Development of Redundancy Model for Co-generation Plant

by

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Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

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(Ir Dr Mohd Amin Abd Majid)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2013

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and the original works contained herein have not been undertaken or done by unspecified sources or persons.

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(Ahmad Zhafran bin Ahmad Redzuan)

ABSTRACT

This study presents development of redundancy model for co-generation plant. The study is focused on small cogeneration plant which produces power below 10MW. UTP-GDC plant was chosen as the model because of its location and accessibility to information. The development of redundancy model is important to provide analysis for future improvement of small co-generation plant. Cogeneration plant did experience some trouble when the turbine fails to operate and results in blackout situation. During this situation, the approach usually taken by small plant is to get electrical supply from TNB. In this study, two alternatives were being compared and investigated in terms of economic that will help the plant manager to make decision. The approaches taken were quantitative analysis based on two mathematical models that includes annual worth analysis and breakeven analysis. Results obtained were evaluated and breakeven point was determined to find the lesser annual cost during failure. The results of this study show that reliability of cogeneration power generation system can be improved further by using generator set. Redundancy model developed showed that annual cost of using public utility is RM 2,310,726 and annual cost of generator set is RM 1,130,971.63. The cost of maximum demand charge contribute to 82% of the total cost of failure when using public utility, 9% was the cost of electricity and 9% was the cost of repair. On the other hand, for gen set, the highest cost was contributed by capital cost which takes up to 69% of the total cost followed by cost of operation with 24% and lastly 7% is due to cost of maintenance. Breakeven analysis was used to find most suitable alternative at given operating hours. The breakeven point was determined at 35.01 hours with the annual cost of RM 668,587.64. Based on this study, generator set alternative is a better option compared to public utility.

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INTRODUCTION

1.1 Background of Study

Cogeneration plant generates electricity using gas turbine as its main source of power. The risk faced by the plant is when the turbine failed to operate and hence electricity will not be available for customers. Normally, the plant will purchase electricity from TNB which is the local provider of electric energy. However, this method is generally more expensive and not cost-effective since TNB will impose maximum demand charge to the plant. An example of cogeneration plant for this case is GDC plant of UTP.

This situation could be improved by using backup generator as the backup power supply. Study of generator set was conducted to find its efficiency and cost-effectiveness and the result was compared with the current method of electricity from TNB as redundancy. The performance of cogeneration system relies on availability and reliability of equipment, maintenance and operation process. A reliable system will provide electrical power without interruption. The system is expected to be available at all time. When the availability and reliability of system decrease, then it is required to make improvement by reducing the failure rate and change current redundancy with new model. A reduction of 1% from the system availability results in $ 500,000 loss of income [1].

Availability and reliability are important to determine the number of failures and downtime hours per year [2]. These variables are essential to calculate cost of cogeneration system as it is time dependent. The use of availability and reliability did showed the performance of cogeneration system, however in order to make decision whether to change the current redundancy or not, economic impact of the choice must be determined.

Thus, this study focuses on developing redundancy model of cogeneration system. The availability and reliability were used to determine the performance of the system. Annual value is used to analyze the impact of failure for redundancy using public utility and generator set and the results were validated using breakeven analysis.

1.2 Problem Statement

Redundancy model is worth investigating in cogeneration system due to its importance of supplying electrical power to end user during blackout situation. Even though redundancy has been implemented in industrial practices, the comparisons in terms of cost-effective between buying power from public utility and generator set have not been studied in details. It is common that, some of the power plants still depend on power supplied by authorities during black-out situation despite the high maximum demand charge. This is to ensure the plant can meet demand requirement although at higher cost. Due to this issue, available alternatives for providing redundancy during blackout are compared.

1.3 Objective

The main objective of the study is to develop a redundancy model for cogeneration plant. The model is to evaluate the cost-effectiveness between two alternatives namely purchasing power from public utility in comparison to using generator set.

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1.4 Scope of Study

To develop redundancy model for cogeneration plant, several scope of study need to be considered in determining the source of problem and identify potential alternatives or solutions to be implemented. Scope of study in this project includes:

1. To use UTP-GDC plant as a model.

2. Considering redundancy from TNB and diesel generator set.

3. Annual Worth (AW) analysis is adopted for the model.

4. Breakeven method is used for sensitivity analysis on the model.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction of Cogeneration

Cogeneration is on-site generation of power by utilizing energy in different forms at the same time. Cogeneration allows the energy to be used at optimum efficiency and cost-effective as well as minimize the effect on environment. There are many types of cogeneration system and most of them primarily generate electricity along with heat which is use back as source of power.

CHP system consists of many components such as prime mover, generator, heat recovery and electrical connections. Prime movers of cogeneration system include gas turbine, steam turbine, reciprocating engine, micro-turbine and fuel cells. Example of cogeneration systems being used is the combine cycle of gas turbine with steam turbine and combine cycle of gas turbine with absorber chiller. Since this study was focused on small co-generation power plant, UTP-GDC power plant was selected as a model as it power production is less than 10 MW per day. Moreover, this plant has no backup generator and depends on electricity from TNB during blackout.

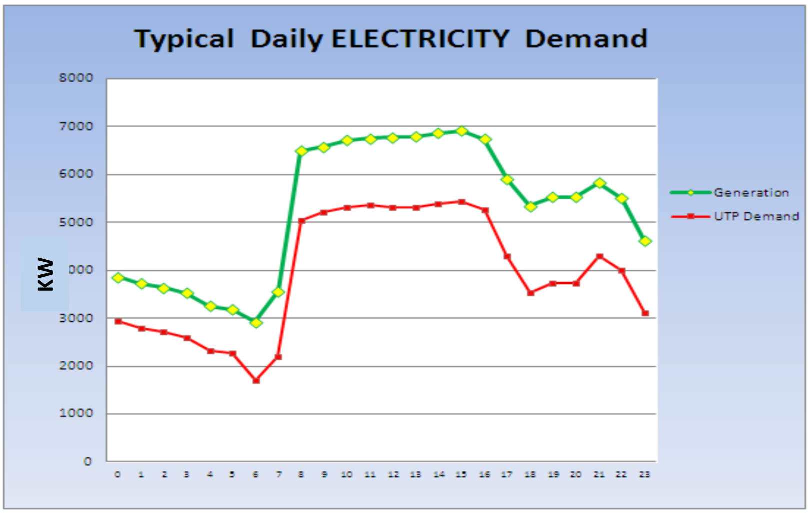


Figure 2.1: UTP-GDC typical daily electricity demand graph [3].

2.1.1 Combine cycle of gas turbine with steam turbine

A typical combined cycle power plant uses the exhaust gases from a gas turbine to produce steam in a boiler to be used in a condensing steam turbine [4]. The combined cycle of gas turbine and steam turbine consists of the combination of Brayton Cycle and Rankine Cycle. The combination of both cycles is one of the most efficient cycles in operation of power generation system.

In most combined cycle, gas turbine is the topping cycle and the steam turbine is the bottoming cycle. Thermal efficiencies of this cycle can reach up to 60 %. Normally, the gas turbine produces about 60% of the power while the remaining 40% produced by steam turbine. Individual thermal efficiencies of gas turbine and the steam turbine are between 30% and 40%. From the overall thermal efficiencies of combined cycle which is 60%, 40% of the energy is converted to power by the gas turbine and the remaining 20% is converted to power by the steam turbine. Figure below shows distribution of energy entering combine cycle power plant.

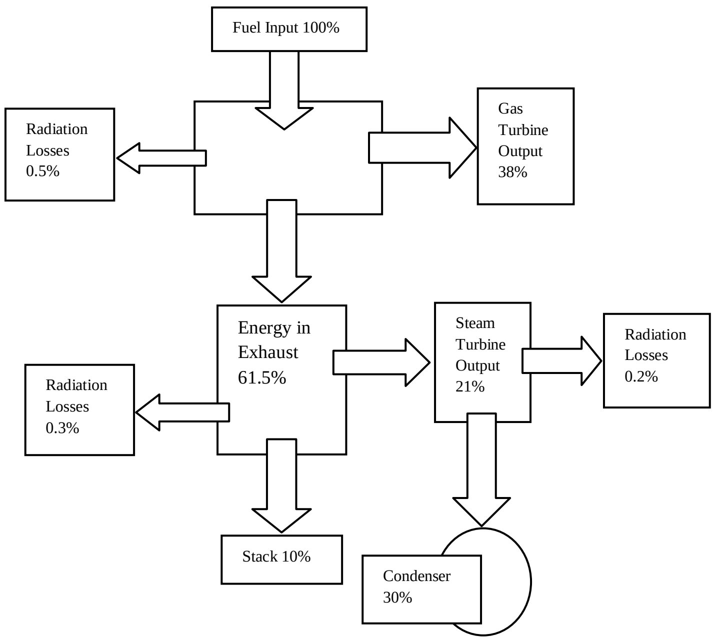


Figure 2.2: Energy flow diagram [4]

2.1.2 Combine cycle of gas turbine with absorber chiller

Absorber chiller is another form of refrigeration that becomes economically attractive as explained by Kolanowski et al. [5]. Hot water generated by generator can be used in making chilled water by using technology called absorption chilling. The absorber chiller works based on the principal of boiling a chemical solution in a vacuum with the resultant chemical vapor acting as a refrigerant to remove heat from water that has been used as a coolant. Once the heat is removed, the chilled water goes back to the process to cool, picking up heat and returning to the absorber chiller to be chilled again.

The most widely used absorption refrigeration system is the ammonia-water system where ammonia serves as the refrigerant and water as the transport medium. Other absorption refrigeration includes system water lithium bromide and water lithium chloride system, where water serves as the refrigerant. The latter two systems are limited to application such as air conditioning where the minimum temperature is above the freezing point of water.

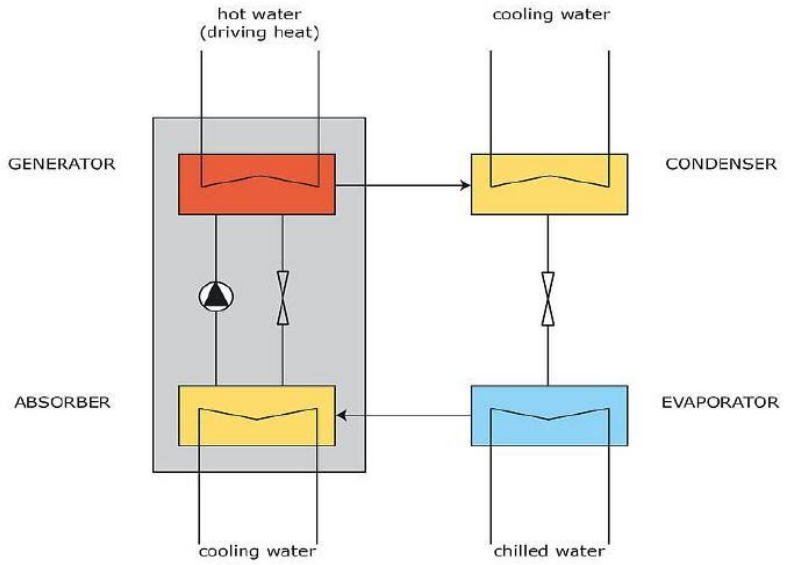


Figure 2.3: Cooling process cycle [6]

2.2 Backup Power for Cogeneration Plant

2.2.1 Generator Set

Power that is produced by CHP plants mainly is distributed in a parallel configuration with the local utility power to meet the facility load. Sometimes, the total load required may exceed capacity of the CHP plant. It is common that power is down in the facility due to an act of nature, an overload condition or equipment failure. During this event, engine generator will trip off and no power is produced. The facility is now without power or 'black' and the operator must restored power as soon as possible.

One of the ways is by using black start generator. Hordeski et al. [7] recommended that diesel engine generator is used for black start. The generator is designed to provide just enough power that is required to support the start up of the CHP plant. The auxiliary loads should be capable of supporting the CTG and the associated HRSG under emergency conditions. Black start generator provides a voltage and frequency that the CHP prime mover can read and synchronized with. When the engine is cooling and had completed its warm-up, plant operator will increase the operating RPM and then bring the generator online. The generator frequency must be synchronized with the line frequency. The synchronization can be done either using automated control or manual mode. The use of hybrid system for cogeneration plant makes an economically efficient power generating system according to Benjamin et al. [8].

Bootstrapping refers to methods for black starting generator. There are usually two methods which are used in the combine cycle plant. Firstly, diesel generator allows a small CTG to start and synchronize to the diesel generator to provide enough power to start the main generator. Secondly, diesel generator fired a standby boiler which then supplies steam to the STG. The STG would then synchronize with diesel generator to provide power to the CTG. Normally, bootstrapping will allow for a smaller, more economical diesel engine to be used.

Environment and Development Division [9] highlighted that cost of generator set can be categorized into installation cost, operating costs, insurance, depreciation and standby charges. Straight-line depreciation method is adopted for their study. The standby charges on the other hand, is the electricity charges that is imported from the grid is the electricity demand of the facility cannot be met by cogeneration system.

2.2.2 Buying power from the public utility

One of the alternatives considered for a combined heat and power plant consist of BAU (buying power from public utility and fuel for thermal requirements) as discussed by Meckler et al. [10] . The BAU case is the least that could be done to meet the thermal and electric demands of the system. Example of BAU is purchasing electricity from public utility to meet required electric loads of the facility. Usually this case happen when co-generator does not generate electricity due to plant failure or plan shut down for maintenance.

Peak periods are when majority of the income is generated. 1% of reduction in availability could cost $500,000 in income on a 100 MW plant. Maximum demand charge is imposed to power plant if the electricity demand cannot be met during peak period. According to TNB, 2013, maximum demand is measured in kilowatts and is calculated as double the highest amount of electricity used (in kilowatt-hours). Hence power must be generated or purchased through purchase agreements that contain capacity payments.

One Alpha Group [11] explained maximum demand charge of TNB on its article. Firstly, the customer is charged for the electrical power that is used. Secondly, maximum demand charge which relates to peak levels of power that the customer used during a given period of time as recorded by maximum demand meter. Maximum demand charge is imposed as pressure is put on the system during peak periods. Hence, TNB must have sufficient machinery and ready to be operated to meet periods of maximum demand.

Table 2.1: Pricing and tariff for industrial top-up and standby [12].

