ENERGY STORAGE (ES) SIZING FOR COMMERCIAL BUILDING WITH SOLAR PV

NUR 'AQILAH BINTI SULAIMAN

BACHELOR OF ELECTRICAL ENGINEERING WITH HONOURS

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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NUR ‘AQILAH BINTI SULAIMAN

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DECLARATION

I declare that this thesis entitled “ENERGY STORAGE (ES) SIZING FOR COMMERCIAL BUILDING WITH SOLAR PV 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 candidature of any other degree.

Signature	:	
Name	:	Nur ‘Aqilah Binti Sulaiman
Date	:	

APPROVAL

I hereby declare that I have checked this report entitled "ENERGY STORAGE (ES) SIZING FOR COMMERCIAL BUILDING WITH SOLAR PV" and in my opinion, this thesis it complies the partial fulfillment for awarding the award of the degree of Bachelor of Mechatronics Engineering with Honours

Signature : ....

Supervisor Name : ....

Date : ....

DEDICATIONS

To my beloved parents, family, friends and supervisor that helped me to complete this report

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ABSTRACT

The market of renewable energy especially solar PV in the power grid has been widely expanding around the world. Most of the solar energy is depend on the sunlight due to the weather conditions. However, high penetration of solar PV must consider the negative impacts on power network such as voltage rises, power fluctuations and reverse power flow. Since the solar PV are unstable and often inconsistent. It must use the most suitable solution that can be stabilize the power generation. Recently, energy storage system has been seen as an effective solution to overcome those challenges while improving load factors and the utilization of network infrastructures. Energy storage system is known as one of the structural units of the smart grid have experienced a rapid growth in cost effectiveness and maturity. The purpose of this project is to reduce peak demand and improve load factor for commercial building with PV by developing energy storage dispatch strategy. It minimizes the cost of electricity by identifying the optimum size of energy storage in commercial building with solar PV. It also evaluates the effect of PV growth on the profitability of deploying ES. In this project, there will be a method to find the sizing energy storage. Firstly, model dispatch strategy for energy storage using analytical method. Secondly, evaluate the dispatch strategy. Lastly, optimization approach which is genetic algorithm (GA) to find the optimum size of energy storage. The sizing energy storage will be used the optimization methods. With the help of the developed methods, energy storage designs can be optimized for any solar PV applications with the necessary changes according to the practical applications. Finally, results show that the proposed of optimization approach can minimizes the electricity bills and optimum size of energy storage for solar PV.

ABSTRAK

Pasaran tenaga boleh diperbaharui terutamanya PV solar dalam grid kuasa telah berkembang secara meluas di seluruh dunia. Kebanyakan tenaga solar bergantung kepada cahaya matahari kerana keadaan cuaca. Walau bagaimanapun, penembusan tinggi PV solar mesti mempertimbangkan kesan negatif terhadap rangkaian kuasa seperti peningkatan voltan, turun naik kuasa dan aliran kuasa terbalik. Sejak PV solar tidak stabil dan sering tidak konsisten. Ia mesti menggunakan penyelesaian yang paling sesuai yang dapat menstabilkan penjanaan kuasa. Baru-baru ini, sistem storan tenaga telah dilihat sebagai penyelesaian yang berkesan untuk mengatasi cabaran-cabaran itu sambil meningkatkan faktor beban dan penggunaan infrastruktur rangkaian. Sistem simpanan tenaga dikenali sebagai salah satu unit struktur grid pintar yang mengalami pertumbuhan pesat dalam keberkesanan kos dan kematangan. Tujuan projek ini adalah untuk mengurangkan permintaan puncak dan meningkatkan faktor beban bangunan komersil dengan PV dengan membangunkan strategi penghantaran penyimpanan tenaga. Ini meminimumkan kos elektrik dengan mengenal pasti saiz optimum penyimpanan tenaga di bangunan komersil dengan PV solar. Ia juga menilai kesan pertumbuhan PV terhadap keuntungan menggerakkan ES. Dalam projek ini, terdapat satu kaedah untuk mencari penyimpanan tenaga ukuran. Pertama, strategi pengiriman model untuk simpanan tenaga menggunakan kaedah analisis. Kedua, menilai strategi penghantaran. Terakhir, pendekatan pengoptimuman yang merupakan algoritma genetik (GA) untuk mencari saiz penyimpanan tenaga yang optimum. Penyimpanan tenaga ukuran akan digunakan kaedah pengoptimuman. Dengan bantuan kaedah yang dibangunkan, reka bentuk storan tenaga boleh dioptimumkan untuk sebarang aplikasi PV solar dengan perubahan yang diperlukan mengikut aplikasi praktikal. Akhirnya, hasil menunjukkan bahawa pendekatan pengoptimuman yang dicadangkan dapat meminimumkan bil-bil elektrik dan saiz optimum penyimpanan tenaga untuk PV solar.

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LIST OF SYMBOLS AND ABBREVIATIONS

ES	-	Energy Storage
UTeM	-	Universiti Teknikal Malaysia Melaka
x	-	Energy Storage Capacity
SoC	-	State of Charge
DoD	-	Depth of Discharge
PV	-	Photovoltaic

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Among the renewable energy sources, such as solar photovoltaic (PV), geothermal, biomass and wind can reduce greenhouse gas emissions and fossil fuels [1]. The fossil energy became exhausted because the demand for electrical energy nowadays is getting higher due to the increasingly rapid of development. So, the non-renewable energy like fuel will run out if it is continuous using by the users. Because of these problems, the worldwide scientists are busy searching for a new solution by using renewable energy like solar, wind, biomass and other energy. These renewable energy sources are the best solution to solve the problem that the world facing nowadays.

Today the fossil fuels still have around 80% of the total primary energy supply in the world. Nowadays, humans have to use the electricity, heat, and transportation for their daily activities. The rising levels of carbon dioxide (CO_2) on the planet may causes greenhouse effect, global warming and a water level of the ocean rise gradually. It also makes the extinction of many animals and plant species and the natural disaster occurs. Therefore, many renewable energy resources have been found and used such as solar, biomass, wind power, hydropower, and others. The renewable energy sources are renewable, constantly replenished and not be depleted on a human timescale. This renewable energy source causes less harm to the environment compared to fossil fuels [2].

The achievement of target 100% in renewable energy will be achieved if the consumers are convinced to become more environmentally friendly and efficient in the way they use the energy. It is rather small ones which it can be supported by high payback time of every equipment must be able to manage the renewable energy instead of decrease price trending. Every researcher and policymakers will advise different strategy to encourage consumers to take an active part on the grid. The meaning of "active" is to look the ways to decrease the energy bills by following the pattern of energy pricing and to adjust the energy consumption based on the received signals. Based on the strategy of the application new network in distribution energy tariff and power trading. The tariffs will be provided in different financial signals which if the consumers used correctly might result in the adjustment of the demand and therefore more opportunities for the intermittent energy sources [2].

In Malaysia, the solar photovoltaic (PV) system has been implemented for a past few years, but it is still at the early stage. This is because of the high initial cost of solar PV and the low solar electricity tariff rates due to the lack of knowledge, research, and information about the solar photovoltaic system. The most important of the system performance is to determine the highest energy yield for a different type of solar PV technology. The natural factors such as solar irradiance and temperature also affect the performance of the system. Furthermore, the reducing of loss factor from the solar equipment need to be considered. Besides that, it must be considered the energy storage that will be implemented in the solar PV. This project is to evaluate the performance of solar PV connected with energy storage grid in Malaysia [3].

1.2 Motivation

With the rapid growth development of electrochemical energy storage and the implementation of renewable energy such as solar PV, it has been started exploring the applications for battery energy storage systems. Normally, energy storage located at the solar PV and microgrid. The energy storage level can provide vital control services, reduce the cost of electricity associated with peak demand periods isolate and island during grid anomalies[4]. Generation from solar PV system and other renewable energy sources will increase power supply variability which means energy storage can help control by storing energy when electricity is oversupply and providing power when generation falls short.[5]

The main target of this project is to reduce demand profile and cost of electricity bills for commercial building. This is because commercial building used a high amount of energy. Consequently, there is strong motivation to minimize peak load growth throughout the electricity network. By deploying a solar PV panel, a commercial building can minimize its dependence on the main grid and eventually reduce its electricity bill. In this project, the energy storage sizing for commercial building with solar PV is determined and evaluated for the energy storage capacity and reduction of demand profile and cost of electricity.

1.3 Problem Statement

Since the source of solar PV are unstable and often inconsistent. It is required to stabilize the power generation of solar energy storage with batteries bank as an energy storage. It will overcome the time without solar energy supplies at a stable and constant power generation. Solar PV cell is commonly known as a solar cell that can convert the thermal energy from sunlight into direct current electricity. Solar energy has many advantages which are better than other renewable energy source such as no noise pollution during power generation. [6]

Even thus the solar is known as a dependable and widely available renewable energy in Malaysia, but the intermittent energy source will cause the power generator to produce the fluctuating power output[7]. For example, it does not generate the energy using a stand-alone PV system at night or bad weather condition due to the no solar radiation. In other words, this system is unable to present a desirable efficiency in generating energy.

Furthermore, solar PV system is needed more land or space to absorb the sun light with larger solar PV panel as much as possible. Therefore, it needs a compact design for solar PV panel and sizing energy storage. It can overcome the constraint of more space due to the high price of land and cost of installation sun tracking solar systems also higher.

