ENERGY RECOVERY STUDIES FOR FLARE SYSTEMS IN OFFSHORE OIL AND GAS FACILITIES

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Energy Recovery Studies For Flare Systems in Offshore Oil and Gas Facilities

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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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 acknowledgments, and the original work contained herein have not been undertaken or done by unspecified sources or persons.

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AZREEL ZAIREE BIN OMAR

ABSTRACT

Flaring is a controlled burning of hydrocarbon gases and it is a common operation in oil and gas facilities. Flare system acts as the safety valve to avoid overpressure in the production line. Flaring involves combustion of precious natural gases which occurs at the flare header. This is indeed a waste of energy, and therefore, the hydrocarbon gases should be recovered for better applications instead of conventional flaring to the atmosphere.

Electricity generation from the combustible gases is the ultimate aim for this study. Auxiliary electrical system such as lighting, water heating, and air conditioning can be supplied through this gas powered electricity generation. Duyong gas platform, operated by PETRONAS Carigali has been selected to be the reference field for this study due to the high energy demand by the platform.

Flare gas data from the field has been used in the modeling process using HYSYS simulation. Results obtained from HYSYS indicate that Duyong field has the potential for flare gas recovery due to high power output generated from the system. Cost analysis was carried out particularly on microturbines as the prime mover, and it shows that high initial investment is needed to fund this project.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Worldwide, oil and gas industry has become one of the most profitable sectors for the producing countries. The industry has undergone a rapid advancement from being a mere hydrocarbon production for export purposes to further process the resources and converted it into commodities. An oil and gas facility consists of complex integration of processes and equipments in the production line.

Flare relief system installed in oil and gas production facility acts as an emergency relief system to avoid over-pressure in the production line. The main purpose of flaring is to keep the facility running safely especially during start-up, planned maintenance or unplanned operational interruptions.

This project intends to develop a comprehensive study on the flare gas energy recovery for offshore oil and gas facilities in Malaysia. Duyong gas platform, operated by PETRONAS Carigali Sdn. Bhd (PCSB) is used as the base reference for this project.

Duyong gas platform started its operation since 1984 and it is the first gas platform wholly owned by PETRONAS Carigali Sdn. Bhd. There are 4 modules for Duyong gas complex namely Living Quarters (LQ), Central Processing Platform (CPP), Gas Compression Platform (GCP), and Drilling Platform B (Bravo).

As Duyong platform is a gas producing platform, and at the same time serves as a hub for the surroundings platform, flaring is a frequent operation twenty-four hours each day. It is an advantage for the platform to reuse the wasted flammable gases to power up auxiliary electricity, indirectly lowers the power load from the main power source which is the gas turbine. It is indeed necessary to devise a more beneficial method of reusing the flare gas instead of conventional flaring or even venting the hydrocarbon gases to the atmosphere. Figure 1.1 best describes Duyong gas complex layout.

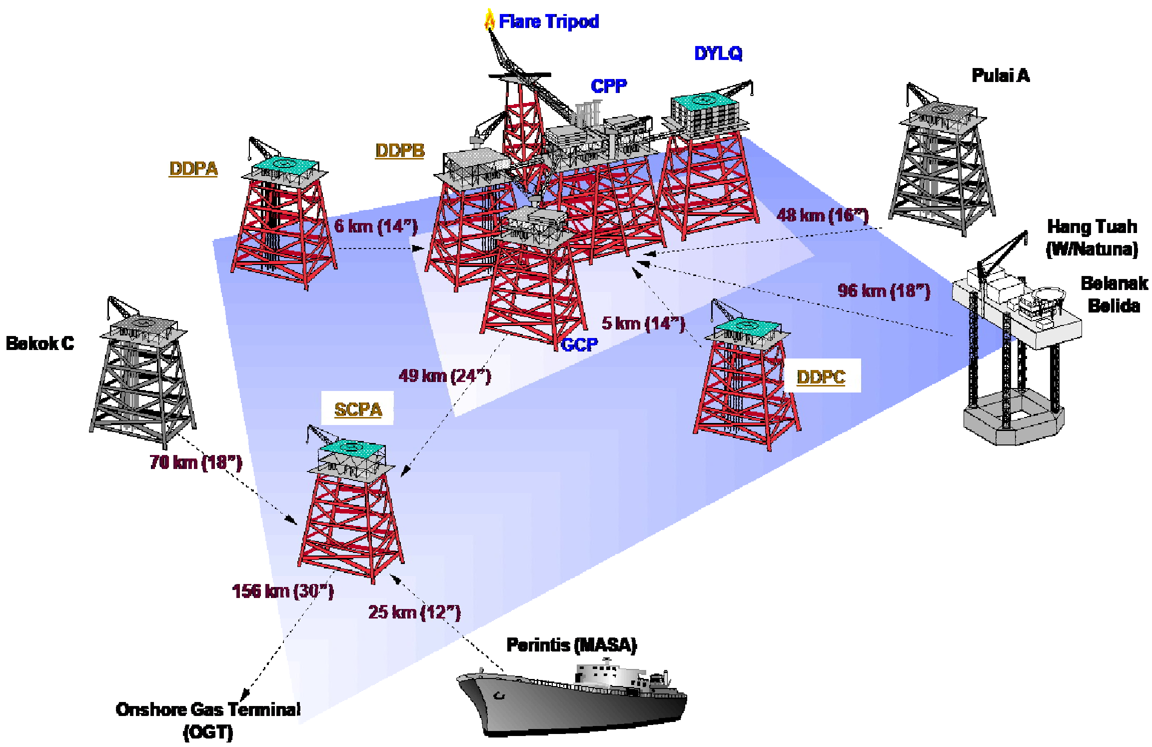


Figure 1.1: Duyong gas complex layout (Carigali, 2009)

1.2 Problem Statement

Duyong gas platform is becoming a critical asset to PCSB PMO due to the fact that it is a hub for receiving gas from Pulai, Ledang, and West Natuna field. In the event of Duyong blackout, an estimate amount of 340MMSCFD of gas production will be lost. In recent years, Duyong have had frequent power failure and indeed, this is undesirable. Hence, it is necessary for Duyong to have backup power source to support the existing low reliability turbine generators.

1.3 Project Objectives

- To investigate the feasibility of using flare gas recovery system at Duyong platform for electricity generation purposes
- To study the amount of potential energy that can be generated from the flare gas
- To propose a flare gas recovery system for Duyong platform

1.4 Scope of the study

- Evaluating the amount of energy output that can be generated via flare recovery system using HYSYS software utilizing input data from the reference field – Duyong platform
- Compare and evaluate HYSYS simulation results with calculated theoretical results based on thermodynamic assumptions
- Performing economic consideration and sensitivity analysis on the proposed systems.

1.5 Relevancy of the project

There are several reasons on the selection of Duyong platform as the reference field for this study which are:

i. Duyong has high potential for flare gas recovery since flaring is a non-stop operation every day
ii. Composition of Methane, CH_4 for Duyong flare gas is comparable with other platforms discussed in the literature review section and it is suitable for gas-fueled engines
iii. Duyong have had frequent power failure in recent years due to low reliability of current gas turbine engines which results in huge loss of production

Hence, it is therefore necessary to have a flare gas recovery system for Duyong platform. Small capacity of power can be generated through this system, besides having longer flare tip service life due to infrequent flaring operations.

CHAPTER 2

LITERATURE REVIEW

2.1 Flare Gas Recovery

Flare relief system installed at oil and gas production facility functions to safely dispose of any gaseous that need to be routed to atmosphere for safety and operational purposes. With the uprising cost of operational upstream operations and the need of producing environmental-friendly gas emissions, flare gas recovery in oil and gas refineries has become one of the popular alternative available today. There are a lot of studies have been carried out pertaining to the recovery of flare gas in oil and gas production refineries around the globe.

(Rahimpour & Jokar, 2012) have conducted a detailed feasibility study of flare gas reformation to practical energy in Farashband gas refinery in Iran. The objectives of this study are to propose 3 methods to recover flare gas instead of conventional gas-burning. The proposed methods are (1) gas-to-liquid (GTL) production, (2) electricity generation with a gas turbine and (3) compression and injection into the refinery pipelines. Simulation method is used to determine the amount of flare gas, the number of GTL barrels, power generated by the gas turbine and the required compression horsepower.

Method 2 is very much related to this project. The outcome of the simulation for method 2 shows that the power output from the gas turbine is 25MW. The details of the simulation are described in tables and figures below.

Table 1.1: Comparison between industrial and simulation data of flare gas (Rahimpour & Jokar, 2012)

Component	Mole fraction (experimental) [52]	Mole fraction (simulation)	% Error
Methane	0.879662	0.884511	−0.55
Ethane	0.034552	0.036113	−4.51
Propane	0.009521	0.008912	6.39
Nitrogen	0.032899	0.029123	11.47
CO_2	0.029666	0.027512	7.26
i-Butane	0.002357	0.002898	−22.95
n-Butane	0.003377	0.003125	7.46
C_5^+	0.004608	0.004721	−2.45
H_2O	0.003052	0.002841	6.91
H_2S	0.000077	0.000080	−3.89
Benzene	0.000067	0.000072	−7.46
Toluene	0.000073	0.000078	−6.84

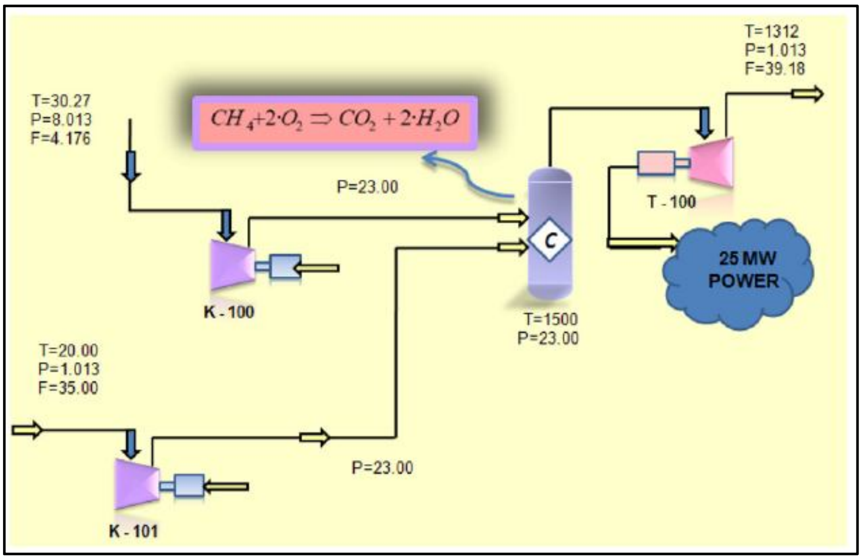


Figure 2.1: Process flow diagram of power plant simulation (Rahimpour & Jokar, 2012)

(Zadakbar, Vatani, & Karimpour, 2008) devised practical method to approach zero flaring through installation of Flare Gas Recovery Unit (FGRU) for oil and gas production facilities. In their work, they present two case studies of reducing, recovering and reusing flare gases from the Tabriz Petroleum Refinery and Shahid Hashemi-Nejad (Khangiran) Gas Refinery, both located in Iran. The flare gases are compressed and returned to the fuel gas header for immediate use as gas fuels. The results of their work are described as below.

Table 2.2: The compositions of flare gases produced by important nods (Zadakbar, Vatani, & Karimpour, 2008)

Component	MDEA flash drum	MDEA regenerator/reflux drum	Residue gas filter	inlet gas separator
Methane	47.07	0.6	98.5	88.38
Ethane	0.16	-	-	0.56
Propane	0.0058	-	-	0.09
i-Butane	0.0019	-	-	0.02
n-Butane	-	-	-	0.03
i-Pentane	-	-	-	0.02
n-Pentane	-	-	-	0.02
n-Hexane	-	-	-	0.1
CO_2	40.85	56.39	0.01	6.41
H_2S	8.06	33.96	4 ppm	3.85
N_2	0.94	-	0.57	0.52
H_2O	2.91	9.05	0.01	0.03
COS	-	91 ppm	8 ppm	17 ppm

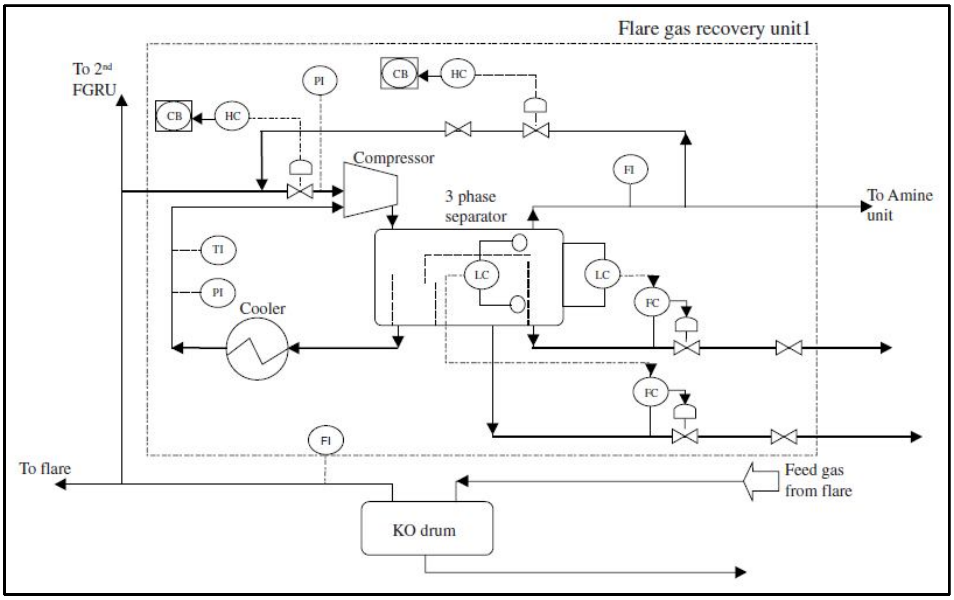


Figure 2.2: The first unit of the FGRU for the Tabriz petroleum refinery (Zadakbar, Vatani, & Karimpour, 2008)

(Mitre, Lacerda, & de Lacerda, 2005) have conducted a study on thermoelectric plant of combined cycle and its environment impact by using HYSYS simulation. The thermoelectric plant uses natural gas as fuel, consists of a natural gas cycle and a steam cycle. Natural gas is burned in a combustion chamber, and the flue gas is expanded in a gas turbine which generates electricity. In their work, Bolivian natural gas with flow rate of 1.2 MMm^3/d (42.4 MSCF/d) is used as their base reference whose composition is shown in table 2.3.

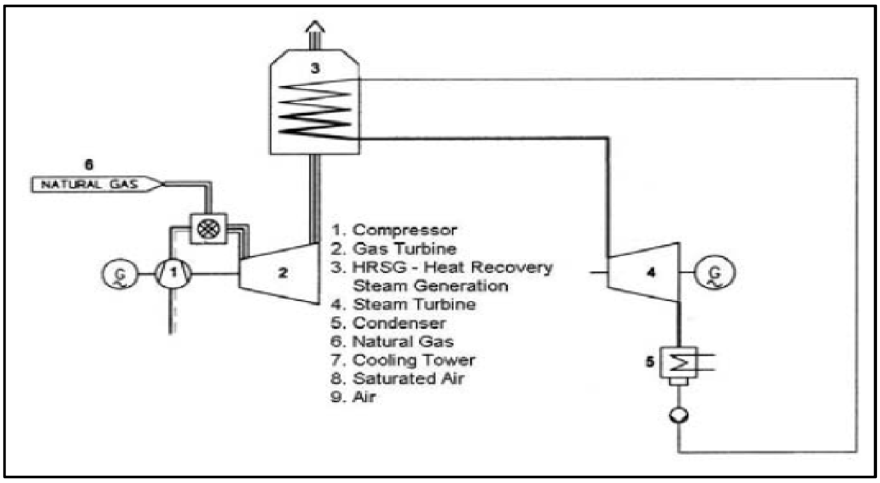


Figure 2.3: Simplified scheme of a thermoelectric plant (Mitre, Lacerda, & de Lacerda, 2005)

Table 2.3: Natural gas composition -Bolivian (Mitre, Lacerda, & de Lacerda, 2005)

Components	Volumetric fraction
Nitrogen	0.01420
Carbon Dioxide	0.00080
Methane	0.91800
Ethane	0.05580
Propane	0.00970
i-Butane	0.00030
n-Butane	0.00020
i-Pentane	0.00050
n-Pentane	0.00050
H_2S	0.00008

Table 2.4: Energy production (Mitre, Lacerda, & de Lacerda, 2005)

Energy	MW
Energy consumption	**140.7**
Air compression	139.6
Water pump	1.1
Energy production	**361.3**
Gas expansion	270.4
Steam expansion	90.9
Net energy production	**220.6**
Gas cycle	130.8
Water cycle	89.8

The result shows that a significant amount of energy is produced from the plant, but at the same time it also produces a high amount of pollutants to the atmosphere (CO, CO_2, SO_2, NO_2).