TARIFF CATEGORY		UNIT	RATES	
			Top-Up	Standby
1.	**Tariff C1 - Medium Voltage General Commercial Tariff**			
	Maximum demand charge per month	RM/kW	25.9	14.0
	For all kWh	sen/kWh	31.2	
2.	**Tariff C2 - Medium Voltage Peak/Off-Peak Commercial Tariff**			
	For each kilowatt of maximum demand per month during the peak period	RM/kW	38.6	14.0
	For all kWh during the peak period	sen/kWh	31.2	
	For all kWh during the off-peak period	sen/kWh	19.2	
3.	**Tariff E1 - Medium Voltage General Industrial Tariff**			
	Maximum demand charge per month	RM/kW	25.3	14.0
	For all kWh	sen/kWh	28.8	
4.	**Tariff E2 – Medium Voltage Peak/Off-Peak Industrial Tariff**			
	For each kilowatt of maximum demand per month during the peak period	RM/kW	31.7	14.0
	For all kWh during the peak period	sen/kWh	30.4	
	For all kWh during the off-peak period	sen/kWh	18.7	
5.	**Tariff E3 – High Voltage Peak/Off-Peak Industrial Tariff**			
	For each kilowatt of maximum demand per month during the peak period	RM/kW	30.4	12.0
	For all kWh during the peak period	sen/kWh	28.8	
	For all kWh during the off-peak period	sen/kWh	17.3	

2.3 Reliability and Availability

2.3.1 Failure rate

Equipment will fail after certain period of operating time which can be predicted by its failure rate [13]. The failure rate varies with type of equipment and the mode of operation. Failure rate is the number of expected failure per unit in a given time interval. The result of the failure rate may not necessarily be true as it is only an assumption of the future behavior of the equipment. An engine with 6 failures per year does not necessarily have one failure every 2 months. In calculating the failure rate the total operating time should be used.

$$Failure\ rate, \lambda = \frac{number\ of\ failure}{total\ operating\ time\ of\ units} \tag{2.1}$$

2.3.2 Reliability

The reliability is considered as the ability of a component to perform required function under stated conditions in a given period of time as discussed by Ali et al. [14]. Reliability is also the probability that the component is operating without failures. N_o is considered as the population at the beginning and λ is the failure rate. The number of failure population is given by N_f and safe population is denoted by N_s respectively. The time rate of increase of N_f is equal to the failure rate multiplied by the number of units in safe population.

The formula is given by

$$R(t) = \frac{N_s}{N_o} = 1 - \frac{N_f}{N_o} \quad (2.2)$$

$$\frac{dR(t)}{dt} = \frac{-1}{N_o}\frac{dN_f}{dt} = -\lambda\frac{N_s}{N_o}$$

$$= -\lambda R(t)$$

$$\int\frac{1}{R}dR = -\int\lambda dt$$

$$\ln R(t) = -\lambda t$$

$$R(t) = e^{-\lambda t} \quad (2.3)$$

R(t) is the reliability of the equipment that survived for a given time period, t. R(t) decreases with time and probability density function can be derived as the area under the curve of reliability function. The probability density function is given by

$$f(t) = \lambda e^{-\lambda t}\, dt \quad (2.4)$$

2.3.3 Mean Time Between Failure (MTBF)

Mean Time Between Failure (MTBF) is a reliability function that is used to find the average time for a failure to occur [14]. MTBF is important in decision making process where the equipment's life span is significant. In industries, MTBF is essential in order to ensure the system works as it is desired. MTBF can be obtained by integrating the reliability model over the overall range of data. The expression is given by

$$MTBF = \int_0^\infty R(t)dt \tag{2.5}$$

The simplified equation becomes

$$MTBF = \int_0^\infty e^{-\lambda t}\, dt = 1/\lambda \tag{2.6}$$

From the equation given, the Mean Time Between Failure (MTBF) is the reciprocal of failure rate, λ. The result is only viable to exponential reliability function only. Higher failure rate will results in lower MTBF which means that the time interval between failures to happen is shorter. The MTBF is assumed to be random variables and the failure due to aging of equipment is not considered in this study.

2.3.4 Mean Time to Repair (MTTR)

Mean Time to Repair (MTTR) is an estimated average elapsed time required to perform maintenance or corrective action whenever the equipment failed or out of service. MTTR is a useful parameter that is used in planning and decision making stage. The estimated MTTR helps in calculating the life cycle cost of equipment which includes the cost of time taken by the technicians to repair the equipment. MTTR can be calculated from the mean of sample data with lower and upper limit bound. However, precise MTTR cannot be obtained as a result of poor documentation of maintenance data.

In the prediction of MTTR, it is assumed that the time recorded does not include maintenance overhead. Non-related repair time such as time for waiting spare parts and break-time is excluded in the analysis. Other than that, the equipment is also considered to have constant failure rate, λ. The maintenance and repairing works are also performed using standard maintenance procedure and well-trained personnel.

Before the calculation of MTTR, the repair rate, μ must be defined. The repair rate is described as expected repair per unit in a given time interval. The equation is given by

$$Repair\ rate, \mu = \frac{number\ of\ repair}{total\ repair\ time\ of\ units} \quad (2.7)$$

The repair rate is reciprocal of mean time to repair and has similar expression with failure rate which is the reciprocal of mean time to failures. The constant repair rate also leads to exponential repair function. Hence, the repair rate is given by the probability of equipment being repaired within a time t.

$$MTTR = \int_0^\infty r(t)dt \quad (2.8)$$

The simplified equation is expressed as

$$MTTR = \int_0^\infty e^{-\mu t}\, dt$$

$$= 1/\mu \quad (2.9)$$

2.3.5 Availability

Availability is given by the percentage of time that the system is functioning. Whereas unavailability is the opposite which defined as the percentage of time that the system is not functioning. Arora et al. [15] assess the availability of steam and power using Markov method. In their study, the system considered working under three operating conditions which are failed, reduced and full operation. Their result showed the impact of repair rates and failure on the availability and of the system.

Availability is determined by reliability, maintainability and serviceability. The calculation is usually based on agreed service time and downtime. The calculation is expressed as

$$Availability, A = \frac{Uptime}{Uptime+Downtime} \quad (2.10)$$

$$Unavailability, \bar{A} = \frac{Downtime}{Uptime+Downtime} \tag{2.11}$$

The uptime of a system can be expressed as MTBF and the downtime taken for the system to be functional again equal to the MTTR. The availability model becomes

$$A = \frac{MTBF}{MTBF+MTTR} \tag{2.12}$$

$$\bar{A} = \frac{MTTR}{MTBF+MTTR} \tag{2.13}$$

The availability of a system can also be expressed by constant failure rate, λ and repair rate, μ.

$$A = \frac{1/\lambda}{1/\lambda + 1/\mu}$$

$$= \frac{\mu}{\lambda+\mu} \tag{2.14}$$

2.4 Annual Worth (AW) Analysis

Economic analysis of a project is a combination of many analysis such as availability, reliability and maintenance analysis. Dougan and Reilly [16] conclude that economic analysis of power generating system is closely linked to system availability and reliability analysis because the production interruption is one of the major worries of plant management. Mahmoodzazeh et al. [17] highlighted that Annual Value (AV) can be used for project selection and Jeffrey L. & Samuel B. shows the development of annual value for evaluating alternatives. In order to evaluating redundancy, all future cash flows are converted to annual amounts at a specific rate of return as suggested by Blank L. & Tarquin A. [18]

There are two types of economic proposals which are mutually exclusives alternatives and independent projects. In mutually exclusive, only one alternative can be selected, whereas for independent projects more than one can be selected. The alternatives must be compared over the same number of years and must end at the same time to satisfy equal-service requirement. If the number of years is not the same, the analysis will always favor the shorter-lived mutually exclusive alternative because fewer periods of costs are involved. Annual worth analysis can be calculated as below:

$$AW = \sum_{n=0}^{N} P_n (A/P, i, n) \quad (2.15)$$

Where P_n is net cash flow at the beginning of the project

i is Minimum Attractive Rate of Return (MARR)

N is service life of the project

2.5 Breakeven Analysis

Breakeven analysis is used to determine the effect of revenue or cost on the project's profitability [14]. Breakeven point is a value at which two alternatives are equal to each other. The value calculated is essential to make selection between two engineering project alternatives. If the estimated outcome is higher or lower than the breakeven point, the best alternative is selected with the desired output. Breakeven analysis can be expressed as

$$AW_A = AW_B \quad (2.16)$$

Where AW_A is the annual worth of alternative A

AW_B is the annual worth of alternative B

The expression can also be compute in term of common factor of y that makes

$$f_1(y) = f_2(y) \quad (2.17)$$

Where y is the common factor of interest affecting the annual worth of alternative A and B

2.6 Summary

Cogeneration is simultaneous generation of multiple form of useful energy such as mechanical and thermal. The main advantage of using cogeneration system is high efficiency, cost-effectiveness and more environmental friendly than conventional power generation system. Combine cycle of gas turbine with steam turbine and combine cycle of gas turbine with absorber chiller are the most popular cogeneration system used. In gas turbine with steam turbine cogeneration system, exhaust gases from a gas turbine is used to produce steam in a boiler to be used in a steam turbine while in absorber chiller, hot water generated is used in making chilled water. There are two redundancies for cogeneration system during blackout situation which are generator set and buying power from public utility. Both methods provide power that is required to support the start up of the CHP plant. Buying power from public utility is higher in cost due to maximum demand charge imposed.

Quantitative analysis which is annual worth was used for making decision for two or more analysis. Both alternatives are compared over the same number of years to find its cost effectiveness. Breakeven analysis where two alternatives are equal to each other is also used to select suitable alternative when the outcome is known. The alternative with lower cost will be selected based on breakeven point.

CHAPTER 3

METHODOLOGY

3.1 Introduction

A reliable cogeneration plant is important to ensure continuous supply of electricity to the customers. Failure of the system will bring negative impact on the customers and the plant itself. Hence, the study of cogeneration system is important to develop redundancy model that can help assess the plant availability as well as making economic decision. Two redundancies are being compared in this study which is purchasing electricity from public utility and generate the required electricity by generator set. The availability of the cogeneration plant will be asses using the data of number of failures and cumulative down time. Using the method of Annual Worth analysis of different-life alternatives, all capital costs, future costs and revenues are transformed into equivalent monetary units. Below are the research approaches:

1. Identify a small cogeneration power plant system configuration that is below 10MW to analyze the energy consumption pattern of the power plant.
2. Investigate the total number of breakdown for a certain number of research studies and cumulative down time.
3. Determine the Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) of the cogeneration plant. The data is then applied to availability and cost analysis.
4. Calculate the availability and average failure frequency of the power plant.
5. Develop redundancy model for both purchasing electricity from public utility and generator set.
6. Calculate annual worth of both redundancies for a given useful life.

7. Perform evaluation using breakeven point for a certain hours of operation.

8. Develop a spreadsheet template to analyze the data and carry out calculation for a given input.

9. Evaluate and select the best solution.

The availability and redundancy model frame work is presented in Figure 3.1.

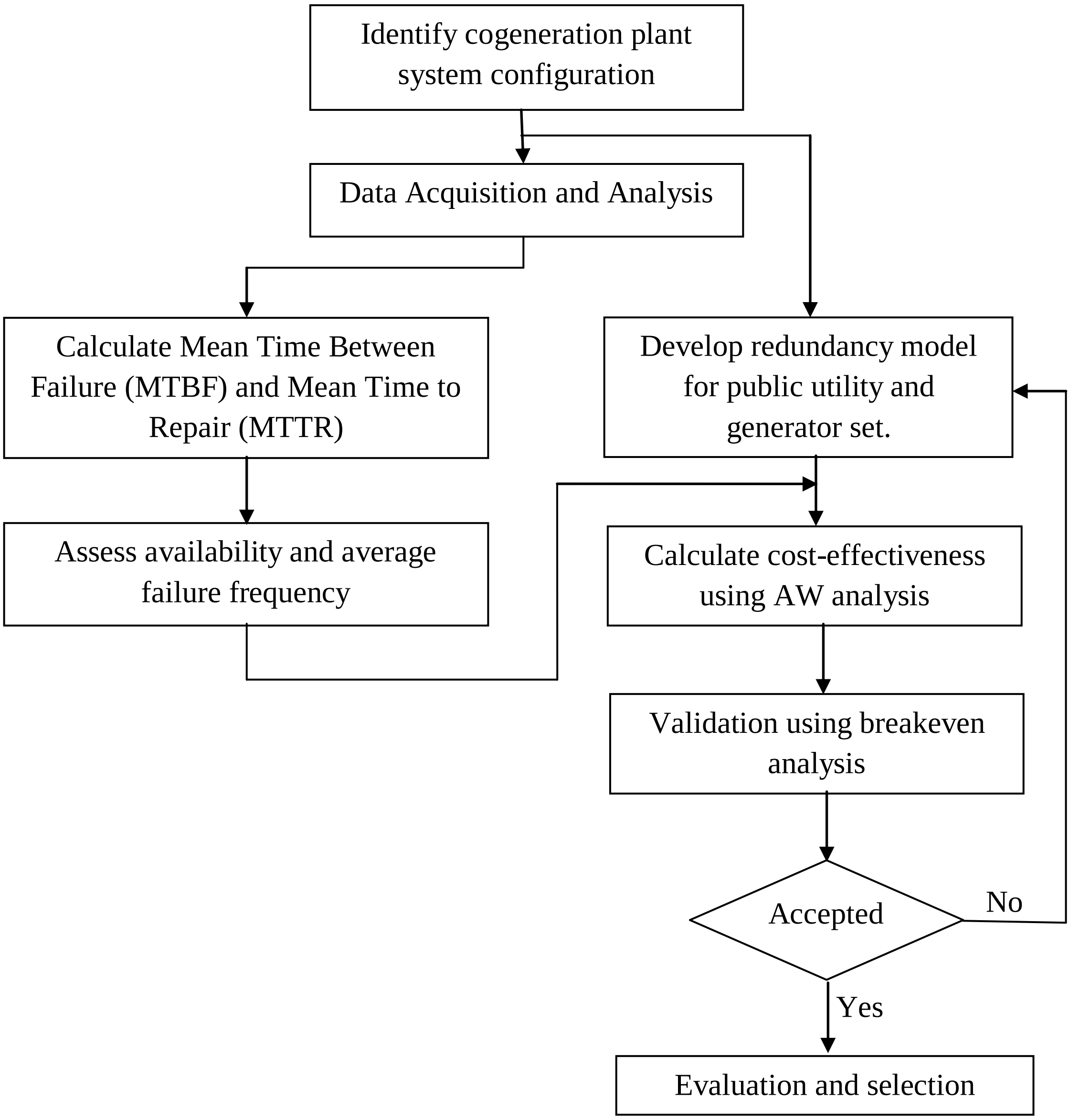


Figure 3.1: Research methodology flowchart

3.1.1 System Configuration and Block Diagram

In order to evaluate the availability and develop redundancy model, cogeneration system configuration must be identified to understand the relationship of the components in the system. Typically, a cogeneration system contains two main systems which are electricity generated system and heat recovery system. In electricity generated system, electricity is produced by means of mechanical or thermal energy. The configuration of the system and selection of components depends on the location and needs of the customers. The system availability is increased with the addition of redundancy into the system.

3.2 Data Acquisition

3.2.1 Power Plant System Load and Total Breakdown per Year

Analysis of power system begins with analysis of the load or demand in a certain period of time. Sets of data have to be acquired to analyze the pattern developed. Data obtained from power plant includes,

- Daily average electricity demands for period of five years.
- Total number of breakdown per year
- Cumulative down time.
- Maintenance and operation cost

The cost of breakdown per hour has to be determined by calculating total cost of electric purchased from local utility and divide with cumulative time of breakdown.

3.2.2 Generator set

Generator set (gen set) cost may vary widely from utility to utility and depending on the geographical factor of the plant. The installation, operating and maintenance cost differ for every manufacturer and operator. Factors affecting the cost include generator market price, project timeline, size of project and specific site problems. In order to estimate cost of gen set, several case studies were used to analyze the pattern available. Cost of the gen set can be a product of one variable or many variables depending on the accuracy of the estimation. Other cost such as installation and switchgear cost can be considered as percentage of cost of gen set whereby cost of installation normally would cost 20-30% [21]. Fuel consumption is one of the major elements of gen set. Consumption of fuel varies with different model, but most gen set would consume between 2.3 and 6.0 liters of fuel per hour of operation [22].