Hence, the solar PV with energy storage was introduced for the operation in day and nighttime. Solar PV can get the highest efficiency during the sunny day in daylight hours. In order to store the energy and achieve the highest penetration for solar PV in whole month, the solar PV with energy storage is one of the optimum solutions to generate and store the energy during anytime and all weathers conditions.

1.4 Objectives

The objectives of this project are:

i) To develop ES dispatch strategy for peak demand reduction and load factor improvement for commercial building with PV.

ii) To identify the optimum size of ES in commercial building with solar PV for minimizing the cost of electricity.

iii) To evaluate the effect of PV growth on the profitability of deploying ES.

1.5 Project Scope

The scope of this project is to focus more on the sizing energy storage for commercial building with solar PV. This project will be evaluated and investigated to get the optimum size of energy storage and electricity cost for commercial building. The objective function for this project is the cost of the electricity. This project conditions are 24 hours for one-month period.

This project also must consider the other parameters that related to the objective function which is new load profile, load factor and vary PV penetration. However, energy storage is modeled to dispatch its active power to flatten the daily load demand profile using iterative method. This approach will assumes the total energy charged by energy storage is equal to the total energy discharged by energy storage in a day. [8]

Furthermore, optimization approach is the final step of this project. Genetic algorithm approach can obtain the optimum value for sizing energy storage and the objective function which is electricity bills. From this kind of approach, it can fully analyze the different between daily load profile with and without energy storage.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this section, it will briefly explain and more details about the solar photovoltaic (PV), energy storage, energy storage system, benefits of the energy storage, applications, specification and technologies that involves in the energy storage. All of these was taken from the research and journals.

2.2 Solar Photovoltaic (PV)

Solar photovoltaic (PV) systems are described as the convert sunlight into electric power generation. Once this technology used almost exclusively on the satellites in space, the photovoltaics has come down to earth to find the expanding energy at markets. Furthermore, many thousands of solar PV has been installed around the world. For certain applications, PV systems provide the most cost-effective source of electric power [9].

The energy markets of the penetration solar photovoltaic renewable energy sources have increased by more than five times since 2010. It is statistically proved by the International Renewable Energy Agency (IRENA) [2]. Figure 2.1 shows the results world capacity of photovoltaic solar panels installed.

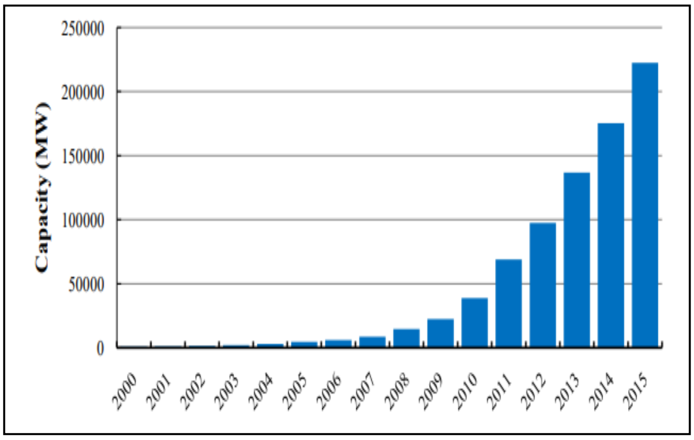


Figure 2-1 Installation of solar panel photovoltaics of world capacity[2]

There are several important characteristics of a solar PV system that make them a desirable source of power which it can rely on sunlight. That's mean the solar does not rely on the electricity grid-like TNB. It will get the energy source from the sunlight during the daytime. Next, it can generate electricity which is the conversion of sunlight into electricity power generation. The solar PV will produce direct current (DC) supply and converted to alternating current (AC) supply by using converter equipment.

It also a modular which can be matched for power at any scale. It can be connected as a grid-connected, stand-alone connected and hybrid connected. Furthermore, solar PV can be used as an independent power source and any combination with another source. An independent power source is a stand-alone connected without any electricity grid or any source. A combination with other source which relates to electricity grid, wind or other sources.

2.3 Energy Storage System

Energy storage is defined as a wide range of technologies that can be store energy for use later. A device that can be store energy such as batteries and accumulator. Energy storage can enhance a predictability of renewable energy by smoothing out fluctuation between load and generation. A system with high penetration of renewable energy source has many benefits from energy storage devices. Energy storage devices can store energy during low peak demand periods and excess energy is available. The electrical energy can be stored in another form of energy such as chemical, mechanical, thermal, electrostatic and electromagnetic [10].

When the power demand is higher, or load is larger than the power generation, it will convert back energy store to electrical form and fed back into the systems. Furthermore, energy storage devices also can provide peak shaving of the power load demand and it will lead back to stability in market prices. The energy storage device can provide demand-side management act as a load during low power demand and as a source during high power demand [10].

Besides that, storage solutions open many other possibilities in the power system to support high penetration of renewable energy source. Energy storage device allows the load to be supplied during power outages which it can reduce downtime and improve system reliability. Power quality and system stability can be improved by dampening the power and frequency oscillations in the power generation system. Storage facilities can provide ancillary services such as reactive power compensation and spinning reserve. Load and energy management capabilities are also can be enhanced in the presence of storage devices. Energy storage device with the installation of renewable energy source can help lower expensive transmission and generation capacity expansion [10].

2.4 Benefits of Energy Storage

The benefits of energy storage can be classified into two categories which are technical benefits and economic benefits. It will make energy storage more interesting. Besides that, high energy of energy storage will help improve profitability. It also can secure economic benefits to the power system generation stakeholders. It will provide technical benefits.

2.4.1 Technical Benefits

There are the following technical benefits: [11]

a) Bulk energy time- it will shift time for peak shaving and load levelling. It also provides electricity price balance. For this benefit, it will represent the electric vehicle as one type of energy storage that can be provided all these power management benefit and will lead to smart grid and renewable energy source integration.

b) Energy storage may act as an important role in the integration of renewable energy sources into the grid.

c) Energy storage became more efficient use and contribution of renewable energy which it very guaranteed by using energy storage device. The use of distributed energy supply in grids are also fomenting.

d) Energy storage has superior load efficiency. This is because some of the baseload generation plants are not designed to operate as a part load or to provide variable outputs. However, energy storage can provide an attractive solution to drawback by setting the optimal operation point, rather than firing standby generators.

e) Efficient energy storage which it can be used to provide up to two times of its capacity for regulation applications by using full discharge (up) and full charge (down).

f) Energy storage output can be changed often by giving a ramping support and black-start to the grid (from none to full either from full to none within second rather than a minute)

g) Energy storage is a good solution to improve grid service reliability

h) Energy storage system has a portable ideal location in a distribution system. For example, the system can be relocated after a certain year or when upgrading the performance of the system, the portable energy storage device can be moved easily and used to perform the same functions of energy storage again.

2.4.2 Economic Benefits

There are the following economic benefits: [11]

a) Energy storage can reduce the costs of electricity for the customers

b) Energy storage can reduce from high peak electricity to off-peak electricity. If the high peak demand for electricity is lower, it may also give a benefit the seller of electricity.

c) It acts as a key role in stabilize the electricity cost and a power sector from the speculations and the reduce the imposed of fossil fuels.

d) The usage of energy storage can override the need of peak demand generation and avoid from any unnecessary additional cost that will burden customers.

e) Energy storage can allow more efficient use of renewable energy and off-peak generation capacity, so that it will encourage more investment opportunities for these technologies.

f) Energy storage also can help to avoid the transmission charges which are high cost and many utilities try to avoid it.

g) Energy storage also can reduce the transmission and distribution capacity upgrade; thus, it will minimize any unnecessary investment.

2.5 Application of Energy Storage

The deployment of energy storage to mitigate the problems involved with the uncertainty of renewable distributed generator units. However, a successful energy storage system with distributed generation in solar PV applications involves many selecting a suitable sized system based on the commercially available technologies[12]. The optimal development and integration of the energy storage system require through an understanding. These understandings are the application for which energy storage was being used and the benefits provided to the applications, energy storage system technologies available and they are suitable for the applications and the requirements of integrating an energy storage system[12]. Some notable current practical renewable energy source and power applications of energy storage are discussed in this subsection:

2.5.1 Electrical Energy Time Shifting

Electrical energy time shifting involves for reducing electrical cost[12]. In this case, a concept of time-of-use (TOU) will be used to reduce electricity cost[13]. It will charge during the off- peak demand where the price of electricity is low. While discharge energy during the peak demand where the price of electricity are high [12].

2.5.2 Community Energy Storage (CES)

It is usually designed grid connected. When a localized section connection of the distribution systems are isolated from the grid, it can give a support and act as a backup power to the users during power demand [13]

2.5.3 Grid-connected PV System

A battery storage system for a grid-connected solar PV will help to manage the challenges of rapid output variation of the power quality harmonic, output variation, the mismatch between solar PV output system and the user's peak demand that is exposed by grid-connected solar PV without energy storage [13].

2.5.4 Energy Storage in Electric Vehicle

The deployment of electrical vehicle (EV) is also another form of customer that has been used energy storage of electricity [12]. This will improve the reliability of energy power supply of the electric grid [13].