(Mourad, Ghazi, & Noureddine, 2009) proposed a method for recovery of flared gas through crude oil stabilization by multi-staged separation with intermediate feeds. They proposed that the separation of gas and oil phases remains the most vital stage in surface production, rather than flaring that produces a great number of harmful by-products. Algerian crude oil data is used as their reference data and the separation of the gases is done in three or four stages through HYSYS simulation. Figure 2.4 shows the separation stages with intermediate feeds.

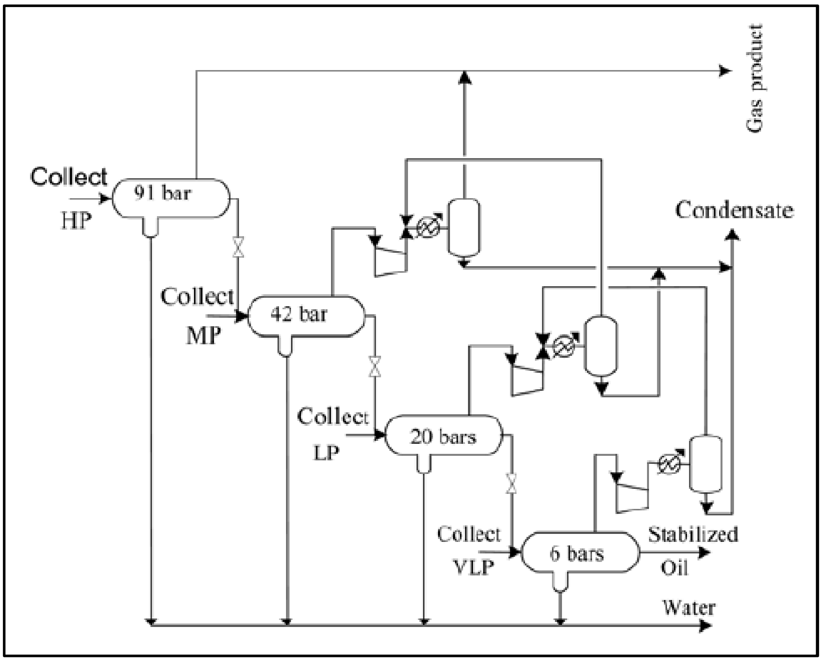


Figure 2.4: Separation stages with intermediate feeds (Mourad, Ghazi, & Noureddine, 2009)

From the results obtained, they conclude that GTL technology is one best alternative to recover the flared gas through crude oil stabilization by a multi-staged separation with intermediate feeds.

However, there is no study that has been carried out to devise practical method of using flare gas energy recovery in Malaysia, particularly for offshore production facility. In addition to that, there is also no comprehensive study of using HYSYS process simulation was carried out with regards to the flare gas energy recovery system. It is hoped that this project will be the base reference for the future flare gas recovery study in Malaysia.

2.2 Flare Gas Recovery System Design

According to (Analysis, Dec 2008), microturbines are currently operating in resource recovery operations at oil and gas production fields, where byproduct gases serve as essentially free fuel. Reliable, less surveillance and monitoring operation is important since these locations may be isolated from the main grid i.e offshore platform. Figure 2.5 below shows the schematic of a microturbine-based combined heat and power (CHP) system for a single shaft.

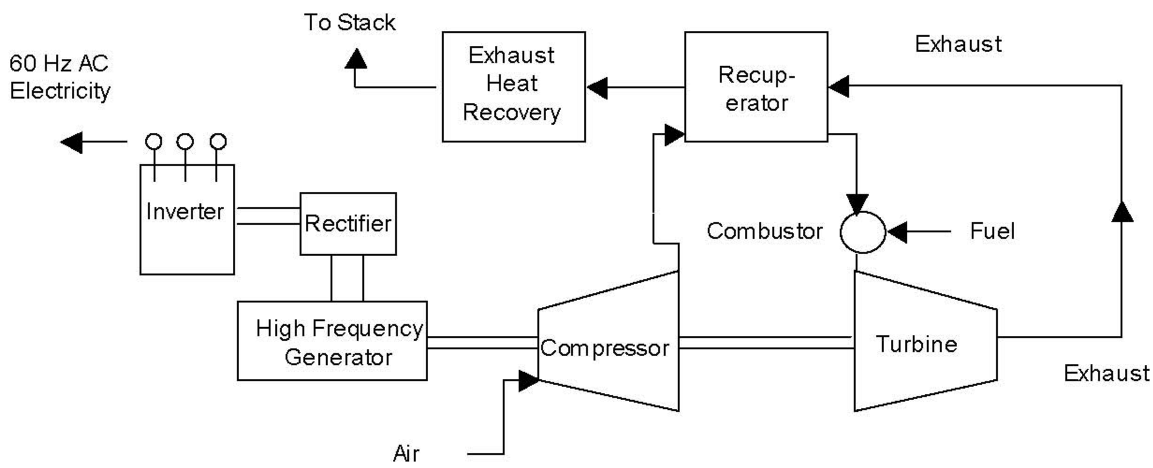
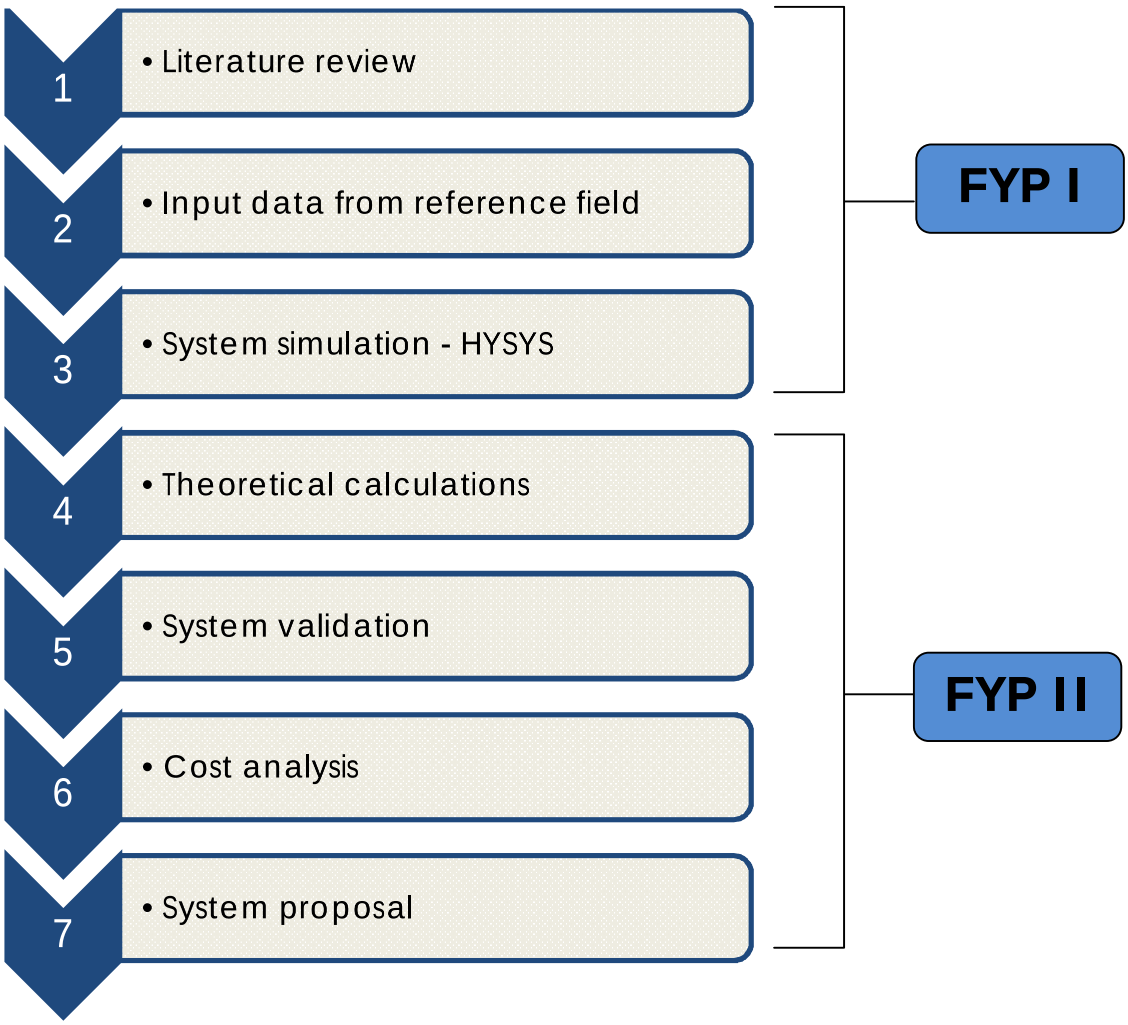


Figure 2.5 : Microturbine-Based CHP System (Single-Shaft Design) (Analysis, Dec 2008)

CHAPTER 3

METHODOLOGY

Project flowchart:



The first part of the project would focus on the fundamental understanding on the topic. This is achieved through detailed analysis on the literature review and past research previously done on the subject. During this part also, it is necessary to establish connection with the reference field to obtain required information especially on the flare gas data which will then be used in HYSYS software for simulation.

The second part of the project is mainly focused on optimizing results obtained during the first part. HYSYS results are compared with theoretical results using thermodynamics. This is to ensure the reliability of the results acquired. Apart from that, cost analysis is also done during the second part of the project to validate the economic feasibility of the system. The last part of the project is to propose the system to the field for future development purposes. The gantt chart of the overall project is available in Appendix I.

All simulations done in HYSYS will be based on the actual flare gas data (Appendix II) obtained from the reference field (Duyong Gas Platform). Table 3.1 and 3.2 show the summarized values of the flare gas data used in the simulation process. The chemical reactions in the natural gas combustion process will solely consider for Methane, CH_4 as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \;\; ; \;\; \Delta H = -891 \text{ kJ/mol (Exothermic process)}$$

The above chemical reaction will theoretically contribute 891 kJ of energy (on a mole basis) if there was a complete combustion. This value serves as a guide/reference for the amount of energy available for recovery into useful form.

As the process components are all gases, the selected fluid package would be the Peng Robinson in the HYSYS simulation. The characteristics of air are taken with reference to the literature review previously done. When all the necessary data are in place, the physical system can be modeled in the HYSYS environment and the results can be achieved with correct components arrangements and integrations.

Table 3.1: Duyong gas composition (Carigali, Important Daily Report, 2012)

DAILY REPORT: 1ST MARCH 2012	
COMPONENTS	**PERCENTAGE**
Methane	83.141295
Ethane	9.697911
Propane	1.856903
N-Butane	0.448056
I-Butane	0.587834
N-Pentane	0.015655

I-Pentane	0.029646
Hexane	0.004939
Heptane	0.049899
Octane	0.032335
Nonane	0.000660
CO_2	3.637937
N_2	0.495610
H_2O	0.001309
H_2S	0.000010

Table 3.2: Characteristics of Duyong flare gas (Carigali, Important Daily Report, 2012)

DAILY REPORT: 1ST MARCH 2012	
Pressure (Bar)	69.17
Temperature (^{0}C)	23.70
Molar flow (MMSCFD)	1.5

Molar flow of the flare gas is showing 1.5 MMSCFD of operation. For the purpose of this study, the amount of molar flow that will be used in HYSYS simulation is 0.75 MMSCFD maximum. This is to consider the fluctuating conditions of the parameter in daily operations.

Microturbine is a small scale turbine generation system which extracts energy from a flow of combustion gas. Microturbines offer several advantages compared to other technologies for a small scale power generation system. It is compact size, small number of moving parts, and most importantly having greater efficiency, it is the best option for power generation at offshore location.

Microturbines can be classified into two general classes which are:

- **Recuperated microturbines**: It employs a sheet-metal heat exchanger that recovers some of the heat from an exhaust stream and preheats the incoming air stream supplied to the combustor. The efficiency for this type of microturbines is between 20 to 40%.

- **Unrecuperated microturbines**: This type of microturbines can be illustrated in a simple cycle, where compressed air is mixed with fuel and burned under constant pressure. Unrecuperated microturbines have lower efficiency at around 15%, but it is lower capital costs.

Hence, for comparison purposes, two options of microturbines will be used in HYSYS simulations which are:

I. OPTION 1: Microturbines with recuperator
II. OPTION 2: Microturbines without recuperator

Characteristics on both of these options will be discussed further in the next preceding sections. In order to complement HYSYS results, thermodynamics calculation using Brayton Cycle is applied on each process and the equation used is:

$$\dot{Q}_x = \dot{m}C_p(T_1 - T_2)$$

Where:

$\dot{Q}_x = Net\ power\ harvested\ at\ x\ stage, kW$
$\dot{m} = Mass\ flow\ rate\ of\ the\ gas, kg/s$
$C_p = Mass\ heat\ capacity\ of\ the\ gas, \frac{kJ}{kg - C}$
$T_1 = Gas\ temperature\ before\ expansion, °C$
$T_2 = Gas\ temperature\ after\ expansion, °C$

Daily operations provide a wide range of possible parameters in the flow line. Hence, the simulated HYSYS arrangements using default parameters are not always accurate all the time. Therefore, in order to obtain better estimation, parameters need to be varied to complement with fluctuating conditions in the flow line. The default parameters used in HYSYS simulation are as follows:

i. Temperature : 23.70^{o}C
ii. Pressure : 8.013 Bar
iii. Molar flow : 0.75 MMSCFD

Sensitivity analysis is carried out to evaluate the effect of 3 main parameters which are temperature, pressure, and molar flow to the power output. The value for each parameter is varied while maintaining the others and the value is changed by means of percentage difference with respect to default parameters obtained using HYSYS.

Graphs of the sensitivity analysis will be showing the level of sensitivity for each parameter. Parameter having the steepest gradient is the most sensitive parameter and vice versa.

CHAPTER 4

RESULTS AND DISCUSSION

There are two available options for microturbines which are recuperated and unrecuperated. The preceding section explains on the results obtained from HYSYS simulation utilizing the actual flare gas data from the field (Temperature, Pressure, Molar Flow, Gas Composition).

4.1 OPTION I: Microturbines with recuperator

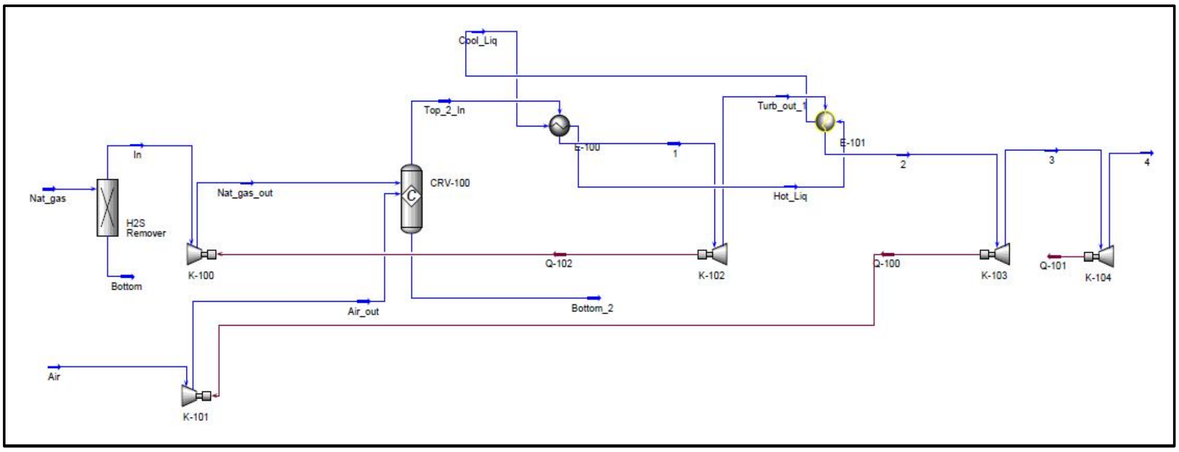


Figure 4.1: HYSYS arrangement for microturbines with recuperator

- Theoretical calculations:

$$\dot{Q}_x = \dot{m}C_p(T_1 - T_2)$$

$$\dot{Q}_1 = (0.365)(2.870)(800 - 762.3) = -39.22\ kW$$

$$\dot{Q}_2 = (0.365)(2.869)(800 - 709.8) = -93.81\ kW$$

$$\dot{Q}_3 = (0.365)(2.768)(709.8 - 200) = 511.53\ kW$$

Total net power = **<u>378.50 kW</u>**

- HYSYS results : **<u>307.12 kW</u>**
- $Percentage\ difference$: $\frac{378.50-307.12}{307.12}\ x$ 100% = **<u>23.24%</u>**

The basic operation of recuperator is similar to that of heat exchanger which allows the heat transfer of two different fluids. In the case of microturbines, the recuperator acts as the heat exchanger between the outlet gas from the combustion chamber/combustor and the working fluid. As the gas outlet temperature from the combustor is too high i.e 1600°C, it needs to be cooled down to around 800°C due to the metallurgical limit of the turbine blade that can only cater for gases with maximum temperature of 800°C.

