AN ECONOMIC ASSESSMENT OF STANDBY DIESEL GENERATOR FOR PEAK SHAVING IN COMMERCIAL AND INDUSTRIAL BUILDINGS

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"AN ECONOMIC ASSESSMENT OF STANDBY DIESEL GENERATOR FOR PEAK SHAVING IN COMMERCIAL AND INDUSTRIAL BUILDINGS"** was prepared by **CHEW JEE XIONG** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

The peak electricity demand has increased every year due to the growth of world economy. The utility has to meet the peak demand during the peak hours, where the cost of operating is high due to the use of peak-load power plant. In order to compensate this operating cost, the utility imposes a charge called maximum demand charge and this has increased the burden to the consumers. Most of the commercial and industrial sector are equipped with standby diesel generator. It can produce its own power supply to reduce business risks caused by power disruption such as power blackout. It also has the potential to be used for peak shaving to reduce the peak demand. This study aims to investigate the cost-benefit of using diesel generator to provide peak shaving service in order to reduce the electricity bills for commercial and industrial customers. Hybrid Optimization Model for Electric Renewable (HOMER Pro) is used to develop an energy dispatch model and evaluate the economic feasibility of using diesel generator for peak shaving. Two types of customer's load profiles are selected to investigate the effects of different load profiles to the cost-effectiveness. The size of the diesel generator and its operational durations are determined based on the lowest cost of electricity and the net present cost obtained from the simulations. The simulation results show that the use of standby diesel generator at commercial and industrial customers' premises is economically viable for peak shaving.

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LIST OF ABBREVIATIONS

BESS	battery energy storage system
CCGT	combined-cycle gas turbine
CO_2	carbon dioxide
ESS	energy storage system
OCGT	open-cycle gas turbine
PV	photovoltaic
HOMER Pro	Hybrid Optimization Model for Electric Renewables
NREL	National Renewable Energy Lab
IEEE	Institute of Electrical and Electronics Engineers
COE	cost of electricity
TNPC	total net present cost
NPC	net present cost

CHAPTER 1

INTRODUCTION

1.1 Background

The energy demand in commercial and industrial sectors is high due to the usage of high power consuming equipment such as motors, air conditionings and lighting equipment. The electrical utility has to meet the demand in "just-in-time" mode. This requires a generation fleet formed by base-load power plants, intermediate-load power plants, and peak-load power plants. Consequently, this results in high generation costs and hence, utility imposes these costs to customers in order to compensate for the increase of operating and maintenance cost of grid operation. The cost is typically introduced as maximum demand charge.

Due to the high maximum demand charge, customers need to find a way to keep the peak demand as low as possible. One of the method is by using peak shaving method. Peak shaving is a method of reducing the peak demand during intervals of high demand. The demand peak-valley gap on the consumer side can be as high as 40% to 50% (Wang & Wang, 2013). By reducing the peak demand, it can help to reduce the maximum demand charge during the billing period.

Most of the commercial and industrial building do have its own standby generator which acts as a backup power supply, when there is a breakdown from the electrical grid. Standby diesel generator provides an advantage of lowering down the load demand profile while customers are able to carry out their usual daily life routines. The standby generator can be operated during the peak demand periods to reduce the peak demand. A Hybrid Optimization Model for Electric Renewable (HOMER Pro) software is used to simulate the cost of electricity and evaluate the feasibility of using standby generator for peak shaving. It is able to perform optimization in sizing and operational strategy of a generating system to generate the lowest total net present cost. Some information required to be analysed was collected such as load profile and price of diesel.

Two load profiles are investigated to determine the cost-effectiveness with different load profiles. During peak hours, there is a rise in demand for electricity for some time and this gradually decreases after time passes. This load profile has a sharp load demand characteristic. But there are some sectors whereby the power consumed by the loads are consistent throughout the working hours and this is known to have flat load profile characteristic.

1.2 Aims and Objectives

The aim of this project is to investigate the economic benefit of using the standby generator for peak shaving.

The objectives of this project are as follows:

- To investigate the feasibility of using standby generator in reducing peak demand in the building.
- To develop a model of power system of standby diesel generator to assess the cost-benefit of standby diesel generator in providing peak shaving.
- To evaluate the performance of the model developed.

1.3 Scope of Project

The scope of this project is to use an analytical tool to simulate the cost that can be saved by using standby diesel generator during peak time. The analytical tool used is HOMER Pro which is able to model power system's physical behaviour and the total cost of installing and operating the system throughout its lifespan. Standby diesel generator will be used in this project to lower the peak demand. There are two types of load profile to be looked into, namely flat and sharp load characteristics. Flat load profile has a constant and flat shape curve, without any peaks or troughs while for sharp load profile, there is a rise of power consumed for a short period of time. The focus of this project is to simulate the use of standby diesel generator for peak shaving in the commercial and industrial sector with the two different load profiles in order to determine the economic viability based on the cost of electricity and net present cost obtained from simulations.

1.4 Schedule of Projects

Table 1.1: Schedule of Project Part 1

Tasks	Duration
Comprehend HOMER Pro	2 weeks
Study related to peak shaving system	2 weeks
Develop a model on HOMER Pro	2 weeks
Find data required	2 weeks
Analyse the data obtained	3 weeks
Documentation	3 weeks

Table 1.2: Schedule of Project Part 2

Tasks	Duration
Develop a model of power system with standby generator and obtaining data required	3 weeks
Investigate the scenarios based on assumptions	3 weeks
Assess the cost-benefit of standby generator providing operating reserve and peak shaving	5weeks
Documentation	3 weeks

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In 9 March 2016, the peak demand in Peninsular Malaysia had breached the 17,000 MW peak demand threshold and reached a historical new record of 17,175 MW due to the hot and dry weather condition (The Star, 2016). The escalating peak demand has forced the grid operators to increase their generating capacity as well as reinforce the transmission and distribution facility to prevent any potential system blackouts. However, the reinforcement of power systems involve huge investments and requires thoughtful planning. In order to compensate the huge investments, this has brought about an increased price of the tariff, especially peak demand charge.

Many studies had been carried out by researchers to shave the peak demand of the load profile in order to reduce the necessity of purchasing power from the electric utility. Studies to be conducted are important in order to identify the worthy of using standby diesel generator for peak shaving in terms of cost of electricity throughout the project lifespan with the help of an analytical tool. The analytical tool will help to analyse the model built in the simulation.

2.2 Existing Power Generation System

There are three types of power plant which are base-load, intermediate-load and peak-load power plants. The base-load power plant will continuously generate power to meet the base load supply. It will operate most of the time at its rated power. Although it uses non-renewable energy such as coal-fired and nuclear and is cheap to operate, but the capital costs are high (Diesendorf, 2010). To compensate for the high capital cost, base-load power stations have to be operated continuously.

The peak-load power plant is designed to operate for a short period of time each day to meet the high demand of electricity. This means that it has a low capacity factor. It will only be used during peak time because this power plant is the most flexible plant where it can adjust its power output level (Diesendorf, 2010). Some examples are gas turbines where it can be fuelled with either natural gas or fuel. Although it has low capital cost, the cost of operating is high mainly due to the cost of fuel.

Intermediate-load power plant is designed to adjust the output power based on the demand that fluctuates during the day. It runs mostly during the day and early evening to fill the gap in supply between base and peak-load power. Its operating cost lies between base- and peak-load. Intermediate load can also be supplied either by gas- or coal-fired stations. Figure 2.1 shows the combination of base-load, intermediate-load and peak-load generation to meet the daily variation demand. It can be seen that, peak demand mostly occurs in early mid-afternoon.

Based on these statements, when peak-load power plants generate electricity, the cost to operate is expensive while the cost for both base- and intermediate- load power plants are cheaper. This is the reason during peak times, where maximum demand mostly occurs, the cost of electricity will be expensive. Due to this reason, the peak demand has to be reduced while maintaining the total power required by the loads. Hence, it will help to reduce the maximum demand charge during the billing period.

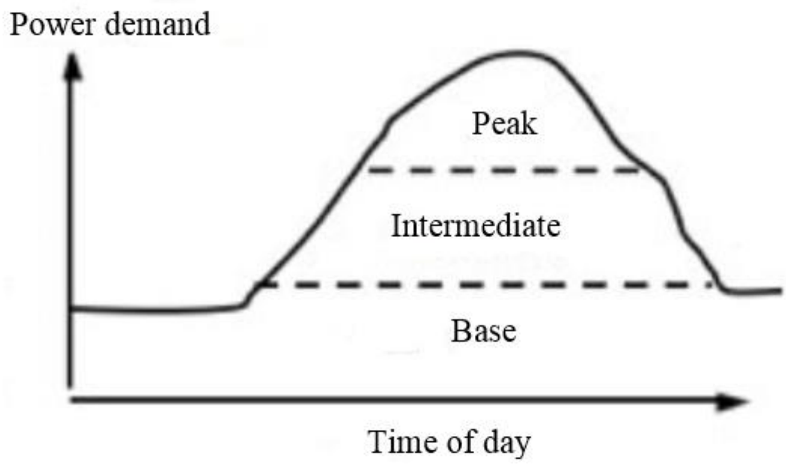


Figure 2.1: Load Curve for Typical Electricity Grid (Diesendorf, 2010)

2.3 Maximum Demand

Maximum demand is the highest level of electrical demand obtained in a month period. It is calculated as double the highest amount of electricity used (in kilowatt-hours) within any consecutive period of thirty minutes in a month (Tenaga Nasional Berhad, 2016). This applies to commercial and industrial sector where these sectors consume the most power. It is calculated based on the tariff categories and applicable to consumers using supply of 6.6kV and above (Tenaga Nasional Berhad, 2016).

For instance, tariff C1 has a maximum demand charge of RM 30.30 per kW. By determining the peak demand of a particular month, it will be multiplied with the maximum demand charge and this is the amount required to be paid for the maximum demand consumption.

2.4 The State-of-the Art of Peak Shaving

Peak shaving is defined as reducing the amount of energy purchased from the utility during peak hours which indirectly reducing the peak demand charges without affecting the productivity. The following are the research results related to peak shaving.

In (Carpinelli, Mottola, Proto, & Bracale, 2012), as microgrids are inadequate to fulfil the load demand during peak hours, it proposes a single-objective optimization model by using electric vehicle. It is able to provide services to the grid since the energy storage system inside electric vehicle can provide multiple role of loads and energy sources (Carpinelli et al., 2012). This helps to optimize the operation of the microgrid. This study is by using schedule strategy in order to minimize the daily energy cost with peak shaving service is taken into account. It uses formulas to formulate the model of distributed generation and microgrid along with electric vehicle. The study has done a comparison between the effect of with and without using peak shaving services. From the results, it is effectively able to optimize the energy daily cost and it is able to shave off the peak demand.

Energy storage system (ESS) is also another method to reduce the peak demand during peak time. Energy storage is able to store energy and able to discharge when it is needed. In prior work (Leadbetter & Swan, 2012), the author uses battery storage system to optimize the peak shaving at a residential area. It states that by using energy storage system, this can help to support the grid in terms of centralized generator limitations and transmission infrastructure constraints (Leadbetter & Swan, 2012). But having energy storage system do have some issues faced such as the increase of consumer’s energy demand, limitation of transmission substation and voltage drop. Battery energy storage systems (BESS) which consist of batteries and inverter are suited to the communities and building. Their paper is to determine the grid interconnectivity with the battery system. The storage system consists of a rechargeable battery, a bi-directional grid-intergrated inverter and a controller as seen in Figure 2.2 (Leadbetter & Swan, 2012).

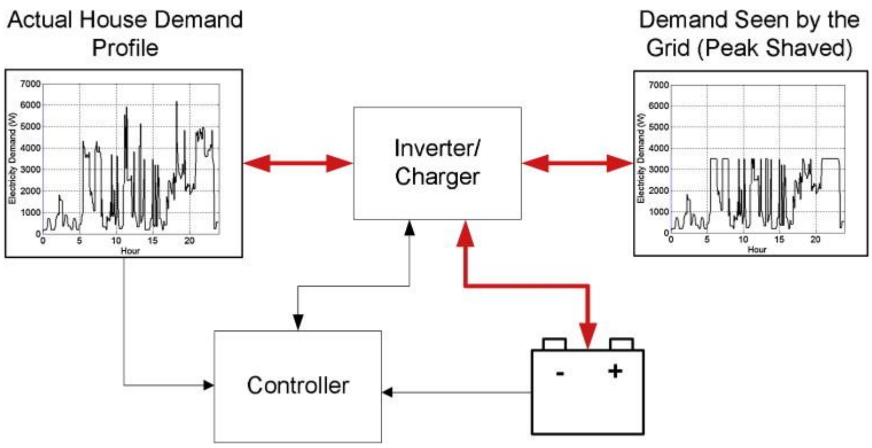


Figure 2.2: Peak Shaving BESS (Leadbetter & Swan, 2012)

By having real-time scheduling of housing appliances, it is able to limit the peak of power of a certain electric loads. It is one of the methods to approach the peak shaving problem. It uses real time scheduling to coordinate the activation of power load set. The study is based on time-triggered loads where it also consider the specific functionality of the device. The time-triggered loads are depend on the percentage of residents purchasing the appliances and the controllability. By analyzing the time-triggered of all loads will be able to determine the activation pattern in the housing area. By using Home Energy Management strategy, it uses real-time scheduling algorithm to limit the peak power consumption of considered residential loads (Caprino, Vedova, & Facchinetti, 2014). Based on with and without the scheduling actions, it can be seen that the power consumption reduces by using coordinated scheduling method. This can conclude that by managing the electric load based on real-time scheduling it can reduce the peak load in household appliances.