2.5.5 Spinning Reserve

Spinning reserve uses the single largest resource that will be serving the system and reserve the capacity which is equivalent from 15% to 20% of the normal capacity power supply [12]. The storage system is being used for the capability through the dedicated power converters that will react with the grid [13]

2.5.6 Transmission and Distribution (T&D) Upgrade Deferral

The transmission and distribution apparatus may be used energy storage to defer and avoid the need for upgrading the system. Since the configuration of the energy storage system(batteries) can serve a small proportion of peak period that means no need to increase the capacity of the transmission and distribution in the short-term. It also helps to extend the lifespan or long duration of the transmission and distribution system [13] .

2.5.7 Uninterruptible Power System (UPS)

Normally it will use energy storage to improve power quality system or provide a backup power during outages [12]. Energy storage, e.g, battery, may be used to provide a reliable and stable power system for critical loads such as emergency lighting, equipment of the communication, to minimize lost productivity and facilities or equipment damage [13] .

2.6 Energy Storage Technologies

Energy storage technologies can be classified into 5 categories of energy storage such as mechanical, electrochemical, chemical, thermal and electromagnetic. For example, batteries, flywheels, compressed air energy storage (CAES), superconducting magnetic energy storage (SMES) and pumped hydro [12]. Furthermore, each of technology has their own characteristic that makes it suitable for the certain grid system. In this section, it has provides the overviews of each technology by using an explanation from different sources presented to be comparable with each other [14].

2.6.1 Battery Energy Storage

Electrochemical battery technologies have a several different that are currently available commercial and domestic applications act as a second life of energy storage[7],[9] .Electrochemical energy storage technologies have a different performance characteristics.

Battery energy storage usually used in photovoltaic system. The energy will be store in battery during the day that will be used at night hours or any bad weather conditions[15]. The power output of the photovoltaic system varies during any day and battery storage can give a constant source of power. Most of utility grid-connected solar PV system does not use batteries but they can be used as an back-up power source during night and bad weather conditions [15].This is an overview of the different electrochemical energy storage technologies[16]:

2.6.1.1 Lead-acid batteries

Lead-Acid batteries were the first rechargeable batteries in 1859. Most of the lead-acid batteries application used in small application such as motor vehicles engines and household appliances all the way to grid system level application on megawatt scale[16]. For the photovoltaic systems, it is required a battery to discharge small amounts of current in long periods and will be recharged under some conditions [15].

Lead-acid batteries is a mature with good battery life, low cost, low maintenance requirements, simple charging technology and short life cycle[14]. However, short life cycle and low energy density are challenges for large-scale deployment of PV system because grid applications must have a storage that can stand for a long time[17]. The main disadvantage is higher discharge power the usable capacity will decrease. It also have a low energy density [12].

2.6.1.2 Nickel-Cadmium (NiCd)

Nickel-Cadmium is a mature battery storage technology was invented by Waldmer Jungner in 1899. Nickel-Cadmium is known as a secondary and rechargeable batteries. It has many advantages compared to lead-acid batteries that make it more attractive for use in solar PV systems. However, this application is very limited due to the cost of material and difficulty to manufacture [13].

The advantages of this battery can perform very well at a low-temperature range between -20 °C to +40 °C [14]. It also has a highly durable which can reach more than 1000 cycles with proper maintenance. Furthermore, it will be charged very fast during low demand. The most important thing is low costs per cycle [16].

2.6.1.3 Lithium Ion (Li-ion)

Lithium-ion is one of the fast developments in 1960. Most of the lithium ion is widely used in mobiles, laptop, and other small appliances. However, it does not use an electric power supply [13]. Lithium-ion batteries have several advantages when compared to another battery technologies. The advantages are high energy density and longer lifetimes [18]. So, lithium-ion will be the most suitable to power management operations such as uninterruptible power source (UPS) and frequency regulation for relatively short discharges within two hours [12].

2.6.1.4 Sodium Sulfur (NaS)

The Sodium-Sulfur battery technology was developed and introduced in 1987 by NGK Insulators and Tokyo Electric Power [13]. Sodium-sulfur is still in the beginning stage of the current grid [14]. This battery is the most proven battery energy storage system technologies for the large scale of electrical applications.

It has been used for power time shift and power quality due to their high a round-trip-efficiency (RTE) range between 75-90% [13]. However, Sodium Sulfur battery is slow to advance compared to Li-ion battery technology in terms of power and energy. But it can maintain a longer discharge range between four to eight hours. It is more suitable for operational price arbitrage and load leveling [12].

2.6.2 Pumped Hydroelectric

A pumped hydroelectric is one of the mature energy storage technologies [14]. This system includes generator or turbine equipment, a waterway, lower reservoir, and upper reservoir. The generator or turbine equipment normally used for hydroelectric power plant system that does not have storage [19].

However, pumped hydroelectric system will store the energy by operating the generator or turbine in reserve [19]. The energy will be stored by using off-peak electricity. It will pump the water from a lower reservoir to an upper reservoir [14]. This is because it will pump water uphill otherwise into an elevated vessel during inexpensive energy is available. When the energy is more valuable, the water will release later. After the releasing of water, it will go through the turbine which can turn the generator to produce electric power [19]. Figure 2.3 shows the hydroelectric pumped storage system.

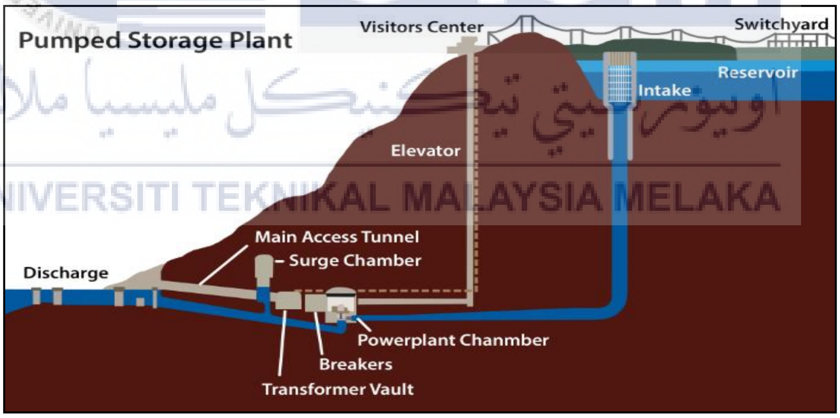


Figure 2-2 Hydroelectric Pumped Storage System[14]

2.6.3 Compressed Air Energy Storage (CAES)

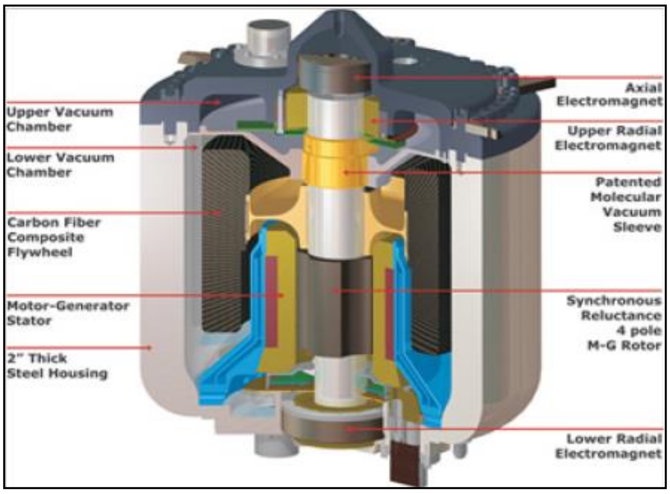
Compressed air energy storage is known as compressing air that will use inexpensive energy to generate electricity [19]. The energy storage will convert into electric energy, which the compressed air will be released into a combustion turbine generator system. When the air is released, the heated will produce and sent through the turbine system. The electricity will generate when the turbine spins and turns the generator [19].

Furthermore, it will store energy either on the above-ground system or in an underground system by running the electric motor. Then, it will compress air and release it through a turbine to generate energy. It will help the grid by storing energy during off-peak (low demand) and release it during high peak load (high demand). The technologies of CAES has a large capacity. However, the main issues of this CAES are low round-trip efficiency and limit of geographic locations. The overall of the process, it consumes this energy which creates around three times of the energy same size with the gas turbine [14].

2.6.4 Flywheels

Flywheels are being used in commercially deployed for frequency regulation. It can be used in electricity converted into spinning discs. From this, it can be slowed down or speed up to rapidly shift energy from or to the grid which ensures steady power frequency (60Hz) supplied to the grid [12].

Flywheels are known as the rotors that charged by accelerating the inertial masses. The energy is stored as a rotational kinetic energy of the flywheel. The extraction by a generator will discharge the kinetic energy which decelerates the rotation. Flywheels have a advantages such as good cycle stability, low maintenance, long life cycle, good environmentally materials, and high power density. It also has a high level of self-discharge and low efficiency [14]. Figure 2.4 shows the construction and components of flywheels.



2.6.5 Superconducting Magnetic Energy Storage (SMES)

Superconducting magnetic energy storage is known as technology to store electrical energy directly to electric current. It will store the electrical energy as a direct electric current through an inductor coil of magnetic field. It is made from superconducting material and circular. So the current can flow circulate with almost zero loss[22]. It has a similarity with supercapacitor in term of ability to respond extremely fast. However, it is still has a limitation from the total energy capacity [21]. Furthermore, the current will increase during charge and decrease during discharge. It must be converted for DC or AC voltage applications[23] . Figure 2.5 shows the SMES system.