3.3 Reliability and Availability

3.3.1 Failure rate

Failure rate of the power plant was calculated using equation (2.1) using the data of total number of breakdown per year.

3.3.2 Reliability

Reliability is the probability that the component is operating without failures. The reliability of power plant was calculated using equation (2.3).

3.3.3 Mean Time Between Failure (MTBF)

Mean Time Between Failure (MTBF) is a reliability function that is used to find the average time for a failure to occur. Mean Time Between Failure (MTBF) is the reciprocal of failure rate, λ. The MTBF was assumed to be random variables and the failure due to aging of equipment was not considered in this study. In this project, MTBF was calculated using equation (2.6).

3.3.4 Mean Time to Repair (MTTR)

MTTR was calculated from the mean of sample data with lower and upper limit bound. However, precise MTTR could be obtained as a result of poor documentation of maintenance data. In the prediction of MTTR, it was assumed that the time recorded did not include maintenance overhead. Non-related repair time such as time for waiting spare parts and break-time is excluded in the analysis. Other than that, the equipment was also considered to have constant failure rate, λ. MTTR was calculated using equation (2.7) and (2.9).

3.3.5 Availability

Availability was calculated using equation (2.10).

3.4 Redundancy for Power Generation of Cogeneration System

A cogeneration power plant generated electricity continuously for 24 hours and is subjected to failure over times. Failure of the system will result in economic loss of the power plant. The cost is related to failure cost and cost of using redundancy during failure. Cost of redundancy depends on the type of redundancy that the plant adopted. The approach that normally taken by small power plant are to either purchase electricity from public utility or by using generator set.

The electricity from public utility is connected to the plant to support the outage power. Other than that, the electricity can also be connected to public utility to support demand of electricity during peak period. Generator set on the other hand, produces electricity by itself by means of conversion from mechanical energy to electrical energy. Normally diesel is used as fuel by the gen set. The Gen set serve as standby equipment whenever failure occurred to the main system. The costs of both redundancies are expensive and the parameter differs from each other. Thus, justification in economic perspective is important in making decision.

3.4.1 Redundancy model of using public utility

The system need to pay for the cost of maximum demand charge, cost of repair, cost of loss opportunity and cost of purchasing electricity when using electricity from public utility. This cost is expected to be constant for every failure given by the assumption that the cogeneration plant experience constant failure rate over the year. The estimated total annual cost of using public utility is given by

Total annual cost using public utility = {(Cost of repair per failure) + (Cost of Maximum demand charge per failure) + (Cost of electricity per failure) + (Cost of opportunity loss per failure)} x Number of failures per year

The total annual cost can be expressed as

$$C_{total\ annual,utility} = \{C_r + C_D + C_e + C_{op}\}\ x\ Number\ of\ failures\ per\ year \tag{3.1}$$

Where C_r is repair cost per failure

C_D is cost of maximum demand charge per failure

C_e is cost of electricity per failure

C_{op} is cost of opportunity lost per failure

a) Cost of annual repair, C_{ar}

Cost of repair is associated with the maintenance and repair cost during failure. The cost is dependent to the number of failures that occur in a year. It is assumed that the cost per failure is constant and using the standard maintenance and repair procedure. The expression of repair cost is given by

$$C_{ar} = N_f C_r Z N_t \tag{3.2}$$

Where C_{ar} is annual cost of repair

N_f is number of failures per year

C_r is cost of repair per failure

Z is ratio of gas turbine hook-up

N_t is number of gas turbines

The value of Z can be expressed as

$$Z = \frac{Number\ of\ gas\ turbine\ hooked\ up}{Total\ number\ of\ gas\ turbines} \tag{3.3}$$

b) Cost of Maximum demand charge, C_D

Maximum demand charge is the capacity of electric usage and it is used by the public utility to assess the capacity of electricity used by customers. The maximum demand is measured in kilowatts and it is related to the peak levels of power that is used in a given period of time. Since electric energy cannot be easily stored, the demand charge for electricity is therefore high especially during peak period where the need to generate power is high. The advantage of having maximum demand charge is that endless supply of electricity is available and can be access at any time. Thus, failure at any given time does not cause total failure of the system. The ability of having redundant supply of electricity does cost the cogeneration plant substantial operating cost. The maximum demand charge can be calculated using equation (3.4).

$$C_{aD} = N_f C_{max} K Z N_t \tag{3.4}$$

Where C_{aD} is annual demand charge cost

N_f is number of failures per year

C_{max} is maximum demand charge cost per kW,

K is capacity of gas turbine in kW

Z is percentage ratio of gas turbine hook-up

N_t is number of gas turbines

c) Cost of electricity by public utility, C_e

During the failure of cogeneration system, in addition to maximum demand charge that needs to be paid to the public utility, the plant is also charged for the actual power that is used. The power is charged for every kilowatt energy used per hour of operation. Thus the cost of electricity is dependent on total hours of connection with public utility and amount of energy supplied.

$$C_{ae} = N_f T_{avg} C_r K Z N_t \tag{3.5}$$

Where C_{ae} is annual cost of electricity by public utility

N_f is number of failures per year

T_{avg} is average time of a failure (hours)

C_r is cost of electricity rate per kWh charged by public utility

K is capacity of gas turbine in kW

Z is percentage ratio of gas turbine hook-up

N_t is number of gas turbine

d) Cost of opportunity loss, C_{op}

The cost of opportunity loss is the expected cost that the cogeneration plant should get from its customers if the failure does not happen. Since electricity is not supplied to the customers, then no income generated during the failure. The cost of opportunity loss is expressed as

$$C_{aop} = N_f CL \tag{3.6}$$

Where C_{aop} is annual opportunity lost

N_f is number of failures per year

C is cost per kWh of electricity charged

L is amount of electricity that should be delivered to customers during no outage

3.4.2 Redundancy model using generator set

When using gen set as redundancy for cogeneration system, several costs need to be considered in making the decision. The costs include capital cost which consisting of cost of gen set and cost of installation, insurance cost, salvage value, operation cost and maintenance cost. The expression is given by

Total annual cost using gen set = (Capital recovery) + (Annual cost of operation) + (Annual cost of maintenance)

The equation can be expressed as

$$C_{total\ annual,genset} = \{(C_{gen})(A/P,i,n) - 0.2C_{gen}(A/F,i,n)\} + C_o + 0.1C_{gen}(A/P,i,n) \quad (3.7)$$

Where C_{gen} is the capital cost of generator set

A/P is annual worth factor for a stated amount of present worth

A/F is annual worth factor for a stated amount of future worth

i is interest rate

n is number of useful life

C_o is cost of annual operation

a) Cost of capital, C_{gen}

C_{gen} is the purchase cost of the gen set inclusive the installed cost. The capital cost of gen set is expressed by equation (3.8).

$$C_{gen} = C_{pur\ gen} + C_{ins} \quad (3.8)$$

Where C_{gen} is capital cost of generator set

$C_{pur\ gen}$ is cost of purchased generator set

C_{ins} is cost of installation and start-up

Since capital cost of gen set varies with different manufacturers and service providers, the cost of gen set is difficult to be estimated, most of the available data from manufacturers were not detailed. In order to solve this problem, review of case studies information from previous projects were used to solve this problem.

A single regression models was developed and superimposed on the data. The trend line result was then used to estimate cost based on case studies information. The results were compared and percentage error was obtained to show relevancy of the model. In addition, two variables regression model was used to study the correlation between two variables with the desired output which was the cost for gen set. Other cost such as installation cost was calculated based on percentage of generator cost. The estimation was also based on information from case studies.

b) Cost of annual operation, C_o

Operating cost of using gen set is considered as cost of fuel consumed by the unit during failure of cogeneration system. Most of the gen set used as redundancy select diesel as the chosen fuel source as it is relatively low priced. Other than that, diesel is preferred because of its availability and predictability as a power producer. The formula of cost of operation is given by

$$C_o = N_f K Z N_t T_{avg} C_{fuel} \tag{3.9}$$

Where C_o is cost of annual operation

N_f is number of failures per year

K is capacity of gas turbine in kW

Z is percentage ratio of gas turbine hook-up

N_t is number of gas turbine

T_{avg} is average time of a failure (hours)

C_{fuel} is cost of generation per kWh power

c) Cost of annual maintenance, C_m

Maintenance involves both the engine and the generator, but most of the time it is performed for the engine to keep it functioning constantly. Maintenance on the engine includes changing oil, filter, coolant fluid, belt replacements and engine block heater hose replacements. Maintenance cost is considered as fixed cot as it is carried out at fixed time intervals without considering the operating hours. There are certain levels of maintenance which is provided by the manufacturer with different scope of work recommended. Previous studies showed that 20 years net present value of maintenance cost is approximately 10% of the cost of the unit [21]. The annual maintenance cost if given by equation (3.10)

$$C_m = 0.1C_{gen}(A/P, i, n) \quad (3.10)$$

Where C_m is cost of annual maintenance

C_{gen} is capital cost of generator set

A/P is annual worth factor for a stated amount of present worth

i is interest rate

n is number of useful life

d) Annualized salvage value, C_{sv}

Salvage value is the estimated value of an asset at the end of its useful life. The salvage value is used in conjunction with the purchase price and accounting method to determine the amount of depreciation of asset over a period of time. In this study, the salvage value is estimated to be 20% of the capital cost of generator set [21] which the relation is given as

$$C_{sv} = 0.2C_{gen}(A/F, i, n) \quad (3.11)$$

Where C_{sv} is annualized salvage value of generator set

C_{gen} is capital cost of generator set

A/F is annual worth factor for a stated amount of future worth

i is interest rate

n is number of useful life

3.5 Annual Worth Analysis

The annual worth expression at the end of period N is calculated using equation (2.15).

3.6 Breakeven Analysis

Breakeven analysis was calculated using equation (2.16). The results were tabulated and plotted in the breakeven graph. From the graph, the intersection between alternative A and B is the breakeven point. The breakeven value is the point which is indifferent whether to reject or accept the project. The economic adequacy is known if the estimated value is higher or lower than the breakeven point.

3.7 Project Gantt Chart

Figure 3.2 and 3.3 show the Gantt chart for FYP 1 and FYP 2 respectively.

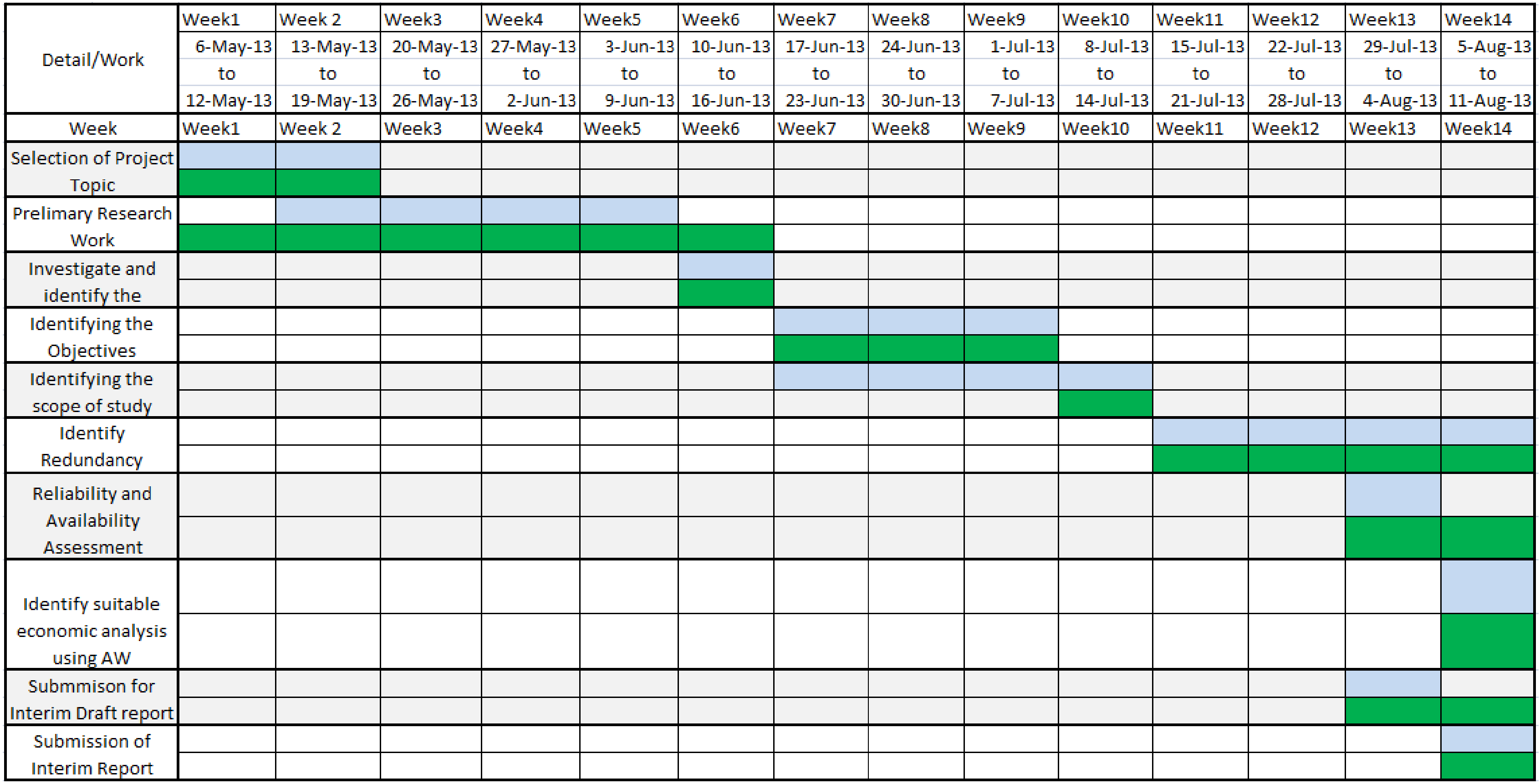


Figure 3.2: Final year project 1 Gantt chart

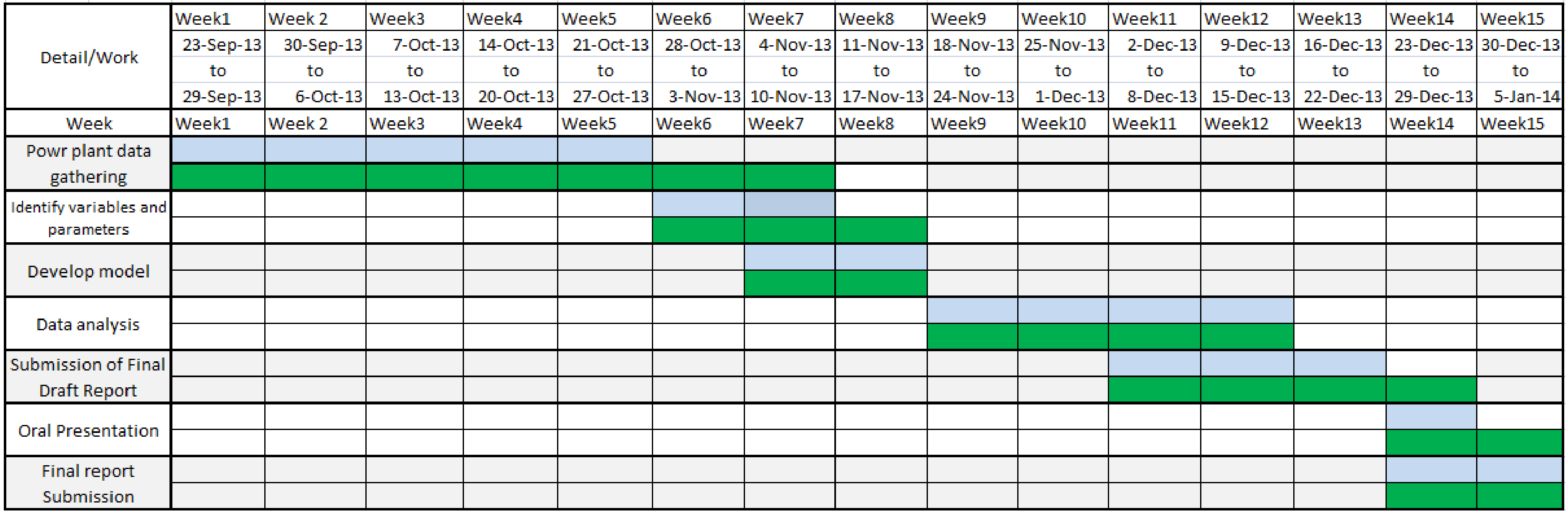


Figure 3.4: Final year project 2 Gantt chart

This project was divided into two sections which are FYP 1 and FYP 2. There were ten activities in FYP 1 and seven activities in FYP 2. The achieved activities were relevant to the objective of the study that is to develop redundancy model for cogeneration plant. Recommendations were also identified in FYP 2. In conclusion, this study can be achieved within the time given and Gantt charts provide guideline to execute the planned activities.

