INTEGRATED RENEWABLE ENERGY MANAGEMENT SYSTEM FOR SUSTAINABLE DEVELOPMENT

By

MOHD HANIFF ABDUL HAMID

FINAL YEAR PROJECT

FINAL REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

INTEGRATED RENEWABLE ENERGY MANAGEMENT SYSTEM FOR SUSTAINABLE DEVELOPMENT

by

Mohd Haniff Abdul Hamid

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

Dr. Balbir Singh Mahinder Singh
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

JUNE 2007

CERTIFICATION OF ORIGINALITY

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

Mohd Haniff Abdul Hamid

ABSTRACT

The focus of this study is to look into the possibility of integrating a solar based system into an existing combined cycle power plant. This new system named as Integrating Solar Combined Cycle Power Plant (ISCCPP) consist 6 main parts which are Gas Turbine (GT), Heat Recovery Steam Generator (HRSG), Steam Turbine (ST), Condenser, Feedwater Tank and Solar Field. The solar energy is the alternative to overcome the crucial problem of the fossil fuel volatility, depletion and increasing of prices. In Eight Malaysia Plan (2000-2005), the expansion in the installed capacity of electricity from 14,291MW to 19,217MW. In year 2010, the installed capacity hike into 25,258MW (Appendix A). Besides it's risky to rely on the single and depleting energy sources. Therefore, the plan and proper management has to be done to ensure the continuously of producing power for sustainable human development. This project is to study the combined cycle power plant equations and merge with the solar radiation from the sun. It is translated into Visual Basic.NET in order to simulate the Combined Cycle Power Plant (CCPP) and Integrated Solar Combined Cycle Power Plant (ISCCPP) and make comparison. The ISCCPP consumes less of natural gas in producing power. Based on the current CCPP type, Lumut Power Plant, the maximum efficiency is 54%. Through the simulation and implementation of solar field by adding the local global solar radiation, at full load, this new system ISCCPP can produce more 59MW of electricity than CCPP. By doing this project work, it was revealed that the solar radiation in Malaysia is still low and only the 6 hours (10am-3pm) can be considered as the peak solar radiation which is very useful. Besides, the cloudy season can interrupt the capture amount of solar radiation by solar absorber. So the deep research has to be done to choose the suitable place for this system. Besides, with the hi-technology today this problem can be overcome.

ACKNOWLEDGEMENT

Alhamdulillah. For this Final Year Project II, I would like to express my gratitude to the Electrical & Electronic Engineering Department, Universiti Teknologi PETRONAS for the learning and experiences I gained during my study in UTP. The special thanks to my supervisor, Dr. Balbir Singh Mahinder Singh for his support, suggestion, criticism and evaluation of my project.

A special gratitude goes to Malaysia Meteorological Departments staff especially Mr Azhar Ishak for his kindness provides me the global solar radiation data and also thanks to Mr Abdul Shalihin Ahmad Sukri who had me in implementing the simulation for this project. A very thank you to the Universiti Teknologi PETRONAS for providing conducive facilities including the online database for journal and publications.

Last but not least to anyone who contribute directly or indirectly during my research project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

GT	Gas turbine
ST	Steam turbine
HRSG	Heat Recovery Steam Generator
CCPP	Combined Cycle Power Plant
ISCCPP	Integrated Solar Combined Cycle Power Plant
Q_1	Heat input for GT
CC	Combined cycle
ME	Methane
Q_2	Heat input for HRSG
Q_3	Heat input for ST
Q_4	Heat output from LP ST
Q_5	Heat input from solar field
Q_6	Heat input for new ST
Q_{HL1}	heat loss between two plants
Q_{HL2}	heat loss in condenser
W_{GT}	GT Power output
W_{ST}	ST power output
$W_{NEW\ ST}$	New ST power output
W_{CCPP}	Total power of CCPP
W_{ISCCS}	Total power of ISCCPP
η_{GT}	GT efficiency
η_{ST}	ST efficiency
η_{ISCCPP}	ISCCPP efficiency
η_{CC}	CCPP efficiency
HP	High pressure