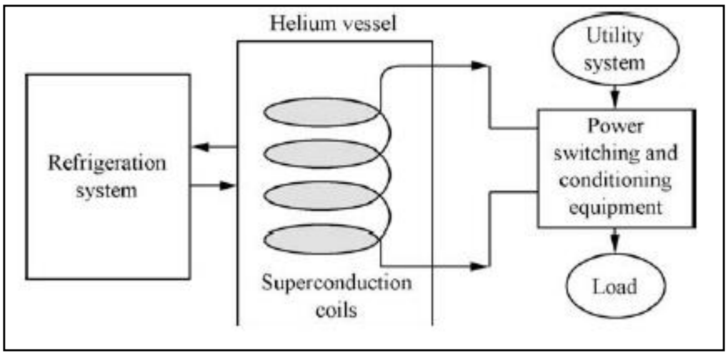


Figure 2-3 SMES system[22]

2.7 Energy Storage Specifications

For the energy storage specification, there are many aspect or parameters that can found in the energy storage. Many aspects need to be considered when selecting the battery for the energy storage in the solar PV system. It is usually can be connected with the utility grid or stand-alone system. The battery energy storage can be used as a backup power supply when the power outage has been takes place in the utility grid. The battery energy storage can be used to give the supply for the load when the grid electricity prices is high for the load to be purchased. Furthermore, the number of charging and discharging cycles normally depend on the way how the battery is being used in the system [24] .

So, the criteria that need to be selected of the energy storage specification or parameters such as storage capacity, available power, depth of discharge (DOD) or power transmission rate, discharge time, efficiency and state of charge (SOC).

2.7.1 Storage Capacity

The meaning of battery capacity or storage capacity can be defined as the amount of energy or charge which can be extracted in the battery bank from its fully charged state to the zero charged state. It is usually measured in Ampere hours (Ah). The battery capacity is not very constant. It is vary significantly which is depends on the several factors such as their lifetime, rate of discharge and charge, history of the battery and temperature [24] .

2.7.2 Available Power

The available power will determine the size or constitution of the motor generator that stored in the conversion chain. Normally, it is expressed as an average value of power while the peak value used to represent as the maximum power of charge or discharge, Pmax. It is usually measured in watt (W) [23] .

2.7.3 State of Charge (SOC)

State of charge (SOC) can be defined as the percentage amount of stored energy in the battery with respect to the nominal battery capacity. State of charge is one of the main specification or parameters that will reveals the current battery energy which is the stored energy in the battery.

The percentage energy stored in the battery with respect to the nominal battery capacity normally known as a state of the charge of the battery. This is the main parameter that reveals about the current battery energy which will be stored in the battery [24] .

2.7.4 Depth of Discharge (DOD)

Depth of discharge (DOD) is refers to the degree to which the batteries are discharged in a relation of its total capacity. Energy storage can be defined as a slow process that quickly release stored energy on power demand. The discharge or power output for power transmission rate can be a limiting factor. The delivery rate usually will determine the time needed to be extracted the stored energy. The power for delivery must always be available during peak hours. The amount of energy storage that being used is represent a non-optimum system and the fundamental limit of energy storage apparatus [24] .

2.7.5 Charging and Discharging Rate

Charging and discharging rate can be defined as the amount of charge that will be added or extracted from the battery per unit time. It is measured in Ampheres or Coulombs/Sec. However, it also can be defined in terms of the hours that normally takes to fully charge and discharge the battery. For example, C20=500 it refers to the battery capacity which is 500Ah and it will fully discharged in 20hours [24] .

2.7.6 Efficiency

There are two ways to describe the efficiency of battery which is coulombic efficiency and voltage efficiency. For coulombic efficiency, it can be defined as the ratio of the amount in charging through the battery during charging. The amount of charge that will be extracted from batteries during discharging. While voltage efficiency is defined as the ratio of the discharge in average voltage to the charge of average voltage.

Furthermore, the roundtrip can be defined as the ratio of energy that will be extracted from the battery and the energy will send through the device. Based on the battery efficiency, the energy loses will never be equal to the 100% [24] .

2.8 Energy Storage Sizing

Optimal sizing of energy storage can ensure high penetration levels of renewable energy with minimal impact to the distribution system. There are three main categories of methods used to determine the optimal allocation of energy storage which are analytical, numerical and meta-heuristic method.

2.8.1 Analytical Method

Analytical method has been proposed by many researchers for sizing energy storage through evaluation and derivation of a series of mathematical equations and algorithms. The objective function and the constraints are examined repeatedly with different set of parameters during the process of optimization and the set of parameters including the energy storage system capacity with performance is chosen as the optimal solution. No specific mathematical programming is employed to solve any of optimization problems.

Table 2-1 Summary of analytical approach for sizing energy storage[25]

Techniques	Objectives	Detailed Method
Cost-Benefit Analysis[26]	Reduce the investment cost of energy storage system the total of a generator operation cost	Cost-benefit investigations focus on ESSs: • capital cost, • charging/discharging • efficiency • lifetime a .
Clustering and sensitivity analysis; multi-period OPF convex relaxation[26]	Minimize the line losses and total sizing energy storage	• Analyzed the sensitivity matrix of the bus voltage where the optimization algorithm • The suitable location and number of BESS in the network with different number of clusters was proposed.
Benders decomposition method[25]	Reduce the investment of storage and generation cost	• The algorithm increased performance of the optimization by splitting the BESS allocation problem into two levels master problem sub-problems
Conditionally exact convex OPF; Benders	Minimize the ESS related cost and daily operation cost	• The stochasticity of load and renewable generation

Decomposition method[27]		were taken into consideration. • The limitations of the Benders Decomposition method optimization problem formula without dual variables for the reduction of the solution space
Improved impedance matrix analysis[27]	Minimize BESS current as a function of solar current	• The voltage changes are evaluated due to modification of the network • The modifications should be reflected either in the current vector impedance matrix

2.8.2 Numerical Method

Numerical method is the approach where the numerical methods are used to develop in finding the optimal sizing energy storage solution. The advantage of the mathematical optimization is the attainment of an optimal solution. But the computational time may increase significantly when the difficulty and the dimension of the problem also increases. For the application in ESS allocation problem is determined, modelled and solved in the form of the numerical representation[25].

Based on table 2, it will summarize the numerical method. From this table 2.2, it will include the techniques, objectives and detailed method. Numerical methods are represent based on a mathematical programming and the analysis.

Table 2-2 Summary of Numerical Methods [25]

Techniques	Objectives	Detailed Method
Linear programming[27]	To reduce storage cost and time-variable price profile	• The non-linear AC optimal power flow was transformed with a Linear Programming problem • It solved by updating the voltage using forward backward sweep optimal power flow
MIP; Monte Carlo simulation[28]	To minimize the operation cost of the MG and investment cost of ESS	• The formulation of ESS sizing was using MILP • During optimization process, Monte Carlo simulation was used to account for the modeling of random component outages.

2.8.3 Meta-Heuristic Method

The meta-heuristic method is not like analytical and numerical approach. It does not require complex calculation as complicated mathematical models and algorithm to obtain the optimal energy storage allocation. Furthermore, meta-heuristic method is to find the solution space, imitating certain naturally existing the behavior and processes. This approach does not guarantee the optimal solution[25].

Table 2.3 shows the summary of meta-heuristic method. The meta-heuristic method is one of the optimization techniques that will be used to select the best possible solution among the set of different possible result. The different methods and techniques have been analyzed and summarized in Table 2.3.

Table 2-3 Summary of Meta-Heuristic Methods [25]

Techniques	Objectives	Detailed Method
Probabilistic optimal power flow (POPF)[29]	To minimize the hourly social cost for optimal sitting of ESS with high amount of wind power in the system	• An energy arbitrage model was utilized to assess the economics of the ESS. • For higher efficiency, ESS should be placed near to renewable energy generation
GA based bi-level optimization[29]	To reduce the voltage fluctuation by utilizing BESS	• It is caused by intermittent solar PV systems. • The goal of this work is to understand the benefit of BESS in distribution networks with high PV penetration.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this section, methodology is one of the important parts of study discovery. This chapter present literature review related to energy storage sizing for commercial building with solar PV. This chapter includes subtopic energy storage system, applications, technologies, characteristics and sizing strategy.

3.2 Overview

Figure 3.1 shows the flow of works to complete the project. This is chapter of the research methodology. It consists of 6 main parts in this project. The flow of works begins with overview, literature review, load and PV modelling, model dispatch strategy for energy storage using analytical method, dispatch strategy verification, develop strategy to size energy storage using optimization approach and sensitivity analysis. After all this process, the data are collected for further analysis in the next chapter.