4.2 OPTION II: Microturbines without recuperator

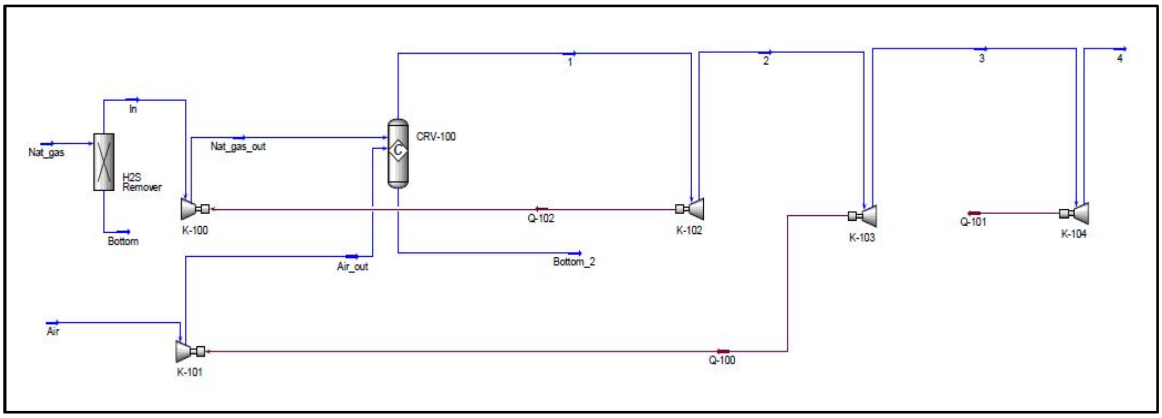


Figure 4.2: HYSYS arrangement for microturbines without recuperator

- Theoretical calculations:

$$\dot{Q}_x = \dot{m}C_p(T_1 - T_2)$$

$$\dot{Q}_1 = (0.365)(2.825)(756.3 - 718) = -39.22\ kW$$

$$\dot{Q}_2 = (0.365)(2.780)(718 - 624.5) = -94.22\ kW$$

$$\dot{Q}_3 = (0.365)(2.660)(624.5 - 200) = 409.32\ kW$$

Total net power = **<u>275.88 kW</u>**

- HYSYS results : **<u>223.12 kW</u>**
- $Percentage\ difference$: $\frac{275.88-223.12}{223.12}\ x$ 100% = **<u>23.65%</u>**

From the results obtained, we can see that there are some differences between HYSYS results and theoretical results. These differences are due to the fact that in HYSYS, it considers efficiencies in the system which results in lower power output generated. Inefficient system will also give some effects on power and heat loss along the way. Whereas in theoretical calculations, it does not consider any efficiency and that is the reason why the net power output generated is higher.

4.3 Sensitivity Analysis

In sensitivity analysis, the default parameters are used as the base reference and each value of the parameters will be varied and calculated with percentage deviations from the original value. The range of the percentage deviations is between -60% to 60%. The results are then presented in graph form to evaluate the sensitivity for each parameter. The graphs are shown below.

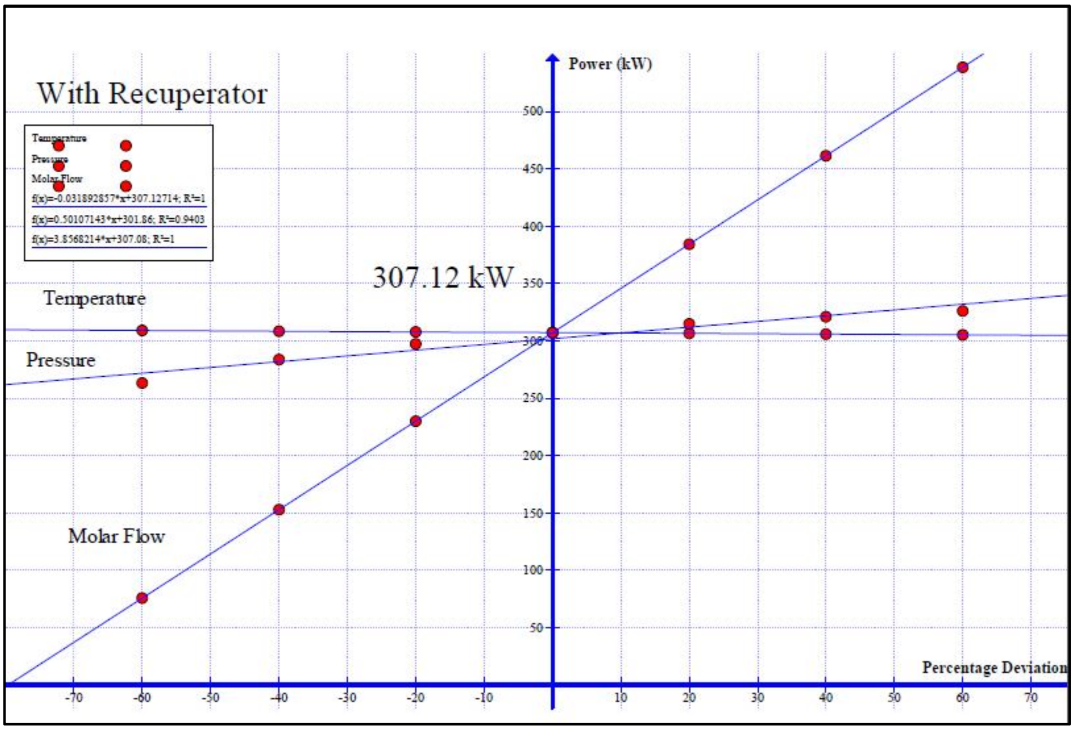


Figure 4.3: Sensitivity analysis for microturbines with recuperator

Equations for the parameters:

- Temperature : $y = -0.03x + 307.12$
- Pressure : $y = 0.50x + 301.86$
- Molar Flow : $y = 3.86x + 307.08$

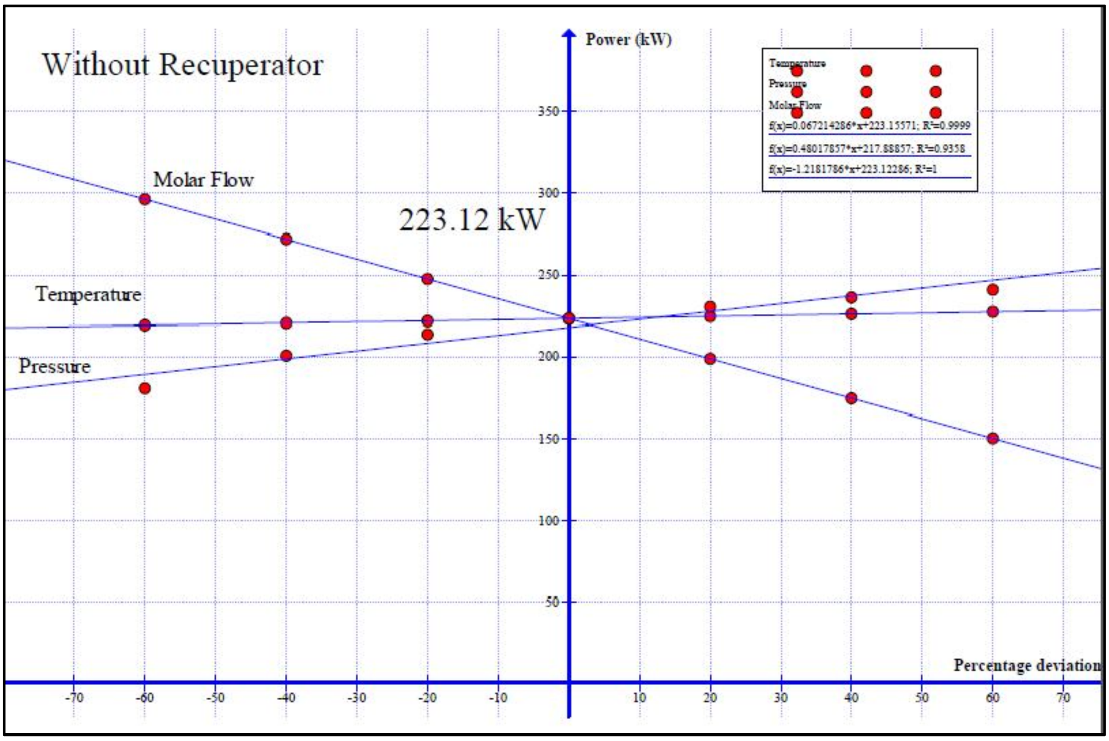


Figure 4.4: Sensitivity analysis for microturbines without recuperator

Equations for the parameters:

- Temperature : $y = 0.07x + 223.16$
- Pressure : $y = 0.48x + 217.89$
- Molar Flow : $y = -1.22x + 223.12$

Gradient of the graph indicates the sensitivity of the parameters. As shown in the graph, we can see that molar flow is the MOST SENSITIVE parameter compared to others while temperature is the LEAST SENSITIVE. It means that, slight changes of molar flow value in the flow line will affect power output significantly. Whereas changes in temperature will not affect power output much. Hence, in order for us to obtain constant power output to supply to the field, we need to priority attention to the volume of the gas in the flow line.

4.4 Cost Analysis

Microturbine with recuperator has been chosen to be the prime mover for this project. A wide range of microturbines manufacturers are available in the market, both local and abroad. A budgetary prices of microturbines obtained from Capstone Turbine Singapore is used as a datum for cost estimation for the proposed project (Refer Appendix IV). Table 4.1 below shows the variety of microturbines model from the Company and its prices.

Table 4.1: Prices of microturbines from Capstone Turbine (Capstone)

MODEL	RATED POWER (kW)	PRICE (USD)	PRICE (RM)*
CR30	30	52,185	165,948
CR65	65	88,515	281,478
CR200	200	294,525	939,590
CR600	600	883,575	2,809,770
CR1000	1000	1,137,780	3,618,140

*Exchange rate: 1 USD = RM3.18

Hence, the suitable microturbine that suits with this project would be CR600 which costs approximately RM2.8 million for the equipments excluding installation and maintenance cost. The high amount of capital investment is indeed needed if microturbines are chosen to be the prime mover for this project. However, the high initial expenditure is complemented by the high annual savings on the electricity in the long run which in turns lowers the operational expenditure. There are also some other alternatives of prime movers apart from microturbines that are available on the shelves. (Refer Appendix V, VI, VII). Table 4.2 below shows the comparison on the prime movers.

Table 4.2: Comparison on prime movers (Smith, 2003)

PRIME MOVERS	COST/KW	EFFICIENCIES
Microturbines	RM2800-RM3800	40%
Gas Turbines	RM1300	38%
Reciprocating Engines	RM900-RM1300	50%

4.5 Justifications

Overall Duyong Complex Electrical Loads can be seen in Appendix III. At current state, the power consumption for Duyong Gas Platform is between 900-1200 kW depending on the load requirement of the production activities. Hence, the percentage of power that can be supported by the Flare Gas Recovery System (FGRS) can be approximated by:

$$\% \, Power = \frac{Power \; from \; FGRS}{Average \; power \; consumption} \; x \; 100\%$$

$$\% \, Power = \frac{307.12}{1050} \; x \; 100\%$$

$$\underline{\boldsymbol{\% \, Power = 29.25\%}}$$

Several vital equipments can utilize the net power harvested from the FGRS. Table 4.3 below shows some of the equipments and its absorbed load obtained from the reference field:

Location: Duyong Complex Living Quarters (LQ)

Table 4.3: Equipments and its absorbed load

EQUIPMENT NO.	DESCRIPTION	MAXIMUM ABSORBED LOAD (KW)
WM-2530	Water Maker	58.52
LP-432	Emergency Lighting	18.75
P-2510	Service Water Pump	33.75
DP-503	Power Distribution Panel	33.75
P-2650	Sump Pump	10.50

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Results obtained prove that the Flare Gas Recovery System (FGRS) has the potential of providing additional power to the field. Vital and auxiliary equipments such as water maker, air conditioning, pumps and lighting can utilize the power generated by the FGRS, thus lowers the load requirement currently supplied by the existing gas turbines.

Both options of the microturbines show positive net power output. However, microturbines with recuperator has the highest net power output since its capability to absorb and preheat the incoming gas before expansion process, hence, it is the best option available. In addition, most microturbines available on the shelves are already equipped with recuperator due to its higher efficiency.

Sensitivity analysis done on both options shows that Molar Flow is the most sensitive parameter to power output generated. It indicates that the volume of gas coming to the FGRS should be given priority compared to other parameters i.e temperature, pressure. Slight changes on the volume of the gas in the flowline will give significant effect to the net power output in the microturbines.

Cost analysis has been taken into consideration to evaluate the economic point of view for this project. It is undeniable that huge capital investment is needed to turn this project a success.

All in all, it is clear that the FGRS is feasible to be implemented at the reference field. As for the future work, It is necessary for the research party – UTP and the industry – PCSB collaborate together especially on the practicality and implementation of the system at the site to ensure the success of this project. It is also hoped that this project will be used as the base reference for future flare gas recovery studies in Malaysia.

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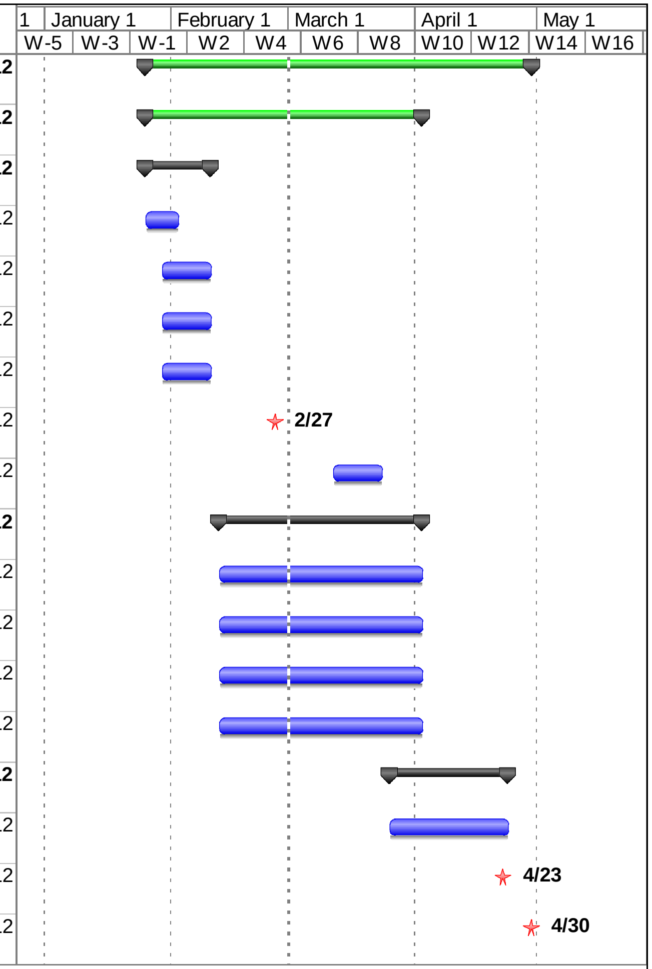
APPENDIX I: Final Year Project Gantt Chart

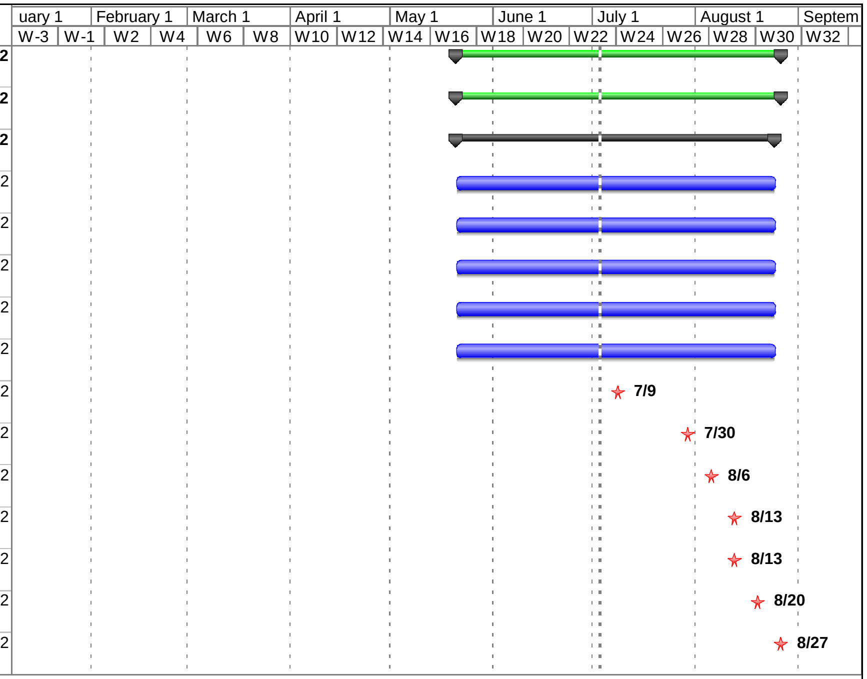
ID	Task Name	Duration	Start	Finish
1	**Student Name : AZREEL ZAIREE BIN OMAR 11442**	**13.4 wks**	**Thu 1/26/12**	**Mon 4/30/12**
2	**Final Year Project I :Energy recovery studies for flare systems in offshore**	**9.6 wks**	**Thu 1/26/12**	**Mon 4/2/12**
3	**Preliminary Understanding**	**2.4 wks**	**Thu 1/26/12**	**Fri 2/10/12**
4	Understand the basis of the project	6 days	Thu 1/26/12	Thu 2/2/12
5	Review on the existing P&ID of reference field	10 days	Mon 1/30/12	Fri 2/10/12
6	Indentify and recognize basic flare system	10 days	Mon 1/30/12	Fri 2/10/12
7	Review on recent studies (jurnals, book, internet)	10 days	Mon 1/30/12	Fri 2/10/12
8	**Submission of Extended Proposal Defence**	0 wks	Mon 2/27/12	Mon 2/27/12
9	**Proposal Defence**	2 wks	Mon 3/12/12	Fri 3/23/12
10	**Data Gathering and Analysis**	**7.2 wks**	**Mon 2/13/12**	**Mon 4/2/12**
11	Project Consultation	36 days	Mon 2/13/12	Mon 4/2/12
12	Data input from the reference field	36 days	Mon 2/13/12	Mon 4/2/12
13	Lab work (if necessary)	36 days	Mon 2/13/12	Mon 4/2/12
14	Work on the simulation (HYSYS)	36 days	Mon 2/13/12	Mon 4/2/12
15	**Report Writing**	**4.2 wks**	**Mon 3/26/12**	**Mon 4/23/12**
16	Compilation of work (Proposal)	21 days	Mon 3/26/12	Mon 4/23/12
17	**Submission of Interim Draft Report**	0 days	Mon 4/23/12	Mon 4/23/12
18	**Submission of Interim Report**	0 wks	Mon 4/30/12	Mon 4/30/12