CHAPTER 4

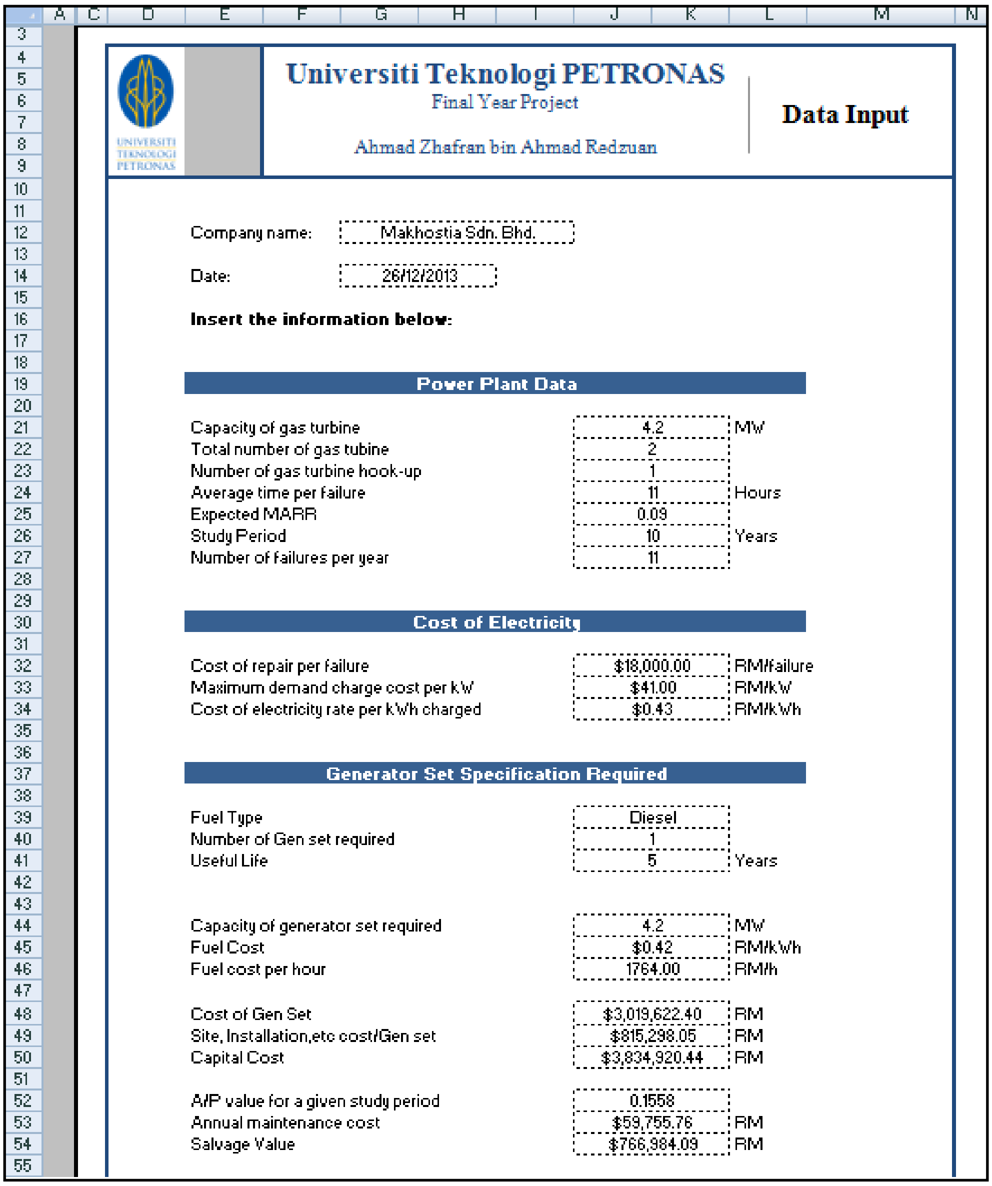
RESULTS AND DISCUSSION

4.1 Introduction

In this chapter, the results of gas turbine performance of power plant and economic evaluation of cogeneration system were presented. UTP-GDC power plant was taken as case study for this project to evaluate the availability, reliability and economic impact caused by failure. From the case study, the cogeneration system availability, reliability, numbers of failure and downtime hours were obtained. Reliability with and without redundancy were also discussed in this section. Other than that, selection of suitable generator set was performed using weighted score matrix. The highest score option was selected as the alternative for cogeneration system. Next, the economic impacts of failure were estimated. Using present worth and future worth analysis, different redundancy options were evaluated. Ahead of that, cost estimation of gen set were carried out using case study by Electric Power Research Institute since the gen set cost varies from different manufacturers. The results of PW and FW were also analyzed using sensitivity analysis and breakeven analysis. Excel software was used to give graphical presentation of data and graphs.

4.2 Spreadsheet

A spreadsheet template was developed to calculate the cost incurred by public utility and generator set as well as determined the annual worth of both alternatives. This template can also be used to decide which alternative is the best by using breakeven analysis with the aid of breakeven graph. Analysis of redundancy of any power plant below 10MW capacity can be carried out by using this spreadsheet template. The plant capacity, number of failures per year and average time per failure must be determined first before using this template. Sample of spreadsheet template is shown in Figure 4.1.


Universiti Teknologi PETRONAS
Final Year Project
Ahmad Zhafran bin Ahmad Redzuan
Data Input

Company name: Makhostia Sdn. Bhd.
Date: 26/12/2013
Insert the information below:

Power Plant Data

Capacity of gas turbine	4.2	MW
Total number of gas tubine	2	
Number of gas turbine hook-up	1	
Average time per failure	11	Hours
Expected MARR	0.09	
Study Period	10	Years
Number of failures per year	11	

Cost of Electricity

Cost of repair per failure	$18,000.00	RM/failure
Maximum demand charge cost per kW	$41.00	RM/kW
Cost of electricity rate per kWh charged	$0.43	RM/kWh

Generator Set Specification Required

Fuel Type	Diesel	
Number of Gen set required	1	
Useful Life	5	Years
Capacity of generator set required	4.2	MW
Fuel Cost	$0.42	RM/kWh
Fuel cost per hour	1764.00	RM/h
Cost of Gen Set	$3,019,622.40	RM
Site, Installation,etc cost/Gen set	$815,298.05	RM
Capital Cost	$3,834,920.44	RM
A/P value for a given study period	0.1558	
Annual maintenance cost	$59,755.76	RM
Salvage Value	$766,984.09	RM

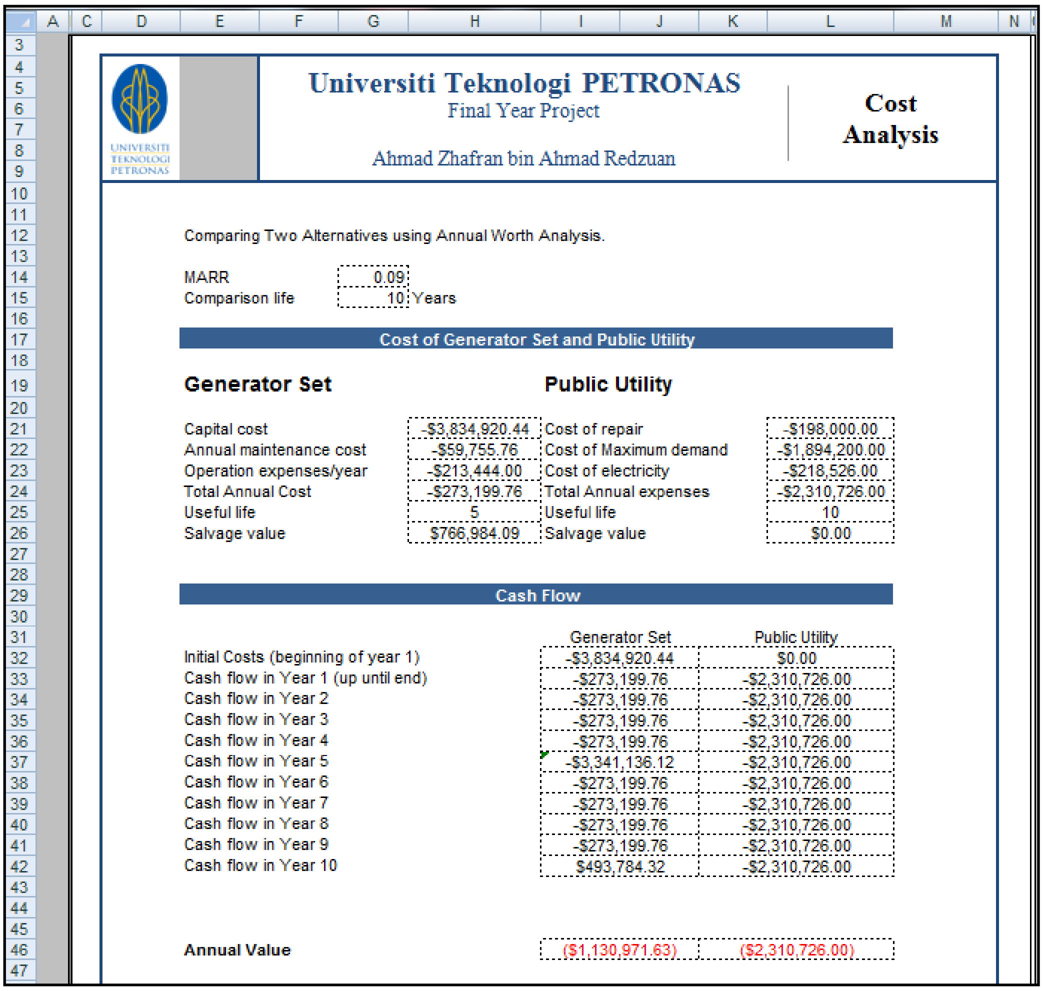
Figure 4.1: Snapshot of data input section

Table 4.1: List of variables and formula for data input

	E	J
46	Fuel cost per hour	=J45*(J44*1000)
48	Cost of Gen set	=-181753.491-(173855.265*(J40))+(803626.465*(J44))
49	Site, Installation,etc cost/Gen set	=0.27*J48

50	Capital Cost	=J48+J49
52	A/P value for a given study period	=LOOKUP(J26,'compound interest factor tables'!A4:A41,'compound interest factor tables'!E4:E41)
53	Annual maintenance cost	=0.1*J50*J52*J40
54	Salvage Value	=0.2*J50

Below is the sample of cost analysis spreadsheet shown by Figure 4.2 and the list of variables with formula shown in Table 4.2.


Universiti Teknologi PETRONAS
Final Year Project
Ahmad Zhafran bin Ahmad Redzuan
Cost Analysis

Comparing Two Alternatives using Annual Worth Analysis.

MARR	0.09	
Comparison life	10	Years

Cost of Generator Set and Public Utility

Generator Set		Public Utility	
Capital cost	-$3,834,920.44	Cost of repair	-$198,000.00
Annual maintenance cost	-$59,755.76	Cost of Maximum demand	-$1,894,200.00
Operation expenses/year	-$213,444.00	Cost of electricity	-$218,526.00
Total Annual Cost	-$273,199.76	Total Annual expenses	-$2,310,726.00
Useful life	5	Useful life	10
Salvage value	$766,984.09	Salvage value	$0.00

Cash Flow

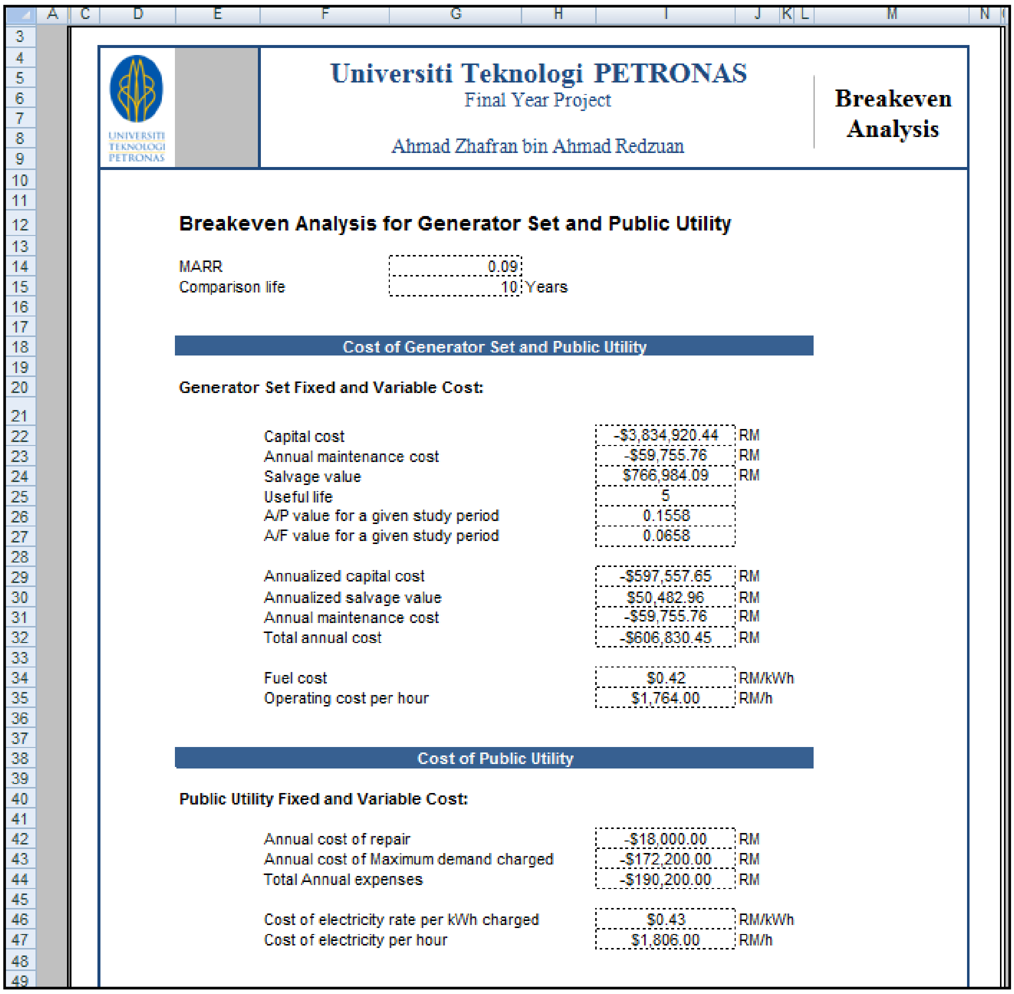
	Generator Set	Public Utility
Initial Costs (beginning of year 1)	-$3,834,920.44	$0.00
Cash flow in Year 1 (up until end)	-$273,199.76	-$2,310,726.00
Cash flow in Year 2	-$273,199.76	-$2,310,726.00
Cash flow in Year 3	-$273,199.76	-$2,310,726.00
Cash flow in Year 4	-$273,199.76	-$2,310,726.00
Cash flow in Year 5	-$3,341,136.12	-$2,310,726.00
Cash flow in Year 6	-$273,199.76	-$2,310,726.00
Cash flow in Year 7	-$273,199.76	-$2,310,726.00
Cash flow in Year 8	-$273,199.76	-$2,310,726.00
Cash flow in Year 9	-$273,199.76	-$2,310,726.00
Cash flow in Year 10	$493,784.32	-$2,310,726.00
Annual Value	($1,130,971.63)	($2,310,726.00)