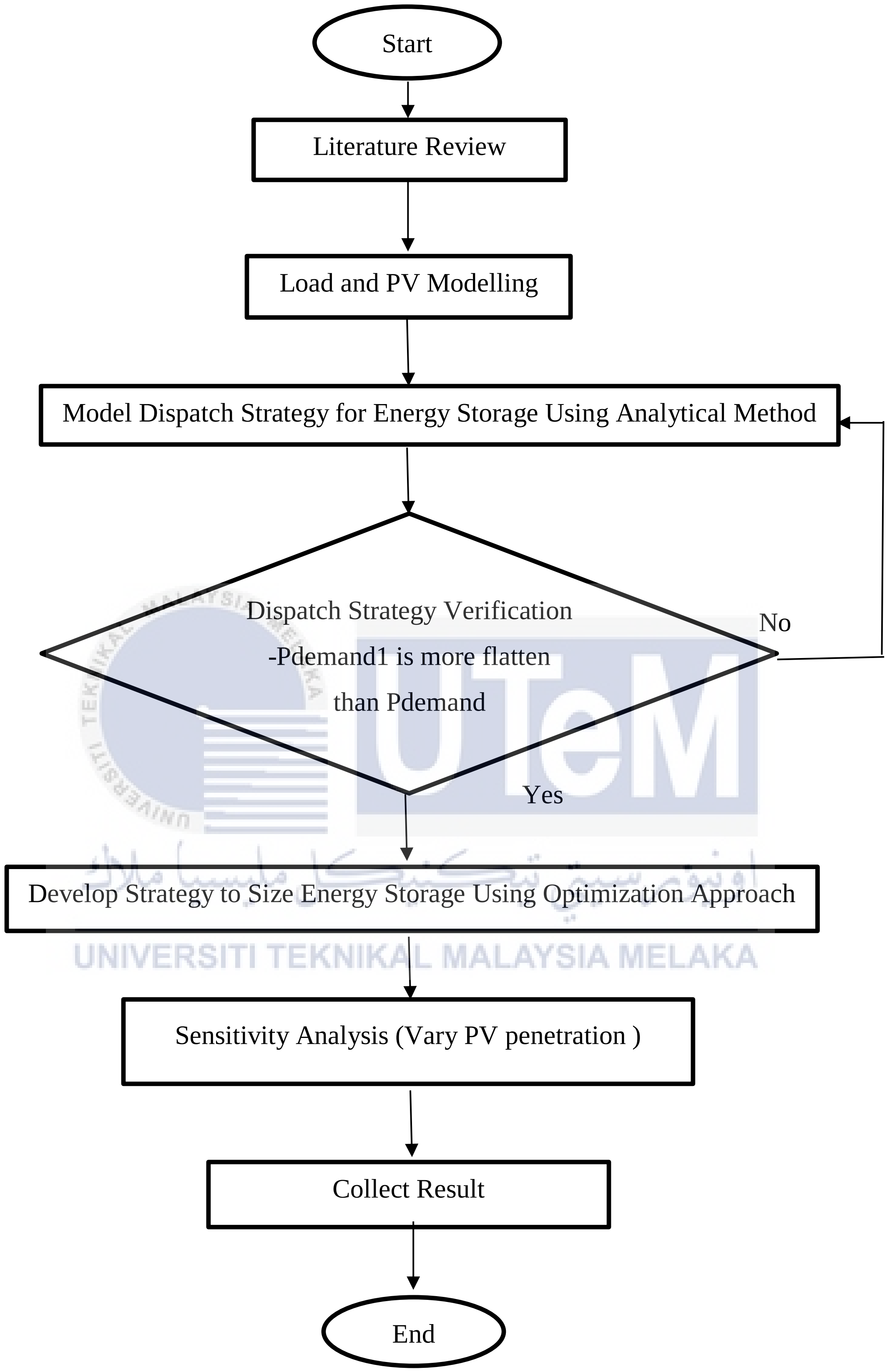


Figure 3-1 Flowchart of The Project

3.3 Literature Review

The research methodology begins with literature review. Review is conducted on energy storage sizing for commercial building with solar PV. From this literature review, it can demonstrate the author's knowledge about the energy storage sizing. Literature review has many information and knowledge such as methods, history and any related to this project. This will give more understanding about the sizing energy storage.

3.4 Load and PV Modelling

Figure 3.2 shows the hourly data load profile and solar PV. The load and PV model is selected one day to follow an hourly commercial load curve which was generated from the historical data based on the commercial building which is UTeM.One day of the load profile UTeM curve is picked from one month to represent any day This the load profile and solar PV data is used for one-month period.

Furthermore, many previous studies have modelled the uncertainty of solar PV output power by computing the probabilistic distribution of solar irradiance based on the historical data from UTeM.

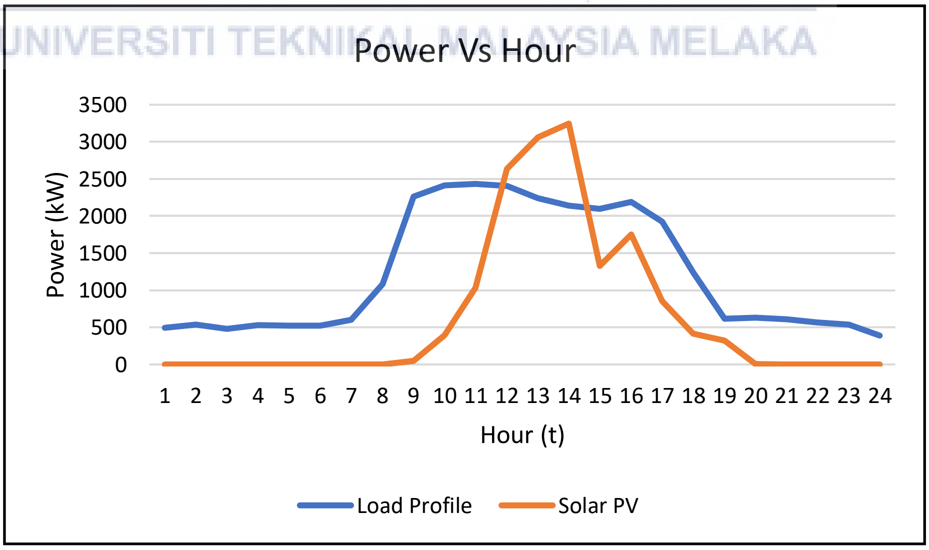


Figure 3-2 Hourly load profile and solar PV

3.5 Dispatch Strategy Energy

The third part for this project is developing the dispatch strategy for energy storage using analytical method. The control method for this purpose is Load Following was developed in MATLAB to charge energy storage during off-peak (low demand) and discharge during on-peak (high demand). The energy in the energy storage system is considered at the beginning of the day is equal to the end of the day.

The control mechanism will be charged the battery if the total subtraction power is below or lower than the charge threshold, P_{Ch} and discharge the battery if total subtraction power is above or larger than discharge threshold, P_{Dis}. These thresholds are determined by using an iterative algorithm.

Data of the load profile and output solar power PV generation need to be collected. There are a few steps must be followed to compute the charge and discharge threshold.

3.5.1 Discharge Threshold

There are a few steps must be followed to get the discharge threshold. The step for this iterative algorithm on discharge threshold:

Step 1: Set the value of the energy storage capacity (kWh)

Step 2: Find demand profile; where n represent day and t is hour

$$P_{Demand(n,t)} = P_{LOAD(n,t)} - P_{PV(n,t)} \quad (3\text{-}1)$$

Step 3: Set the initial values of P_{Ch} and P_{Dis} as the maximum and minimum of the active power

$$P_{Ch(n)} = \max(P_{Demand(n,:)}) \quad (3\text{-}2)$$

$$P_{Dis(n)} = \min(P_{Demand(n,:)}) \quad (3\text{-}3)$$

Step 4: Set the P_{ave} equal to the mean of demand profile

$$P_{ave(n)} = \text{mean}(P_{Demand(n,:)}) \quad (3\text{-}4)$$

Step 5: The condition for discharging threshold, Tp_{Dis};

$$ES - Tp_{Dis(n)} > 0.1 \quad (3\text{-}5)$$

$$P_{Dis(n)} \geq P_{Ave(n)} \quad (3\text{-}6)$$

Step 6: The new discharging, Pp_{dis}

$$Pp_{dis(n,t)} = P_{Demand(n,t)} - P_{dis(n)} \quad (3\text{-}7)$$

Step 7: If the difference between the diurnal discharging energy and the total capacity of the energy storage is more than 0.1, then decrease the P_{dis} by 0.01.

$$P_{dis(n)} = P_{dis(n)} - 0.01 \quad (3\text{-}8)$$

Step 8: If not more than 0.1, it will have the final value of discharge threshold, Tp_{dis}

$$Tp_{dis(n)} = sum\ Pp_{dis(n,:)} \quad (3\text{-}9)$$

3.5.2 Charge Threshold

There are a few steps must be followed to get the charge threshold. It will continue the step from the previous step in discharge threshold. Repeat step 1-4 for charge threshold part. The step for this iterative algorithm on charge threshold:

Step 1: Repeat step 1-4 from the previous iterative method for charging threshold

Step 2: The condition for charging threshold; Tp_{Ch}

$$ES - Tp_{Ch(n)} > 0.1 \tag{3-10}$$

$$P_{Ch(n)} \leq P_{Ave(n)} \tag{3-11}$$

Step 3: The new discharging, Pp_{Ch}

$$Pp_{Ch(n,t)} = P_{Ch(n)} - P_{Demand(n,t)} \tag{3-12}$$

Step 4: If the difference between the diurnal discharging energy and the total capacity of the energy storage is more than 0.1, then increase the P_{Ch} by 0.01.

$$P_{Ch(n)} = P_{Ch(n)} + 0.01 \tag{3-13}$$

Step 5: If not more than 0.1, it will have the final value of charge threshold

$$Tp_{Ch(n)} = sum\ Pp_{Ch(n)} \tag{3-14}$$

3.5.3 Power Dispatch Strategy Energy

Using the values of P_{Dis} and P_{Ch} that obtained from the above iterative method, the total active power dispatched by power energy storage at suitable hour and day, $P_{ES(n,t)}$ can be computed as follows:

$$PES_{Ch(n,t)} = P_{Ch(n)} - P_{Demand(n,t)} \in P_{Demand(n,t)} \leq P_{Ch(n)} \quad (3\text{-}15)$$

$$PES_{Dis(n,t)} = P_{Demand(n,t)} - P_{Dis(n)} \in P_{Demand(n,t)} \geq P_{Dis(n)} \quad (3\text{-}16)$$

After that, it can be obtained total energy storage, P_{ES} by the addition between power energy storage charge and discharge

$$P_{ES(n,:)} = PES_{Dis(n,:)} + PES_{Ch(n,:)} \quad (3\text{-}17)$$

From the observation, the energy storage will be charged during off-peak period (low power demand) and discharged during on-peak period (high power demand). For this allocation strategy can bring some benefits to the utility in battery, which is round-trip efficiency, the maximum depth of discharge in terms of reduce the energy cost that can obtained from the proposed dispatch strategy.