Photovoltaic (PV) systems have potential to reduce the demand stress during peak hours because their generation profiles has high correlation with the demand profiles (Rüther, Knob, da Silva Jardim, & Rebechi, 2008). However, intermittence of supply due to weather condition is the shortcoming of this technology. The uncertain energy generation makes these energy sources unreliable and difficult to be implemented for peak shaving. In addition, high penetration of PV systems into the grid has the potential to destabilize the grid (Poudineh & Jamasb, 2014).

In order to deal the intermittency of the PV resources, Yang et al., (2014) proposes on using battery energy storage system (BESS) together with photovoltaic (PV) in distribution system. When there is high PV penetration levels, it will produce large reverse power that can lead to rise in voltage and there will be some issues faced by the distribution system. BESS comes in where it can store power and help to prevent overvoltage during high penetration PV levels. BESS will be charged up between morning and afternoon, where solar radiation is high. In the evening, due to power consumption is high, BESS will deliver energy to the load to shave the peak demand of the load (Yang et al., 2014). In terms of cost of BESS, the annual cost are positive, which means BESS is not economic profit. It states that this is due to the current battery price is expensive, and may gain economic revenue when price of batteries drop in the future (Yang et al., 2014). But there's a disadvantage of using with only PV when there is intermittence of sunlight source due to foreseen weather condition. Nevertheless, integration of PV systems with energy storage systems is a promising solution to deal with the intermittency of the photovoltaic resources (Enslin, 2014).

2.5 Barriers to Use Standby Generator for Peak Shaving at Customer-End

2.5.1 Expensive Fuel and Volatiles Prices

Expensive fuel price is the major obstacle for standby diesel generator to be used for peak shaving. Diesel is much more expensive than the coal and natural gas in electricity generation. The fuel generation costs for coal, natural gas and diesel in 2014 are USD 25.2/ MWh, USD 40.1/ MWh and USD184.9/ MWh, respectively (Nuclear Energy Institution, 2015). It can be seen that diesel is 7.3 times more expensive than coal and 4.6 times more expensive than natural gas. Furthermore, oil is one of the most volatile commodity due to numerous factors such as politic, economic, demand-supply balance, and speculations. The uncertain diesel prices bring a lot of challenges to adopt the standby diesel generator for peak shaving because the price changes could affect the return of investment and revenue of peak deduction.

2.5.2 Low Efficiency

Figure 2.3 shows the efficiency curve of the diesel generator, open-cycle gas turbine (OCGT) and combined-cycle gas turbine (CCGT) with respect to its loading conditions. CCGT plants are usually used to serve as load following plants while OCGT plants are assigned as peaking plants to meet the highest daily loads (Marissa, Paul, Jennie, & David, 2013; Stan, 2008). Diesel generators have lower efficiency than that of the CCGT plants but higher efficiency than that of the OCGT. Nevertheless, the efficiency of diesel generators is still relatively low.

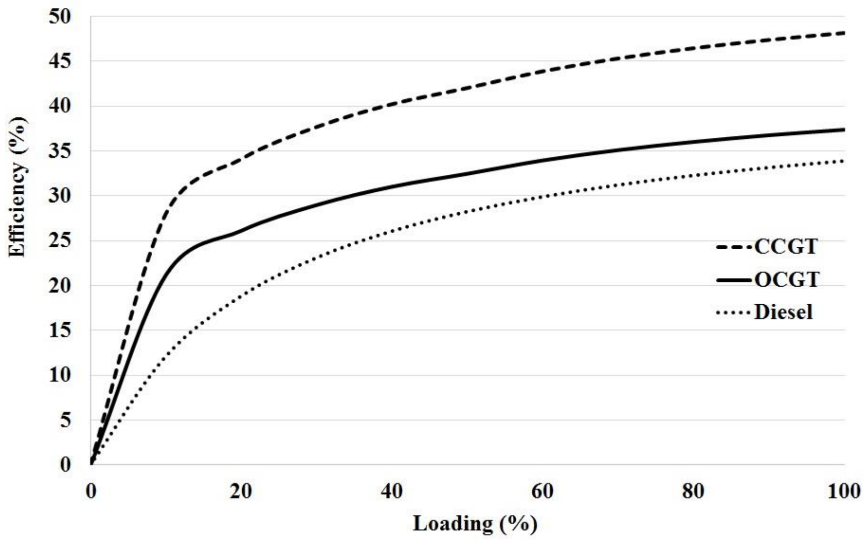


Figure 2.3: Efficiency of Diesel Generator, OCGT and CCGT with respect to its Loading Conditions

2.5.3 Issues on Storing and Transporting the Fuel

Standby diesel generators are meant to provide power during a contingency outage. Usually the standby diesel generator can supply continuous power for 8 to 24 hours during outage. If the standby diesel generator were to use for peak shaving, it may require relatively big storage fuel tank or additional fuel tank space to store the necessary fuel for peak shaving as well as contingency outage. The fuel tanks need to be filled more frequently for peak shaving as compared to the need for emergency.

This increases carbon dioxide emissions in transporting the diesel fuel from one location to another. The location to store the diesel fuel must comply with the fire safety regulation. Nevertheless, it is safer to store diesel fuel as it doesn't ignite as readily as gasoline. Diesel fuel is difficult to ignite intentionally at atmospheric pressure. However, additional precaution must be taken as the diesel generator are installed inside the building.

In terms of transporting the fuel to the location, delivering diesel supply can be a problem to be delivered to the remote locations such as rural areas and isolated islands as weather and transportation availability plays the main role. But if diesel trucks are able to deliver, fuel supply wouldn't be a problem.

2.5.4 Increased of Maintenance and Replacement Cost

It is common practice to inspect and maintain the standby diesel generator every two or three months to ensure the functionality of the standby diesel generator for contingency outage. With the increased starts, the maintenance cost of the standby diesel generator will be increased and the risk of the generator failure will be increased too. In addition, the generator may need to be replaced earlier than its original schedule due to extended operating hours.

2.5.5 Lack of Obligation and Regulatory Frameworks for the Interconnection of Standby Generator

The existing policy does not allow interconnection of standby generator to the grid. This is to ensure that the grid is islanded and there will be no back-feeding onto the grid especially during outage to protect the technicians who are maintaining the power lines. Currently, there is no specific regulatory guidance for anti-islanding characteristics, voltage tolerances, fault level, and standard operating procedure during outage. Nevertheless, the existing IEEE standard for distributed generation can be adopted to facilitate the formation of obligation and regulatory frameworks for the interconnection of standby generator ("IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems," 2003).

2.5.6 Issues on pollutions

The use of standby diesel generator to reduce peak demand increases the amount of diesel fuel to be transported and result in an increase of greenhouse gas emission. In addition, the operation of standby diesel generator produces more greenhouse gas per kW as compared to gas-fired power plants. According to International Energy Agency, the average CO_2 emissions from electricity generation for coal, natural gas, and diesel are 1035 gCO_2/kWh, 400 gCO_2/kWh, and 725 gCO_2/kWh, respectively (IEA, 2015). Although diesel oil doesn't emit as much CO_2 gasses as coal, but it emits more than natural gas emitted.

2.5.7 Technical Issues on Interconnection

Existing standby diesel generator may not comply with the standard requirement for the synchronization to the grid. For a generator to synchronize to the grid, four conditions must be met, namely the phase sequence, voltage magnitude, frequency and phase angle (Edward, 2013). An automatic parallel connection system is usually adopted to ensure the system stability of the synchronization. In fact, most of the standby diesel generators have the automatic transfer switch to constantly monitor utility voltage. When there is a power interruption, the automatic transfer switch will start the generator and connect it to the network. The architecture of the existing standby diesel generator system needs to be modified if it is desired to use it for peak shaving. This has further increased the investment costs.

2.5.8 Issues on system reliability

Standby diesel generators are installed to ensure the reliability and security of power supply to customers. Using them for peak shaving has increased the risk of generator failure and defeated their purpose to provide power supply during contingency outage. Furthermore, connecting a large number of standby generators to the grid poses a significant threat to the integrity and stability of the grid. The used of the standby diesel generators for peak shaving increases the difficulty to the grid operators in predicting the overall power demand and affects their planning in building power plants.

2.6 Potential Benefits to Use Standby Diesel Generator for Peak Shaving at Customer-end

2.6.1 Avoidance of Additional Cost for Peak Shaving at Customer's Premise

Most of the commercial and industrial buildings have at least one standby diesel generator to supply emergency power in case of power outage. Hence, they is no need for them to purchase additional generator to reduce peak demand.

2.6.2 Avoidance of Capacity Cost for Grid Operator

The reduction of peak demand may reduce or defer the need for investment in new generation, transmission, and distribution systems.

2.6.3 Deferral of Transmission and Distribution (T&D) Reinforcement

Utility companies are required to reinforce the T&D facility in line with the growth of electricity demand. Usually standby diesel generators are dispersed across the distribution network and located at the extremities. During peak time, the standby diesel generators able to deliver power to customers and reduce the dependency of power being transmitted by the T&D networks. As a result, the current flows through the T&D facility will be relatively low and consequently the T&D losses will be reduced. In addition, the reinforcement of T&D facility can be delayed before it reaches the technical limits. The T&D facilities' service life can also be prolonged because they are operated at low temperature (Chris & Rich, 2012; Gil & Joos, 2006).

2.6.4 Reduce of T&D Losses and Voltage Drop

The use of standby diesel generator at end-user premise can reduce the T&D losses and voltage drops.

2.7 Diesel Generator for Peak Shaving

Most of the commercial and industrial customers have one or more diesel generators for standby diesel power to ensure continuous business and operations during power outage. These generators are only operated during the outage and hence their utilization factor is very low. Diesel generators have the potential to reduce the customer's peak demand during peak periods. However, there is a dearth of research that investigate the feasibility of using standby diesel generators for peak shaving.

Hayden, (1979) is one of the pioneer to investigate the feasibility of peak shaving using standby diesel generator. He presented the requirements and criteria of peak shaving using standby diesel generator and suggested that the system can achieve one-year payback. In (Malinowski & Kaderly, 2004), a feasibility implementation was conducted on reducing utility cost of a motor plant whereby, a series of diesel generators were opted to install which can be used for two purposes, as a standby generator and load shedding during peak time. With installation new sets of generators along with new rate plan set by the utility grid, there's a dropped in energy consume along with cost reduction of $75,000 per year (Malinowski & Kaderly, 2004).

Daley & Castenschiold, (1982) outlined the economic and operational considerations to reduce peak demand using standby diesel generator. Two power management systems have been proposed to operate the standby diesel generator in line with the load demand profiles to achieve optimal peak deduction. Parianen & Oree, (2015) analyzed the energy consumption pattern of a company and investigated the feasibility of reducing peak demand charge using standby diesel generator. The authors found that there is a potential to reduce the total electricity bill by 6 % and achieve 3 years payback period for the investment in the energy management system that enables the integration of the generator into the grid.

2.8 Simulation Tool for Economic Assessment

Hybrid power system requires good planning of the project. Without it, there are cases which lack of optimum designing or proper sizing, either been oversized or not properly designed that has led to high installation cost. This involves sophisticated technical and economical analyses to simulate the complexity of hybrid power system given. This has brought to analytical software tools which can help to design, analyse, optimize and economical planning of the hybrid system (Sinha & Chandel, 2014). There are software that have been developed to help analysts analyse most cases given which can help to save valuable time. With the result able to generate much faster compared to manual calculation, implementation of the project will be faster. Besides that, this will help to maximize the designing of hybrid system and take advantage of using renewable sources.

By understanding the availability of software tools in terms of its features, benefits and flaw are required before choosing the right software. There are a few types of analytical software tools been provided to do comparative analysis.

2.8.1 HOMER Pro

HOMER stands for Hybrid Optimization Model for Electric Renewables. This software has been widely used by analysts to help analysing the hybrid power system. There's either free trial for 30 days or buy its license. It was developed by National Renewable Energy Laboratory (NREL) which can simulate both off-grid and on-grid system. It uses visual C++ program to be able to simulate (Sinha & Chandel, 2014). Various inputs have been provided for the user to key in such as the cost of the equipment used, manufacturer's data and resources availability. After inputting the data, it is able to simulate the system based on cases set by the user. It is user-friendly as it is easy to understand and the presentation of the results are presentable efficiently. But it doesn't consider the voltage variation on the busbar along with intra-hour variability.

2.8.2 HYBRID 2

Hybrid 2 is developed by NREL and University of Massachusetts. It was developed during the year 1996. This software has been programmed using Microsoft Visual BASIC and uses Microsoft Access Database. It is a combination of probabilistic/time series model designed with a variety of hybrid power systems cases able to be studied. It is able to perform detailed long term performance, economic analysis and predict the performance of various hybrid systems (Sinha & Chandel, 2014). With Graphical User Interface (GUI), projects can be easily constructed by the user while maintaining the projects with well-organized structure. It is user-friendly, have multiple electrical load options and detailed dispatching option. But it can't be used in computers later than Windows XP, which put a great disadvantage and although projects are correctly done, sometimes simulation will give an error.

2.8.3 IHOGA 2

IHOGA 2 is known as Hybrid Optimization by Genetic Algorithm. It is developed using C++ program to do simulation and optimization of Hybrid Renewable Systems and developed by University of Zaragoza, Spain. It can help to simulate and optimize the hybrid power system which includes renewable energy, diesel generator and batteries storage. IHOGA is able to optimize the slope of photovoltaic, calculates life cycle emissions, and allows probability analysis and has purchase and selling energy options to the electrical grid with net metering system (Sinha & Chandel, 2014). But there are some limitations of using this software. It is as follows:

i) Maximum average daily load it able to simulate is 10 kWh.
ii) Sensitivity and probability analysis not provided. (Sinha & Chandel, 2014)
iii) Net metering is not provided.