Figure 4.2: Snapshot of cost analysis section

Table 4.2: List of variables and formula for cost analysis

	E	H
23	Operation expenses/year	=-(Input!J27*Input!J45*Input!J44*1000*Input!J24*(Input!J23/Input!J22)*Input!J22)
24	Total Annual Cost	=H22+H23
	I	L
22	Cost of Maximum demand	=-(Input!J27*Input!J33*(Input!J44*1000)*(Input!J23/Input!J22)*Input!J22)
23	Cost of electricity	=-(Input!J27*Input!J24*Input!J34*(Input!J44*1000)*(Input!J23/Input!J22)*Input!J22)
24	Total Annual expenses	=L21+L22+L23
	E	I
37	Cash flow in Year 5	=H21+H24+H26
42	Cash flow in Year 10	=H24+H26
46	Annual Value	=PMT(G14,G15,-(I32+NPV(G14,I33:J42)))
	E	K
46	Annual Value	=PMT(G14,G15,-(K32+NPV(G14,K33:L42)))

Next is the spreadsheet template for breakeven analysis which is shown in Figure 4.3. The data from breakeven analysis will be used to generate graph in order to determine breakeven point. Alternative with lower annual cost will be selected as the best alternative for this project.


Universiti Teknologi PETRONAS
Final Year Project
Ahmad Zhafran bin Ahmad Redzuan
Breakeven Analysis

Breakeven Analysis for Generator Set and Public Utility

MARR	0.09	
Comparison life	10	Years

Cost of Generator Set and Public Utility

Generator Set Fixed and Variable Cost:

Capital cost	-$3,834,920.44	RM
Annual maintenance cost	-$59,755.76	RM
Salvage value	$766,984.09	RM
Useful life	5	
A/P value for a given study period	0.1558	
A/F value for a given study period	0.0658	
Annualized capital cost	-$597,557.65	RM
Annualized salvage value	$50,482.96	RM
Annual maintenance cost	-$59,755.76	RM
Total annual cost	-$606,830.45	RM
Fuel cost	$0.42	RM/kWh
Operating cost per hour	$1,764.00	RM/h

Cost of Public Utility

Public Utility Fixed and Variable Cost:

Annual cost of repair	-$18,000.00	RM
Annual cost of Maximum demand charged	-$172,200.00	RM
Total Annual expenses	-$190,200.00	RM
Cost of electricity rate per kWh charged	$0.43	RM/kWh
Cost of electricity per hour	$1,806.00	RM/h

Figure 4.3: Snapshot of breakeven analysis section

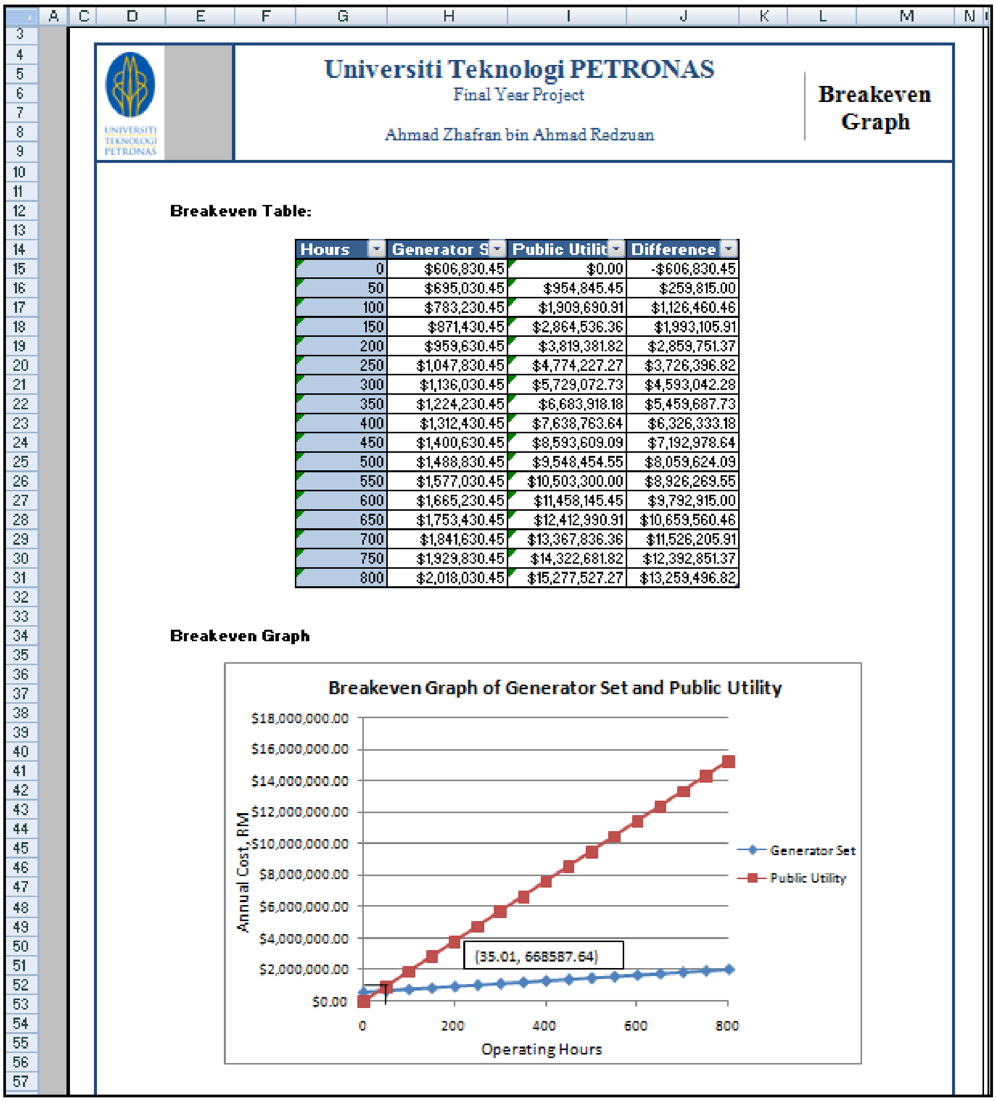
List of variables and formula for breakeven analysis were shown below in Table 4.3.

Table 4.3: List of variables and formula for breakeven analysis

	F	I
29	Annualized capital cost	=I22*I26
30	Annualized salvage value	=I24*I27
32	Total annual cost	=I29+I30+I31
35	Operating cost per hour	=I34*Input!J44*1000*(Input!J23/Input!J22)*Input!J22

44	Total Annual expenses	=I42+I43
47	Cost of electricity per hour	=I46*Input!J21*1000*(Input!J23/Input!J22)*Input!J22

Lastly, the data calculated from breakeven analysis section will be used to generate breakeven graph.



Hours	Generator S	Public Utilit	Difference
0	$606,830.45	$0.00	-$606,830.45
50	$695,030.45	$954,845.45	$259,815.00
100	$783,230.45	$1,909,690.91	$1,126,460.46
150	$871,430.45	$2,864,536.36	$1,993,105.91
200	$959,630.45	$3,819,381.82	$2,859,751.37
250	$1,047,830.45	$4,774,227.27	$3,726,396.82
300	$1,136,030.45	$5,729,072.73	$4,593,042.28
350	$1,224,230.45	$6,683,918.18	$5,459,687.73
400	$1,312,430.45	$7,638,763.64	$6,326,333.18
450	$1,400,630.45	$8,593,609.09	$7,192,978.64
500	$1,488,830.45	$9,548,454.55	$8,059,624.09
550	$1,577,030.45	$10,503,300.00	$8,926,269.55
600	$1,665,230.45	$11,458,145.45	$9,792,915.00
650	$1,753,430.45	$12,412,990.91	$10,659,560.46
700	$1,841,630.45	$13,367,836.36	$11,526,205.91
750	$1,929,830.45	$14,322,681.82	$12,392,851.37
800	$2,018,030.45	$15,277,527.27	$13,259,496.82

Figure 4.4: Snapshot of breakeven graph section

Table 4.4: List of variables and formula for breakeven graph

	G	H
15	0	=-('Breakeven Analysis'!$I$32+(-('Breakeven Analysis'!$I$35)*'Breakeven Graph'!G15))
	G	I
15	50	=-(('Breakeven Analysis'!$I$44*Table1[[#This Row],[Hours]]/11)+(-('Breakeven Analysis'!$I$47)*'Breakeven Graph'!G16))
	G	J
15	0	=Table1[[#This Row],[Public Utility]]-Table1[[#This Row],[Generator Set]]

4.3 Case Study

In this study, UTP-GDC plant selected as case study to evaluate the performance of power generation. It was selected due to its location and accessibility of data required for this study. Other than that, UTP-GDC plant still relies on electrical power from national grid during plant failure which makes it a fine subject to study.

The construction phase of UTP-GDC plant was started in 2001 and started its operation for supply of chilled water and electricity to UTP campus in April 2003. This power plant was build due to the quality of available electrical power from power distribution plant was not able to meet the university requirements. The plant is able to produce 4000 RT of chilled water and 8.4 MW of electrical power. It is predicted that the production of UTP-GDC plant will increased to 11,000 RT and 20 MW in the future to meet the increasing population and demand of this university. Figure 4.5 showed the plant configuration.

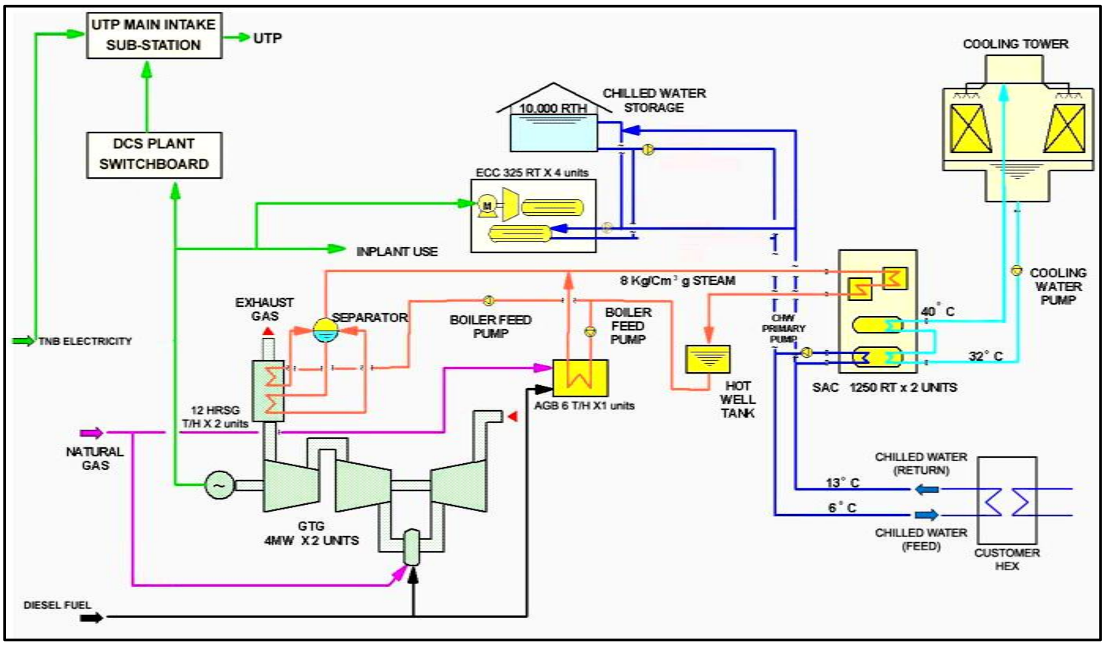


Figure 4.5: UTP-GDC plant layout [23]

For electrical power generation, the plant used two units of 4.2 MW Solar gas turbine generators. Connection to national grid is available as redundancy during plant failure. Each of the turbines is connected to a Vickers heat recovery steam generators. The heat recovery steam generators produce steam to be used by steam absorption chillers. Auxiliary fire tubes gas boiler act as backup for the steam generators. The chilled water supply system consists of two units of steam absorption chillers. There are two direct fired chillers which act as backups during plant startup. Table 4.5 showed the list of major equipment in UTP-GDC plant. This plant was operated for 24 hours per day and designed to be working on with two turbines during peak period and with one turbine at night.

Table 4.5: UTP-GDC plant major equipments

<table>
<tr><th colspan="3">Universiti Teknologi PETRONAS Plant System</th></tr>
<tr><td colspan="2">Plant installed Capacity:
Electricity: 8.4 MW
Chilled Water: 4,000 Rt</td><td></td></tr>
<tr><th>Equipment</th><th>Quantity</th><th>Description</th></tr>
<tr><td>Gas Turbine Generators</td><td>2</td><td>4.2 MW Solar Taurus 60S</td></tr>
<tr><td>Steam Generators</td><td>2</td><td>12 ton/hr Vickers Heat Recovery Steam Generator</td></tr>
<tr><td></td><td>1</td><td>6 ton/hr Vickers Auxiliary Gas Boiler</td></tr>
<tr><td>Chilled Water</td><td>4</td><td>325 RT Dunham Bush Electric Air-Cooled Chillers</td></tr>
<tr><td></td><td>2</td><td>1250 RT Ebara Steam Absorption Chillers</td></tr>
<tr><td>Thermal Storage</td><td>1</td><td>10,000 Rth thermal storage tank</td></tr>
</table>

In order to enhance the performance and reduce economical loss of the plant, it is important to analyze the performance of the plant as well as comparing the existing system with other alternative. UTP-GDC plant can be classified into two main systems which are power generation system and chilled water system. However, in this study, the author only analyzes the power generation system (PGS) since it depends on external electrical power supply during failure. Chilled water system on the other hand had internal backup which are direct fired chillers. The use of electrical power from external source do has an impact on the economical loss of power plant. Thus, it is essential to study the power generation system of UTP-GDC plant to enhance performance and reduce economical loss.