Project: FYP1.mpp
Date: Thu 3/1/12

Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline

ID	Task Name	Duration	Start	Finish
1	**Student Name : AZREEL ZAIREE BIN OMAR 11442**	**14 wks**	**Mon 5/21/12**	**Mon 8/27/12**
2	**Final Year Project II :Energy recovery studies for flare systems in offshore c**	**14 wks**	**Mon 5/21/12**	**Mon 8/27/12**
3	**Data Gathering and Analysis**	**14 wks**	**Mon 5/21/12**	**Fri 8/24/12**
4	Process optimization on the existing system	70 days	Mon 5/21/12	Fri 8/24/12
5	Compare simulation results and theoretical calculation	14 wks	Mon 5/21/12	Fri 8/24/12
6	Cost evaluation on the overall systems	70 days	Mon 5/21/12	Fri 8/24/12
7	Equipment downsizing	14 wks	Mon 5/21/12	Fri 8/24/12
8	Validation of the proposed systems from third party	14 wks	Mon 5/21/12	Fri 8/24/12
9	Submission of Progress Report	0 wks	Mon 7/9/12	Mon 7/9/12
10	Pre-EDX	0 wks	Mon 7/30/12	Mon 7/30/12
11	Submission of Draft Report	0 wks	Mon 8/6/12	Mon 8/6/12
12	Submission of Dissertation (soft bound)	0 wks	Mon 8/13/12	Mon 8/13/12
13	Submission of Technical Paper	0 wks	Mon 8/13/12	Mon 8/13/12
14	Oral Presentation	0 wks	Mon 8/20/12	Mon 8/20/12
15	Submission of Project Dissertation (hard bound)	0 wks	Mon 8/27/12	Mon 8/27/12



Project: FYP2
Date: Tue 7/3/12

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

APPENDIX II: Duyong Flare Gas Data

Imp Daily Rpt

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DUYONG DAILY REPORT (BASETIME 0:00) 03/01/2012 00:00:00

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FQI-2650

	CUMULATIVE	PERIOD
GVOL	1698.5131	1.5584 MMCF
SVOL	147575.4856	125.9864 MMSCF
MASS	7465.894297	6.520485 MM.lbs
ENERGY	160977.1260	139.1327 BBTU

FWA PRESSURE : 1003.196 psig
FWA TEMPERATURE: 74.665 Deg.F
FWA STD DENS : 0.05176 lbs/scf
FWA MASS FR : 6.5248 MM.lbs/d
FWA DP : 190.487 inH20
FWA LINE DENS : 4.18434 lbs/cf
FWA GHV : 1104.360 btu/scf
FWA SVOL FR : 126.0698 MMSCF/d
FWA GVOL FR : 1.5592 MMCF/d
FWA ENGY FR : 139.2254 BBTU/d

FWA METHANE : 83.141295
FWA ETHANE : 9.697911
FWA PROPANE : 1.856903
FWA N-BUTANE : 0.448056
FWA I-BUTANE : 0.587834
FWA N-PENTANE : 0.015655
FWA I-PENTANE : 0.029646
FWA HEXANE : 0.004939
FWA HEPTANE : 0.049899
FWA OCTANE : 0.032335
FWA NONANE : 0.000660
FWA CO2 : 3.637937
FWA N2 : 0.495610
FWA H2O : 0.001309
FWA H2S : 0.000010

==

APPENDIX III: Overall Duyong Complex Electrical Loads

Overall Duyong Compl   :lectrical Loads

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
CCP-SWG-401 3.3kV Switchgear (1250A, 3Ph, 40kA)																		
P-1020	M	Slug Catcher Pump			x		62.25	75.00	0.83	0.93	0.82			66.94	46.72			3.3kV motor
P-1025	M	Slug Catcher Pump			x		62.25	75.00	0.83	0.93	0.82			66.94	46.72			3.3kV motor
P-1520	M	Coalescer Pump		x			62.25	75.00	0.83	0.93	0.82					66.94	46.72	3.3kV motor
P-1524	M	Coalescer Pump		x			62.25	75.00	0.83	0.93	0.82	66.94	46.72					3.3kV motor
P-1528	M	Coalescer Pump		x			62.25	75.00	0.83	0.93	0.82	66.94	46.72					3.3kV motor
		SUB-TOTAL										133.87	46.72	133.87	93.44	66.94	46.72	
CCP-MCC-408 415V MCC Train No.1 (800A, 3Ph, 42kA)																		
DCS-3	F	DCS 3 Main 1	x				17.25	23.00	0.75	0.98	0.95	17.60	5.79					
	M	Pre-Lube Pump (Stage 1)					3.92	5.60	0.70	0.85	0.73							Future
	F	Lube Oil Heater (Stage 1)					5.25	7.50	0.70	0.98	0.95							Future
PM-2210	M	xxxx			x		1.05	1.50	0.70	0.85	0.73			1.24	1.16			
	M	Oil Cooler (Stage 1)					2.59	3.70	0.70	0.85	0.73							Future
AUM-2530	M	xxxx			x		3.92	5.60	0.70	0.85	0.73			4.61	4.32			
	M	Lube Oil Heater (Stage 2)					5.25	7.50	0.70	0.85	0.73							Future
	M	Fan (Stage 2)					1.05	1.50	0.70	0.85	0.73							Future
	M	Oil Cooler (Stage 2)					2.59	3.70	0.70	0.85	0.73							Future
MCC-440	M	Turbine Generator Auxiliary MCC	x				22.50	30.00	0.75	0.91	0.78	24.73	19.84					
WR-1/2	F	Welding Receptacle - Platform B (2 nos)			x		22.50	30.00	0.75	0.98	0.95					22.96	7.55	Located at DDP-B
M-110B	M	Production Cooler Fan		x			10.50	15.00	0.70	0.85	0.73	12.35	11.57					Located at DDP-B
M-111B	M	Production Cooler Fan		x			10.50	15.00	0.70	0.85	0.73	12.35	11.57					Located at DDP-B
M-112B	M	Production Cooler Fan		x			10.50	15.00	0.70	0.85	0.73	12.35	11.57					Located at DDP-B
DCS-1	F	DCS 1 Bypass	x				2.10	3.00	0.70	0.98	0.95					2.14	0.70	
	F	90A Spare Feeder						0.00		0.98	0.95							
P-1140	M	Skimmer Pump			x		10.50	15.00	0.70	0.85	0.73	12.35	11.57					
SC-2000	M	Survival Capsule Motor Starter	x				20.25	27.00	0.75	0.91	0.78			22.25	17.85			
	F	Control Room HVAC		x			3.50	5.00	0.70	0.98	0.95	3.57	1.17					
WR-1/2	F	Welding Receptacle (1 no.) - Upper Deck			x		10.50	15.00	0.70	0.98	0.95					10.71	3.52	
DP-406	F	Power Distr. Pnl - Lab Buildg Lower Deck			x		15.00	20.00	0.75	0.98	0.95	15.31	5.03					
P-1280	M	Glycol Pump		x			13.95	18.60	0.75	0.91	0.78	15.33	12.30					
P-1285	M	Glycol Pump		x			13.95	18.60	0.75	0.91	0.78			15.33	12.30			
E-1815	***F***	***Fuel Gas Heater***		***x***			***30.00***	***40.00***	***0.75***	***0.98***	***0.95***							***To be removed in WN Ph***
P-1905	M	Glycol Transfer Pump		x			1.05	1.50	0.70	0.85	0.73			1.24	1.16			
	F	250A Spare Feeder						0.00		0.98	0.95							
	M	After Cooler Fan (Stage 1)					16.50	22.00	0.75	0.91	0.78							Future
	M	After Cooler Fan (Stage 2)					22.50	30.00	0.75	0.91	0.78							Future
	F	15A Spare Feeder						0.00		0.98	0.95							
WR-2	F	Welding Receptacle (1 no.) - Lower Deck			x		10.50	15.00	0.70	0.98	0.95					10.71	3.52	

Overall Duyong Compl :lectrical Loads

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
E-1812	***F***	***Fuel Gas Super Heater***		***x***			***30.00***	***40.00***	***0.75***	***0.98***	***0.95***							***To be removed in WN Ph***
P-1027	M	Slug Catcher Booster Pump			x		1.54	2.20	0.70	0.85	0.73			1.81	1.70			
		SUB-TOTAL										125.95	90.39	46.48	38.48	46.53	15.29	
CCP-MCC-409 415V MCC Train No.2 (800A, 3Ph, 42kA)																		
UPS-500	F	240V AC UPS Main Feeder	x				10.50	15.00	0.70	0.98	0.95	10.71	3.52					
UPS-500	F	240V AC UPS Bypass Feeder	x				10.50	15.00	0.70	0.98	0.95					10.71	3.52	
DP-471	F	MOV Distr Board		x			26.25	35.00	0.75	0.98	0.95			26.79	8.80			
KM-5430	***M***	***Instrument Air Compressor***		***x***			***58.10***	***70.00***	***0.83***	***0.93***	***0.82***	***62.47***	***43.61***					***Upgrade Inst Comp in WN***
P-1028	M	Slug Catcher Booster Pump			x		1.54	2.20	0.70	0.85	0.73			1.81	1.70			
P-1145	M	Skimmer Pump			x		10.50	15.00	0.70	0.85	0.73					12.35	11.57	
	M	Space					0.00	0.00	0.70									
P-1350	M	Glycol Pump		x			13.95	18.60	0.75	0.91	0.78	15.33	12.30					
P-1355	M	Glycol Pump		x			13.95	18.60	0.75	0.91	0.78			15.33	12.30			
AUM-2630	M	xxxx			x		3.92	5.60	0.70	0.85	0.73							
	F	Lube Oil Heater (Stage 1)					5.25	7.50	0.70	0.98	0.95							Future
PM-2220	M	xxxx			x		1.05	1.50	0.70	0.85	0.73							
	M	Oil Cooler (Stage 1)					2.59	3.70	0.70	0.85	0.73							Future
	M	Pre-Lube Pump (Stage 2)					3.92	5.60	0.70	0.85	0.73							Future
	F	Lube Oil Heater (Stage 2)					5.25	7.50	0.70	0.98	0.95							Future
	M	Fan (Stage 2)					1.05	1.50	0.70	0.85	0.73							Future
	M	Oil Cooler (Stage 2)					2.59	3.70	0.70	0.85	0.73							Future
	F	15A Equipped Spare						0.00		0.98	0.95							
	F	Space						0.00		0.98	0.95							
	F	50A Equipped Spare						0.00		0.98	0.95							
M-113B	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73	12.35	11.57					Located at DDP-B
M-114B	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73	12.35	11.57					Located at DDP-B
M-115B	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73	12.35	11.57					Located at DDP-B
M-180B	M	Continuous Downhole Injection Pump			x		1.05	1.50	0.70	0.85	0.73							Future
M-170B	M	Continuous Flowline Injection Pump			x		0.53	0.75	0.70	0.85	0.73	0.62	0.58					Located at DDP-B
P-150B	M	Sump Pump			x		2.59	3.70	0.70	0.85	0.73			3.05	2.85			Located at DDP-B
	M	50A Equipped Spare						0.00										
	M	After Cooler Fan (Stage 1)					16.50	22.00	0.75	0.91	0.78							
	M	After Cooler Fan (Stage 2)					22.50	30.00	0.75	0.91	0.78							
DP-404	F	Platform Small Power			x		30.00	40.00	0.75	0.98	0.95	30.61	10.06					
WR-3	F	Welding Receptacle (1 no.) - Upper Deck			x		10.50	15.00	0.70	0.98	0.95					10.71	3.52	
LP-201	F	Lighting & Small Power - DDP-B Platform			x		15.00	20.00	0.75	0.98	0.95	15.31	5.03					Located at DDP-B
DP-403	F	Small Power - Gen. & Control Building			x		15.00	20.00	0.75	0.98	0.95	15.31	5.03					
	F	Gas Metering Panel - Cond. Metering Skid		x			1.40	2.00	0.70	0.98	0.95	1.43	0.47					
	F	15A Equipped Space					1.40	2.00	0.70	0.98	0.95							

Overall Duyong Compl :lectrical Loads

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
E-1912	***F***	***Fuel Gas Heater***		*x*			***53.95***	***65.00***	***0.83***	***0.98***	***0.95***							***To be removed in WN Ph***
E-1915	***F***	***Fuel Gas Heater***		*x*			***53.95***	***65.00***	***0.83***	***0.98***	***0.95***							***To be removed in WN Ph***
		Space																
		SUB-TOTAL										188.85	115.29	46.97	25.65	33.78	18.61	
CCP-MCC-410 415V MCC Train No.3 (800A, 3Ph, 42kA)																		
	F	Air Cond System (Standby)			x		3.50	5.00	0.70	0.98	0.95					3.57	1.17	
	M	Pre-Lube Pump (Stage 1)					3.92	5.60	0.70	0.85	0.73							Future
	F	Lube Oil Heater (Stage 1)					5.25	7.50	0.70	0.98	0.95							Future
	M	Fan (Stage 1)					1.05	1.50	0.70	0.85	0.73							Future
	M	Oil Cooler (Stage 1)					2.59	3.70	0.70	0.85	0.73							Future
	M	Pre-Lube Pump (Stage 2)					3.92	5.60	0.70	0.85	0.73							Future
	F	Lube Oil Heater (Stage 2)					5.25	7.50	0.70	0.98	0.95							Future
	M	Fan (Stage 2)					1.05	1.50	0.70	0.85	0.73							Future
	M	Oil Cooler (Stage 2)					2.59	3.70	0.70	0.85	0.73							Future
KM-5420	***M***	***Instrument Air Compressor***	*x*				***58.10***	***70.00***	***0.83***	***0.93***	***0.82***					***62.47***	***43.61***	***Upgrade Inst Comp in WN***
	F	***Instrument Air Compressor Starter Panel***	*x*				***15.00***	***20.00***	***0.75***	***0.98***	***0.95***							***To be removed in WN Ph***
LP-402	M	Platform Normal Lighting Panel		x			22.50	30.00	0.75	0.91	0.78	24.73	19.84					
LP-501	F	Lighting Panel LQ Platform (Normal Ltg.)		x			7.00	10.00	0.70	0.98	0.95	7.14	2.35					
P-1150	F	Sump Pump			x		2.59	3.70	0.70	0.98	0.95			2.64	0.87			
HVAC-04	M	HVAC			x		10.50	15.00	0.70	0.85	0.73	12.35	11.57					
P-1420	F	Glycol Pump		x			13.95	18.60	0.75	0.98	0.95	14.23	4.68					
P-1425	M	Glycol Pump		x			13.95	18.60	0.75	0.91	0.78					15.33	12.30	
P-1900	M	Glycol Transfer Pump		x			1.05	1.50	0.70	0.85	0.73	1.24	1.16					
SC-2000	M	Survival Capsule - Lower Deck	x				20.25	27.00	0.75	0.91	0.78					22.25	17.85	
WR-5	M	Welding Receptacle - Upper Deck			x		10.50	15.00	0.70	0.85	0.73					12.35	11.57	
	M	Lube Oil Heater (1st stage) (Future)						0.00										
P-1750	M	Pipeline Inhibitor Pump			x		0.26	0.37	0.70	0.85	0.73	0.30	0.29					
P-1760	M	Gas Inhibitor Pump			x		0.53	0.75	0.70	0.85	0.73	0.62	0.58					
P-1800	M	Mix Pump (Future)					0.13	0.19	0.70	0.85	0.73							
P-1790	M	Continuous Transfer Pump			x		0.26	0.37	0.70	0.85	0.73	0.30	0.29					
P-1795	M	Continuous Transfer Pump			x		0.26	0.37	0.70	0.85	0.73	0.30	0.29					
P-1770	F	Batch Injection Pump (Future)					10.50	15.00	0.70	0.98	0.95							
P-1780	F	Batch Transfer Pump (Future)					0.39	0.56	0.70	0.98	0.95							
	F	Spare Space						0.00		0.98	0.95							
	F	After Cooler Fan (Stage 1)					16.50	22.00	0.75	0.98	0.95							Future
	F	After Cooler Fan (Stage 2)					22.50	30.00	0.75	0.98	0.95							Future
S-1165	F	xxxx					7.00	10.00	0.70	0.98	0.95			7.14	2.35			
	M	50A Spare Feeder						0.00		0.94	0.84							
	M	Spare Space						0.00		0.94	0.84							