It is good as it requires less computation time, which means result able to produce faster as compare to others. It also has option for the electrical grid to either purchase or selling energy back to the grid. But it requires to have internet connection in order to activate and use the software.

2.9 Introduction to HOMER Pro

After looking through the advantages and disadvantages of the software, HOMER Pro was chosen to be used to simulate the hybrid power system. This software can only be run only on Windows platform but not on Macintosh and Linux operating system (Sinha & Chandel, 2014). This analysis software tool simulates mostly depends on the user's data inputs and some will be automatically filled by the software.

HOMER Pro uses the system configuration and data inputs to simulate, which it will provide the simulation results with a variety of tables and graphs been plotted out. The displays enable the user to compare and evaluate to configuration build, enabling to do some economic and technical analysis on it. A different system will have different cost-effectiveness, so the model can simulate using this software. It also able to simulate variable data for one input. This allows the HOMER Pro to perform sensitivity analysis on the model and by looking at the result will be able to have some general idea the factors that have the greatest impact.

HOMER Pro simulates the consumption of energy and it will be calculated based on 8,760 hours in a year. Based on energy balance calculations for each model being built on, it can help the user to determine the electric demand based on the user's specified. Not only the energy balance, the user's system cost will also be taken account of it. For example, capital replacement, operation and maintenance, and fuel cost. By using this cost, HOMER Pro can estimate the cost of the whole system, depending on the lifetime of the project been set.

There are three principle tasks that will be performed by the HOMER Pro software, which is as follows:

i) HOMER Simulation

HOMER simulates the operation of the user's model design. In this study, diesel generator and grid are the components are the components to be analyzed. HOMER simulates the system based on the user's inputs such as operation and maintenance cost, capital cost, fuel price, and the price of grid sold by the utility.

ii) HOMER Optimization

After it simulates all possible system configurations, HOMER will optimize the model and displays a list of configurations of to search the lowest life-cycle cost that satisfies the technical constraints. It is sorted depends on Total Net Present Cost (TNPC) and will arrange from lowest to highest based on TNPC after it compares different types of configuration.

iii) HOMER Sensitivity Analysis

HOMER will repeat the optimization process based on the inputs inserted. An example of the sensitive variable is future diesel price. It will use this sensitive variable and include it during optimization. Then, a list of system configurations will be tabulated, arranging from lowest to highest TNPC.

2.9.1 Using HOMER Pro for Simulation

HOMER Pro software has been used by many in order to optimize the design of its own model to be build. A research carried out by (Razak, bin Othman, & Musirin, 2010), describe the design of hybrid renewable energy system, using wind and solar energy, in order to reduce the use of diesel generator on an island. The simulation gives an optimal result for the hybrid system. Having renewable energy resources was able to reduce the greenhouse gases emission compared to only using diesel generator.

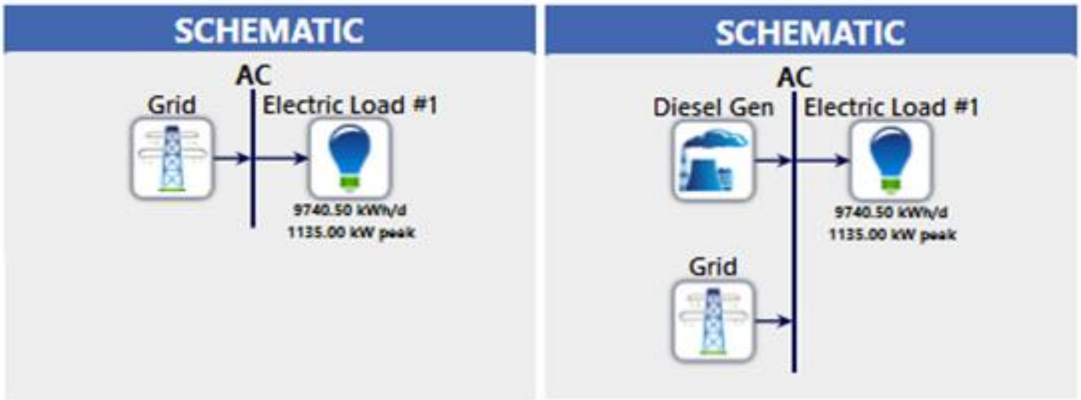
An economic feasibility was conducted by (Tan et al., 2014), of hybrid solar and standalone diesel generator in a rural area. In this study, hybrid means is a combination of using solar and diesel generator. As diesel price is fluctuating, this has brought to implementing of renewable energy into the system. Therefore, the system has to be simulated by using HOMER Pro software in order to determine the cost of electrical by comparing between standalone and hybrid system. Based on simulation, diesel generator will have lower total net present cost (TNPC) and cost of electricity compared to hybrid system. But the operating cost for the hybrid system is lower than standalone system. Although hybrid system has higher net present cost (NPC), it is able to be compensated with a project lifetime of 25 years (Tan et al., 2014). This means that it could achieve lower TNPC and cost of electricity (COE) than the standalone system with a project lifespan of 25 years. It has a potential to upgrade by using hybrid system.

CHAPTER 3

METHODOLOGY

3.1 Electrical System Configurations

The power system with- and without diesel generator are modelled in HOMER as shown in Figure 3.1. The system without diesel generator is chosen as a benchmark for the economic assessment.



(a) (b)

Figure 3.1: Schematic of Electrical System in HOMER (a) System without Diesel Generator (b) System with Diesel Generator Diagram

The key parameters for the project set in HOMER such as discount rate, inflation rate, and project lifetime are illustrated in Table 3.1.

Table 3.1: Key Parameters for the Project Set in HOMER

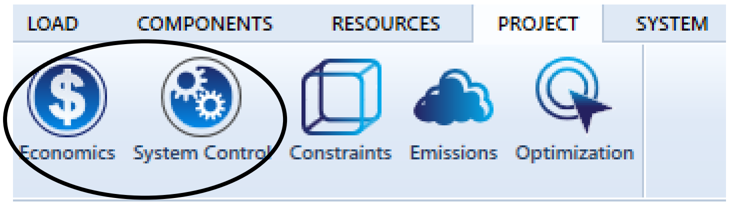
Discount rate (%)	6[a]
Inflation rate (%)	2.1[b]
Optimization option	Economic minimization
Dispatch strategy	Cycle charging
Project lifetime (year)	20

Footnotes:

a- Discount rate is according to (Chua, Lim, & Morris, 2015)

b- Data is collected from (Anna & Lucky, 2014)

Under the Project tab at the top of the screen, there are four subtab, which the rates and project lifetime will be keyed under Economics tab. While optimization option and dispatch strategy will be selected under System Control Tab. This can be seen in Figure 3.2. The key parameters will be entered into the provided spaces.



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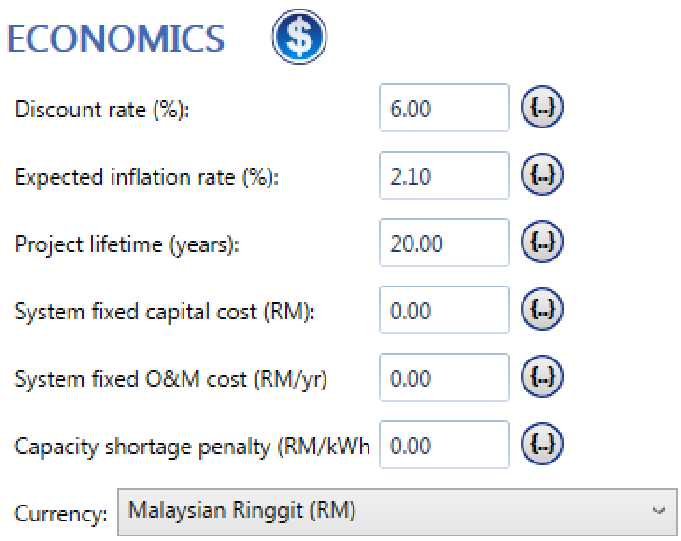

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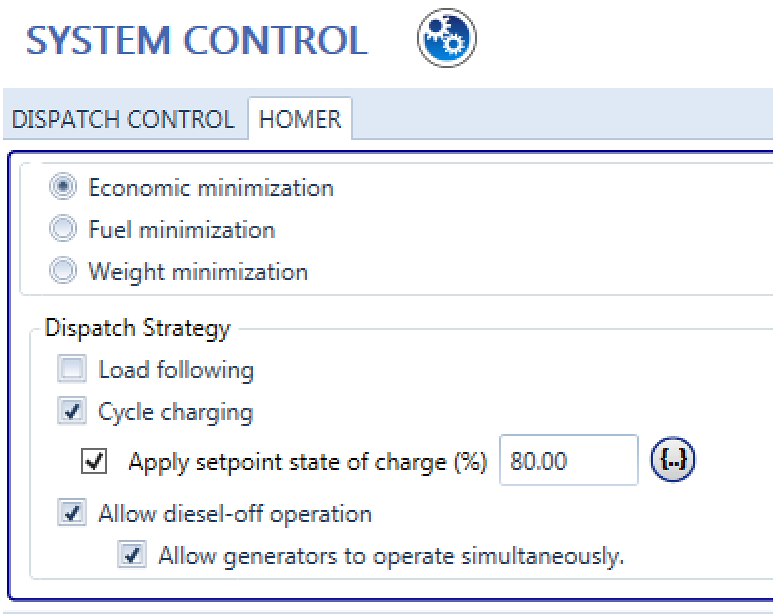
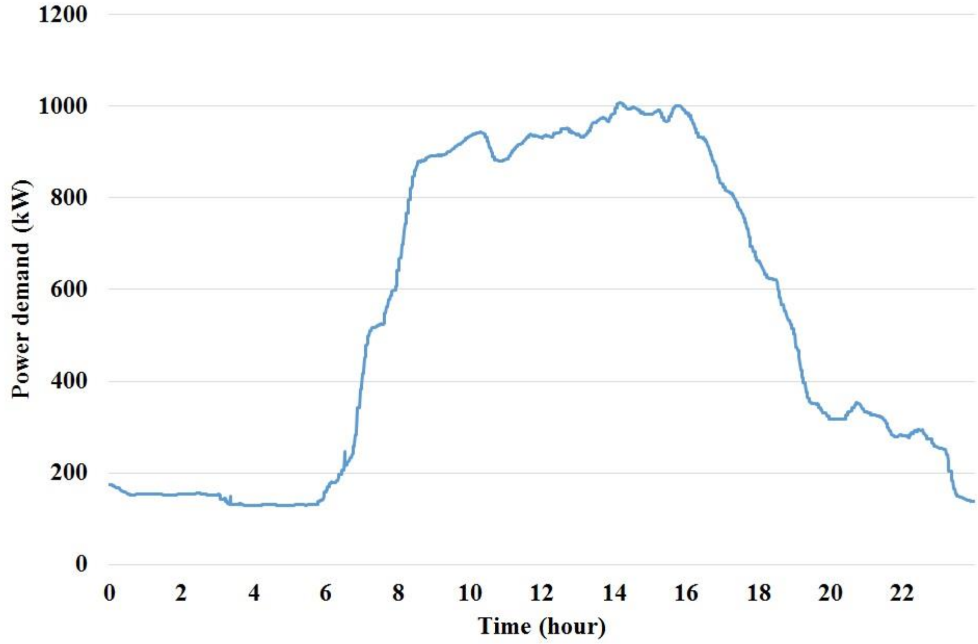


(c)

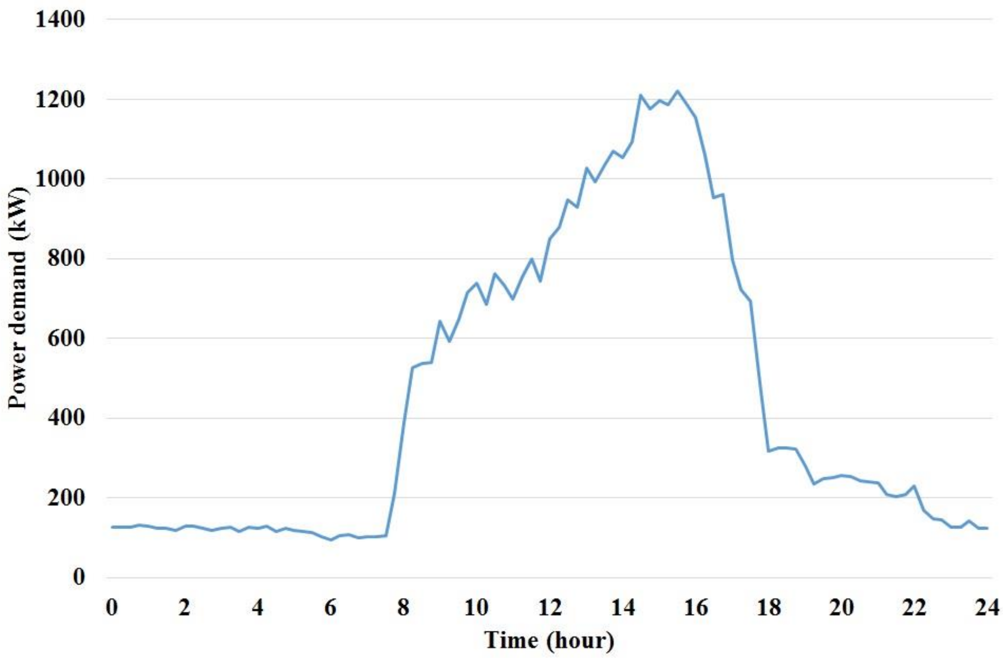
Figure 3.2: Project Setting for (a) Project (b) Economics (c) System Control

3.2 Electric Load Profile

This study also investigates the effect of different load profiles to the cost of electricity. The electric load characteristic is important to the system optimization because it determines the size of the standby diesel generator and the operating duration of the generator for peak shaving. Two load profiles with different characteristics are selected for evaluations, namely, load profile A and load profile B. Load profile A is collected from one of the building of Universiti Tunku Abdul Rahman (UTAR) located at Sungai Long. The load profile has relatively even load demand distribution across office hours. Load profile B is collected from one of the buildings of UTAR located at Setapak. The load profile B has sharper load demand during office hours and has lower power consumption than that of the load profile A. In order to compare the two different load characteristics under the same baseline in HOMER, the load profile B is scaled up to the respective load profile A based on the annual average energy consumption. Figure 3.3 illustrates the daily electrical energy consumption for load profile A and load profile B respectively. It can be seen that load profile A has more evenly distributed power demand than that of the load profile B.