3.6 Dispatch Strategy Verification

The fourth part is dispatch strategy verification. In this task, it will verify the dispatch strategy. Besides, it will evaluate the new load demand profile after develop energy storage. The new load demand profile, Pdemand1 will be more flatten compared to load demand before develop energy storage.

Based on the dispatch strategy verification, the load demand profile with and without energy storage will be compared between it. The result of this dispatch strategy verification is load demand profile with energy storage more flatten. The dispatch strategy is verified.

3.7 Optimization Approach

The optimization approach for developing strategy to size energy storage using optimization. This step will be conducted on Final Year Project 2. From this task, the energy storage sizing can be obtained by using optimization method which is genetic algorithm.

This part describes a methodology or process that is proposed in this energy storage work planning. The aim of the problem formulation is to optimally size energy storage in a system with distributed PV generation. In this procedure, the inputs include distribution system data, the probabilistic generation model of PV, the price of every load profile and maximum demand. The variables that used in this procedure are the optimal size of energy storage units in kW h. The genetic algorithm (GA) toolbox in MATLAB is used to solve the problem of the optimization due to its robustness and its capability of handling integer variables.

Figure 3.2 briefly illustrates the procedure of the methodology for energy storage planning. At the beginning of the procedure, genetic algorithm will generate an initial population for the optimization problem.

The following step for genetic algorithm to evaluate and determined the size of energy storage (ES):

Step 1: Generates an initial population for sizing energy storage is known as $x = M_{ES}$

Step 2: Based on initial population energy storage, the active power dispatched by energy storage units, $P_{ES(n,:)}$ are determined by using iterative and analytical method.

Step 3: It will be calculated based on the computed value $P_{ES(n,:)}$, the technical characteristic of adopted energy storage technology and M_{ES}

Step 4: New load profile with energy storage are determined by subtraction the old demand profile, $P_{Demand1(n,t)}$ and P_{ES}

$$P_{demand1(n,:)} = P_{Demand(n,:)} - P_{ES(n,:)} \quad (3\text{-}18)$$

Step 5: Determine load factor with & without energy storage

$$Load\ Fac_{ES(i)} = mean(\ P_{Demand(i,:)})/max(\ P_{Demand(i,:)}) \quad (3\text{-}19)$$

$$Load\ Fac_{(i)} = mean(\ P_{Demand1(i,:)})/max(\ P_{Demand1(i,:)}) \quad (3\text{-}20)$$

Step 6: Objective function is evaluated to get the minimum cost of electricity bill.

- Price for every load profile

$$P_{dem(n,t)} = P_{demand1(n,t)} * 0.36 \quad (3\text{-}21)$$

- Price for max load demand profile

$$P_{dem1} = max(max(\ P_{demand1})) \quad (3\text{-}22)$$

$$P_{newdem} = P_{dem1} * 3 \quad (3\text{-}23)$$

- Total cost electricity bill for one-month period

$$f = sum(sum(P_{dem(n,t)})) + (P_{newdem}) \quad (3\text{-}24)$$

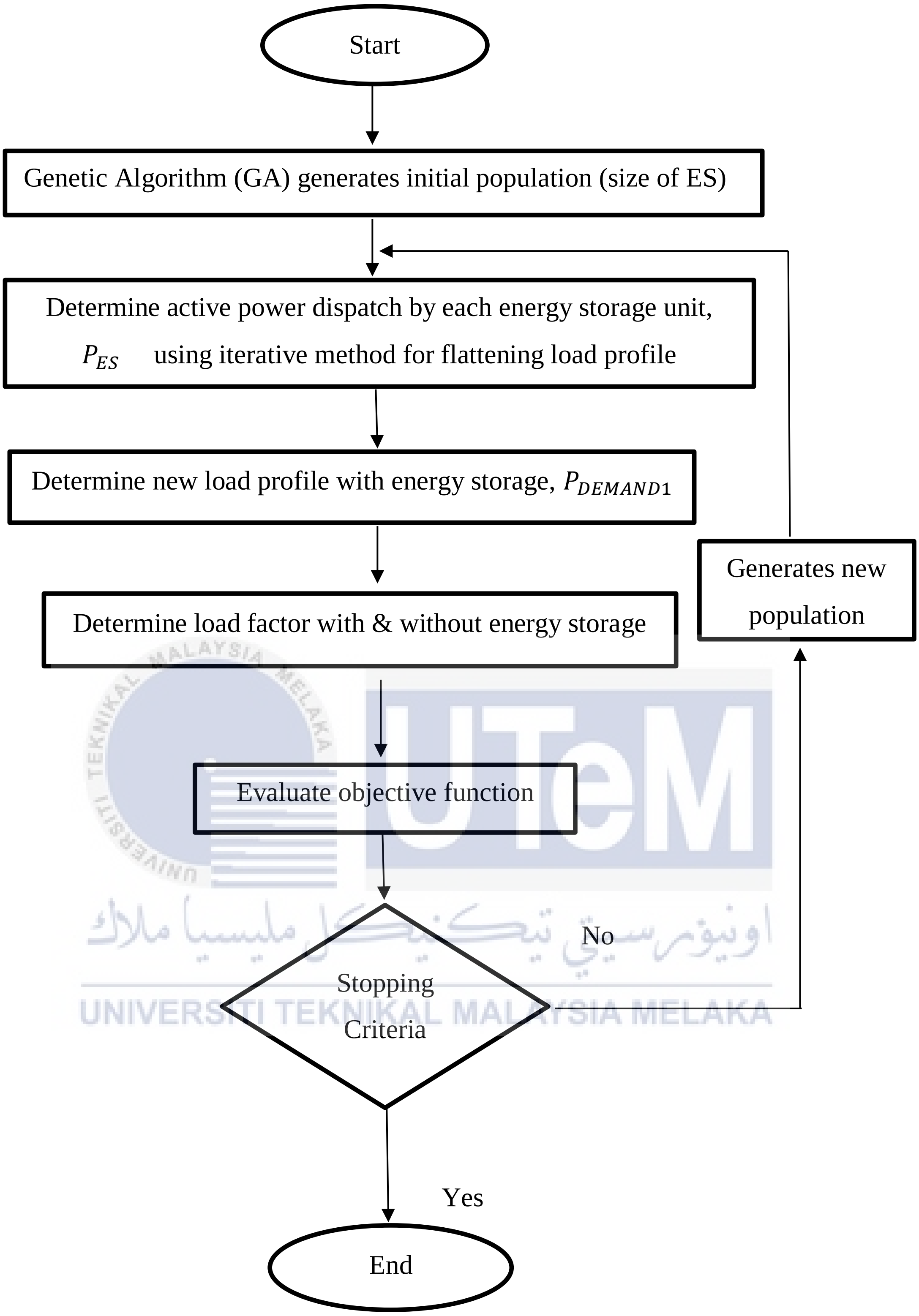


Figure 3-3 Flowchart of the proposed methodology

3.8 Sensitivity Analysis

This is the last part in this flow of works in this project which is sensitivity analysis. From previous part 1 until 5, it will evaluate the optimization problem. The optimum value of sizing energy storage and electricity bill is determined in this section.

In this task, sensitivity analysis is evaluated by varying the PV penetration levels. The PV penetration level is varied from 0% to 100% by every 10%. This is because the different between PV penetration levels give the different value of energy storage capacity and cost of electricity. The formula of PV penetration:

$$PV_{net} = (E_{pv}/E_{load}) * 100 \quad (3\text{-}25)$$

Where E is energy (kWh)

Next, the data will be collected to be analyzed in the next chapter. All the result will be discussed in the chapter 4 which is result and analysis. From the result, it can be analyzed the different between using with & without energy storage and vary PV penetration.

3.9 Summary

In a nutshell, sizing energy storage capacity has been completed and determined by using optimization genetic algorithm method. All the data is collected for further discussion. The cost of electricity and optimum size of energy storage has been analyzed and evaluated as one of the objectives in this project. The PV penetration level is varied for sensitivity analysis.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This section will discuss the result based on the simulation that have been done in the duration on Projek Sarjana Muda 2. The analysis of the result based on the objective in this project. It consists of energy storage dispatch strategy, optimum size of energy storage in PV and effect of PV penetration.

4.2 Energy Storage Dispatch Strategy

The first objective for this project is to develop energy storage dispatch strategy for peak demand reduction and load factor improvement for commercial building with PV. Energy storage dispatch strategy will show the pattern of the charging and discharging threshold.