4.4 UTP-GDC Power Generation System (PGS)

Before analyze the performance of power generation system, the author described the system configuration with the help of block diagram. In the case of UTP-GDC, the power generation system depends on two parallel gas turbine generators. Failure of one of the generators will results in reduced electrical power being generated. For worst case scenario, if both gas turbine generators cannot be operated, then no power supplied to the customers. During failure, UTP-GDC plant will purchase electricity from national grid. This practice does not benefit this plant due to high cost of maximum demand charge imposed by TNB. The power generation system configuration is as below

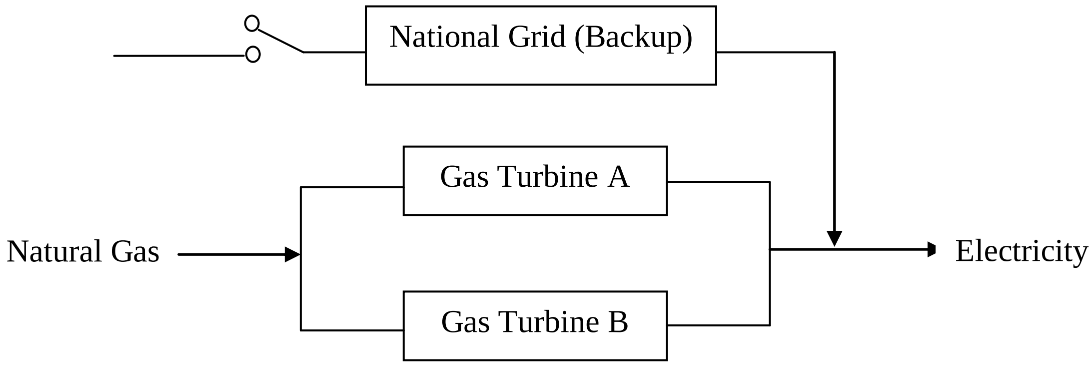


Figure 4.6: Power generation system block diagram

4.5 Power Generation System (PGS) Performance Data

In this study, in order to determine the performance of PGS of UTP-GDC, historical performance data of gas turbines were collected in the period of 2007 to 2011. The samples were presented in appendix. The data collected were taken 23 hours per day during the peak and non-peak period. In order to find optimal cluster group or state for the gas turbines, subtractive data clustering was employed.

This method was done by Meseret Nasir [23] in 2012 for his PhD thesis in UTP. According to him, to prevent closely spaced center, r_b is set greater than r_a in which r_a= 1.5r_b. The result indicated that the gas turbine performance can be categorized into three levels which are normal operating, reduced capacity and zero performance levels. The centriod as well as upper and low boundaries for each level were presented in Table 4.6.

Table 4.6: Performance level of UTP-GDC PGS [23]

Performance Level	Centriod (kW)	Boundary	
		Upper (kW)	Lower (kW)
Normal Operating	3297	4200	2851
Reduced Capacity	2571	2851	1497
Zero performance	0	1497	0

From Table 4.6, the condition for normal operating performance is between 4200 kW and 2851 kW. In this level, the gas turbine is expected to be working at normal condition until maximum performance without fail. If the performance drops in the range of 1497 kW until 2851 kW, the turbine experience reduced capacity due to minor failure in the system. This level is not critical since it can be restored back into normal operating level by performing minor maintenance or repair. Lastly, when the performance of gas turbine drops to 1497 kW and below, it is consider as zero performance. This is because, at performance of 1497 kW and below, gas turbine will be shut down as it is not efficient and will cause economic loss to the power plant if it continues to operate.

As seen on Table 4.6, the centriod of zero performance level is equal to zero since no gas turbine is working at this stage. Gas turbine performance can be restored back to its normal operating condition by major repair. During the repair phase, power generation system of UTP-GDC plant will relies on national grid to supply electrical power in order to meet customers demand. The performance of gas turbine for five years during peak period from 10 am until 5 pm is shown in Figure 4.7 below.

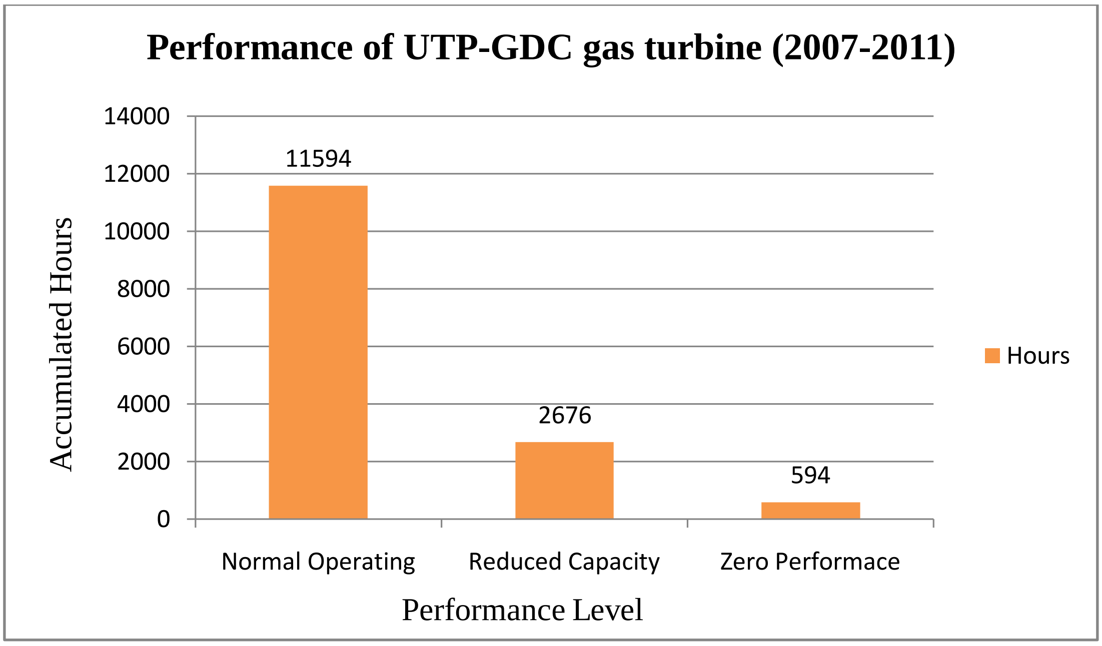


Figure 4.7: Performance of UTP-GDC gas turbine from 2007 until 2011

The results of five year performance data of gas turbine during peak period of 8 hours form 10am until 5 pm showed that for normal operating level, it is observe that 11594 hours reside in this state. Next, 2676 hours in reduced capacity level and 594 hours in zero performance level. The numbers of occurrence of zero performance were 54 in 5 year period. The normal operating level take 78% of total accumulated hours, followed by 18% for reduced capacity and 4% of zero performance level. This data showed only 4% of the total time that the power plant experienced major failure and insufficient electrical power. Thus, the average time in which UTP-GDC plant purchased electricity from national grid is 118.8 hours for every year.

4.6 Availability and Reliability

After the data for PGS of UTP-GDC plant was collected, it was analyzed using availability and reliability analysis. Before calculating MTBF and MTTR, failure rate and repair rate were calculated using equation (2.1) and equation (2.7). The result is given by

Failure rate, $\lambda = \frac{594}{14864}$

$$= 0.00123 \; failures/year$$

Repair rate, $\mu = \frac{54}{594}$

$$= 0.09091 \; repairs/year$$

Mean Time before Failure (MTBF) and Mean Time to Repair (MTTR) were then calculated from the results of failure rate and repair rate. After determining the MTBF and MTTR, the author then proceeds with availability and reliability of PGS of UTP-GDC plant. The results are tabulated in Table 4.7.

Table 4.7: MTBF, MTTR, availability and reliability of UTP-GDC plant

Mean Time before Failure (MTBF)	Mean Time to Repair (MTTR)	Availability	Reliability
811.111 hours	11 hours	0.98662	0.9865

From the result, the time taken for a failure to occur is 811.111 hours and the time taken to fix the problem is 11 hours per failure. The occurrence of failure is high due to long operation hour in a year. Gas turbines of UTP-GDC plant operate for 24 hours with both turbines working during the day especially at peak period and one turbine working at night. This operation caused several parts to wear faster and thus causing failure to the system.

The time taken to fix each failure was predicted to be 11 hours. In order to repair the gas turbine, extensive time is needed since the failure considered for zero performance phase was major failure. Other than that, the availability of power generation system is 0.98662 which is high since it is more than 0.95 which was set as the benchmark for reliability of UTP-GDC power plant. The availability is high due to redundancy from national grid. Next, the reliability of power plant was calculated to be 0.9798 for 100 hours of operating. The reliability of PGS is decreasing with time as shown in Figure 4.8. The failure free operation is approaching zero after 4300 operating hours. Hence, after 4300 operating hours the probability of failure occurrence is very high for this system. Thus it is required to focus more on maintenance work when operating at longer period since failure can occur at any time.

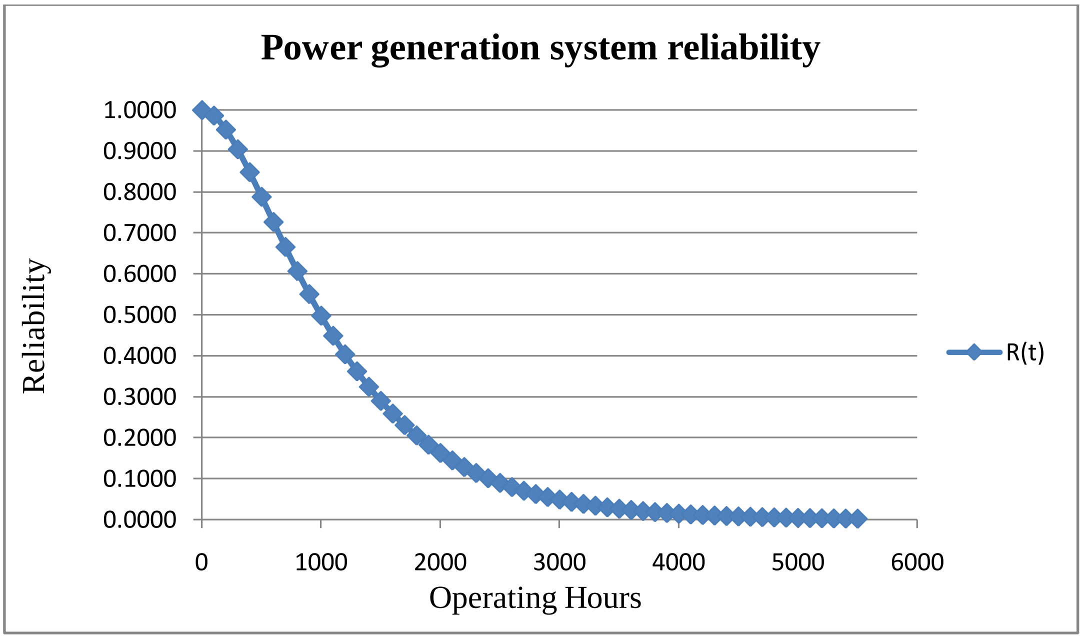


Figure 4.8: UTP-GDC power generation system reliability

4.5.1 Reliability with and without redundancy

As stated previously, the reliability of PGS decreasing with time. The reliability for this plant is high because of redundancy from national grid. In order to replace the existing redundancy with other alternative, the reliability of the new system must be more or the same as previous method. Higher reliability of system requires less maintenance and repair since it has lower probability of failure. The Unplanned Outage Factor (EUOF) of TNB from 2006 to 2010 was reported to be 0.33 [24]. The generator set on the other hand is claimed to be working approximately 99.67 to 99.99 percent annually by MTU Onsite Energy Corp. [25]. National grid and generator set has more or less the same system since both apply N+1 system design. Using this system, the generator set will start and run when intended. The generator set start when there is an interruption in the power generation system. After a time, when the PGS run normally, generator set will shut down. The reliability of PGS without redundancy, with national grid redundancy and with gen set redundancy was expressed in Figure 4.9.

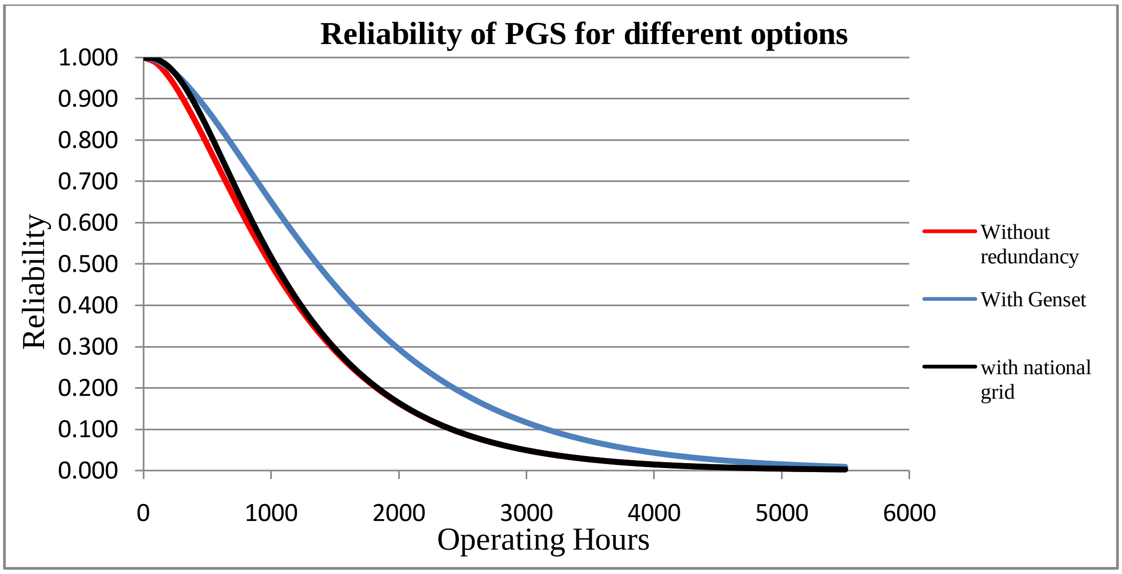


Figure 4.9: Power generation system reliability comparison

4.7 Estimation of Gen Set Cost

As discussed in the methodology chapter, the cost of gen set varies from different manufacturers and service providers. Thus, in this study cost estimating relationship (CER) was employed in order to solve this problem. The CER described the cost of an engineering project as a function of one or more variables. Case study from Electric Power Research Institute which entitled 'Costs of Utility Distributed Generators, 1-10 MW [21] was used since there was no complete case study of Malaysia's cost of generator available. In this report, a range of total installed cost and variables influencing cost were included. Table 4.8 below shows the summary of cases overview.