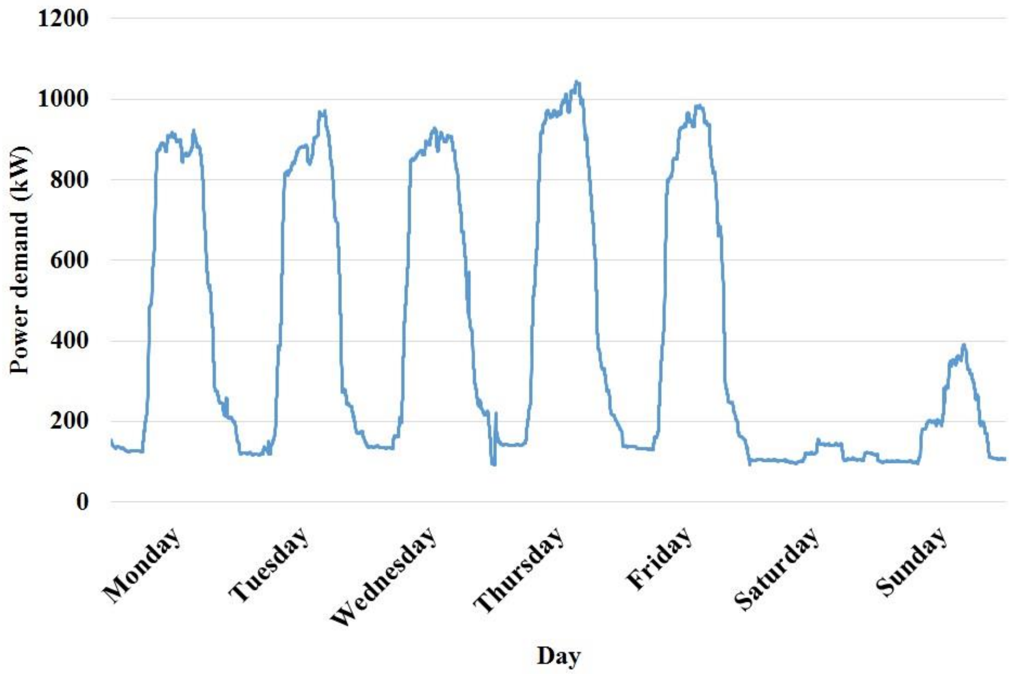
(a)



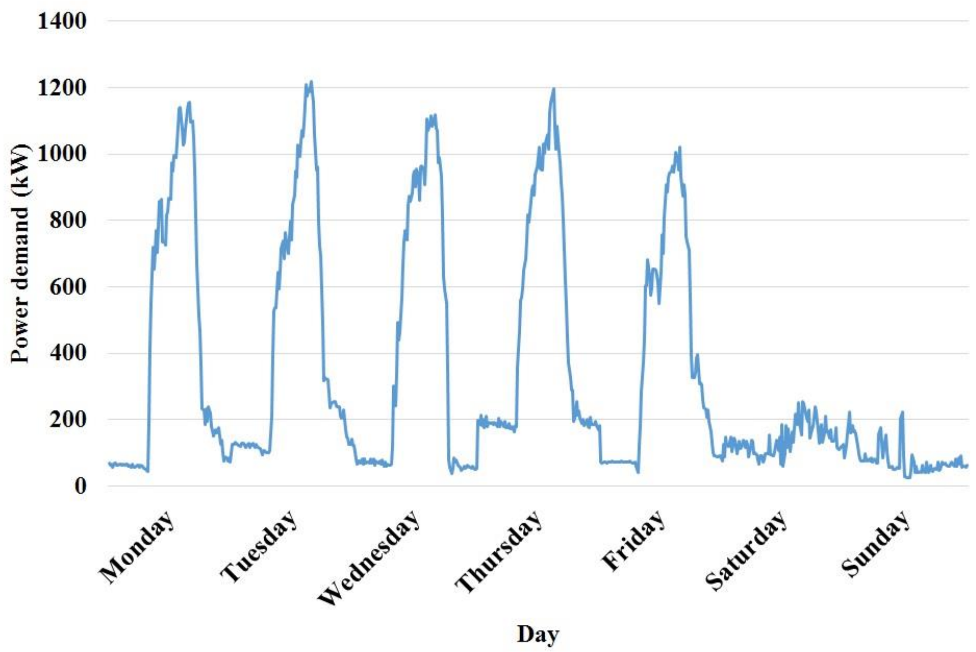
(b)

Figure 3.3: Daily Electrical Energy Consumption for (a) Load Profile A (b) Load Profile B

A weekly energy consumption for load profile A and load profile B are illustrated in Figure 3.4.



(a)



(b)

Figure 3.4: Weekly Electrical Energy Consumption for (a) Load Profile A (b) Load Profile B

There are two types of load options that can be chosen from in HOMER, either by creating synthetic load or by importing a time series file. The synthetic load will be generated by HOMER itself based on the pre-set load profiles such as residential, commercial, industrial and community load profiles.

In order to simulate our own load data, importing a file containing the load data will be the option as seen in Figure 3.5. A text file is used which contains the electric load with time step for a complete year. For example, if the file contains 8760 lines, it means that it is an hourly data. Here, the data taken is a minute-data, having 525,600 lines in the text file. The text file that was imported to HOMER, it will make a copy of the data and integrates it with HOMER file. HOMER will not be using the data given to simulate but instead, it will calculate the average of 24-hour load profile of the whole year based on the data provided. By confirming the daily load profile entered, HOMER will use the newly data generated by it, taken from the calculated data from the text file, and sorted it into twelve monthly average load profile. It is to be taken note that, January 1st is always begin on Monday.

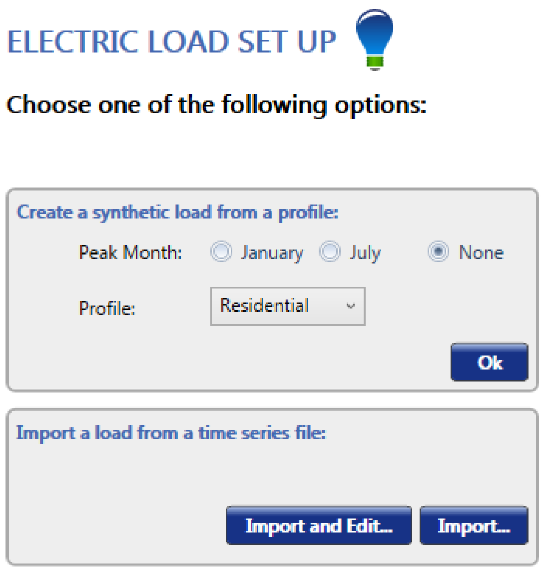


Figure 3.5: Electric Load Set Up

Figure 3.6 shows the daily profile in bar chart for each hour represented in HOMER for load profile A.

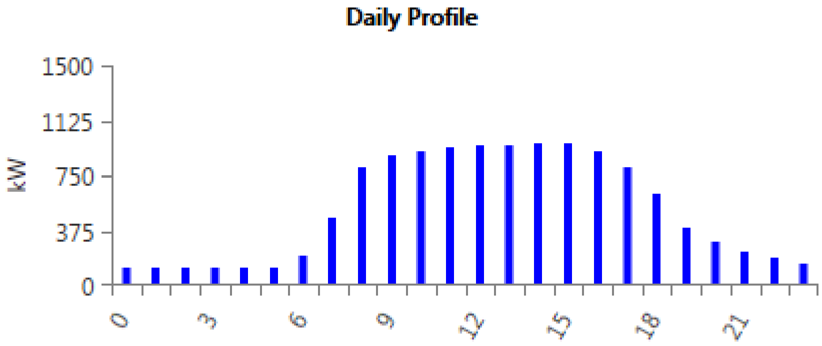


Figure 3.6: HOMER Generated Average Daily Load Profile for Load Profile A

HOMER is also able to plot a line graph of one year based on the user's data. Figure 3.7 shows the line graph of a week data.

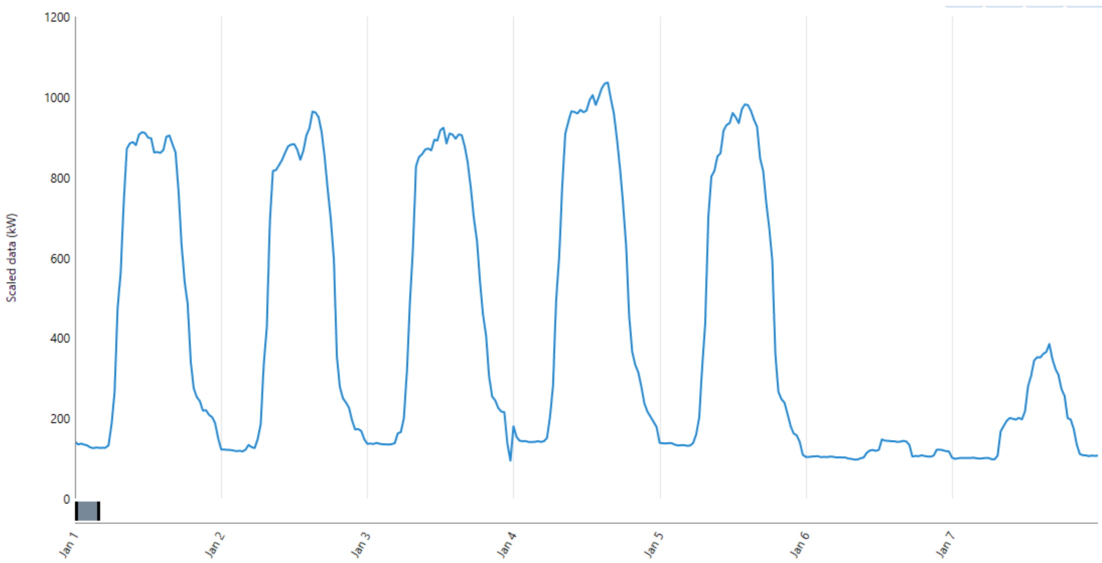


Figure 3.7: HOMER Generated Weekly Load Profile for Load Profile A

The load variation of load profile A for each month is as shown in Figure 3.1. The maximum demand shown in the figure is about 1100 kW while the mean demand is 400 kW. These 12 months are having the same demand due to the each of the month load data are the same.

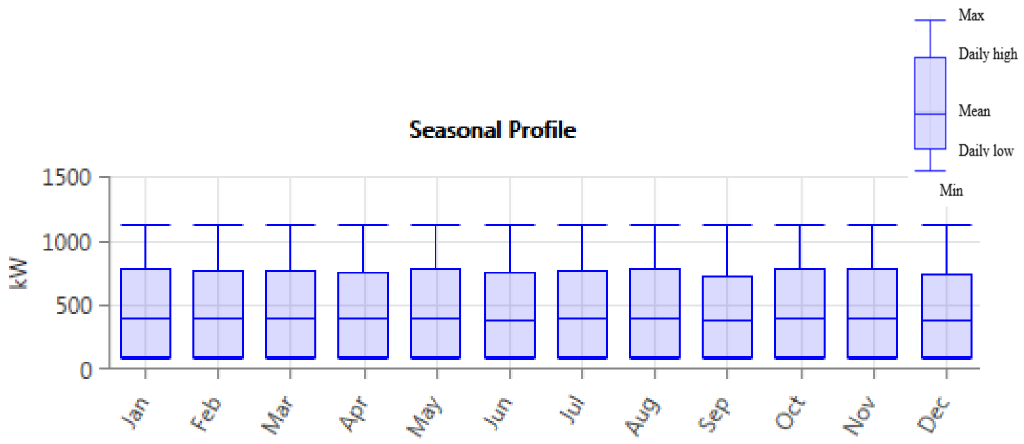


Figure 3.8: Load Variations in a Year for Load Profile A

Due to both load profile doesn't have the same baseline, load profile B is required to be scaled up to the respective load profile A by changing the scaled annual average. This can be done by changing the scaled data to match with the load profile A as shown in Figure 3.9.

Metric	Baseline	Scaled
Average (kWh/d)	1,050.0	9,450
Average (kW)	43.75	393.75
Peak (kW)	161.98	1,457.7
Load Factor	.27	.27

Figure 3.9: Normalized Scaled Annual Average

3.3 Electricity Tariffs

The analysis is carried out on the four tariff rates for commercial and industrial consumer in Malaysia, tariff C1, C2, E1 and E2. Tariff C1 and C2 are applied to commercial customers while E1 and E2 are applied to industrial customers. Table 3.2

shows the rate of the four tariffs for commercial and industrial consumers. There are two different rates for kWh charge for C2 and E2 customers based on the time when the energy is consumed. The peak period is from 8:00 to 22:00 while the off-peak is from 22:00 to 8:00 of the following day.