Overall Duyong Compl Electrical Loads

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
P-1970	M	Jet Fuel Transfer Pump			x		2.80	4.00	0.70	0.91	0.86	3.08	1.83					
WR-4	F	Welding Receptacle (1 no.) - Lower Deck			x		10.50	15.00	0.70	0.91	0.86					11.54	6.85	
A-2600A/B/C	F	Gas Metering Skid			x		1.40	2.00	0.70	0.91	0.86			1.54	0.91			
		SUB-TOTAL										**64.30**	**42.84**	11.32	4.13	**127.52**	93.34	
GCP-MCC-101 415V MCC Compression Train No.1 (1000A, 3Ph, 50kA)																		
CM-2020-1	M	AC Starter Motor		x			170.00	200.00	0.85	0.94	0.91					180.85	82.40	
CM-2020-2	M	Pre/Post Lube Oil Pump	x				7.70	11.00	0.70	0.85	0.73					9.06	8.48	
CM-2020-3	M	Turbine Enclosure Fan A	x				3.85	5.50	0.70	0.85	0.73	4.53	4.24					
CM-2020-4	M	Turbine Enclosure Fan B	x				3.85	5.50	0.70	0.85	0.73					4.53	4.24	
EM-2030-1	M	Inter-Stage Cooler Fan #1		x			27.75	37.00	0.75	0.79	0.83	35.13	23.61					
EM-2030-2	M	Inter-Stage Cooler Fan #2		x			27.75	37.00	0.75	0.84	0.86	33.04	19.60					
EM-2050-1	M	After Cooler Fan #1		x			27.75	37.00	0.75	0.79	0.83	35.13	23.61					
EM-2050-2	M	After Cooler Fan #2		x			27.75	37.00	0.75	0.91	0.78	30.49	24.47					
EM-2060-1	M	Lube Oil Cooler Fan #1		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
EM-2060-2	M	Lube Oil Cooler Fan #2		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
EM-2060-3	M	Lube Oil Cooler Fan #3		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
CUM-2510A	M	MCR HVAC Cond. Unit - Compressor			x		22.50	30.00	0.75	0.91	0.78	24.73	19.84					
CUM-2510B	M	MCR HVAC Cond. Unit - Condensing Fan			x		1.54	2.20	0.70	0.85	0.73			1.81	1.70			
CUM-2510C	M	MCR HVAC Cond. Unit - Condensing Fan			x		1.54	2.20	0.70	0.85	0.73			1.81	1.70			
H-2540	F	Duct Heater			x		8.40	12.00	0.70	0.98	0.95			8.57	2.82			
H-2020	F	Lube Oil Heater			x		10.50	15.00	0.70	0.98	0.95			10.71	3.52			
BC-101	F	24V Battery Charger for Instr. & Control	x				1.49	2.50	0.60	0.98	0.95	1.52	0.50					
BC-103	F	110V Battery Charger for Gas Compr. Pre/P	x				15.56	18.50	0.84	0.98	0.95			15.88	5.22			
LC-101	F	Line Conditioner - 240V AC UPS	x				0.75	7.50	0.10	0.98	0.95					0.77	0.25	
	F	Spare Starter (37kW)					27.75	37.00	0.75	0.98	0.95							
	F	Spare Starter (11kW)					7.70	11.00	0.70	0.98	0.95							
	F	Spare Feeder (15A)					6.30	9.00	0.70	0.98	0.95							
LP-101	F	Lighting Distr. Board			x		12.78	14.20	0.90	0.98	0.95	13.04	4.29					
MR-2500	M	Monorail Hoist A			x		5.25	7.50	0.70	0.85	0.73			6.18	5.78			
		SUB-TOTAL										**204.77**	145.58	44.96	20.73	**195.20**	95.37	
GCP-MCC-102 415V MCC Compression Train No.2 (1000A, 3Ph, 50kA)																		
CM-3020-1	M	AC Starter Motor		x			170.00	200.00	0.85	0.94	0.91					0.00	0.00	
CM-3020-2	M	Pre/Post Lube Oil Pump	x				7.70	11.00	0.70	0.85	0.73					9.06	8.48	
CM-3020-3	M	Turbine Enclosure Fan A	x				3.85	5.50	0.70	0.85	0.73	4.53	4.24					
CM-2020-4	M	Turbine Enclosure Fan B	x				3.85	5.50	0.70	0.85	0.73					4.53	4.24	
EM-3030-1	M	Inter-Stage Cooler Fan #1		x			27.75	37.00	0.75	0.91	0.78	30.49	24.47					
EM-3030-2	M	Inter-Stage Cooler Fan #2		x			27.75	37.00	0.75	0.91	0.78	30.49	24.47					
EM-3050-1	M	After Cooler Fan #1		x			27.75	37.00	0.75	0.91	0.78	30.49	24.47					

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	kVAR	Intermittent And Spares [F] kW	kVAR	Standby [G] kW	kVAR	Remarks
EM-3050-2	M	After Cooler Fan #2		x			27.75	37.00	0.75	0.91	0.78	30.49	24.47					
EM-3060-1	M	Lube Oil Cooler Fan #1		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
EM-3060-2	M	Lube Oil Cooler Fan #2		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
EM-3060-3	M	Lube Oil Cooler Fan #3		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
H-3020	F	Lube Oil Heater		0			10.50	15.00	0.70	0.98	0.95			10.71	3.52			
E-2120	F	Fuel Gas Heater		x			49.80	60.00	0.83	0.98	0.95	50.82	16.70					
E-2160	F	Fuel Gas Super-Heater		x			30.00	40.00	0.75	0.93	0.82	32.26	22.52					
BC-102	F	24V Battery Charger for Instr. & Control	x				2.50	4.20	0.60	0.98	0.95	2.55	0.84					
UPS-101	F	240VAC UPS (10kVA) for Instr. & Control	x				7.50	8.00	0.94	0.98	0.95	7.66	2.52					
	M	Spare Starter (37kW)					27.75	37.00	0.75	0.91	0.78							
	M	Spare Starter (30kW)					22.50	30.00	0.75	0.91	0.78							
	M	Spare Starter (5.5kW)					7.70	11.00	0.70	0.85	0.73							
	F	Spare Feeder (15A)					6.30	9.00	0.70	0.98	0.95							
LP-101	F	Lighting Distr. Board			x		12.78	14.20	0.90	0.98	0.95	13.04	4.29					
MR-3500	M	Monorail Hoist B			x		5.25	7.50	0.70	0.85	0.73			6.18	5.78			
		SUB-TOTAL										260.01	174.40	16.89	9.30	13.59	12.72	
GCP-MCC-103 415V MCC Compression Train No.3 (1000A, 3Ph, 50kA)																		
CM-4020-1	M	AC Starter Motor		x			170.00	200.00	0.85	0.94	0.91					0.00	0.00	
CM-4020-2	M	Pre/Post Lube Oil Pump		x			7.70	11.00	0.70	0.85	0.73					9.06	8.48	
CM-4020-3	M	Turbine Enclosure Fan A	x				3.85	5.50	0.70	0.85	0.73	4.53	4.24					
CM-4020-4	M	Turbine Enclosure Fan B	x				3.85	5.50	0.70	0.85	0.73					4.53	4.24	
EM-4030-1	M	Inter-Stage Cooler Fan #1 (Decomissioned)		x			27.75	37.00	0.75	0.91	0.78							
EM-4030-2	M	Inter-Stage Cooler Fan #2 (Decomissioned)		x			27.75	37.00	0.75	0.91	0.78							
EM-4070-1	***M***	***After Cooler Fan #1***		***x***			***31.71***	***37.00***	***0.86***	***0.91***	***0.78***	***34.85***	***27.96***					***Upgrade Cooler in WN Pł***
EM-4070-2	***M***	***After Cooler Fan #2***		***x***			***31.71***	***37.00***	***0.86***	***0.91***	***0.78***	***34.85***	***27.96***					***Upgrade Cooler in WN Pł***
EM-4080-1	***M***	***After Cooler Fan #1***		***x***			***31.71***	***37.00***	***0.86***	***0.91***	***0.78***	***34.85***	***27.96***					***Upgrade Cooler in WN Pł***
EM-4080-2	***M***	***After Cooler Fan #2***		***x***			***31.71***	***37.00***	***0.86***	***0.91***	***0.78***	***34.85***	***27.96***					***Upgrade Cooler in WN Pł***
EM-4060-1	M	Lube Oil Cooler Fan #1		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
EM-4060-2	M	Lube Oil Cooler Fan #2		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
EM-4060-3	M	Lube Oil Cooler Fan #3		x			7.70	11.00	0.70	0.85	0.73	9.06	8.48					
CUM-2610A	M	MCR HVAC Cond. Unit - Compressor			x		22.50	30.00	0.75	0.91	0.78	24.73	19.84					
CUM-2610B	M	MCR HVAC Cond. Unit - Condensing Fan			x		1.54	2.20	0.70	0.85	0.73			1.81	1.70			
CUM-2610C	M	MCR HVAC Cond. Unit - Condensing Fan			x		1.54	2.20	0.70	0.85	0.73			1.81	1.70			
H-4020	F	Lube Oil Heater			x		10.50	15.00	0.70	0.98	0.95			10.71	3.52			
H-2640	F	Duct Heater			x		10.50	15.00	0.70	0.98	0.95			10.71	3.52			
E-2170	F	Fuel Gas Heater		x			30.00	40.00	0.75	0.98	0.95	30.61	10.06					
E-2110	F	Fuel Gas Super Heater		x			49.80	60.00	0.83	0.98	0.95	50.82	16.70					
PM-2220	M	Chemical Injection Pump		x			1.54	2.20	0.70	0.85	0.73			1.81	1.70			
	M	Spare Starter (30kW)					22.50	30.00	0.75	0.91	0.78							

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
	M	Spare Starter (2.2kW)					1.54	2.20	0.70	0.85	0.73							
	F	Spare Feeder (40A)					6.30	9.00	0.70	0.98	0.95							
	F	Spare Feeder (15A)					6.30	9.00	0.70	0.98	0.95							
MR-4500	M	Monorail Hoist C			x		5.25	7.50	0.70	0.85	0.73			6.18	5.78			
		SUB-TOTAL										277.24	188.11	33.04	17.91	13.59	12.72	
LQ-MCC-508 415V MCC Living Quarters (1000A, 3Ph, 50kA)																		
DP-516	F	Main Distribution Panel		x			595.00	700.00	0.85	0.98	0.95	607.14	199.56					
	F	Equip Spare					7.00	10.00	0.70	0.98	0.95							
DP-503	F	Power Distribution Panel - Comm Bldg		x			33.75	45.00	0.75	0.98	0.95	34.44	11.32					
	M	Air Conditioning Unit A			x		22.50	30.00	0.75	0.91	0.78	24.73	19.84					
DP-504	F	Power Distribution Panel - Elect Bldg		x			18.75	25.00	0.75	0.98	0.95	19.13	6.29					
	M	Air Conditioning Unit B			x		14.25	19.00	0.75	0.91	0.78	15.66	12.56					
	F	Space					7.00	10.00	0.70	0.98	0.95							
P-2510	M	Service Water Pump		x			33.75	45.00	0.75	0.93	0.82	36.29	25.33					
P-2515	M	Service Water Pump		x			33.75	45.00	0.75	0.93	0.82			36.29	25.33			
P-2650	M	Sump Pump		x			10.50	15.00	0.70	0.85	0.73			12.35	11.57			
LCP-2640	***F***	***LCP for Diesel Centrifuge Skid***					***1.05***	***1.50***	***1.00***	***0.98***	***0.95***			***1.07***	***0.35***			
SC-2700	M	Survival Capsule	x				20.25	27.00	0.75	0.91	0.78					22.25	17.85	
SC-2710	M	Survival Capsule	x				20.25	27.00	0.75	0.91	0.78					22.25	17.85	
WM-2530	M	Water Maker	x				58.52	70.50	0.83	0.93	0.82	62.92	43.92					
DB-7800	***F***	***Lighting & Small Power DB for GCM***					***7.00***	***10.00***	***0.70***	***0.98***	***0.95***			***7.14***	***2.35***			
P-2640/2641	***F***	***Diesel Centrifuge Skid***					***1.05***	***1.50***	***0.70***	***0.98***	***0.95***			***1.07***	***0.35***			
	F	Equip Spare					3.50	5.00	0.70	0.98	0.95							
LP-432	F	Emergency Lighting	x				18.75	25.00	0.75	0.98	0.95			19.13	6.29			
DU-7900B	***F***	***120V DC Battery Charger (160A) No.2***					***23.80***	***28.00***	***0.75***	***0.98***	***0.95***					***26.44***	***8.69***	
	F	Equip Spare					7.00	10.00	0.70	0.98	0.95							
SC-2720	M	Survical Capsule	x				20.25	27.00	0.75	0.91	0.78					22.25	17.85	
SC-2730	M	Survical Capsule	x				20.25	27.00	0.75	0.91	0.78					22.25	17.85	
P-2550	M	Potable Water Pump		x			5.25	7.50	0.70	0.85	0.73	6.18	5.78					
P-2555	M	Potable Water Pump		x			5.25	7.50	0.70	0.85	0.73					6.18	5.78	
	F	Equip Spare					7.00	10.00	0.70	0.98	0.95							
	F	Space					7.00	10.00	0.70	0.98	0.95							
	F	Space					7.00	10.00	0.70	0.98	0.95							
WR-1	F	Welding Receptacle Lower Deck			x		15.00	15.00	1.00	0.98	0.95					15.31	5.03	
	F	Equip Spare					7.00	10.00	0.70	0.98	0.95							
	F	Space					7.00	10.00	0.70	0.98	0.95							
SU-2600	M	Sewage Unit / CI Blower		x			0.70	1.00	0.70	0.85	0.73	0.82	0.77					
WR-2	F	Welding Receptacle Lower Deck			x		10.50	15.00	0.70	0.98	0.95					10.71	3.52	
P-2635	***M***	***Diesel Transfer Pump***					***1.05***	***1.50***	***0.70***	***0.85***	***0.73***			***1.24***	***1.16***			

