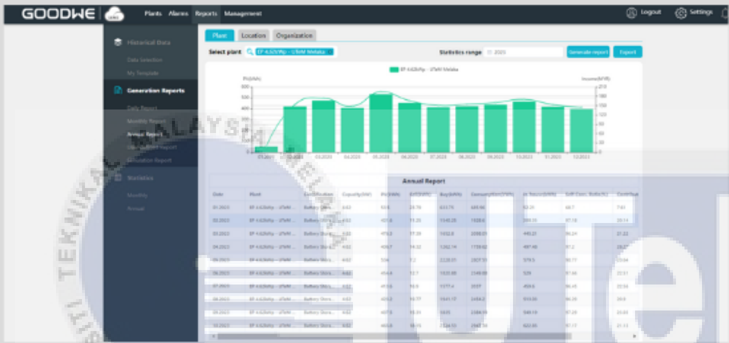
The data for PV Generation and Consumption

Monthly Report



- The data shows every day energy consumption and can be to export to get in excel file.
- The graph show PV generation every day and income if sell the PV generation.

Annual Report



PV(kWh) = PV Generation
SELL(kWh) = Surplus from solar generation that supply load
BUY(kWh) = Energy that use from grid
Consumption(kWh) = Total energy consumption
In-house (kWh) = PV+ BESS
Contribution Ratio = (In-house / Consumption * 100%)
Self Ratio = (In-house / PV * 100%)
Income (MYR) = PV(kWh) * 0.365

EXAMPLE RESULT

Peak Shaving Mode

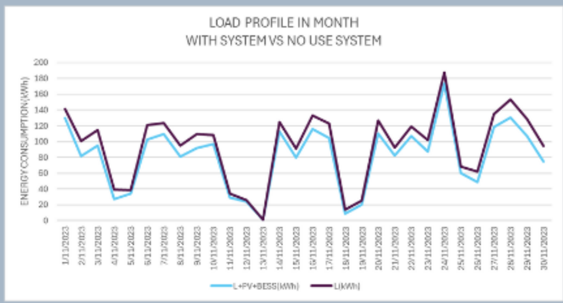
Operating system:

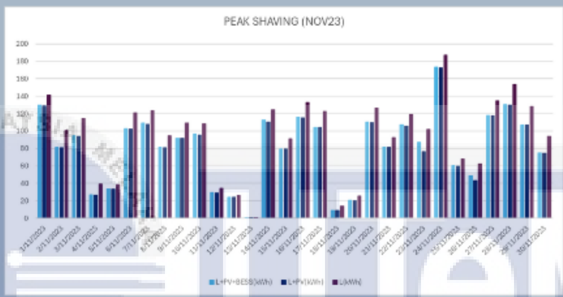
- The battery will discharge when the energy used from the Grid exceeds 500W
- The battery will be recharged when the load usage is less than 500W

From the picture above, it shows the production of energy from solar as well as energy consumption and can see the data produced at the selected time.

EXAMPLE RESULT

Peak Shaving Mode





	L+PV+BESS	L+PV	L
TOTAL(kWh)	2445.5kWh	2412.336kWh	2832.136kWh
MD(kW)	20.1437kW	20.7537kW	23.9492kW
Bill(RM)	RM 1502.962	RM 1509.34	RM 1759.39
LOAD FACTOR	0.1686	0.1614	0.1642

By using daily data or monthly data, we can extract data if use a hybrid inverter PV with BESS or do not use the system.