Table 3.2: Classification of Tariff Rates for Commercial and Industrial Sectors

Tariff	C1[a]	C2[b]	E1[c]	E2[d]
Peak (RM/kWh)	-	0.365	-	0.365
Off-peak (RM/kWh)	-	0.224	-	0.219
Total energy (RM/kWh)	0.365	-	0.337	-
Maximum demand (RM/kWh)	30.3	45.1	29.6	37.0

Footnotes:

a- C1 denoted as Medium Voltage General Commercial (Tenaga Nasional Berhad, 2014)

b- C2 denoted as Medium Voltage Peak/Off-Peak Commercial (Tenaga Nasional Berhad, 2014)

c- E1 denoted as Medium Voltage General Industrial (Tenaga Nasional Berhad, 2014)

d- E2 denoted as Medium Voltage Peak/Off-Peak Industrial (Tenaga Nasional Berhad, 2014)

The maximum demand charge is calculated based on the highest energy consumed in kilowatt-hours within any consecutive period of 30 minutes in a month and then it will be multiplied by two. This duration of time is defined as the demand evaluation period (Chua, Lim, & Morris, 2015). The electricity bill (B_{charge}) for commercial and industrial customers is determined as follows:-

$$B_{charge} = \int_{t_{start}}^{t_{end}} P(t) \cdot C_E \cdot dt + \int_{tA}^{tB} 2P(t) \cdot C_M \cdot dt \qquad (3.1)$$

where

t_{start} and t_{end} = periods of time during the billing cycle in a month

$P(t)$ = power demand during the time interval

t_A and t_B = demand evaluation period in the same month

C_E = energy usage charge, RM/kWh

C_M = maximum demand charge, RM/kW

It is possible to calculate the potential saving of using a standby diesel generator to reduce the maximum demand of commercial and industrial buildings during peak period to reduce their electricity cost. The potential monthly savings (M_{saving}) can be calculated as follows:-

$$M_{saving} = (P_{shave} \times C_M) \tag{3.2}$$

where

P_{shave} = peak shaved by the standby diesel generator, kW

C_M = maximum demand charge, RM/kW

In HOMER, there are four types of grid setting, simple rate, real time rate, scheduled rate and grid extension. Since the data provided is based on scheduling, scheduled rate option is used. In scheduled rate, there are a few tabs that requires data to be entered. In the parameter tab, the annual purchase capacity is required to be entered as this is the maximum amount of power required for the grid to supply power to the load. The value has to be bigger the load power.

In the rate definition tab, there is a rate table. It is to indicate the rates when applying in the scheduling. In here, rates can be added with different buy and sell power rate. By clicking the ‘edit’ button, there will be rate properties which is to enter the required data such as grid power price and the sellback rate. For single rate, only one rate will be set while for multiple rates, such as tariff C2 and E2, it is required to have two different rates set into the rate table. The rate definition is shown in Figure 3.10.

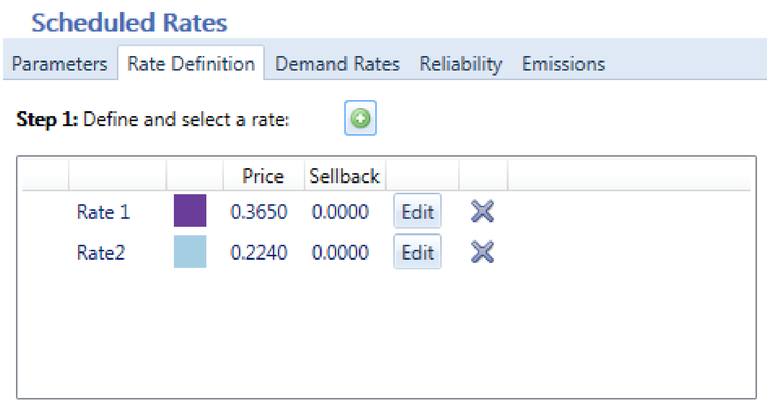


Figure 3.10: Scheduled Rates

There is also demand rates where this is the maximum demand charge rate. The method to set is similar to the rate definition. But for maximum demand charge, setting for multiple rates is important to be taken note of. In this project, there are only two type of schedule rate, on-peak and off-peak time. The maximum demand only appears during the on-peak time based on the load data. Therefore, the maximum demand charge rate will only be set for on-peak time, while for the off-peak time, it is not required to include any maximum demand price.

There is a grid rate schedule where it is based on the scheduled time for the rates to become effective. For tariff C1 and E1, since there is only one rate, the total energy, the schedule for the rate and maximum demand will be a whole day schedule. But when there is more than one rate, which can be seen in tariff C2 and E2, there will be two different schedules in the rate schedule chart. For the on-peak charge, it will be from 8:00 to 22:00 while the off-peak is from 22:00 to 8:00 of the following day. This also applies the same as in maximum demand chart. The grid schedule is shown in Figure 3.11.

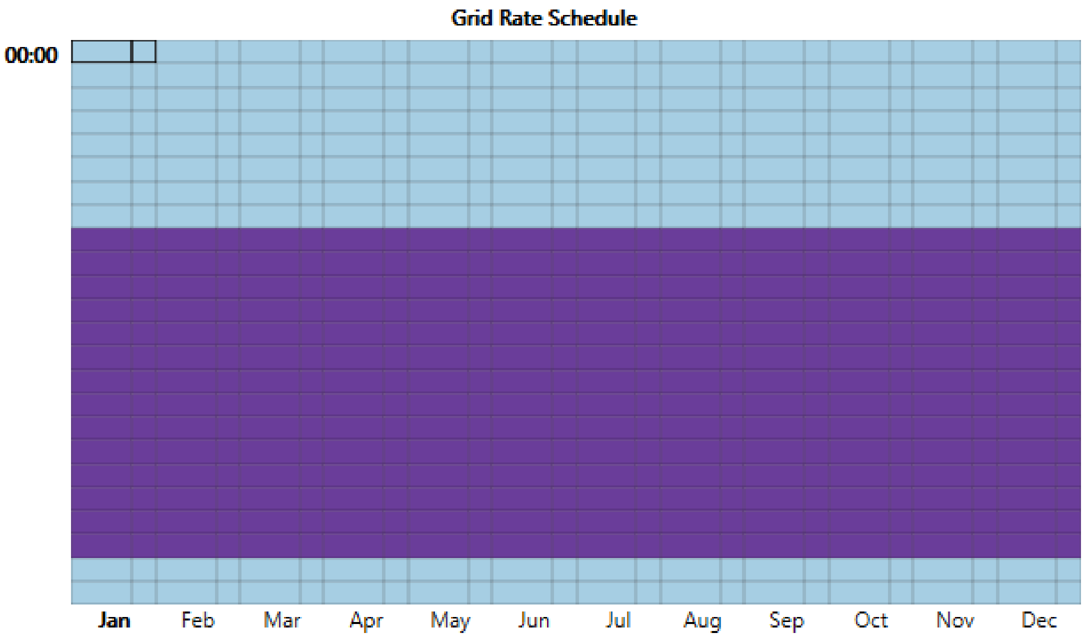


Figure 3.11: Grid Scheduled Rates

3.4 Standby Diesel Generator

A commercial standby diesel generator is chosen for the investigation. The key parameters for the standby diesel generator is shown in Table 3.3.

Table 3.3: Key Parameters for Standby Diesel Generator in HOMER

Capital cost [RM (USD) / kW][a]	900(225)[b]
Replacement cost [RM (USD) / kWh][a]	720(180)[b]
O&M [RM (USD) / hour][a]	0.12(0.03)[b]
Average diesel fuel cost [RM/L]	1.91
Service life (h)	15,000
Fuel consumption slope (L/hour/kW)	0.244
Intercept Coefficient (L/hour/kW rated)	0.014

Footnotes:

a- The conversion rate of USD to RM is 1 : 4

b- Data obtained from (Ngan & Tan, 2012)

The size of the standby diesel generator and its corresponding operating durations are determined based on the lowest levelized cost of electricity (COE) and their total net present cost (NPC). The levelized COE is the net present value of the unit-cost of electricity over the service life of a generating asset. It is a summary measure of the overall competitiveness of different generating technologies. The levelized COE (*LCOE*) is expressed as follows:

$$LCOE = \frac{\sum_{i=1}^{n} \frac{C_i + M_i + FE_i}{(1+r)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1+r)^i}} \tag{3.3}$$

where

C_i = investment expenditure in the year i

M_i = operations and maintenance expenditure in the year i

FE_i = fuel expenditure in the year i

E_i = electricity generation in the year i

n = expected lifetime of the system

r = discount rate, %

The total NPC is used to represent the life-cycle cost of the system that includes all costs and revenues that occur within the project lifetime with future cash flows discounted to the present. The total NPC is expressed as follows:

$$NPC = \frac{C_{tot}}{CRF(i, T_p)} \tag{3.4}$$

where

C_{tot} is the total annualized cost of the system, RM/year

i = annual real interest rate, %

T_p = project lifetime, year

CRF() = function returning of the capital recovery factor

The capital recovery factor is expressed as follows:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{3.5}$$

where

N = number of years.

When standby generator is included into the simulation, the generator icon is selected to be added into the model. The key parameters will be inserted into the HOMER based on Table 3.3. The service life, fuel consumption slope and intercept coefficient is provided by the HOMER. The HOMER interface to enter the data is shown in Figure 3.12. Since the fuel consumption data for the standby generator wasn’t able to be obtained, the data provided by HOMER software itself was used. Based on the fuel consumption data, together with fuel consumption slope and intercept coefficient, the software will calculate the parameters and plot out the fuel curve and efficiency of the generator which can be seen in Figure 3.13 and 3.14 respectively.

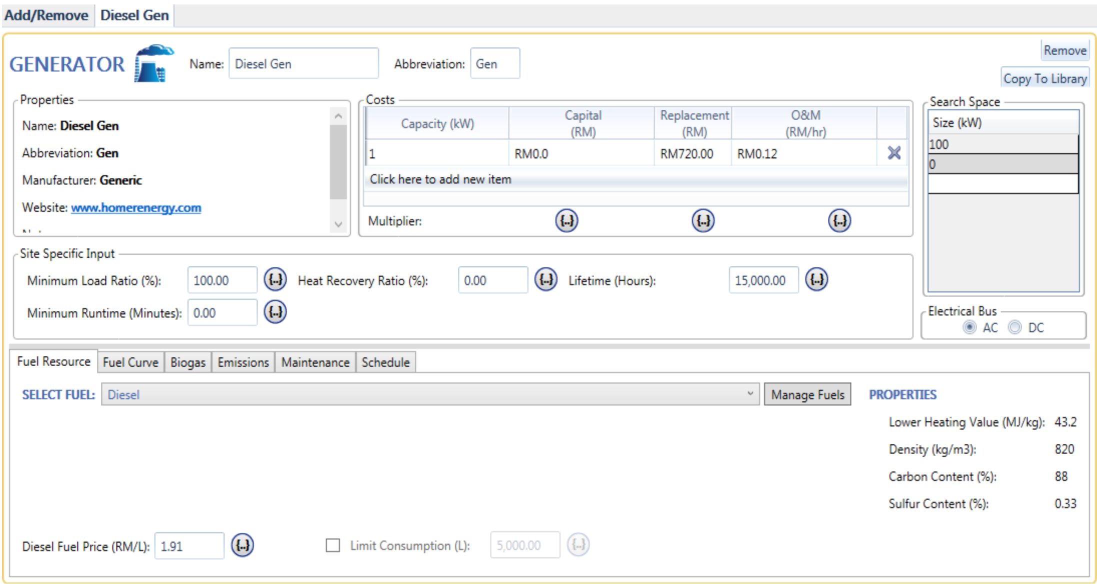


Figure 3.12: HOMER Generator Set Up Interface

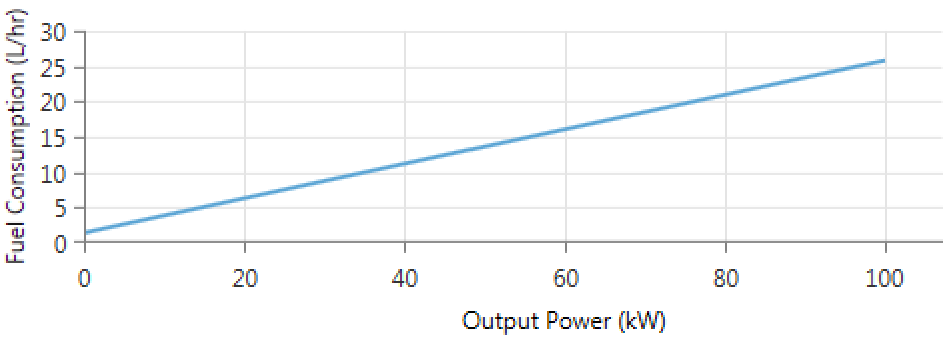


Figure 3.13: Fuel Consumption Curve of Standby Generator

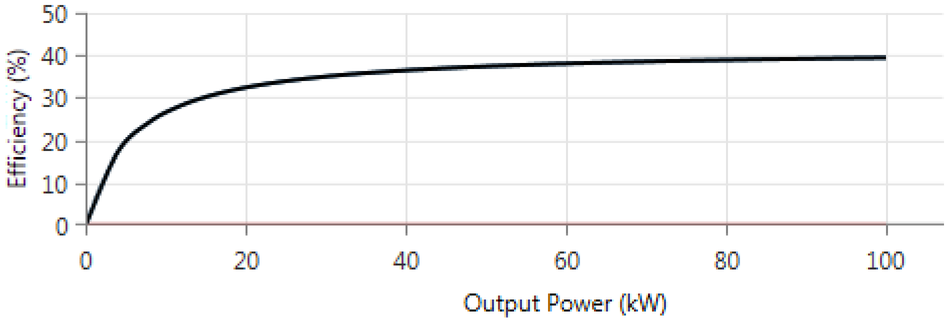


Figure 3.14: Efficiency Curve of Standby Generator

By default, HOMER will decide when to operate the generator based on the load demand and generator's economics versus with other power sources. But the user can force the generator to operate for a certain time. The size of the generator and schedule for the generator to operate are the two required input needed to be varied throughout the simulation. The size of the generator is to be varied from 50 kW up to 250 kW. This will be entered into the search space that can be seen in Figure 3.12. For the schedule to operate, in order to force the generator to operate, the 'forced on' option is used. The standby generator is only allowed to operate during weekdays for peak shaving. Therefore, weekdays option in the time period is selected. The generator schedule chart is where the time is selected for the generator to operate. For example, the generator requires to operate from 10:00 to 15:00, by clicking 'forced on' button together with highlighting the generator schedule, which is the green highlighted, this will allow the generator to operate as user requested, as seen in Figure 3.15. The operating schedule is applied for the whole project lifetime.