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
	F	Equip Spare					7.00	10.00	0.70	0.98	0.95							
	F	Equip Spare					7.00	10.00	0.70	0.98	0.95							
C-1636	M	Standby Compressor	x				18.75	25.00	0.75	0.91	0.78					20.60	16.53	
P-2634	M	Diesel Transfer Pump	x				1.05	1.50	0.70	0.85	0.73			1.24	1.16			
CL-2520/25	F	Chlorine Unit		x			3.50	5.00	0.70	0.98	0.95	3.57	1.17					
LP-515	F	LQ Emergency Lighting Panel	x				22.50	30.00	0.75	0.98	0.95	22.96	7.55					
LP-501	F	LQ Normal Lighting Panel		x			15.00	20.00	0.75	0.98	0.95	15.31	5.03					
		SUB-TOTAL										849.15	339.12	79.53	48.55	168.26	110.97	
DDP-A 415V MCC (800A, 3Ph, 42kA)																		
P-210A	M	Continuous Downhole Injection Pump		x			1.05	1.50	0.70	0.85	0.73	1.24	1.16					
P-220A	M	Continuous Downhole Injection Pump		x			1.05	1.50	0.70	0.85	0.73	1.24	1.16					
P-250A	M	Mix Pump		x			0.18	0.25	0.70	0.85	0.73	0.21	0.19					
P-260A	M	Continuous Flowline Injection Pump		x			0.53	0.75	0.70	0.85	0.73	0.62	0.58					
P-165A	M	Sump Pump		x			2.63	3.75	0.70	0.85	0.73			3.09	2.89			
M-110A	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-111A	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-120A	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73			12.35	11.57			
P-145A	M	Transfer Pump		x			14.06	18.75	0.75	0.91	0.78			15.45	12.40			
P-146A	M	Transfer Pump		x			14.06	18.75	0.75	0.91	0.78					15.45	12.40	
P-381A	M	Diesel Transfer Pump		x			1.75	2.50	0.70	0.85	0.73			2.06	1.93			
SWBD 318	F	Platform Switchboard			x		41.50	50.00	0.83	0.98	0.95	42.35	13.92					
	F	Spare Feeder					0.00	0.00	0.70	0.98	0.95							
M-112A	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-113A	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-121A	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73			12.35	11.57			
		SUB-TOTAL										82.54	51.54	45.31	40.35	15.45	12.40	
DDP-B 415V MCC (800A, 3Ph, 42kA)																		
	LOADS ARE POWER DIRECTLY FROM CPP-MCC-408 AND CPP-MCC-409																	
DDP-C 415V MCC (800A, 3Ph, 42kA)																		
P-210C	M	Continuous Downhole Injection Pump		x			1.05	1.50	0.70	0.85	0.73	1.24	1.16					
P-220C	M	Continuous Downhole Injection Pump		x			1.05	1.50	0.70	0.85	0.73	1.24	1.16					
P-250C	M	Mix Pump		x			0.18	0.25	0.70	0.85	0.73	0.21	0.19					
P-260C	M	Continuous Flowline Injection Pump		x			0.53	0.75	0.70	0.85	0.73	0.62	0.58					
P-165C	M	Sump Pump		x			2.63	3.75	0.70	0.85	0.73			3.09	2.89			
M-110C	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
M-111C	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-120C	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73			12.35	11.57			
P-145C	M	Transfer Pump		x			14.06	18.75	0.75	0.91	0.78			15.45	12.40			
P-146C	M	Transfer Pump		x			14.06	18.75	0.75	0.91	0.78					15.45	12.40	
P-381C	M	Diesel Transfer Pump		x			1.75	2.50	0.70	0.85	0.73					2.06	1.93	
SWBD 318	F	Platform Switchboard			x		41.50	50.00	0.83	0.98	0.95	42.35	13.92					
	F	Spare Feeder					0.00	0.00	0.70	0.98	0.95							
M-112C	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-113C	M	Production Cooler Fan		x			7.84	11.20	0.70	0.85	0.73	9.22	8.64					
M-121C	M	Test Cooler Fan		x			10.50	15.00	0.70	0.85	0.73			12.35	11.57			
		SUB-TOTAL										82.54	51.54	43.25	38.42	17.51	14.33	
CPP-MCC-411 415V MCC Train No.4 (1250A, 3Ph, 50kA) New loads for West Natuna Phase 2 Project																		
		EXPORT COMPRESSOR																
CM-6020-1	M	Gas Turbine Starter Motor		x			127.50	150.00	0.85	0.94	0.91					0.00	0.00	VFD Driven VFD-6020-1
												0.00	0.00					
CM-6020-3	M	Turbine Enclosure Fan #1	x				10.50	15.00	0.70	0.85	0.73					12.35	11.57	
CM-6020-4	M	Turbine Enclosure Fan #2	x				10.50	15.00	0.70	0.85	0.73	12.35	11.57					
EM-6040-1	M	Lube Oil Cooler Fan #1		x			16.50	22.00	0.75	0.91	0.78					18.13	14.55	
EM-6040-2	M	Lube Oil Cooler Fan #2		x			16.50	22.00	0.75	0.91	0.78	18.13	14.55					
PM-6020-1	M	Compr. Main Lube Oil Pump		x			16.50	22.00	0.75	0.91	0.78	18.13	14.55					VFD Driven VFD-6020-2
PM-6020-2	M	Compr. Standby Lube Oil Pump		x			16.50	22.00	0.75	0.91	0.78					18.13	14.55	VFD Driven VFD-6020-3
CM-6020-2	M	Pre/Post Lube Oil Pump	x				7.70	11.00	0.70	0.85	0.73	9.06	8.48					
H-6021	F	Lube Oil Tank Heater		x			10.50	15.00	0.70	0.98	0.95			10.71	3.52			
EM-6030-1	M	Discharge Cooler Fan No.1		x			29.01	37.00	0.75	0.91	0.78	31.88	25.57					
EM-6030-2	M	Discharge Cooler Fan No.2		x			29.01	37.00	0.75	0.91	0.78	31.88	25.57					
DU-7900A	F	120V DC Battery Charger (160A) No.1	x				23.80	28.00	0.85	0.98	0.95	26.44	8.69					
BC-6020	F	120V DC LO Pump Charger (20A)	x				8.50	10.00	0.85	0.90	0.95	9.44	3.10					
		GT Dual Fuel System																
PM-6751	M	Diesel Booster Pump No.1	x				0.53	0.75	0.70	0.85	0.73					0.62	0.58	
PM-6761	M	Diesel Booster Pump No.2	x				0.53	0.75	0.70	0.85	0.73					0.62	0.58	
SK-1830	F	Dual Fuel Skid (G-1830)			x		1.54	2.20	0.70	0.98	0.95					1.57	0.52	
SK-1840	F	Dual Fuel Skid (G-1840)			x		1.54	2.20	0.70	0.98	0.95					1.57	0.52	
		HVAC SYSTEM																

Overall Duyong Compl lectrical Loads

Equipment No.:	Load Type	Description	Vital	Essential	Non-Essential	Restarting	Absorbed Load kW [A]	Load Rating kW [B]	Load Factor [A]/[B] [C]	Efficiency at Load Factor [C] [D]	Power Factor at Load Factor [C]	kW = [A]/[D] CONSUMED LOAD kVAR = kW * Tan @ Continuous [E] kW	Continuous [E] kVAR	Intermittent And Spares [F] kW	Intermittent And Spares [F] kVAR	Standby [G] kW	Standby [G] kVAR	Remarks
PF-5010-1	M	AHU Supply Fan No.1	x				2.00	3.00	0.70	0.85	0.73	2.35	2.20					
PF-5010-2	M	AHU Supply Fan No.2	x				2.00	3.00	0.70	0.85	0.73					2.35	2.20	
CU-5020A	M	ACCU Compressor A		x			9.50	11.00	0.70	0.85	0.73	11.18	10.47					
CU-5020A-1	M	ACCU 'A' Condenser Fan No.1		x			1.50	2.20	0.70	0.85	0.73	1.76	1.65					
CU-5020A-2	M	ACCU 'A' Condenser Fan No.2		x			1.50	2.20	0.70	0.85	0.73					1.76	1.65	
CU-5020B	M	ACCU Compressor B		x			9.50	11.00	0.70	0.85	0.73					11.18	10.47	
CU-5020B-1	M	ACCU 'B' Condenser Fan No.1		x			1.50	2.20	0.70	0.85	0.73					1.76	1.65	
CU-5020B-2	M	ACCU 'B' Condenser Fan No.2		x			1.50	2.20	0.70	0.85	0.73					1.76	1.65	
HW-5050	F	Electric Heater		x			6.30	9.00	0.70	0.98	0.95			6.43	2.11			
HCP-5000	F	HVAC Control Panel	x				0.70	1.00	0.70	0.98	0.95	0.71	0.23					Supplied fr 120V DC UPS
EF-5030A	M	Battery Room Exhaust Fan No.1	x				0.50	0.75	0.67	0.85	0.73	0.59	0.55					
EF-5030B	M	Battery Room Exhaust Fan No.2	x				0.50	0.75	0.67	0.85	0.73					0.59	0.55	
		UTILITIES																
DB-7800	F	Lighting & Small Power			x		9.00	10.00	0.90	0.98	0.95	9.18	3.02					
BM-7390	F	Monorail Hoist			x		5.25	7.50	0.70	0.98	0.95			5.36	1.76			
BM-7391	F	Monorail Hoist			x		5.25	7.50	0.70	0.98	0.95					5.36	1.76	
E-3110	F	Start-Up Seal Gas Preheater		x			3.88	4.31	0.70	0.98	0.95	3.96	1.30					
E-3160	F	Fuel Gas Superheater		x			98.10	109.00	0.83	0.98	0.95	100.10	32.90					
E-3170	F	Fuel Gas Superheater		x			98.10	109.00	0.83	0.98	0.95					100.10	32.90	
WR-1	F	63A, 5P, Welding Receptacle			x		18.00	20.00	0.90	0.98	0.95					18.37	6.04	
		SUB-TOTAL										287.16	164.41	22.50	7.40	196.22	101.71	

APPENDIX IV: Microturbines from Capstone Turbine

Product Catalog




Reliable power when and where you need it.
Clean and simple.

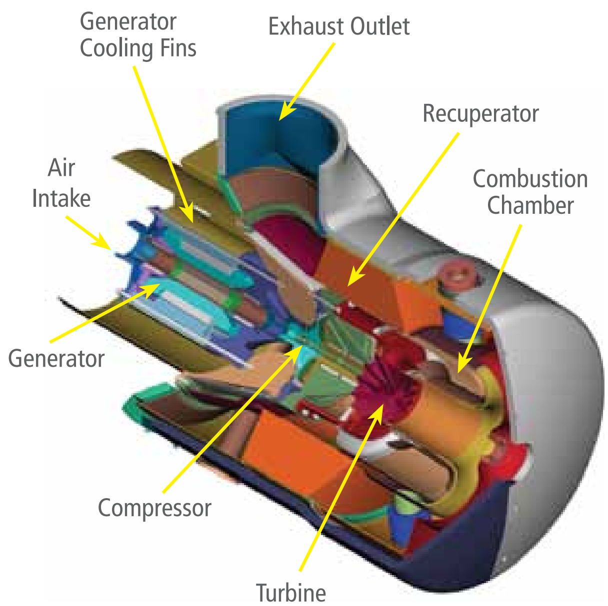
Capstone Microturbines

Capstone microturbines are used in distributed power generation applications including cogeneration, resource recovery, secure power, and hybrid electric vehicles (HEV).

Low-emission, clean-and-green Capstone microturbines are scalable from 30kW to 10MW. The C1000 Power Package, the world's first megawatt microturbine power system, can be configured into smaller 800kW and 600kW solutions – all within a single ISO-type container. Models are available that operate on: Natural Gas, Propane, Landfill Gas, Digester Gas, Diesel, Aviation, and Kerosene fuels.

- Ultra-low emissions
- One moving part – minimal maintenance and downtime
- Patented air bearing – no lubricating oil or coolant required
- 5 and 9 year Factory Protection Plans available
- Remote monitoring and diagnostic capabilities
- Integrated synchronization and protection
- Reliable – tens of millions of run hours and counting

PATENTED AIR BEARING



C30

C65

C65 ICHP

C65 CARB

HAZARDOUS LOCATIONS

Model	Fuels	Power Output [1]	Electrical Efficiency	Exhaust Gas Flow		Exhaust Temperature		Net Heat Rate		Dimensions [2] (W x D x H)	
		kW	%	kg/s	lbm/s	C°	F°	MJ/kWh	btu/kWh	m	in
GASEOUS FUELS [3]											
C30 LP	NG	28	25	0.31	0.68	275	530	13.8	13,100	0.76 x 1.5 x 1.8	30 x 60 x 70
C30 HP	NG, P, LG, DG	30	26	0.31	0.68	275	530	13.8	13,100	0.76 x 1.5 x 1.8	30 x 60 x 70
C30 HZLC [4]	NG	30	26	0.32	0.70	275	530	13.8	13,100	0.87 x 2.9 x 2.2	34 x 112 x 85
C65	NG, P	65	29	0.49	1.08	309	588	12.4	11,800	0.76 x 1.9 x 1.8	30 x 77 x 76
C65 ICHP	NG, P, LG, DG	65	29	0.49	1.08	309	588	12.4	11,800	0.76 x 2.2 x 2.4	30 x 87 x 93
C65 CARB	NG	65	28	0.51	1.13	311	592	12.9	12,200	0.76 x 2.2 x 2.6	30 x 87 x 103
C65 CARB	LG, DG	65	29	0.49	1.08	309	588	12.4	11,800	0.76 x 2.2 x 2.6	30 x 77 x 85
C65 HZLC [4]	NG	65	29	0.50	1.09	325	617	12.9	12,200	0.87 x 3.2 x 2.3	35 x 128 x 90
C200 LP	NG	190	31	1.3	2.9	280	535	11.6	11,000	1.7 x 3.8 x 2.5	67 x 150 x 98
C200 HP	NG, P, LG, DG	200	33	1.3	2.9	280	535	10.9	10,300	1.7 x 3.8 x 2.5	67 x 150 x 98
C200 HZLC [4]	NG	200	33	1.3	2.9	280	535	10.9	10,300	1.9 x 3.2 x 3.1	74 x 126 x 122
C600 LP	NG	570	31	4.0	8.8	280	535	11.6	11,000	2.4 x 9.1 x 2.9	96 x 360 x 114
C600 HP	NG, P, LG, DG	600	33	4.0	8.8	280	535	10.9	10,300	2.4 x 9.1 x 2.9	96 x 360 x 114
C800 LP	NG	760	31	5.3	11.7	280	535	11.6	11,000	2.4 x 9.1 x 2.9	96 x 360 x 114
C800 HP	NG, P, LG, DG	800	33	5.3	11.7	280	535	10.9	10,300	2.4 x 9.1 x 2.9	96 x 360 x 114
C1000 LP	NG	950	31	6.7	14.7	280	535	11.6	11,000	2.4 x 9.1 x 2.9	96 x 360 x 114
C1000 HP	NG, P, LG, DG	1000	33	6.7	14.7	280	535	10.9	10,300	2.4 x 9.1 x 2.9	96 x 360 x 114
LIQUID FUELS [5]											
C30	D, A, K	29	25	0.31	0.69	275	530	14.4	13,700	0.76 x 1.5 x 1.9	30 x 60 x 70
C65	D, A, K	65	29	0.49	1.08	309	588	12.4	11,800	0.76 x 1.9 x 1.8	30 x 77 x 76
C65 ICHP	D, A, K	65	29	0.49	1.08	309	588	12.4	11,800	0.76 x 2.2 x 2.4	30 x 87 x 93
C200	D	190	30	1.3	2.9	280	535	10.9	10,300	1.7 x 3.8 x 2.5	67 x 150 x 98

[1] Nominal full power performance at ISO conditions: 59° F, 14.696 psia, 60% RH
[2] Height dimensions are to the roofline. Exhaust outlet can extend up to 7 inches above the roofline.
[3] Models available to operate on these different fuels: NG – Natural Gas; P – Propane; LG – Landfill Gas; DG – Digester Gas
[4] Hazardous Location units suitable for use in potentially explosive atmospheres (UL Class I, Division 2 or Atex Class I, Zone 2)
[5] Models available to operate on these different fuels: D – Diesel; A – Aviation; K – Kerosene
Specifications are not warrantied and are subject to change without notice.

C200

C1000

Capstone Turbine Corporation® is the world's leading producer of low-emission microturbine systems, and was first to market with commercially viable air bearing turbine technology. The company has shipped thousands of Capstone turbines to customers worldwide. These award-winning systems have logged millions of documented runtime operating hours.

Capstone is a member of the U.S. Environmental Protection Agency's Combined Heat and Power Partnership which is committed to improving the efficiency of the nation's energy infrastructure and reducing emissions of pollutants and greenhouse gases.

A UL-Certified ISO 9001:2008 and ISO 14001:2004 company, Capstone is headquartered in the Los Angeles area with sales and/or service centers in China, Mexico, Singapore, South America, the United Kingdom, and the United States.

For more information about Capstone Turbine Corporation and its clean-and-green microturbine technology solutions, please visit www.capstoneturbine.com or call 818.734.5300.

Capstone®

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866.422.7786 • www.capstoneturbine.com

APPENDIX V: Waukesha natural gas generator

Waukesha natural gas generator

FOB Price: US $ 2,400 - 215,000 / Set

Specifications

1.waukesha natural gas generator
2.professional manufacturer

specifications of waukesha natural gas generator:

Gas gen-set Model	50HZ, 1500rpm,400/230V, 3P 4W		Rated Current (A)	Gas-Engine			Alternator	
	Rated Power (kW/kVA)	Standby Power (kW/kVA)		Model	Type	Rated Power (kW)	Model	Rated Power (kW/kVA)
SPT10GF	10/12.5	11/13.75	18	SP2100DT	four stroke, water cooled, wet cylinder liner	14	XN164C	10.8
SPT20GF	20/25	22/27.5	36	SP4100DT		23	XN184EF	20
SPT30GF	30/37.5	33/41.25	54	SP4105DT		38	XN184H	30
SPT40GF	40/50	44/55	72	SP6105DT		60	XN224D	40
SPT50GF	50/62.5	55/68.75	90	SP6105DT		60	XN224E	50
SPT70GF	70/87.5	77/96.25	126	SP6135DT		82	XN224G	70
SPT90GF	90/112.5	99/123.75	162	SP6135ADT		100	XN274D	90
SPT120GF	120/150	132/165	216	SP6140ADT		130	XN274F	120
SPT160GF	160/200	176/220	288	SP12V135DT		175	XN274H	160
SPT200GF	200/250	220/275	360	SP12V138DT		220	XN4C	200
SPT400GF	400/500	440/550	720	SP12V190DT		450	1FC	400
SPT500GF	500/625	550/687.5	900	SP12V190ZDT		550	1FC	500
SPT700GF	700/875	770/962.5	1260	SPG12V190ZLDT		750	1FC	700
SPT800GF	800/1000	880/1100	1440	SPA12V190ZLDT		850	1FC	800
SPT1000GF	1000/1250	1100/1375	1800	SPAD12V192ZLT2		1100	1FC	1000

1) Rated power from 10kW to 1000kW
2) power by famous and good quality gas engine and alternator
3) Longer life: natural gas engine has a life of over several years if it is properly operated and maintained
4) Low operation cost: natural gas has a rich reserve with low cost and a high rate of return
5) High profit: low operation cost, supply of electricity and thermal power at the same time, low maintenance cost
6) Coupled with brushless alternators of Leroy Somer / Engga
7) Well performed control system, high quality monitor instrument, with sound and light alarm devices, auto shutdown
8) Protection function: over-current, under-voltage, auto-regulate voltage, reverse power
9) Monitor function: speed, water temperature, lube-oil temperature, lube-oil pressure, exhaust temperature
10) Gas consumption: less than 0.33cbm/kWh
11) Supply connection: 3 phase, 4 lines
12) Rated voltage: 400V
13) Rated speed: 1,500rpm/1,800rpm
14) Rated frequency: 50Hz / 60Hz
15) Rated power factor: 0.8
16) Exciting way: brushless
17) Starting mode: 24V DC electric starting system
18) Cooling mode: closed-circuit cooling system

packing in wooden case

APPENDIX VI: Greenpower 600kW natural gas generator

600KW natural gas generator/GPEC-600T

Product Details:

Place of Origin	Jiangsu, China (Mainland)
Brand Name	Greenpower
Model Number	GPEC-600T
Output Type	AC Three Phase
Speed	1000RPM
Frequency	50HZ
Rated Power	600KW
Rated Voltage	400V
Rated Current	1082
Color	optional

Payment & Shipping Terms:

Price:	FOB USD 90000~100000 / Set
Minimum Order Quantity:	1 Set/Sets
Port:	Shanghai
Packaging Details:	Standard Export Packing
Delivery Time:	within one month
Payment Terms:	L/C,D/A,D/P,T/T,Western Union,MoneyGram
Supply Ability:	25 Set/Sets per Week

APPENDIX VII: General Electric natural gas generator

GE
Energy

Jenbacher type 3

efficient, durable, reliable

Long service intervals, maintenance-friendly engine design and low fuel consumption ensure maximum efficiency in our type 3 engines. Optimized components prolong service life even when using non-pipeline gases such as landfill gas. The type 3 stands out in its 500 to 1,100 kW power range due to its technical maturity and high degree of reliability.

reference installations

model, plant	key technical data	description	
J312 GS **Containerized solution** **Landfill site;** **Cavenago, Italy**	Fuel .... Landfill gas Engine type .... 3 x JMC 312 GS-L.L Electrical output .... 1,803 kW Thermal output .... 2,241 kW Commissioning .... September 1999	Every system has its own landfill gas feeder line and exhaust gas treatment line. The generated electricity is used on-site, excess power is fed into the public grid. The employment of the CL.AIR® system ensures the purification of the exhaust gas to meet stringent Italian emission requirements. As a special feature, at this plant the thermal energy is used for landfill leachate treatment, as well as for greenhouse heating.	
J316 GS **Profusa,** **producer of coke;** **Bilbao, Spain**	Fuel .... Coke gas and natural gas Engine type .... 12 x JGS 316 GS-S/N.L Electrical output a) with 100% coke gas .... 5,642 kW b) with 60% coke gas and 40% natural gas, or 100% natural gas .... 6,528 kW Commissioning .... November 1995	This installation designed by GE's Jenbacher product team enables Profusa to convert the residual coke gas with a hydrogen content of approximately 50% into valuable electrical energy.	
J320 GS **Ecoparc I;** **Barcelona, Spain**	Fuel .... Biogas and natural gas Engine type .... 5 x JMS 320 GS-B/N.L Electrical output .... 5,240 kW Thermal output a) with biogas .... 2,960 kW b) with natural gas .... 3,005 kW Commissioning .... December 2001 to January 2002	In Ecoparc I, organic waste is processed into biogas, which serves as energy source for our gas engines. The generated electricity is used on-site as well as fed into the public power grid. A portion of the thermal energy is used as process heat in the digesters, and the excess heat is bled off in the air coolers.	
J320 GS **Amtex Spinning Mills;** **Faisalabad, Pakistan**	Fuel .... Natural gas Engine type .... 4 x JGS 320 GS-N.L Electrical output .... 4,024 kW Commissioning .... November 2002, May 2003	The natural gas-driven units generate electricity for spinning mills in one of Pakistan's most important textile centers. Special features of this Jenbacher plant allow for high ambient temperature, dusty inlet air, and operation in island mode.	

GE imagination at work

technical data

Configuration	V 70°
Bore (mm)	135
Stroke (mm)	170
Displacement/cylinder (lit)	2.43
Speed (rpm)	1,500 (50 Hz) 1,200/1,800 (60 Hz)
Mean piston speed (m/s)	8.5 (1,500 rpm) 6.8 (1,200 rpm) 10.2 (1,800 rpm)
Scope of supply	Generator set, cogeneration system, generator set/cogeneration in container
Applicable gas types	Natural gas, flare gas, propane, biogas, landfill gas, sewage gas. Special gases (e.g., coal mine gas, coke gas, wood gas, pyrolysis gas)

Engine type	J312 GS	J316 GS	J320 GS
No. of cylinders	12	16	20
Total displacement (lit)	29.2	38.9	48.7

Dimensions l x w x h (mm)

Generator set	J312 GS	4,700 x 1,800 x 2,300
	J316 GS	5,200 x 1,800 x 2,300
	J320 GS	5,700 x 1,700 x 2,300
Cogeneration system	J312 GS	4,700 x 2,300 x 2,300
	J316 GS	5,300 x 2,300 x 2,300
	J320 GS	5,700 x 1,900 x 2,300
Container	J312 GS	12,200 x 2,500 x 2,600
	J316 GS	12,200 x 2,500 x 2,600
	J320 GS	12,200 x 2,500 x 2,600

Weights empty (kg)

	J312 GS	J316 GS	J320 GS
Generator set	8,000	8,800	10,500
Cogeneration system	9,400	9,900	11,000
Container (generator set)	19,400	22,100	26,000
Container (cogeneration)	20,800	23,200	26,500

outputs and efficiencies

Natural gas

		1,200 rpm | 60 Hz					1,500 rpm | 50 Hz					1,800 rpm | 60 Hz				
NOx <	Type	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)
500 mg/m^3_N	312						[3] 526	39.4	635	47.6	87.0	540	37.2	723	49.8	87.0
	312	435	39.8	497	45.4	85.2	625	39.8	731	46.6	86.4	633	38.1	808	48.6	86.7
	316	582	40.3	649	44.9	85.2	834	39.9	988	47.3	87.2	848	38.2	1,079	48.7	86.9
	320	794	40.7	870	44.5	85.2	1,063	40.8	1,190	45.6	86.4	1,060	39.0	1,313	48.3	87.3
250 mg/m^3_N	312						526	38.6	659	48.4	87.0	540	36.1	767	51.3	87.4
	312						601	38.9	726	47.0	85.9	633	36.7	854	49.5	86.2
	316						802	39.0	967	47.0	86.0	848	36.9	1,140	49.6	86.5
	320						1,063	39.9	1,238	46.4	86.3	1,060	38.1	1,361	49.0	87.1
350 mg/m^3_N	312	418	38.7	500	46.2	84.9	601	39.1	736	47.9	87.0					
	316	559	38.8	666	46.2	85.0	802	39.2	983	48.0	87.2					
	320	729	39.1	858	46.0	85.1	1,064	40.1	1,222	46.1	86.2					

Biogas

		1,200 rpm | 60 Hz					1,500 rpm | 50 Hz					1,800 rpm | 60 Hz				
NOx <	Type	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)
500 mg/m^3_N	312						[3] 526	40.4	558	42.9	83.3	540	37.2	703	48.4	85.6
	312						625	40.0	680	43.6	83.6	633	38.1	787	48.4	86.5
	316						[3] 703	40.5	744	42.9	83.4					
	316						834	39.9	910	43.7	83.6	848	38.2	1,048	47.3	85.5
	320						1,063	40.8	1,088	41.7	82.5	1,060	39.0	1,274	46.9	85.9
250 mg/m^3_N	312											633	36.7	836	48.5	85.2
	316											848	36.9	1,114	48.4	85.3
	320											1,060	36.9	1,387	48.3	85.2

Propane

		1,200 rpm | 60 Hz					1,500 rpm | 50 Hz				
NOx <	Type	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)	Pel (kW)[1]	ηel (%)	Pth (kW)[2]	ηth (%)	ηtot (%)
500 mg/m^3_N	312	340	36.4	461	49.4	85.8	407	36.0	576	50.9	86.9
	316	455	36.6	616	49.5	86.1	544	36.1	769	51.0	87.1
	320	570	36.7	769	49.5	86.2	681	36.1	960	50.9	87.0
250 mg/m^3_N	312						407	33.9	630	52.5	86.4
	316						544	34.0	841	52.5	86.5
	320						681	34.0	1,049	52.4	86.4

1) Electrical output based on ISO standard output and standard reference conditions according to ISO 3046/I-1991 and p.f. = 1.0 according to VDE 0530 REM with respective tolerance; minimum methane number 70 for natural gas
2) Total heat output with a tolerance of +/- 8%, exhaust gas outlet temperature 120°C, for biogas exhaust gas outlet temperature 180°C
3) Special version with higher compression ratio

All data according to full load and subject to technical development and modification.

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APPENDIX VIII: Technical Report

Energy Recovery Studies for Flare Systems in Offshore Oil and Gas Facilities

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***Abstract*— Flaring is a controlled burning of hydrocarbon gases and it is a common operation in oil and gas facilities. Flare system acts as the safety valve to avoid overpressure in the production line. Flaring involves combustion of precious natural gases which occurs at the flare header. This is indeed a waste of energy, and therefore, the hydrocarbon gases should be recovered for better applications instead of conventional flaring to the atmosphere. Electricity generation from the combustible gases is the ultimate aim for this study. Auxiliary electrical system such as lighting, water heating, and air conditioning can be supplied through this gas powered electricity generation. Duyong gas platform, operated by PETRONAS Carigali has been selected to be the reference field for this study due to the high energy demand by the platform. Flare gas data from the field has been used in the modeling process using HYSYS simulation. Results obtained from HYSYS indicate that Duyong field has the potential for flare gas recovery due to high power output generated from the system. Cost analysis was carried out particularly on microturbines as the prime mover, and it shows that high initial investment is needed to fund this project.**

***Keywords*— Recovery, flare, HYSYS, Duyong, microturbines**

I. Introduction

Worldwide, oil and gas industry has become one of the most profitable sectors for the producing countries. The industry has undergone a rapid advancement from being a mere hydrocarbon production for export purposes to further process the resources and converted it into commodities. An oil and gas refinery consists of complex integration of processes and equipments in the production line.

Flare relief system installed in oil and gas production facility acts as an emergency relief system to avoid over-pressure in the production line. The main purpose of flaring is to keep the facility running safely especially during start-up, planned maintenance or unplanned operational interruptions.

This project intends to develop a comprehensive study on the flare gas energy recovery for offshore oil and gas facilities in Malaysia. Duyong gas platform, operated by PETRONAS Carigali Sdn. Bhd (PCSB) is used as the base reference for this project.

The selection of Duyong as the reference field is due to the fact that it is a hub platform which integrates surrounding platforms. This explains on the 24-hours flaring operation at the site. In addition to that, Duyong have had frequent power failure which results in huge production lost. Hence, it is necessary for the platform to have a backup power system to avoid recurrence in the future. The objectives of this project are to validate the feasibility of using flare gas recovery system at Duyong platform for electricity generation and to provide system modelling of the flare gas recovery system for Duyong platform using HYSYS software.

II. LITERATURE REVIEW

A. *Flare Gas Recovery System*

(Rahimpour & Jokar, 2012) have conducted a detailed feasibility study of flare gas reformation to practical energy in Farashband gas refinery in Iran. The objectives of this study are to propose 3 methods to recover flare gas instead of conventional gas-burning. The proposed methods are (1) gas-to-liquid (GTL) production, (2) electricity generation with a gas turbine and (3) compression and injection into the refinery pipelines. Simulation method is used to determine the amount of flare gas, the number of GTL barrels, power generated by the gas turbine and the required compression horsepower. Method 2 is very much related to this project. The outcome of the simulation for method 2 shows that the power output from the gas turbine is 25MW. The details of the simulation are described in tables and figures below.

Table 1: Comparison between industrial and simulation data of flare gas

Component	Mole fraction (experimental) [52]	Mole fraction (simulation)	% Error
Methane	0.879662	0.884511	−0.55
Ethane	0.034552	0.036113	−4.51
Propane	0.009521	0.008912	6.39
Nitrogen	0.032899	0.029123	11.47
CO_2	0.029666	0.027512	7.26
i-Butane	0.002357	0.002898	−22.95
n-Butane	0.003377	0.003125	7.46
C_5^+	0.004608	0.004721	−2.45
H_2O	0.003052	0.002841	6.91
H_2S	0.000077	0.000080	−3.89
Benzene	0.000067	0.000072	−7.46
Toluene	0.000073	0.000078	−6.84

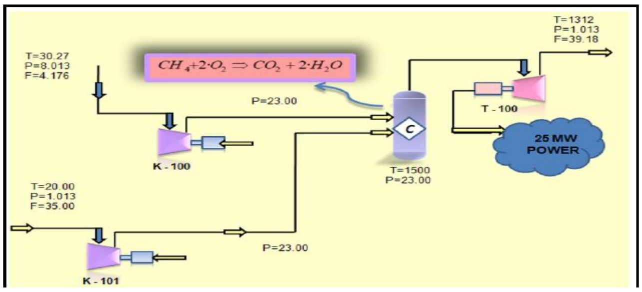

Fig. 1: Process flow diagram of power plant simulation

(Zadakbar, Vatani, & Karimpour, 2008) devised practical method to approach zero flaring through installation of Flare Gas Recovery Unit (FGRU) for oil and gas production facilities. In their work, they present two case studies of reducing, recovering and reusing flare gases from the Tabriz Petroleum Refinery and Shahid Hashemi-Nejad (Khangiran) Gas Refinery, both located in Iran. The flare gases are compressed and returned to the fuel gas header for immediate use as gas fuels. The results of their work are described as below.

Table 2: The compositions of flare gases produced by important nods

Component	MDEA flash drum	MDEA regenerator/reflux drum	Residue gas filter	inlet gas separator
Methane	47.07	0.6	98.5	88.38
Ethane	0.16	-	-	0.56
Propane	0.0058	-	-	0.09
i-Butane	0.0019	-	-	0.02
n-Butane	-	-	-	0.03
i-Pentane	-	-	-	0.02
n-Pentane	-	-	-	0.02
n-Hexane	-	-	-	0.1
CO_2	40.85	56.39	0.01	6.41
H_2S	8.06	33.96	4 ppm	3.85
N_2	0.94	-	0.57	0.52
H_2O	2.91	9.05	0.01	0.03
COS	-	91 ppm	8 ppm	17 ppm

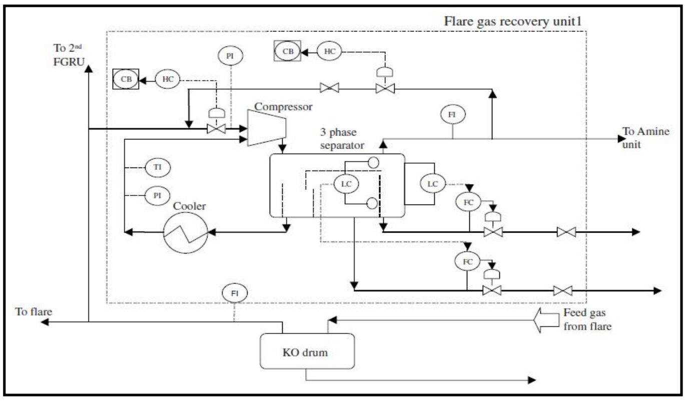

Fig. 2: The first unit of the FGRU for the Tabriz petroleum refinery

(Mitre, Lacerda, & de Lacerda, 2005) have conducted a study on thermoelectric plant of combined cycle and its environment impact by using HYSYS simulation. The thermoelectric plant uses natural gas as fuel, consists of a natural gas cycle and a steam cycle. Natural gas is burned in a combustion chamber, and the flue gas is expanded in a gas turbine which generates electricity. In their work, Bolivian natural gas with flow rate of 1.2 MMm^3/d (42.4 MSCF/d) is used as their base reference whose composition is shown in table 3.

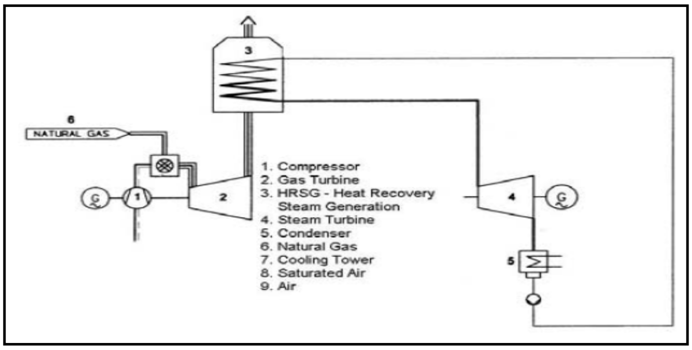

Fig. 3: Simplified scheme of a thermoelectric plant

Table 3: Natural gas composition (Bolivian)

Components	Volumetric fraction
Nitrogen	0.01420
Carbon Dioxide	0.00080
Methane	0.91800
Ethane	0.05580
Propane	0.00970
i-Butane	0.00030
n-Butane	0.00020
i-Pentane	0.00050
n-Pentane	0.00050
H_2S	0.00008

Table 4: Energy production

Energy	MW
Energy consumption	**140.7**
Air compression	139.6
Water pump	1.1
Energy production	**361.3**
Gas expansion	270.4
Steam expansion	90.9
Net energy production	**220.6**
Gas cycle	130.8
Water cycle	89.8

The result shows that a significant amount of energy is produced from the plant, but at the same time it also produces a high amount of pollutants to the atmosphere (CO, CO_2, SO_2, NO_2).