Table 4.8: Cases overview

Utility	Utility Type	No. of Gen sets	Site Capacity (MW)	New or Used	Average Warranties (years)	Fuel Type	Cost of Gen sets (RM)
Anonymous Utility A	C	3	3.1	Mx	1	D	1,793,942
Anonymous Utility B	PP	2	3.6	New	2	D	2,124,371
Anonymous Utility C	PP	3	5.5	New	10	D	3,433,490
Anonymous Utility D	PP	1	1.825	New	10	D	1,162,800

Central Virginia EC	C	10	18.2	New	n/a	D	13,672,913
City of Fennimore	PP	3	5.5	New	n/a	D	2,727,722
City of Garnett	PP	1	2.5	Used	3	D	2,254,217
City of New Knoxville	PP	1	1	Used	0	D	717,383
City of Owensville	PP	2	3.6	New	5	D	4,167,346
City of Rock Falls	PP	5	9.1	New	12	D	6,284,288
City of Wrangell	PP	3	5.5	Used	0	D	3,204,806
East of Mississippi (Canton)	C	5	9.1	New	10	D	6,164,455
East of Mississippi (Henderson)	C	5	9.1	New	10	D	5,835,318
East of Mississippi (Perry Davis)	C	5	9.1	New	10	D	6,974,216
South Plains EC	C	1	1.6	Used	0	D	561,051
Waverly Power & Light	PP	6	11	New	5	D	6,107,930

n/a- information not available or insufficient quality
Utility Type: C – Coop, PP – Public Power
Fuel Type: D - Diesel

Table above showed 16 case studies from different areas in America. All the generators in the cases are diesel-fueled engines. The generators are between 1 to 10 MW except for the case for Central Virginia EC and Waverly Power & Light. Most of the gen sets were newly installed which is suitable to be implemented in this study since the author assumed that new gen set will be installed for this project. As shown in the table, the highest cost is RM 13,672,913 and the lowest is RM 561,051. Number of installed gen sets and site capacity differ for each case depending on the needs of the area. Public power utility dominates the coop utility for this research.

4.7.1 CER equation development

After the data had been collected, the author then developed the CER equation for single variable regression using linear and exponential type of relationship and two variables regression model using SigmaPlot 11.0 software. In the case of single variable regression model, the relationship between cost of gen sets and project size was studied.

On the other hand, for two variables regression model, number of gen sets and project size were taken as the variables to determine the cost of gen sets. A linear and exponential regression trend line were created and superimposed on the data. Figure 4.10 and 4.11 both show the relationship of CER for cost of gen sets with project size (MW). The equation and r square function were tabulated in Table 4.9

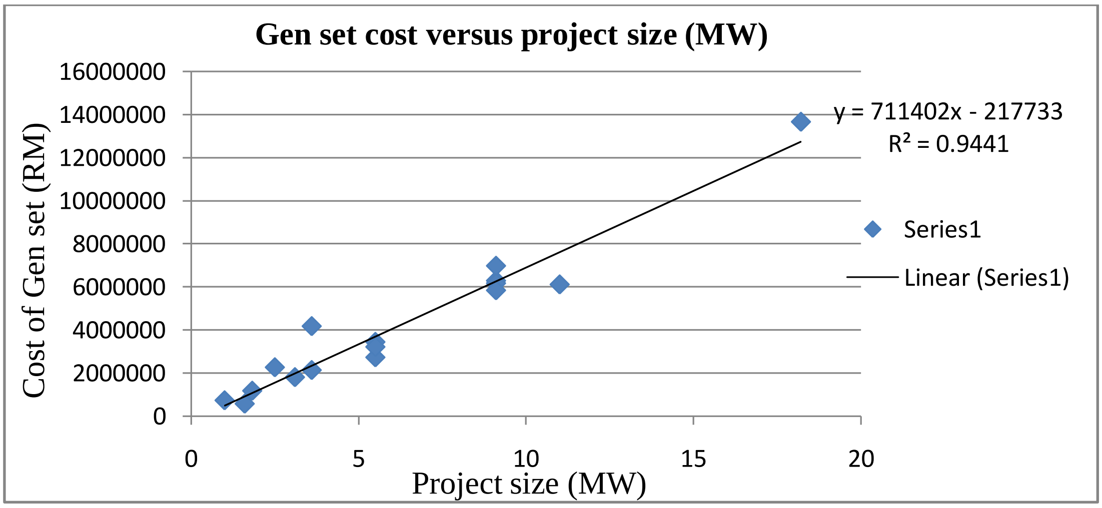


Figure 4.10: Linear single regression model of gen set cost versus project size

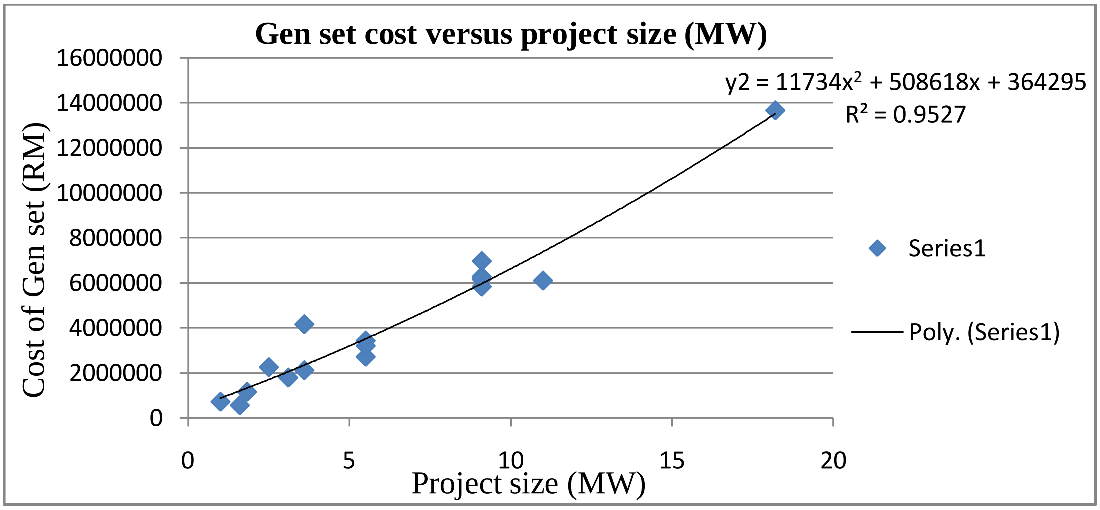


Figure 4.11: Exponential single regression model of gen set cost versus project size

Table 4.9: Generalized equation and r square for CER

Single/ Two variable	Type of relationship	Generalized equation	R square
Single	Linear	y_1 = 711402(Project Size(MW)) – 217733	0.9441
	Exponential	y_2 = 17734 (Project Size (MW))^2 + 508618 (Project Size (MW)) + 364295	0.9527
Two	Linear	y_3 = -181753.491 - (173855.265(Number of Gen set) + (803626.465(Project Size(MW)))	0.944

The results in Figure 4.10 and 4.11 showed the costs of gen set which were above and below the normal level. All the generalized equations were acceptable since the r square of all equations greater than 0.94 which was set as the benchmark. From the analysis of the graph, it can be observed that certain data can be considered as unreliable as it does not follow the pattern. These case studies have percentage error greater than 25% which are very high. Those case studies include city of Fennimore, city of Garnett, city of Knoxville, city of Owensville and South Plains EC with the highest percentage error of 65.79% recorded by South Plains EC. These five case studies were deviated from the normal level of gen set cost as a result of projects were completed in a hurry. Thus, the cost increased dramatically as per agreed by the plant management to complete the installation faster. Next, in order to select the best CER equation, the three generalized equations were compared with the actual cost and model with the least percentage error was selected.

Table 4.10: Percentage error of regression model

Utility	y1	% Error	y2	% Error	y3	% Error
Anonymous Utility A	1987613.2	10.80	2053774.54	14.48	1787922.76	0.34
Anonymous Utility B	2343314.2	10.31	2347392.44	10.50	2363591.25	11.26
Anonymous Utility C	3694978	7.62	3516647.50	2.42	3716626.27	8.25
Anonymous Utility D	1080575.65	7.07	1331604.40	14.52	1111009.54	4.45
Central Virginia EC	12729783.4	6.90	13507912.76	1.21	12705695.52	7.07
City of Rock Falls	6256025.2	0.45	5964411.34	5.09	6261971.02	0.36
City of Wrangell	3694978	15.29	3516647.50	9.73	3716626.27	15.97
East Mississippi (C)	6256025.2	1.49	5964411.34	3.25	6261971.02	1.58
East Mississippi (H)	6256025.2	7.21	5964411.34	2.21	6261971.02	7.31
East Mississippi (P)	6256025.2	10.30	5964411.34	14.48	6261971.02	10.21
Waverly Power & Light	7607689	24.55	7378907.00	20.81	7615006.03	24.67
Average Error %		**9.27**		**8.97**		**8.31**

The results obtained satisfied the requirement of this project which is less than 10% error. The highest recorded percentage error is 24.67% by Waverly Power & Light whereas the lowest is 0.34% by anonymous utility A. The two variables regression model has the lowest percentage of error compared to both single variable regression models. The error of two variables regression model is the lowest as it used more variables than the other models and thus produce more accurate results.

4.8 Evaluation of Failure Consequences of PGS

4.8.1 Annual worth

A failure in the PGS causes the unit to be shutdown and thus cannot continue to operate. Failure can decrease the plant capability and hence affect the availability and reliability. It is important to have high availability and reliability since it affect the safety and cost of electricity generation. The failure cost is highly dependent on the frequency of failure and total number of downtime. The annual worth was used to measure the impact of failure on power generation system. All the cost incurred by UTP-GDC plant was tabulated in Table 4.11.

Table 4.11: Cost of failure per year for UTP-GDC plant

Cost of Repair (RM)	**Cost of Maximum Demand (RM)**	**Cost of Electricity (RM)**
198,000	1,894,200	218,526
Annual Worth (RM)	2,310,726	

As shown in Table 4.11, the annual value for 10 years of failure assuming that the tariff price does not change and the failure rate is constant for period of 10 years is RM 2,310,726.00. The distribution of each failure is presented in Figure 4.8. The cost of maximum demand charge contribute to 82% of the total cost of failure, 9% was the cost of electricity and 9% was the cost of repair. This concludes that the penalty imposed to power plant affect the greatest during failure. In order to reduce the cost of maximum demand charge, number of failures should be reduced by increasing availability and reliability of the system.

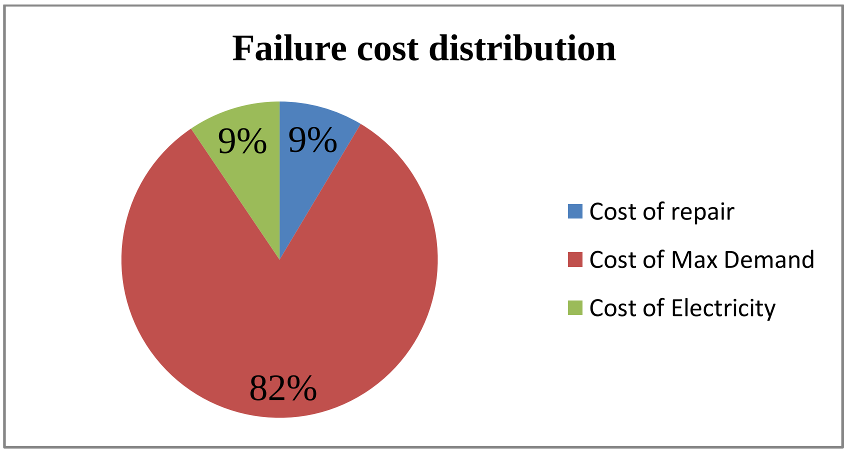


Figure 4.12: Failure cost distribution for public utility

Table 4.12: Cost of Gen set

Annualized capital cost (RM)	Cost of annual maintenance (RM)	Annual cost of Operation (RM)	Annualized salvage value (RM)
595,922.60	59,755.76	213,444	50,467.55
Annual Worth (RM)	1,130,971.63		

The annual worth of every year was calculated as RM 1,130,971.63 as per Table 4.12. Figure 4.13 showed the distribution of every cost present for the gen set. The highest cost was contributed by capital cost which takes up to 69% of the total cost. Next is cost of operation with 24% and lastly 7% is due to cost of maintenance. Annual worth of gen set is lesser than public utility. The difference between annual worth is RM 1,179,754.37. Hence by changing the redundancy of PGS, UTP-GDC plant can save an amount of RM 1,179,754.37every year.

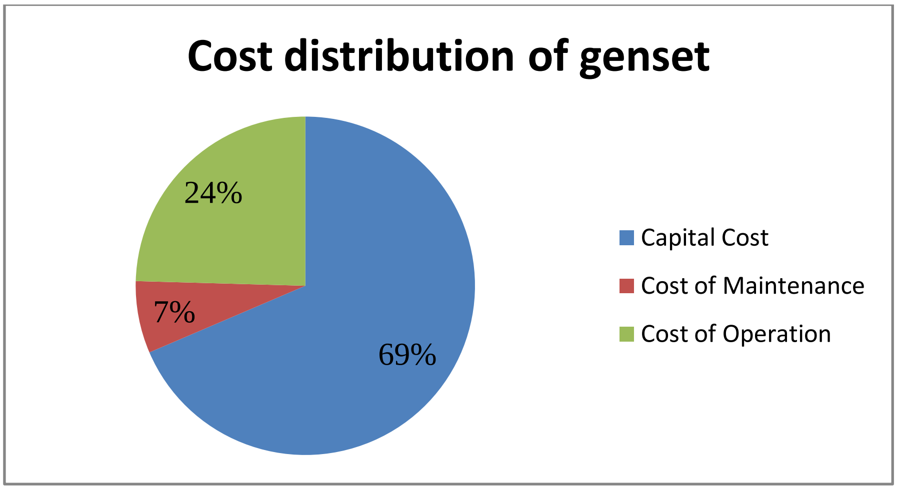


Figure 4.13: Cost distribution of gen set

4.8.2 Breakeven analysis

The next step the author applied in this study to select the best solution for redundancy of power generation system of UTP-GDC plant was by using breakeven analysis. In order to select either national grid or generator set redundancy, it is important to evaluate the effect of each redundancy. To evaluate the redundancies, the operating hours in a year factor was used. Figure 4.14 showed the annual cost of public utility and generator set with respect to operating hours. As observed, the cost of generator set is lower than public utility after 35.01 hours of operation. The breakeven point was determined at 35.01 hours with annual cost of RM 668,587.64. The decision of redundancy was based on the number of operating hours of the plant. In the case of operating hours less than 35.01 hours, the public utility is chosen as redundancy. On the other hand, if it is greater than 35.01 hours, generator set is a better alternative. Since the operating hours of UTP-GDC was 121 hours, hence generator set is a better option as redundancy for power generation system.