Before energy storage dispatch is evaluated, the simulation will be run in MATLAB to find the optimum energy storage. The simulation will be run the solar PV penetration as 70%. The excessive of solar PV will be stored in the energy storage. The result for energy storage is determined as 558.2769 kWh. Peak demand reduction and load factor improvement will be analyzed in this section.

4.2.1 Peak Demand Reduction

Figure 4.1 shows the comparison between demand profiles with and without energy storage. One day of the energy storage dispatch strategy is picked from one month to represent any day. The demand profile will be more flatten in this energy storage dispatch strategy.

Based on the graph below, P_{Demand} is old demand profile and Pdemand1 is new demand profile for commercial building. The blue colour is power demand without energy storage act as P_{Demand}. While orange colour is power demand with energy storage will be as $P_{Demand1}$. From the result, P_{Demand} increase because no energy storage in the solar PV system. However, $P_{Demand1}$ decrease after using energy storage for solar PV.

Furthermore, energy storage is usually to flatten demand profiles. The energy storage will be charge during the off-peak period and discharge during on-peak period. In additional, the energy remaining in the energy storage at the beginning of the day is equal to the end of the day. The battery storage will be charge if the total power commercial building is below the charge threshold, P_{Ch}. While discharge the battery if the total power commercial building is above the discharge threshold, P_{Dis}

Using the values of P_{Dis} and P_{Ch} obtained from the iterative method, the total active power dispatch by energy storage at every hour, $P_{ES(t)}$. The positive value represents the power discharged by energy storage during off-peak. While, negative value represents the power charged by energy storage during on-peak. Therefore, P_{Demand} demand profile become more flatten after discharge the energy storage.

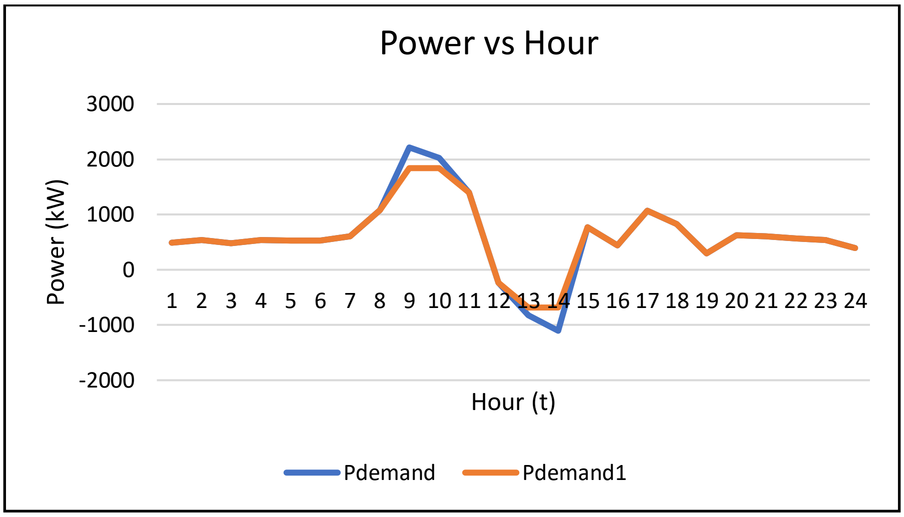


Figure 4-1 Demand profiles with and without energy storage

4.2.2 Load Factor Improvement

Figure 4.2 shows the improvement of load factor. The comparison between with and without energy storage can be analyzed for this load factor. When no energy storage, the load factor is 0.108874461. While the energy storage is 558.27 kWh, the load factor is 0.270487414. From this result, the improvement of load factor is 0.161613.

Based on this result, the higher energy storage will give the higher of load factor. The improvement of load factor is depending on the energy storage capacity.

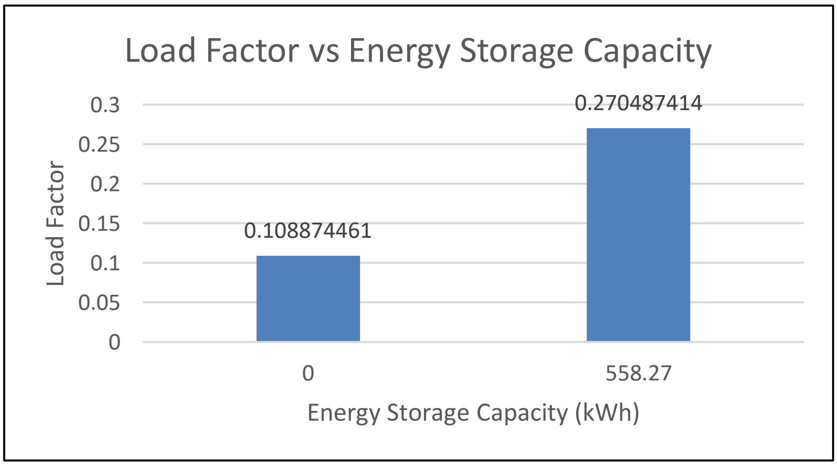


Figure 4-2 Improvement of load factor

4.3 Optimum Size of Energy Storage

The second objective of this project to identify the optimum size of ES in commercial building with solar PV for minimizing the cost of electricity. In this part, it has two type of case which is case 1 and case 2. Every case has solar PV penetration level as 20%.

Table 4.1 shows the Table 4.2 shows the variation of GA over 10 runs for Case 2. This case is run with varying solar PV penetration which is 20%. The simulation will be having 10 runs until it gets the optimum value of energy storage and electricity cost. Based on the result, the minimum size of energy storage is 568.9194 kWh and electricity price are RM 276939.78304. The highest of electricity bills is RM 276780.135 at energy storage capacity 761.178608 kWh. Basically, it will run until get the most minimum and optimum cost of electricity

Table 4-1 Optimization for 10 times running

No of Run	Energy Storage Capacity (kWh)	Cost of Electricity (RM)
1	761.1786	276780.14
2	531.7893	276976.93
3	599.6874	276908.98
4	591.8949	276916.71
5	599.7998	276908.78
6	542.1807	276966.5
7	680.4573	276840.72
8	497.1104	277011.68
9	569.2177	276949.5
10	568.9194	276939.78

Table 4.2 shows the type of case with different energy storage. The energy storage capacity for case 1 and case 2 are 0 kWh and 568.9194 kWh. The energy storage capacity for case 2 is determined from the optimization method which is Genetic Algorithm. The function of genetic algorithm to evaluate the optimum size of energy storage capacity.

This evaluation of energy storage capacity is determined for one-month period which is 31 days. From this result, it can be seen the comparison of the different energy storage in terms of electricity bills, peak demand, load factor and demand profiles.

Table 4-2 Type of case with different energy storage

Type of case	Energy Storage Capacity (kWh)
Case 1	0
Case 2	568.9194

4.3.1 Cost of Electricity

Table 4.3 shows the cost of electricity with different energy storage capacity. The objective function for this project is cost of electricity bills. The simulation has been done with and without optimization method for case 1 and case 2 is used optimization method. Based on the result below, the cost of electricity for case 1 is RM 277959.9786. While case 2 is RM 276939.7830 electricity bill at 568.9194 kWh.

From this result, the reduction of electricity bills for commercial building has been analyzed. The total cost of electricity reduction is RM 1020.1956. The reduction of the electricity bill because of the energy storage. When no energy storage, it cannot reduce the cost of electricity. So, the higher of energy storage capacity, it will decrease the cost of electricity.

Table 4-3 Electricity bills with different energy storage

Energy Storage Capacity (kWh)	Electricity Bill (RM)
0	277959.9786
568.9194	276939.7830

4.3.2 Peak Demand

Table 4.4 shows the peak demand with different energy storage. In this section, peak demand will be evaluated to see the reduction between two different values of energy storages capacity. Peak demand is known as the highest load demand in one-month period. So, the peak demand for commercial building during 0 kWh is 4204.8672 kWh. While, peak demand during energy storage capacity at 568.9194 kWh is about 3864.7072 kWh.

From this result, the load peak demand is reduced about 340.16 kWh for one-month period. Load peak demand can be reduce or minimize by using energy storage. The high of energy storage capacity will decrease the peak demand for commercial building in one-month period.

Table 4-4 Peak demand with different energy storage capacity

Energy Storage (kWh)	Peak Demand (kWh)
0	4204.8672
568.9194	3864.7072

4.3.3 Load Factor

Figure 4.3 shows the load factor with different energy storage capacity. For load factor, it can be analyzed and determined from this simulation in MATLAB. Different values of energy storages will affect the load factor. When the energy storage capacity is 0 kWh, the load factor is 0.4940. Next, the energy storage capacity at 568.9194 kWh will give the load factor about 0.5891. The load factor increases almost to 0.0951 for one-month period.

From the result, it shows that the load factor is getting increase when the energy storage capacity is increase. Furthermore, when the load factor is increase, the generation cost for the same maximum demand is decrease.