EXAMPLE RESULT

General Mode

Operating system:

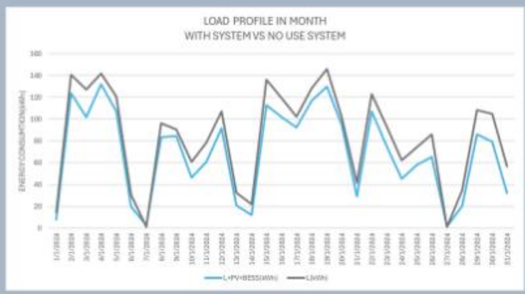
- PV generation will supply energy to the load first, if there is excess it will charge the battery.
- The battery will discharge when the Grid usage exceeds 500W.
- The battery will only be charged using energy from the PV

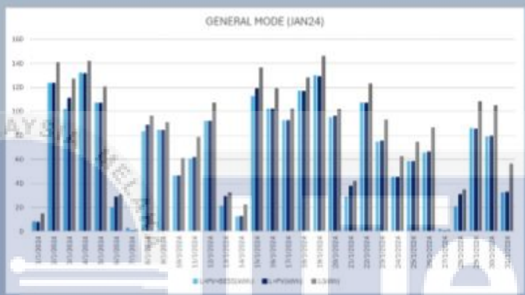
Weekday

Weekend

EXAMPLE RESULT

General Mode





	L+PV+BESS	L+PV	L
TOTAL(kWh)	2141.438kWh	2198.706kWh	2583.378kWh
MD(kW)	15.47kW	15.47kW	16.6957kW
BILL(RM)	RM1250.36587	RM1271.26869	RM1448.81268
LOAD FACTOR	0.19225724	0.19739873	0.21490713

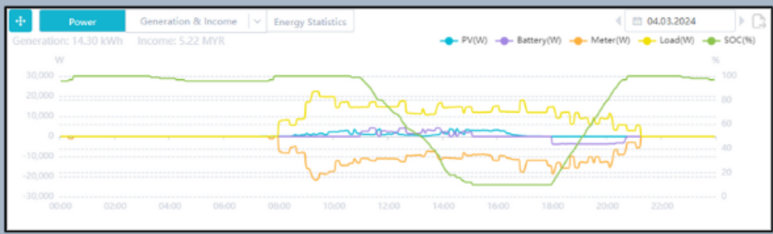
EXAMPLE RESULT

Economic Mode

Operating system:
It depends on the user to determine the charging and discharging time.
In this result:

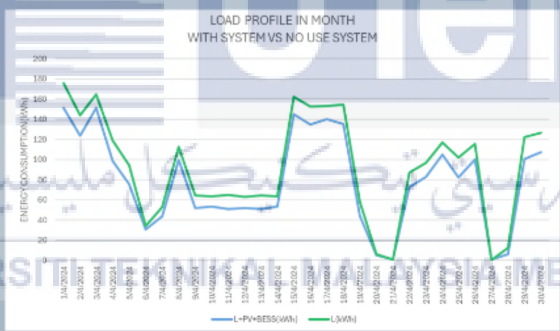
- 00.00 - 15.59 = Recharge
- 11.00 - 18.00 = Discharge
- 18.01 - 11.59 = Recharge

To setting the time recharge and discharge, need to use Solar Go application.



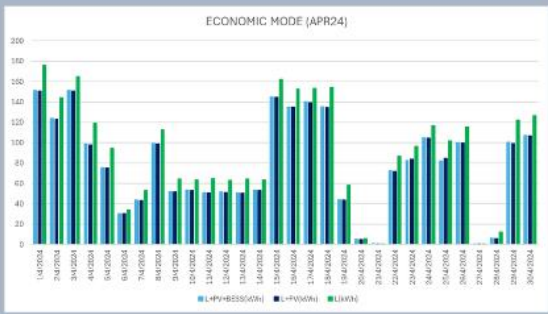
Discharge time

Recharge time



EXAMPLE RESULT

Economic Mode



	L+PV+BESS	L+PV	L
TOTAL(kWh)	2349.836kWh	2338.232kWh	2749.953kWh
MD(kW)	19.5057kW	18.6443kW	20.3291kW
BILL(RM)	RM 1448.713	RM 1418.377	RM 1619.704
LOAD FACTOR	0.16731833	0.17418431	0.18787744