(Mourad, Ghazi, & Noureddine, 2009) proposed a method for recovery of flared gas through crude oil stabilization by multi-staged separation with intermediate feeds. They proposed that the separation of gas and oil phases remains the most vital stage in surface production, rather than flaring that produces a great number of harmful by-products. Algerian crude oil data is used as their reference data and the separation of the gases is done in three or four stages through HYSYS simulation. Figure 4 below shows the separation stages with intermediate feeds.

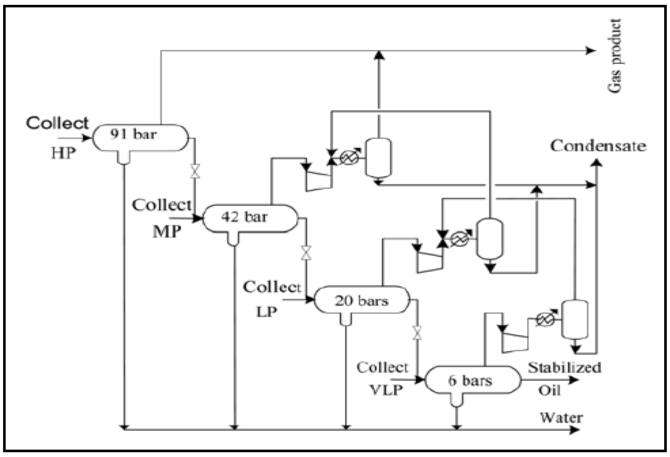

Fig. 4: Separation stages with intermediate feeds

From the results obtained, they conclude that GTL technology is one best alternative to recover the flared gas through crude oil stabilization by a multi-staged separation with intermediate feeds.

However, there is no study that has been carried out to devise practical method of using flare gas energy recovery in Malaysia, particularly for offshore production facility. In addition to that, there is also no comprehensive study of using HYSYS process simulation was carried out with regards to the flare gas energy recovery system. It is hoped that this project will be the base reference for the future flare gas recovery study in Malaysia.

B. Flare Gas Recovery System Design

According to (Analysis, Dec 2008), microturbines are currently operating in resource recovery operations at oil and gas production fields, where by-product gases serve as essentially free fuel. Reliable, less surveillance and monitoring operation is important since these locations may be isolated from the main grid i.e offshore platform. Figure 5 below shows the schematic of a microturbine-based combined heat and power (CHP) system for a single shaft.

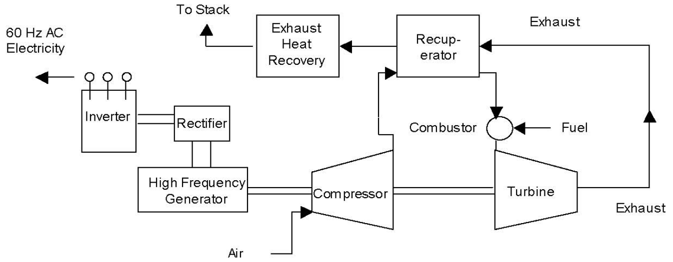

Fig. 5: Microturbine-Based CHP System (Single-Shaft Design)

III. METHODOLOGY

The first part of the project would focus on the fundamental understanding on the topic. This is achieved through detailed analysis on the literature review and past research previously done on the subject. During this part also, it is necessary to establish connection with the reference field to obtain required information especially on the flare gas data which will then be used in HYSYS software for simulation.

The second part of the project is mainly focused on optimizing results obtained during the first part. HYSYS results are compared with theoretical results using thermodynamics. This is to ensure the reliability of the results acquired. Apart from that, cost analysis is also done during the second part of the project to validate the economic feasibility of the system. The last part of the project is to propose the system to the field for future development purposes.

All simulations done in HYSYS will be based on the actual flare gas data obtained from the reference field (Duyong Gas Platform). Table 5 and 6 show the values of the flare gas data used in the simulation process. The chemical reactions in the natural gas combustion process will solely consider for Methane, CH_4 as follows:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \;\; ; \Delta H = -891 \text{ kJ/mol} \quad (1)$$

The above chemical reaction will theoretically contribute 891 kJ of energy (on a mole basis) if there was a complete combustion. This value serves as a guide/reference for the amount of energy available for recovery into useful form.

As the process components are all gases, the selected fluid package would be the Peng Robinson in the HYSYS simulation. The characteristics of air are taken with reference to the literature review previously done. When all the necessary data are in place, the physical system can be modeled in the HYSYS environment and the results can be achieved with correct components arrangements and integrations.

Table 5: Duyong gas composition (Carigali, Important Daily Report, 2012)

DAILY REPORT: 1ST MARCH 2012	
COMPONENTS	**COMPOSITION**
METHANE	83.141295
ETHANE	9.697911
PROPANE	1.856903
N-BUTANE	0.448056
I-BUTANE	0.587834
N-PENTANE	0.015655
I-PENTANE	0.029646
HEXANE	0.004939
HEPTANE	0.049899
OCTANE	0.032335
NONANE	0.000660
CO2	3.637937
N2	0.495610

H2O	0.001309
H2S	0.000010

Table 6: Characteristics of Duyong flare gas (Carigali, Important Daily Report, 2012)

Pressure (Bar)	69.17
Temperature (^{O}C)	23.70
Molar flow (MMSCFD)	1.5

Molar flow of the flare gas is showing 1.5 MMSCFD of operation. For the purpose of this study, the amount of molar flow that will be used in HYSYS simulation is 0.75 MMSCFD maximum. This is to consider the fluctuating conditions of the parameter in daily operations.

Microturbine is a small scale turbine generation system which extracts energy from a flow of combustion gas. Microturbines offer several advantages compared to other technologies for a small scale power generation system. It is compact size, small number of moving parts, and most importantly having greater efficiency, it is the best option for power generation at offshore location.

Microturbines can be classified into two general classes which are:

- **Recuperated microturbines**: It employs a sheet-metal heat exchanger that recovers some of the heat from an exhaust stream and preheats the incoming air stream supplied to the combustor. The efficiency for this type of microturbines is between 20 to 40%.
- **Unrecuperated microturbines**: This type of microturbines can be illustrated in a simple cycle, where compressed air is mixed with fuel and burned under constant pressure. Unrecuperated microturbines have lower efficiency at around 15%, but it is lower capital costs.

Hence, for comparison purposes, two options of microturbines will be used in HYSYS simulations which are:

i. OPTION 1: Microturbines with recuperator
ii. OPTION 2: Microturbines without recuperator

Characteristics on both of these options will be discussed further in the next preceding sections. In order to complement HYSYS results, thermodynamics calculation using Brayton Cycle is applied on each process and the equation used is:

$$\dot{Q}_x = \dot{m}C_p(T_1 - T_2) \qquad (2)$$

Where:

$\dot{Q}_x = Net\ power\ harvested\ at\ x\ stage, kW$

$\dot{m} = Mass\ flow\ rate\ of\ the\ gas, kg/s$

$C_p = Mass\ heat\ capacity\ of\ the\ gas, \frac{kJ}{kg-C}$

$T_1 = Gas\ temperature\ before\ expansion, °C$

$T_2 = Gas\ temperature\ after\ expansion, °C$

Daily operations provide a wide range of possible parameters in the flow line. Hence, the simulated HYSYS arrangements using default parameters are not always accurate all the time. Therefore, in order to obtain better estimation, parameters need to be varied to complement with fluctuating conditions in the flow line. The default parameters used in HYSYS simulation are as follows:

i. Temperature : 23.70^{o}C
ii. Pressure : 8.013 Bar
iii. Molar flow : 0.75 MMSCFD

Sensitivity analysis is carried out to evaluate the effect of 3 main parameters which are temperature, pressure, and molar flow to the power output. The value for each parameter is varied while maintaining the others and the value is changed by means of percentage difference with respect to default parameters obtained using HYSYS.

Graphs of the sensitivity analysis will be showing the level of sensitivity for each parameter. Parameter having the steepest gradient is the most sensitive parameter and vice versa.

IV. RESULTS AND DISCUSSION

There are two available options for microturbines which are recuperated and unrecuperated. The preceding section explains on the results obtained from HYSYS simulation utilizing the actual flare gas data from the field (Temperature, Pressure, Molar Flow, Gas Composition).

A. *Option I: Microturbines with recuperator*

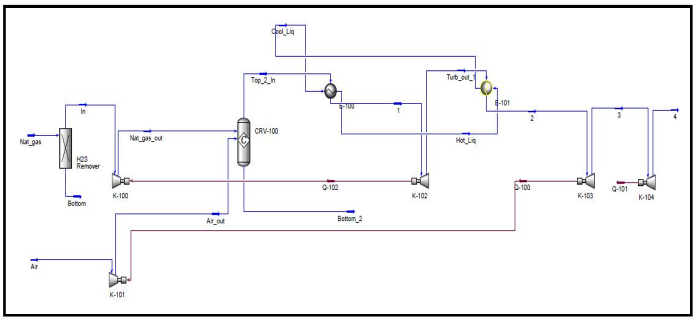

Fig. 6: HYSYS arrangements for microturbine with recuperator

Theoretical calculations:

$$\dot{Q}_x = \dot{m}C_p(T_1 - T_2)$$

$$\dot{Q}_1 = (0.365)(2.870)(800 - 762.3) = -39.22\ kW$$

$$\dot{Q}_2 = (0.365)(2.869)(800 - 709.8) = -93.81\ kW$$

$$\dot{Q}_3 = (0.365)(2.768)(709.8 - 200) = 511.53\ kW$$

Total net power = **378.50 kW**
HYSYS results = **307.12 kW**
Percentage different = **23.24%**

The basic operation of recuperator is similar to that of heat exchanger which allows the heat transfer of two different fluids. In the case of microturbines, the recuperator acts as the heat exchanger between the outlet gas from the combustion chamber/combustor and the working fluid. As the gas outlet temperature from the combustor is too high i.e 1600^{o}C, it needs to be cooled down to around 800^{o}C due to the metallurgical limit of the turbine blade that can only cater for gases with maximum temperature of 800^{o}C.

B. Option II: Microturbines without recuperator

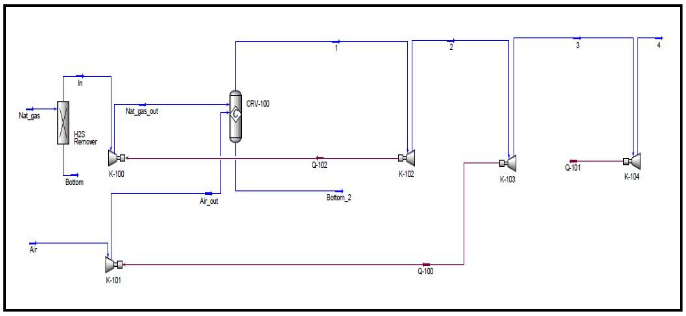

Fig. 7: HYSYS arrangements for microturbines without recuperator

Theoretical calculations:

$$\dot{Q}_x = \dot{m}C_p(T_1 - T_2)$$
$$\dot{Q}_1 = (0.365)(2.825)(756.3 - 718) = -39.22\ kW$$
$$\dot{Q}_2 = (0.365)(2.780)(718 - 624.5) = -94.22\ kW$$
$$\dot{Q}_3 = (0.365)(2.660)(624.5 - 200) = 409.32\ kW$$

Total net power = **275.88 kW**
HYSYS results = **223.12 kW**
Percentage difference = **23.65%**

From the results obtained, we can see that there are some differences between HYSYS results and theoretical results. These differences are due to the fact that in HYSYS, it considers efficiencies in the system which results in lower power output generated. Inefficient system will also give some effects on power and heat loss along the way. Whereas in theoretical calculations, it does not consider any efficiency and that is the reason why the net power output generated is higher.

C. Sensitivity Analysis

In sensitivity analysis, the default parameters are used as the base reference and each value of the parameters will be varied and calculated with percentage deviations from the original value. The range of the percentage deviations is between -60% to 60%. The results are then presented in graph form to evaluate the sensitivity for each parameter. The graphs are shown below.

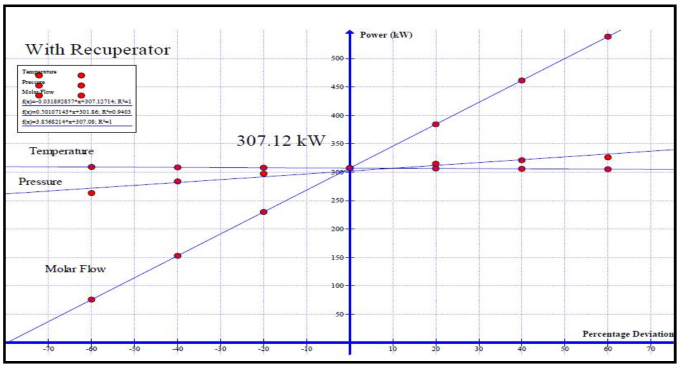

Fig. 8: Sensitivity analysis for microturbines with recuperator

Equations for the parameters:

- Temperature : y = -0.03x + 307.12
- Pressure : y = 0.50x + 301.86
- Molar Flow : y = 3.86x + 307.08

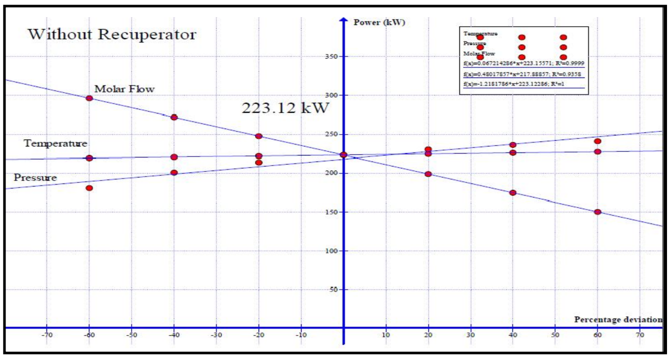

Fig. 9 Sensitivity analysis for microturbines without recuperator

Equations for the parameters:

- Temperature : y = 0.07x + 223.16
- Pressure : y = 0.48x + 217.89
- Molar Flow : y = -1.22x + 223.12

Gradient of the graph indicates the sensitivity of the parameters. As shown in the graph, we can see that molar flow is the most sensitive parameter compared to others while temperature is the least sensitive. It means that, slight changes of molar flow value in the flow line will affect power output significantly. Whereas changes in temperature will not affect power output much. Hence, in order for us to obtain constant power output to supply to the field, we need to priority attention to the volume of the gas in the flow line.

D. Cost Analysis

Microturbine with recuperator has been chosen to be the prime mover for this project. A wide range of microturbines manufacturers are available in the market, both local and abroad. A budgetary prices of microturbines obtained from Capstone Turbine Singapore is used as a datum for cost estimation for the proposed project. Table 7 below shows the variety of microturbines model from the Company and its prices.

Table 7: Prices of microturbine from Capstone Turbine (Capstone)

MODEL	RATED POWER (kW)	PRICE (USD)	PRICE (RM)*
CR30	30	52,185	165,948
CR65	65	88,515	281,478
CR200	200	294,525	939,590
CR600	600	883,575	2,809,770
CR1000	1000	1,137,780	3,618,140

* Exchange rate: 1USD = RM3.18

Hence, the suitable microturbine that suits with this project would be CR600 which costs approximately RM2.8 million for the equipments excluding installation and maintenance cost. The high amount of capital investment is indeed needed if microturbine is chosen to be the prime mover for this project. There are also some other alternatives of prime movers apart from microturbines that are available on the shelves. Table 8 below shows the comparison on the prime movers.

Table 8: Comparison on prime movers (Smith,2003)

PRIME MOVERS	COST/KW	EFFICIENCIES
Microturbines	RM2800-RM3800	40%
Gas Turbines	RM1300	38%
Reciprocating Engines	RM900-RM1300	50%

V. CONCLUSIONS AND RECOMMENDATIONS

Results obtained prove that the Flare Gas Recovery System (FGRS) has the potential of providing additional power to Duyong field. Vital and auxiliary equipments such as water maker, air conditioning, pumps and lighting can utilize the power generated by the FGRS, thus lowers the load requirement currently supplied by the existing gas turbines.

Both options of the microturbines show positive net power output. However, microturbines with recuperator has the highest net power output since its capability to absorb and preheat the incoming gas before expansion process, hence, it is the best option available. In addition, most microturbines available on the shelves are already equipped with recuperator due to its higher efficiency.

Sensitivity analysis done on both options shows that Molar Flow is the most sensitive parameter to power output generated. It indicates that the volume of gas coming to the FGRS should be given priority compared to other parameters i.e temperature, pressure. Slight changes on the volume of the gas in the flowline will give significant effect to the net power output in the microturbines.

All in all, it is clear that the FGRS is feasible to be implemented at the reference field. As for the future work, It is necessary for the research party – UTP and the industry – PCSB collaborate together especially on the practicality and implementation of the system at the site to ensure the success of this project. It is also hoped that this project will be used as the base reference for future flare gas recovery studies in Malaysia.

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