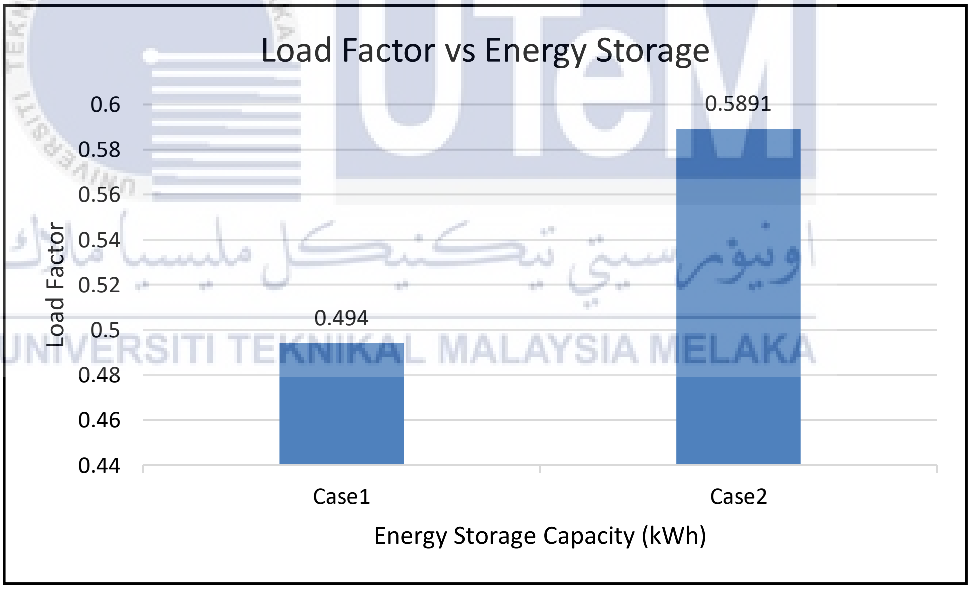


Figure 4-3 Load factor with different energy storage

4.3.4 Demand Profiles

Figure 4.4 shows the demand profiles for one-month. M_{demand} is max demand without energy storage. While $M_{demand1}$ is maximum demand with energy storage. From this result, the reduction of max demand after using energy storage. The max demand for $M_{demand1}$ is more flatten than M_{demand}. This is because when the PV penetration is 20%, the energy storage capacity is 568.9194 kWh.

Based on the result, the energy storage can reduce the maximum demand profile for commercial building with solar PV penetration. If there has PV penetration, the energy storage can be stored and used later to reduce the demand profile.

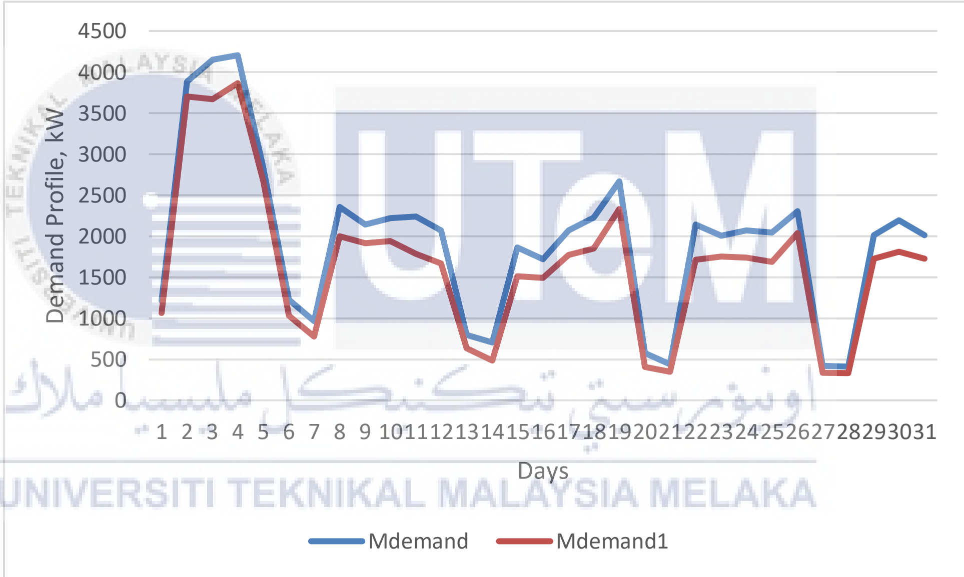


Figure 4-4 Demand profile for one-month

4.4 Effect of Varying PV Penetration Level

The effect of PV growth on the profitability of deploying energy storage is evaluated in this project. In this part, the sensitivity analysis has been done by varying solar PV penetration levels. The PV penetration level is varied from 0% to 100% by every 10%. This will give the different value on energy storage capacity and cost of electricity.

Figure 4.5 shows the optimum energy storage and cost of electricity with different PV penetration levels. From the result, the lowest energy storage capacity is 558.2769 kWh. While the highest energy storage capacity is 576.0526 kWh. Based on result, the PV penetration levels does not affect energy storage capacity. So, the energy storage is not depending on the solar PV penetration. The higher value of solar PV penetration will not give the higher energy storage capacity.

For cost of electricity, the highest value is RM 345886.87 during no solar PV penetration. Then, the lowest electricity bill is RM 5322.16. This is because the highest solar PV penetration. It also shows the electricity bills reduce when varying the solar PV. For this sensitivity analysis, the higher of solar PV penetration will give the lower price electricity bill. So, the electricity bill can reduce by varying the solar PV penetration levels.

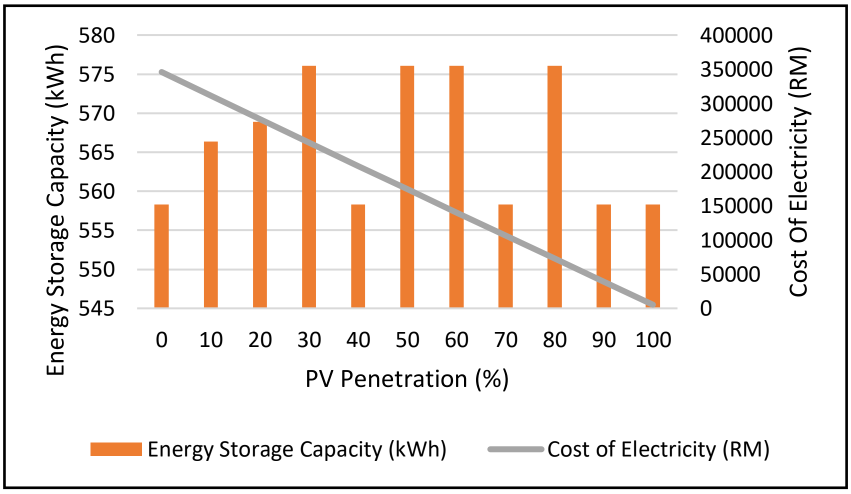


Figure 4-5 Optimum Energy Storage Capacity and Cost of Electricity with varying PV penetration level

4.5 Summary

In a conclusion, the objective of this project has been analayzed. The peak demand reduction and load factor improvement is evaluated in this section. Next, the optimum size of energy storage using optimization which is genetic algorithm. When the optimum size of energy storage increase, the peak demand decrease. The cost of electricity also decrease. While the load factor is increase as energy storage capacity increase. Lastly, the sensitivity analysis has been done by varying the solar PV penetration. Combination of optimal size of ES deployment and Increment in solar PV penetration may reduce the cost of electricity for commercial building.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this project aims to size energy storage for commercial building with solar PV by using optimization in MATLAB coding. The case study on the peak demand, load factor, electricity bills and energy storage has been evaluated for one-month period in this project. Based on the simulation result, the electricity bill can be reduced when using energy storage for commercial building. The peak demand is decreased and load factor has an improvement. Next active power dispatch strategy of energy storage is developed for flattening the daily demand profile. The positive value represents the power discharged by energy storage during off-peak. While, negative value represents the power charged by energy storage during on-peak.

Data collection for load profile and solar PV from the UTeM was done for one-month period. For the optimization method is used genetic algorithm. By using the optimization method, the optimum energy storage and minimum price of electricity bills is evaluated in the MATLAB. For the case of without using energy storage, the peak demand is increased and no improvement of load factor. The electricity bill is higher. Furthermore, the sensitivity analysis has been done by varying the solar PV penetration. The higher of solar PV penetration can be reduced the electricity bill for commercial building.

5.2 Future Works

For the future recommendation, the next target can be developed in this project. The future recommendation is developing the reactive power of energy storage, Q_{ES} . Q_{ES} will dispatched to improve the voltage profile within its specified limits. In this work, energy storage is allowed to dispatch the reactive power, Q_{ES} through the capability of the inverters. The inverters will ensure the operating voltage within its limit. Next, the cost of electricity for one-year period can be evaluate and verify for the next project. This will give the comparison of electricity bills for every month in one-year period.

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APPENDICES

APPENDIX A DAILY LOAD PROFILE AND SOLAR PV DATA

Time	P_{load} (kWh)	P_{PV}(kWh)
0:00:00	494	0
1:00:00	535	0
2:00:00	482	0
3:00:00	533	0
4:00:00	525	0
5:00:00	524	0
6:00:00	602	0
7:00:00	1083	0
8:00:00	2262	48.2748
9:00:00	2415	391.9391
10:00:00	2433	1031.853
11:00:00	2403	2637.933
12:00:00	2240	3061.424
13:00:00	2142	3246.456
14:00:00	2097	1330.878
15:00:00	2188	1751.454
16:00:00	1921	854.7273
17:00:00	1240	417.0026
18:00:00	618	324.0279
19:00:00	633	6.195701
20:00:00	608	0
21:00:00	568	0
22:00:00	538	0
23:00:00	389	0

APPENDIX B GANTT CHART