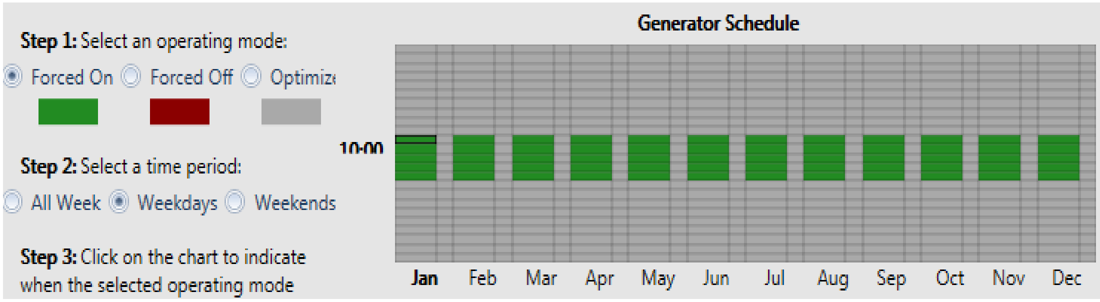


Figure 3.15: Standby Generator Operating Schedule

3.5 Evaluations in HOMER

Once all inputs have been inserted into the HOMER, by clicking the 'calculate' button, it will simulate the model based on the inputs. The COE and NPC will be obtained from the results generated by HOMER. For COE result, it can be seen in the optimization result table shown in Figure 3.16. But for NPC, the value shown beside COE should not be used as the total NPC includes both the grid and standby generator.

Export... Optimization Results: Left Double Click on a particular system to see its detailed Simulation Results

Architecture			Cost				System	Gen					Grid	
Gen (kW)	Grid (kW)	Dispatch	COE (RM)	NPC (RM)	Operating cost (RM)	Initial capital (RM)	Ren Frac (%)	Hours	Production	Fuel (L)	O&M Cost	Fuel Cost	Energy Purchased	Energy Sold
	1,900	CC	RM0.480	RM23.6M	RM1.71M	RM0.00	0.0						3,555,944	0
100	1,900	CC	RM0.490	RM24.1M	RM1.74M	RM0.00	0.0	1,305	130,500	33,669	15,660	64,309	3,425,444	0

Figure 3.16: Optimization Results

By double clicking the result, more results will be shown in detailed. The total NPC for only the standby generator can be obtained from the cash flow tab. The NPC includes capital, replacement, operating and maintenance (O&M), as well as the fuel consumption cost as shown in Figure 3.17.

	0	1	2	3	4
Nominal					
Diesel Gen					
Capital	RM0	RM0	RM0	RM0	RM0
Fuel	RM0	(RM64,309)	(RM64,309)	(RM64,309)	(RM64,309)
Operating	RM0	(RM15,660)	(RM15,660)	(RM15,660)	(RM15,660)
Replacement	RM0	RM0	RM0	RM0	RM0
Salvage	RM0	RM0	RM0	RM0	RM0
Diesel Gen Total	**RM0**	**(RM79,969)**	**(RM79,969)**	**(RM79,969)**	**(RM79,969)**

Figure 3.17: Cash Flow Table for Each Month

To check the total amount of each pollutant annually is by clicking the emissions tab. Pollutants are generated from due to burning of fuel in generators along with the grid power. The quantity of pollutants generated can be seen in Figure 3.18.

Quantity	Value	Units
Carbon Dioxide	2,253,543.00	kg/yr
Carbon Monoxide	218.85	kg/yr
Unburned Hydrocarbons	24.24	kg/yr
Particulate Matter	16.50	kg/yr
Sulfur Dioxide	9,563.80	kg/yr
Nitrogen Oxides	6,542.90	kg/yr

Figure 3.18: Total Quantity Pollutant Emission

3.6 Assumptions and Limitations

There are some assumptions being made in the model used in this project. The load data collected from the building is a one-month data and it is then repeatedly used for the twelve-month loads. Next is the specification for the generator such as service life, fuel consumption slope and intercept coefficient was obtained from the HOMER due to the specification of the generator can't be obtained.

There are some limitations of using HOMER. The generator schedule provided is in terms of monthly schedule. Due to that, HOMER can't select the days required for the standby generator to operate in a particular month. This project is dealing with peak shaving whereby it is to reduce the peak demand on certain days, and it only requires the standby generator to operate selected days with high peak demand in order to shave the peak. Due to this limitation, HOMER only allows the generator to operate based on a monthly selection. Therefore, the COE obtained from the result, might be more than operating the standby generator on selected days.

Besides that, when energy storage system is inserted into the model, HOMER unable to allow the battery to be charged using power from the grid. This is due to the insertion of the generator into the model. When the generator is present, the energy storage system opted to use the generator rather than grid as its power source to charge the battery. Since the generator has supplied all its power to the load, there is isn't any power left to charge the battery.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the analysis results that was carried out using HOMER. The economic viability of using the standby diesel generator to reduce peak demand is evaluated based on cost of electricity (COE) and total net present cost (NPC) for various tariffs, size and operational duration of the standby generator. The simulation was performed by varying the standby generator sizing for both load profiles. The project lifetime is 20 years old with a real interest rate of 3.82%.

4.1 System without Standby Diesel Generator

The model is built and simulated between utility grid and electrical load. This study doesn’t involve with standby generator. Table 4.1 shows the COE obtained for the system without the diesel generator for load profile A and B. It can be seen that the COE of load profile B is higher than that of the COE of load profile A for all of the tariffs. This is due to the fact that the load profile B has sharper load demand characteristics with higher peak demand as compared to the load profile A. It is also found that the tariff C2 has the highest COE among the tariffs. The COE obtained from the simulation for the system without the diesel generator is chosen to be the threshold for the following cases to be studied.

Table 4.1: COE for the System without Diesel Generator for Load Profile A and B

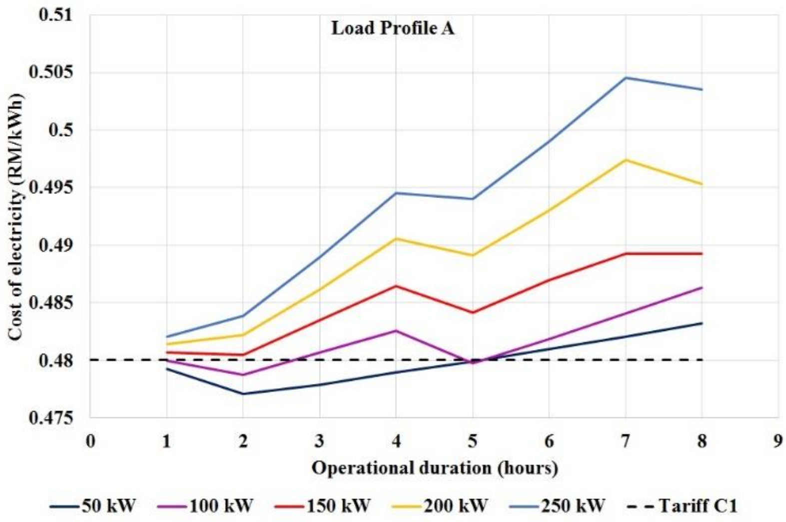
Tariff	COE (RM / kWh)		Difference (%)
	Load profile A	Load profile B	
C1	0.4801	0.5133	6.9
C2	0.5142	0.5649	9.9
E1	0.4495	0.4819	7.2
E2	0.4827	0.5246	8.7

4.2 System with Standby Diesel Generator without Considering Capital Cost

In this case study, the COE is investigated for different sizing and operational duration of the standby generator for two load profiles. The generator studied is from 50 kW up to 250 kW as there was a study conducted where to use a standby generator for peak reduction purposes, only 20 % of the load's peak demand is allowed as the cost to provide power onsite will be higher than the COE produced by the utility (Daley & Castenschiold, 1982). In this project, based on the load data, the highest peak demand for load profile A and B is 1150 kW and 1440 kW respectively.

Firstly is to discuss the comparison of COE between both load profiles. Capital cost is not included in this case study. Figure 4.1 until Figure 4.4 shows the comparison of COE for both load profiles with different sizing generators using different tariffs. Having lower COE as compared to COE of the grid will provide benefit in terms of economical cost saving and peak shaving. Therefore, the COE of the grid will act as the threshold for all figures. The COE which are close to the threshold will not be chosen.

Figure 4.1 shows the comparison between load profile A and B in terms of COE based on the size of standby generator and operational duration for Tariff C1. For load profile A, the lowest COE obtained is RM 0.4771 per kWh, by using 50 kW standby generator operating for 2 hours. Although 100 kW generator obtained is lower COE than the threshold, it is too close to the threshold. For load profile B, the lowest COE obtained is RM 0.5097 per kWh. The size of the standby generator is 100 kW, operate for 2 hours. There are a few more options that can be chosen from such as 100 kW operating for 1 to 4 hours, 50 kW operating for 1 to 2 hours, 150 kW and 200 kW operating for only 1 hour.



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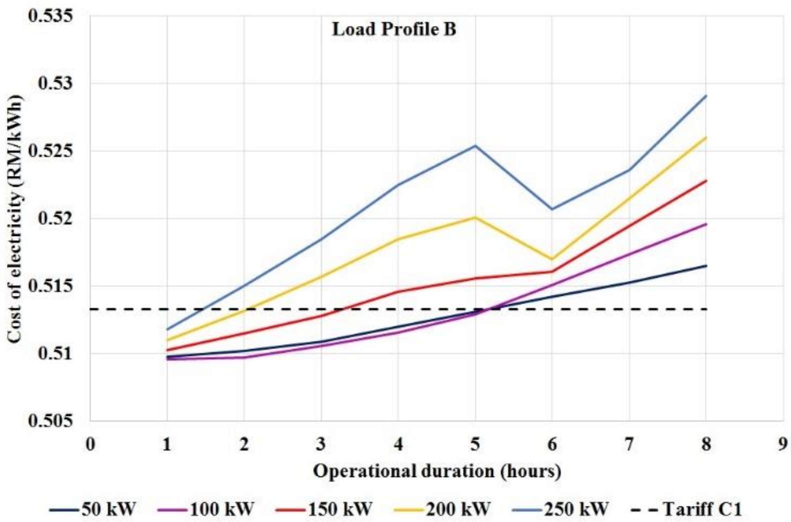
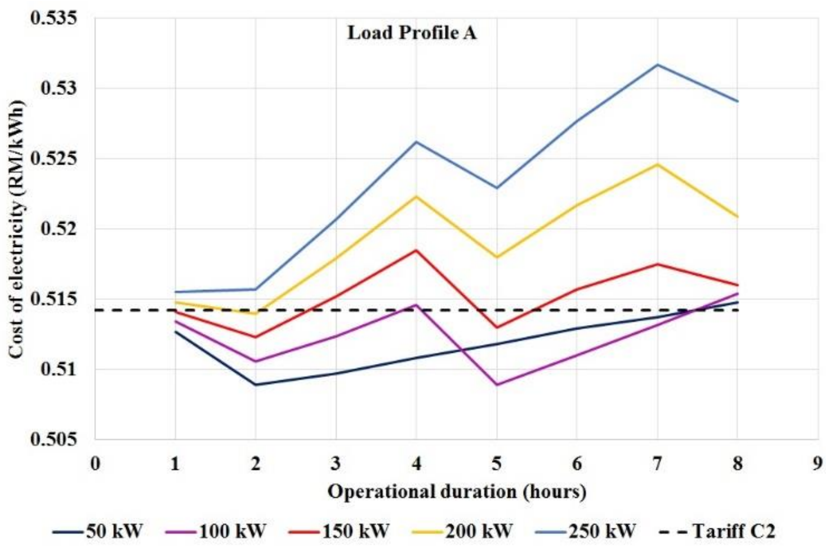


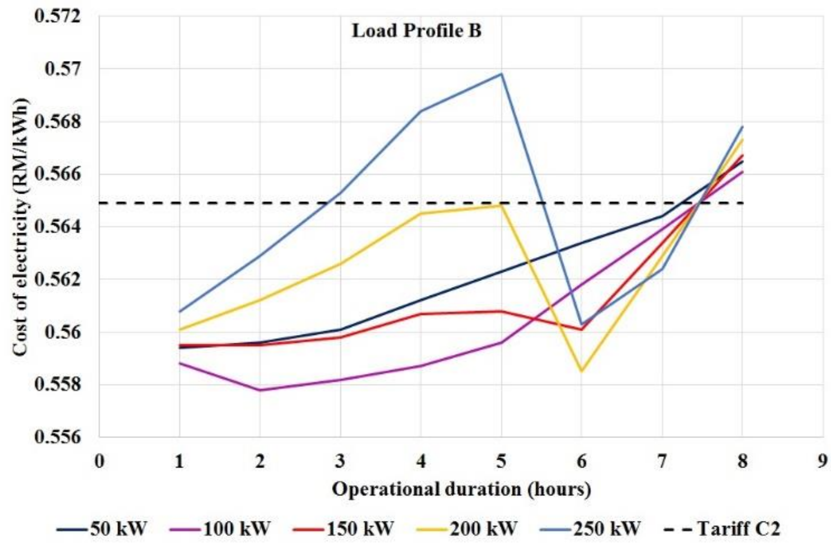
(b)

Figure 4.1: Comparison of Cost of Electricity between (a) Load Profile A and (b) Load Profile B based on Size of Standby Generator and Operational Duration for Tariff C1

Figure 4.2 shows the comparison of COE between load profile A and B for tariff C2. The lowest COE obtained is RM 0.5089 per kWh whereby there are two conditions having the same COE, which are 50 kW and 100 kW standby generator, operating for 2 hours and 5 hours respectively. There is a small drop with operation duration of 5 hours. For load profile B, the lowest COE obtained is RM 0.5578 per kWh. It can be obtained using 100 kW generator operating for 2 hours. There are many available options that can be chosen from as most of the COE obtained is lower than the threshold. This is due to a big drop in COE during the 6 hours of operating the generators.