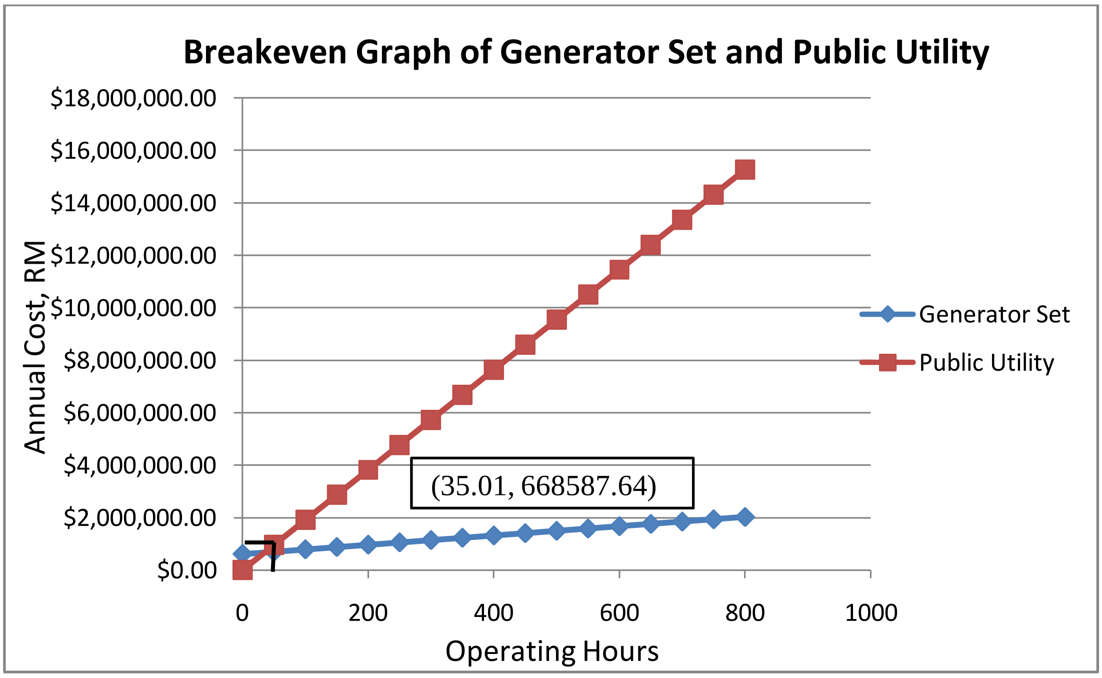


Figure 4.14: Breakeven analysis of public utility and generator set

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The results of this study show that the most appropriate redundancy for power generation system of small cogeneration plant is generator set. The developed models presented in this thesis provide useful tool in making decisions for redundancy. The conclusion if this project is as below:

- The methodology of this project was developed by considering the small cogeneration plant case. Collected data of failure and downtime hours were used in the calculation annual worth. Availability and reliability of the plant were studied to determine the plant performance. The results were compared with the reliability of generator set to prove that the reliability of the plant can be further enhanced.
- The redundancy models were developed for public utility and generator set. Two models were developed as the factors were different from each other. The case study shows that 82 % of total annual cost during failure for public utility comes from cost of maximum demand charge and 69% of total generator set annual cost is capital cost.
- The effect of annual worth of public utility and generator set with respect to operating hours were determined by using breakeven analysis. The result of this study shows that the breakeven point is 35.01 hours with annual cost of RM 668,587.64. The annual cost of generator set increased slower than public utility. This is due to high cost of maximum demand charge and higher cost of operation compared to generator set. Based on this study, the gen set alternative is a better option compared to public utility.

5.2 Recommendation

- This study can be extended by taking into account the failure occur due to aging of equipment. Model of aging components can be developed to predict failure rate and downtime hours of the system.
- The redundancy model can be improved by using power plant data from Malaysia. Hence a more accurate cost of generator set can be applied for the case of small power plant in Malaysia. Other than that, detailed cost of operation and personnel can e include.
- The effect of inflation and economic instability can be studied to improve the accuracy of redundancy model.

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APPENDIX

SAMPLE PERFORMANCE DATA FROM 2007 TO 2011

UNIVERSITI TEKNOLOGI PETRONAS
DCS/COGEN PLANT
DAILY REPORT

GAS DISTRICT COOLING (UTP)

							MAX	MIN		
	DATE:	16-Mar-07	TEMP.	27.8	DEG C		36.6	23.7		
			HUMD.	86.4	RH %		104.9	50.6		
	GT-A	GT-B	SAC A	SAC-B	HRSG	EC-A	EC-B	EC-C	EC-D	TES
HOUR	POWER IN kWH		HEAT SUMMATION (RT)		STEAM (KG)	HEAT SUMMATION (RT)				TES HOLDING CAL(RT)
0:00	452	3060	0	0	0	263	224	150	270	292
1:00	0	3410	0	0	0	265	246	128	288	914
2:00	0	3332	0	0	0	265	250	216	291	2317
3:00	0	3316	0	0	0	264	249	267	271	3161
4:00	0	3268	0	0	0	250	246	266	269	4917
5:00	0	3220	0	0	0	0	217	5	261	5522
6:00	382	2572	160	0	1131	0	203	0	245	5876
7:00	2165	2179	768	224	4315	0	219	0	216	6217
8:00	2712	2694	1058	945	5629	0	4	0	0	5355
9:00	2758	2743	1076	1060	5500	0	0	0	0	3794
10:00	2809	2819	1070	1068	5425	0	0	0	0	2973
11:00	2871	2890	1067	1061	5389	0	0	0	0	1446
12:00	2874	2892	1067	1064	5385	0	0	0	0	916
13:00	2817	2833	1074	1060	5438	0	0	0	0	0
14:00	2789	2787	1047	1042	5358	0	0	0	0	0
15:00	2731	2739	1066	1057	5387	0	0	0	0	0
16:00	2806	2816	1079	1081	5434	1	0	0	0	0
17:00	2801	2806	1093	1101	5513	204	121	144	0	0
18:00	2785	2781	1113	1119	5572	272	259	270	166	0
19:00	2550	2555	335	904	1024	273	257	270	308	0
20:00	2481	2500	0	1056	0	273	256	270	306	0
21:00	2466	2484	0	1118	0	272	257	270	307	0
22:00	2225	2235	0	403	0	270	255	268	305	0
23:00	1817	1820	0	0	0	259	214	257	260	146
AVERAGE	2781	2781	545	640.17	2891.41		145	116	157	1827
TOTAL		66750	3410	######				2784		43845
MAX	####		1113	1119.21	5628.65		259	270	308	6217
MIN	0.0	1820	0	0.00	0.11		0	0	0	0

GAS DISTRICT COOLING (UTP)		UNIVERSITI TEKNOLOGI PETRONAS DCS/COGEN PLANT								
		DAILY REPORT								
							MAX	MIN		
		DATE :	16-Jun-08	TEMP.	31.0	DEG C	38.3	26.2		
				HUMD.	106.3	RH%	106.3	106.3		
	GT-A	GT-B	SAC - A	SAC -B	HRSG	EC-A	EC-B	EC-C	EC-D.	TES
HOUR	POWER IN kWH		HEAT SUMMATION (RT)		STEAM (KG)	HEAT SUMMATION (RT)				TES HOLDING CAL(RT)
0:00	2826	0	0	0	0	253	284	0	0	5612
1:00	2782	0	0	0	0	253	284	0	0	6442
2:00	2754	0	0	0	0	254	283	0	0	7279
3:00	2696	0	0	0	0	254	285	0	0	8167
4:00	2416	0	0	0	0	255	286	0	0	8940
5:00	2935	0	0	0	0	255	286	0	0	9546
6:00	2525	250	259	21	2727	255	287	0	0	10107
7:00	2060	2442	856	612	5438	257	250	78	0	10594
8:00	2889	3088	1001	945	5859	253	0	294	0	9218
9:00	2914	3151	1001	958	5925	248	0	295	0	7404
10:00	2993	3173	1008	955	5947	246	0	290	0	5812
11:00	3225	3241	1029	969	6057	242	0	284	0	4590
12:00	3151	3260	1039	980	6154	13	119	279	0	3543
13:00	3174	3279	1059	989	6287	0	162	281	0	2510
14:00	3201	3307	1095	1016	6417	0	264	278	0	1687
15:00	2995	3302	1114	1043	6544	37	35	277	0	1233
16:00	3088	3308	1119	1054	6580	232	0	281	0	734
17:00	2682	3286	1098	1033	6545	241	139	282	186	568
18:00	2407	2899	1018	972	6136	247	272	283	261	1035
19:00	2201	2341	614	736	2915	248	274	290	267	1868
20:00	1950	2319	0	647	1	252	279	293	271	2780
21:00	1950	2117	0	162	0	252	280	295	272	3745
22:00	1705	1988	0	0	0	252	280	296	274	4746
23:00	1532	1919	0	0	0	253	282	297	275	5867
AVERAGE										
TOTAL	61517	48671	3308	#######				4674		124028
MAX	3225		1119	6579.87			257	297	275	10594
MIN	1704	0	0	0.00			0	0	0	568

	UNIVERSITI TEKNOLOGI PETRONAS DCS/COGEN PLANT									
	DAILY REPORT									
							MAX	MIN		
	DATE :	17-Mar-09	TEMP.	29.3	DEG C		35.7	23.9		
			HUMD.	106.3	RH%		106.3	106.3		
	GT-A	GT-B	SAC A	SAC -B	HRSG	EC-A	EC-B	EC-C	EC-D	TES.
HOUR	POWER IN kWH		HEAT SUMMATION (RT)		STEAM (KG)	HEAT SUMMATION (RT)				TES HOLDING CAL(RT)
0:00	1473	2609	0	0	0	285	264	207	276	9653
1:00	94	3556	0	0	0	285	267	212	0	10606
2:00	0	3440	0	0	0	231	200	197	0	11428
3:00	0	3116	0	0	0	144	97	133	0	11858
4:00	0	3085	0	0	0	114	62	113	0	12169
5:00	0	3252	0	0	0	100	48	104	0	12402
6:00	4	3081	39	0	0	98	48	100	0	12660
7:00	1584	3158	624	499	3828	166	114	145	0	12907
8:00	3317	3423	789	713	4375	236	39	200	0	12993
9:00	3695	3514	946	947	5802	280	0	194	0	11974
10:00	3762	3166	929	930	5364	271	0	200	0	10851
11:00	3758	3295	991	948	5820	273	0	205	0	10497
12:00	3757	3286	973	955	5717	267	0	204	0	9806
13:00	3757	3300	985	956	5702	268	0	209	0	9077
14:00	3757	3313	967	937	5683	264	0	207	0	8141
15:00	3757	3368	966	938	5649	264	0	207	0	7256
16:00	3758	3265	986	948	5685	267	0	207	0	6394
17:00	3143	3318	969	939	5674	266	0	204	162	6057
18:00	3105	3372	970	937	5666	267	156	206	271	6825
19:00	3110	3179	940	910	5628	275	254	211	277	7822
20:00	2990	3210	766	819	4572	274	252	210	278	8847
21:00	2632	3129	10	889	5616	273	251	197	278	9927
22:00	1360	3109	0	319	1171	155	140	87	164	10814
23:00	0	3753	0	0	0	0	225	0	0	10804
AVERAGE	3262	3262	535	565.98	3563.12		101	173	71	10074
TOTAL		78296	3753	13583.45				4160		241767
MAX	#####		991	956.19	5820.32		267	212	278	12993
MIN	0.0	2609	0	0.00	0.00		0	0	0	6057

GAS DISTRICT COOLING (UTP)

UNIVERSITI TEKNOLOGI PETRONAS
DCS/COGEN PLANT

DAILY REPORT

					MAX	MIN
DATE:	25-Nov-10	TEMP.	27.2	DEG C	35.2	23.6
		HUMD.	*****	RH%	*****	*****

	GT-A	GT-B	SAC -A	SAC -B	HRSG	EC-A	EC-B	EC-C	EC-D	TES
HOUR	POWER IN kWH		HEAT SUMMATION (RT)		STEAM (KG)	HEAT SUMMATION (RT)				TES HOLDING CAL(RT)
0:00	0	2938	0	0	0	73	13	0	288	10051
1:00	0	2979	0	0	0	70	60	0	268	10726
2:00	0	2823	0	0	0	44	44	0	137	11485
3:00	0	2660	0	0	0	39	41	0	101	12285
4:00	0	2700	0	0	0	38	39	0	99	13056
5:00	0	3011	0	0	0	38	39	0	96	13681
6:00	14	2785	14	0	0	39	40	0	93	14005
7:00	1975	3190	637	523	5199	236	236	0	192	14104
8:00	3154	3442	966	913	6533	274	279	2	288	12988
9:00	3235	3434	948	901	6384	269	273	0	285	12449
10:00	3389	3424	939	895	6317	266	266	0	285	11787
11:00	3422	3502	942	899	6336	263	263	0	281	11107
12:00	3243	3723	946	891	6367	260	259	0	288	10155
13:00	3239	3722	924	875	6337	256	255	1	283	9134
14:00	3320	3719	909	868	6202	259	257	0	282	7914
15:00	3216	3725	924	877	6251	263	262	0	286	6518
16:00	3249	3429	963	905	6425	268	274	0	284	5189
17:00	2989	3203	960	902	6440	271	272	129	288	4109
18:00	2994	2996	960	902	6496	271	270	272	288	3392
19:00	2843	2947	829	823	5235	271	270	273	288	4028
20:00	2685	3001	539	721	2827	270	268	272	289	4952
21:00	2420	2588	0	831	0	247	20	271	287	5946
22:00	1371	2912	0	426	0	144	0	121	280	6998
23:00	0	3423	0	0	0	0	0	0	112	7983
AVERAGE										
TOTAL	46757	76275	3725					1340		224041
MAX	3421		966				274	273	289	14104
MIN	0.0	2588	0				0	0	93	3392

GAS DISTRICT COOLING (UTP)		UNIVERSITI TEKNOLOGI PETRONAS DCS/COGEN PLANT								
		DAILY REPORT								
						MAX	MIN	MIN		
		19-Sep-11	TEMP.	28.1	DEGC	33.9	23.7	24.7		
			HUMD .	*****	RH%	*****	*****	*****		
	GT-A	GT-B	SAC - A	SA C -B	HRSG	EC-A	EC-B	EC-C	EC-D	TES .
HOUR	POWER IN kWH		HEAT SUMMATION (RTh)		STEAM (KG)	HEAT SUMMATION (RT)				TES HOLDING CAL(RT)
0:00	3395	0	0	0	0	272	275	7	287	6914
1:00	3164	0	0	0	0	229	274	179	287	8036
2:00	2737	0	0	0	0	117	273	166	286	9161
3:00	2565	0	0	0	0	88	274	167	284	10232
4:00	2580	0	0	0	0	70	259	165	180	11355
5:00	2908	0	0	0	0	52	149	153	111	11827
6:00	2715	0	567	0	59	53	119	111	102	12199
7:00	3290	0	939	0	5162	207	219	99	232	12416
8:00	3573	0	1026	0	5756	279	271	127	287	11015
9:00	3585	0	952	0	5589	278	269	160	288	9497
10:00	3585	0	987	0	5927	282	265	157	284	8595
11:00	3578	0	976	0	6116	278	259	178	280	7615
12:00	3593	0	987	0	6150	272	255	173	272	6650
13:00	3614	0	995	0	6238	273	245	175	252	5657
14:00	3647	0	995	0	6280	112	78	174	124	4505
15:00	3650	0	983	0	6341	-1	0	176	0	3271
16:00	3633	0	984	0	6285	-1	81	178	105	2046
17:00	3644	0	997	0	6434	156	275	185	283	1055
18:00	3656	0	982	0	6357	272	279	185	287	1184
19:00	3639	0	1000	0	6444	247	277	184	290	2064
20:00	3648	0	991	0	6486	276	275	189	290	2920
21:00	3656	0	1009	0	6511	277	276	127	289	3809
22:00	3637	0	1063	0	6546	277	277	188	289	4762
23:00	3561	0	1011	0	6546	277	277	192	289	5668
AVERAGE										
TOTAL	77690	0	0					3794		162454
MAX	3656.5		1063				6546	192	290	12416
MIN	25647	0	0				0	7	0	1055