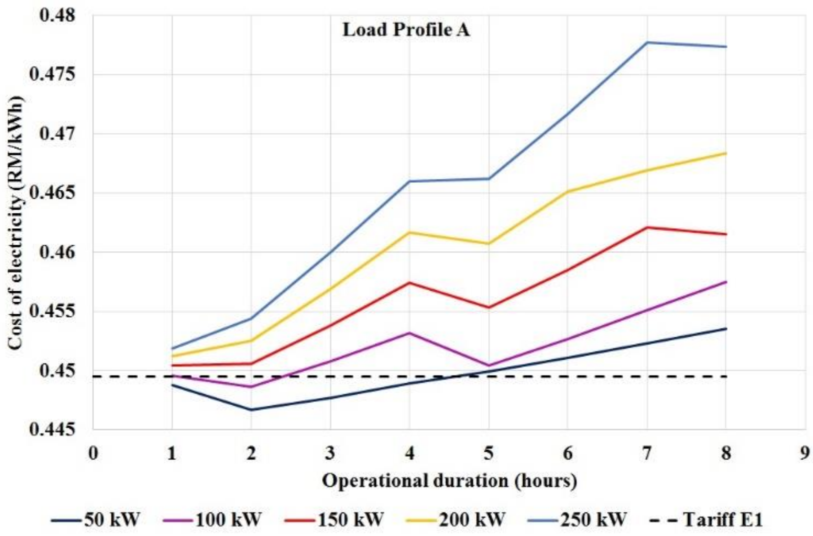
(a)



(b)

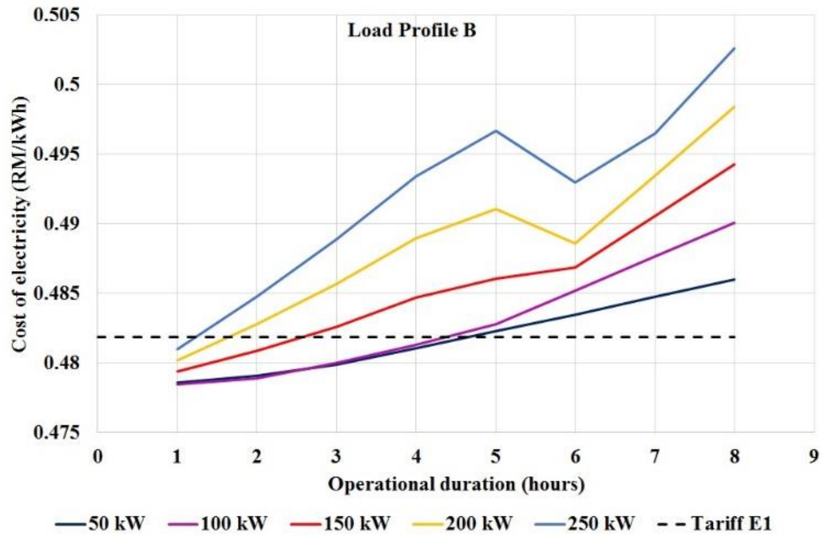
Figure 4.2: Comparison of Cost of Electricity between (a) Load Profile A and (b) Load Profile B based on Size of Standby Generator and Operational Duration for Tariff C2

Figure 4.3 is the comparison of COE between load profile A and B for tariff E1. For load profile A, the lowest COE obtained is RM 0.4486 per kWh, operating for 2 hours and the generator’s size is 50 kW. There is a small drop for generators, 100 kW until 250 kW. For load profile B, the lowest COE obtained is RM 0.4789 per kWh, operating for 2 hours and the generator’s size is 100 kW. For generator size of 50 kW and 100 kW, the COE obtained are almost the same when it operates between 1 hour to 4 hours. Besides that, when the generator operating for 6 hours, there is a drop in COE for 200 kW and 250 kW generator.



C2.

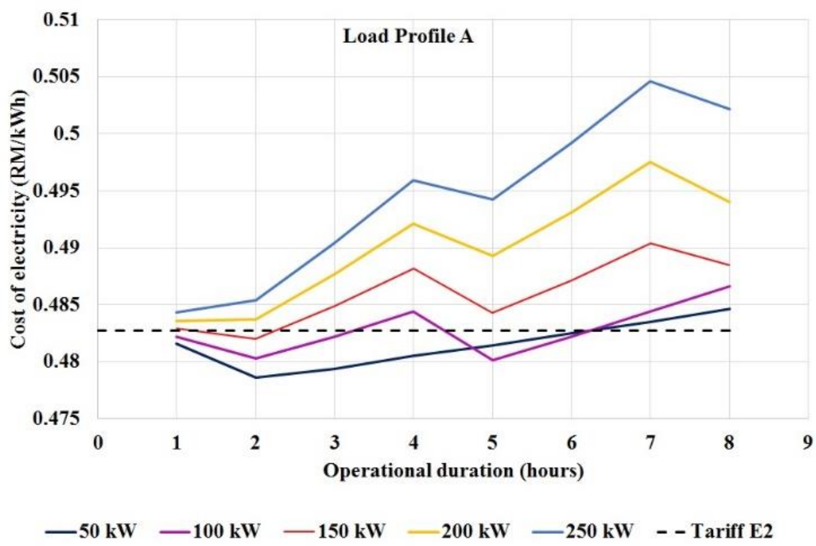
(a)



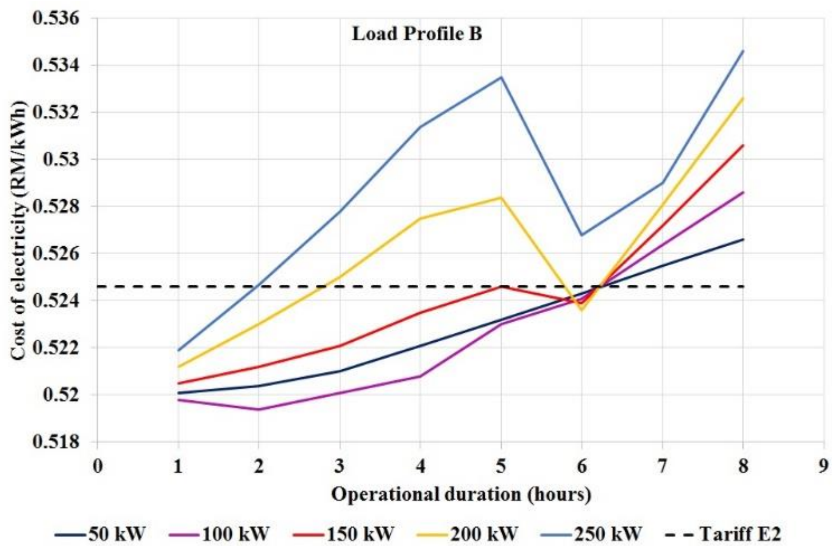
(b)

Figure 4.3: Comparison of Cost of Electricity between (a) Load Profile A and (b) Load Profile B based on Size of Standby Generator and Operational Duration for Tariff E1

Figure 4.4 shows the comparision of COE between load profile A and B for tariff E2. For load profile A, the lowest COE obtained is RM 0.4786 per kWh, operating for 2 hours and the generator's size is 50 kW. There is a small drop when the generators of 100 kW until 250 kW are operating for 5 hours. Due to the drop, the COE for 100 kW generator drops below the threshold, obtaining RM 0.4801 per kWh. For load profile B, the lowest COE obtained is RM 0.5194 per kWh, operating for 2 hours and the generator's size is 100 kW. Same as tariff C2, there are many available options that can be chosen from as most of the COE obtained is lower than the threshold. There is also a significant drop when the generators for 200 kW and 250 kW operate for 6 hours. For generator size of 50 kW, 100 kW, 150 kW and 200 kW operate for 6 hours, all are having almost the same COE .



(a)



(b)

Figure 4.4: Comparison of Cost of Electricity between (a) Load Profile A and (b) Load Profile B based on Size of Standby Generator and Operational Duration for Tariff E2

Load profile B can have a bigger standby generator and the operational duration is longer as compared to load profile A. This means that load profile B has more option in order to have lower COE. This shows that in order for peak shaving to be able to achieve more effectively, it is required to have a sharp peak curve. We are able to control the total amount required to shave the peak by controlling the operational duration. But with flat load curve, the standby generator unable to achieve effectively as the standby generator is required to operate longer hours to reduce the peak demand. Even though it is able to reduce the peak demand and power consumption charge, the COE will increase due to other factors such as fuel consumption is high for long operating hours. Therefore, with sharp peak curve, the COE obtained will be lower compared to flat load profile. It is not advisable to use standby generator for flat shape curve as it doesn't shave much of the peak demand.

Secondly, there is a common trend for both the load profiles. When the size of standby generator along with operational duration increases, the COE will also increase. With the increase of operational duration, for size of 100 kW until 250 kW, there is a drop in COE for both load profile. It did not increase as expected. The drop occurs when generators for load profile A operated for five hours while generators for load profile B operates for six hours for all the tariffs. The drop can be obviously seen for tariff C2 and E2. The reason it can be obviously be seen is because both of these tariffs have on-peak and off-peak charge as compared to tariff C1 and E1 where it only have one charge, which is total energy. By having the off-peak charge together with the reduction of maximum demand charge, the drop of COE can be seen clearly. With the low COE, this will be a better chance to shave the peak more effectively.

The size of generator is determine based on obtaining the lowest COE obtained for the four tariffs applied. Based on explanation given from Figure 4.1 to Figure 4.4, it can be concluded that with flat curve profile, the suitable generator size is 50 kW standby generator operating for 2 hours while having sharp curve profile, the generator that should use is 100 kW standby generator operating for 2 hours as well.

4.3 System with Standby Generator by Considering Their Capital Cost

In this case study, it is to study the effect of COE with the addition of capital cost for the standby generator into the simulation. Capital cost is a one-time expenses, as an initial investment in buying and installing the standby generator. The purpose of adding capital cost is for new owner who plans to install new diesel generators into their new premises, building or install it to function as to shave the peak. The capital cost for the standby generator is RM 900 per kW. Based on previous case study, the most optimum operational time for the standby generator to operate in order to obtain low COE is 2 hours of operation. Therefore, it will also be used in this case study as well.

Figure 4.5 illustrates the comparison of COE between load profile A and B for tariff C1. For load profile A, the lowest COE obtained is RM 0.478 per kWh, using the generator size of 50 kW. For load profile B, the lowest COE obtained is RM 0.5111 per kWh, using the generator size of 50 kW. For 100 kW, it can also be considered due to its COE is below the threshold, with COE of RM 0.5116 per kWh.

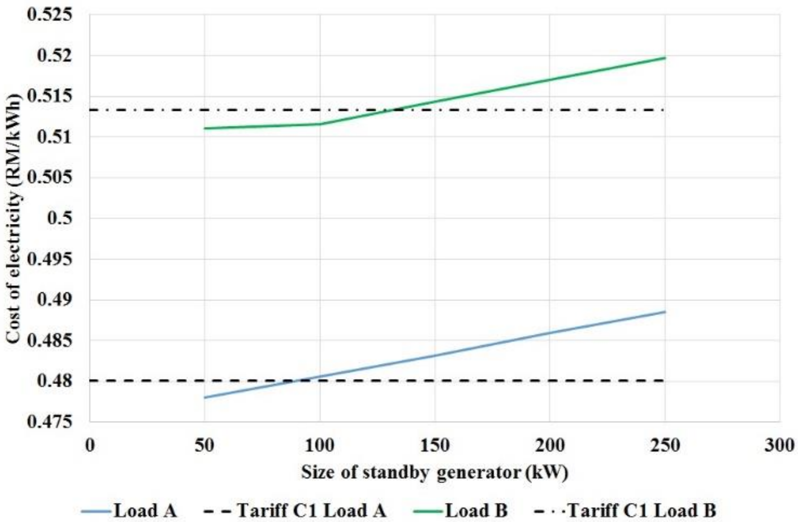


Figure 4.5: Comparison of Cost of Electricity with Two Different Load Profiles and Size of Standby Generators for Tariff C1 with Capital Cost

Figure 4.6 illustrates the comparison of COE between load profile A and B for tariff C2. For load profile A, the lowest COE obtained is RM 0.5098 per kWh, using the generator size of 50 kW. For load profile B, the lowest COE obtained is RM 0.5596 per kWh, using the generator size of 100 kW. For 50 kW, it can also be considered due to its COE is below the threshold, with COE of RM 0.5605 per kWh.

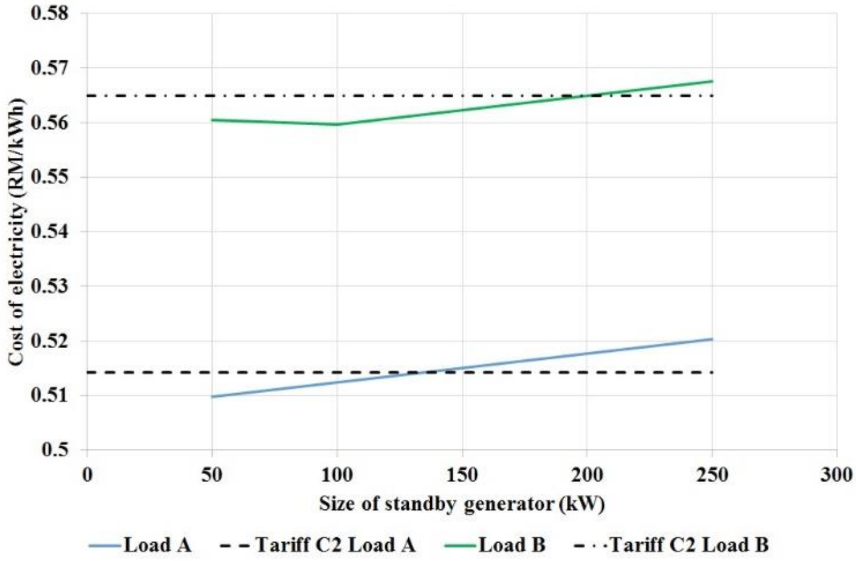


Figure 4.6: Comparison of Cost of Electricity with Two Different Load Profiles and Size of Standby Generators for Tariff C2 with Capital Cost

Figure 4.7 illustrates the comparison of COE between load profile A and B for tariff E1. For load profile A, the lowest COE obtained is RM 0.4476 per kWh, using the generator size of 50 kW. For load profile B, the lowest COE obtained is RM 0.4800 per kWh, using the generator size of 50 kW. For 100 kW, it can also be considered due to its COE is below the threshold, with COE of RM 0.4808 per kWh.

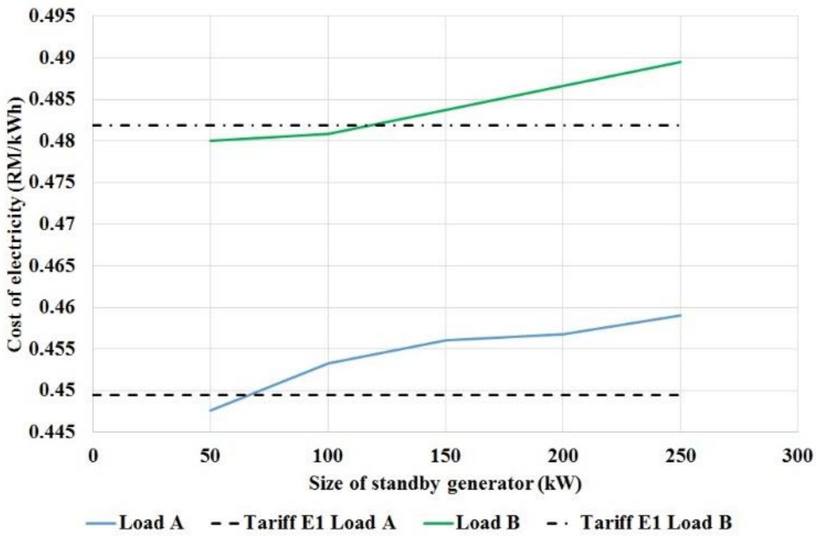


Figure 4.7: Comparison of Cost of Electricity with Two Different Load Profiles and Size of Standby Generators for Tariff E1 with Capital Cost

Figure 4.8 illustrates the comparison of COE between load profile A and B for tariff C2. For load profile A, the lowest COE obtained is RM 0.4795 per kWh, using the generator size of 50 kW. For load profile B, the lowest COE obtained is RM 0.5215 per kWh, using the generator size of 50 kW. For 100 kW, it can also be considered due to its COE is below the threshold, with a value of RM 0.5216 per kWh.

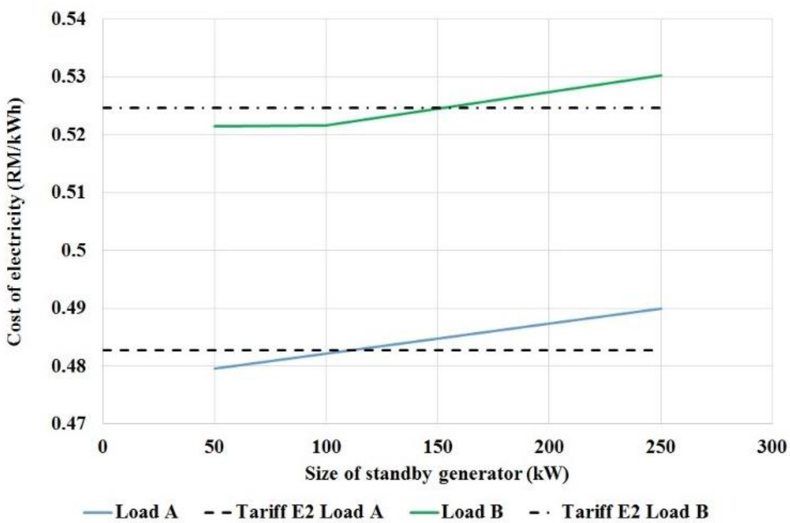


Figure 4.8: Comparison of Cost of Electricity with Two Different Load Profiles and Size of Standby Generators for Tariff E2 with Capital Cost

For load profile A, the available standby generator is 50 kW while load profile B has two sizes that can be considered, either 50 kW or 100 kW standby generator. Although the COE obtained is lower than the COE without standby generator, the result obtained is still quite close to the threshold.

This means that having higher capital cost will increase the COE, which may prevent users from using newly owned standby generator as peak shaving generator. Due to power consumption is small, only small standby generator can be used in order to have low COE. Unless the load consumes more power in terms of MW, bigger standby generator can be used to reduce the peak.

4.4 Total Net Present Cost

After simulating all possible operational duration through previous case studies, the optimum operational duration for the generator to operate is for 2 hours. So, the total net present cost is studied based on the standby generator operating for 2 hours with no capital cost was included. By making use of the standby generator to shave the peak demand, there is a potential saving in terms of maximum demand charge reduction due to a decrease in peak demand. But there will also be NPC taken into account when standby generator is operated to generate power. HOMER is able to calculate the NPC of the system and the whole project lifetime. The NPC includes capital, replacement, operating and maintenance (O&M), as well as the fuel consumption cost. In this simulation, there is no capital and replacement cost taken place. For the capital cost, it is equal to zero assuming that the standby generator is preinstalled on-site. While for replacement cost, due to the standby generator hasn’t reached its lifetime, the replacement of standby generator is not required.

The potential saving, NPC, net saving and percentage saving can be seen in Table 4.2. Both load profile A and B are having the same cost shown in Table 4.2 as both load profiles are using the same standby generator and operational duration. Based on Table 4.2, all the tariffs will be able to gain benefit from using standby generator. But tariff C2 will gain more benefit using standby generator for peak shaving as it has a higher percentage saving as compared to other tariffs, saving up to 41 % of its potential savings. One of the reason is due to the maximum demand rate is the highest among the tariffs. By shaving off the peak demand, consumer are able to gain some profit from it. This also apply the same for tariff E2. But for tariff C1 and E1, it doesn't achieve as much saving as the other tariffs.

With the small profit that the consumers gain financially in the long run, consumers are able to operate the standby generators during peak time with high peak demand. Not only that, by having consumers generating electricity, the burden load connecting to the electrical grid can be reduced, especially during peak demand periods. This may even help to increase the grid reliability.

Table 4.2: Total Annual Saving for Tariff C1, C2, E1 and E2

Tariff	Size of standby generator (kW)	Potential saving (RM)	NPC (RM)	Net saving (RM)	Percentage saving (%)
Tariff C1	50	18,180	15,993	2,187	12
	100	36,360	31,987	4,373	
	150	54,540	47,981	6,559	
	200	72,720	63,974	8,746	
	250	90,900	79,968	10,932	
Tariff C2	Size of standby generator (kW)	Potential saving (RM)	NPC (RM)	Net saving (RM)	Percentage saving (%)
	50	27,060	15,993	11,067	41
	100	54,120	31,987	22,133	
	150	81,810	47,981	33,829	
	200	108,240	63,974	44,226	
	250	135,300	79,968	55,332	
Tariff E1	Size of standby generator (kW)	Potential saving (RM)	NPC (RM)	Net saving (RM)	Percentage saving (%)
	50	17,760	15,993	1,767	9
	100	35,520	31,987	3,533	
	150	53,280	47,981	5,229	
	200	71,040	63,974	7,066	
	250	88,800	79,968	8,832	
Tariff E2	Size of standby generator (kW)	Potential saving (RM)	NPC (RM)	Net saving (RM)	Percentage saving (%)
	50	22,220	15,993	6,227	28
	100	44,440	31,987	12,453	
	150	66,600	47,981	18,619	
	200	88,800	63,974	24,826	
	250	111,000	79,968	31,032	

4.5 Reduction of Carbon Dioxide Emissions

By using diesel fuel as the source of energy, the standby generator will release greenhouse gases such as carbon dioxide (CO_2). In this section, a comparison between the grid system and grid/diesel system was done, in terms of CO_2 emissions. It is noted that this analysis is assumed that there is no cost penalty been imposed for the pollutants released. However, if there is cost penalty, HOMER will add the cost into O&M cost of the system. Table 4.3 and 4.4 shows the annual CO_2 emissions for grid and grid/diesel system for load profile A and B respectively. As seen from Table 4.3 and 4.4, by using standby generator, there is a small reduction in CO_2 emissions.

Table 4.3: CO_2 Emissions Released by Grid and Grid/diesel System for Load Profile A

Size of standby generator	Grid (kg/year)	Grid + Generator (kg/year)	Net reduction (kg/year)
50	2,634,954	2,633,347	1,607
100	2,634,954	2,631,739	3,215
150	2,634,954	2,630,131	4,823
200	2,634,954	2,628,523	6,431
250	2,634,954	2,626,915	8,039

Table 4.4: CO_2 Emissions Released by Grid and Grid/diesel System for Load Profile B

Size of standby generator	Grid (kg/year)	Grid + Generator (kg/year)	Net reduction (kg/year)
50	2,555,884	2,554,276	1,608
100	2,555,884	2,552,668	3,216
150	2,555,884	2,551,061	4,823
200	2,555,884	2,549,453	6,431
250	2,555,884	2,547,846	8,038

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Every commercial and industrial building will have at least one standby diesel generator as a backup power supply which is a contingency plan for power blackout. By making use of its power generation capability, it can also provide power when the demand for power is high. In this paper, the economic assessment of a standby diesel generator to reduce peak demand for commercial and industrial customers are presented. With the help of HOMER software simulation, the study has demonstrated that there is a potential to reduce the electricity bills for commercial and industrial customers under the existing fuel price and tariffs. The study conducted was on the cost of electricity, total net present cost and carbon dioxide emissions.

Based on the simulation result, the diesel generator is able to provide peak shaving during peak hours in order to reduce the purchase of electricity from the grid. It has also been shown that the standby generator has the potential to reduce the cost of electricity for customers. There are two types of load profile studied in this project, both flat and sharp load characteristics. In the case of flat load profile, the available standby generator size is 50 kW while for sharp load profile, there are two sizing that can be considered, either 50 kW or 100 kW standby generator. But the best option to choose is by using 100 kW generator. The optimum time for the standby generator to operate for both load profile is up to 2 hours only. Beyond that, it is not economically viable in terms of cost of electricity and total net present cost.

Besides that, sharp load profile will be able to gain benefit as compared to flat load profile, which can be seen through the result of cost of electricity.

In terms of net present cost, all the tariffs are able to obtain some profit. But tariff C2 are able to gain more profit as compared to other tariffs, saving of about 41 % of the total potential savings which is gained from the maximum demand charge. With the use of standby generator, although burning fuel will increase pollutants such as carbon dioxide, but the results shows that, by reducing the dependency of purchasing power from the grid, using standby generator to generate during peak time will be able to reduce the carbon dioxide emissions, even though the reduction is small.

Standby generator has the potential to be used in commercial and industrial buildings to shave the peak demand and it is economically viable. Due to HOMER limitation for the standby generator to operate on selected days, the COE obtained from the simulation is high. But if the analytical tool is able to control the daily operation of the standby generator instead of monthly operation, the COE result obtained might be lower than expected.

5.2 Recommendations

For future improvements, it is required to obtain an analytical tool that has the function of controlling the generator operating time in terms of daily operation. This will enable the user to obtain a better results. Besides that, the analytical tool needs to allow the grid to charge the battery in the energy storage system with generator included into the simulation. With this feature, adding an energy storage system into the model will enable the analytical tool to simulate it. Energy storage is quite useful as it can charge during off peak time and discharge during on peak time. This will help in reducing power consumed from the grid, and this in turn may be able to reduce the maximum demand charge.

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