LP	Low pressure
m	Mass flow rate
C_P	Enthalpy of the exhaust gas from the GT
σ	Total mass flow
T_{STACK}	Temperature at the stack
$\dot{m}_{LP}$	LP mass flow
$\dot{m}_{HP}$	HP mass flow
C_{LP}	Specific enthalpy drop in LP turbine
C_{HP}	Specific enthalpy drop in HP turbine
Q_u	Useful heat gain
T_{fo}	Outlet temperature
T_{fi}	Inlet temperature
U_{LR}	Overall heat loss coefficient
T_a	Ambient temperature
F_R	Heat removal factor
A_{eff}	Receiver effective area
S_R	Absorbed flux
C	Receiver concentration ratio
L	Length
D_o	Outer diameter of absorber tube
I_b	Beam radiation
ρ	Specular reflectivity of receiver surface
γ	Intercept factor
$(\tau\alpha)_b$	Average value of the transmissivity – absorptivity product for beam radiation
W	Aperture

V_w	Average velocity of the fluid inside the absorber tube
R_e	Reynolds number
D_i	Inner diameter of absorber tube
v	Kinematics viscocity
Nu_w	Nusselt number
P_r	Prandlt number
h_f	Heat transfer coeeficient
F_{RF}	Receiver efficiency factor
δT_1	
δT_2	
δT_3	Temperature coefficient
δT_4	
δT_5	
k	Thermal conductivity
D_{co}	Outer diameter of glass cover
D_{ci}	Inner diameter of glass cover
T_c	Cover temperature
V_{air}	Mean flow velocity
ε_p	Receiver tube emissivity
ε_c	Glass cover emissivity
σ	Stefan-Boltzmann constant
$\dot{m}$	Collector inlet mass flow rate LP side

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Currently, natural gas is the most preferable choice for electricity generation worldwide, where electrical power is generated by using both gas and steam turbines. Natural gas is cheaper and cleaner than other fossil fuels like oil and coal where less greenhouse gas is produced [1]. Being a clean fuel is a reason why this natural gas demand has grown so much especially for power generation. In Malaysia, there is tremendous growth of natural gas power plant, both in gas fired and combined cycle power plant. Altogether, there are 19 gas fuel and combined cycle power stations in Malaysia. Almost 86% of electricity in our country is still produced by conventional power plant by using the fossil fuels like natural gas, oil and coal. The efficiency of this plant is around 33% - 52% and the remaining energy is converted to heat which contain pollutant carbon dioxide (CO_2) and methane (CH_4) [2].

Our government is looking towards utilizing the renewable energy. The small renewable energy power programme (SREP) is now under proposal. This is an initiative of the Special Committee on Renewable Energy (SCORE) under to intensify the development of renewable energy as the fifth fuel resource. This strategy is to accomplish a significant share of renewable energy in the fuel mix of power generation industry in the long term. The renewable energy includes solar, biomass, biogas, municipal waste, mini-hydro and wind [3]. Malaysia is now under Ninth Malaysia Plan (2006-2010) and one of the thrust is to enhance the energy sector as an enabler towards strengthening economic growth. The government is looking at the possibility to diversify energy resource and try to reduce the dependency of petroleum products by increasing the use of alternative energy gradually. This is under sustainable energy development to ensure the efficient utilization of energy resource, to meet the increasing demand, to minimize wastage of energy, and reduce global warming cause. The other alarming factor is the world price of crude oil is volatile and has increased from an average RM 113.80 per barrel in 2000 to RM 210 in 2005. In order, to enhance the quality of life, concerted efforts are needed to manage resources wisely, utilizing them efficiently, in a scenario of rising energy prices. Therefore, the research and development of renewable energy technologies are being formulated where efforts will continue to circle a more conducive environment to support the implementation [4].

1.2 Combined Cycle Power Plant (CCPP)

Combined cycle power plant produces electricity from both the gas turbine and steam turbine. The main fuel that being used by this plant is gas (methane) and diesel is a backup. The main compartments in this plant are the gas turbine (GT), heat recovery steam generator (HRSG), steam turbine (ST), condenser and feedwater tank (FWT). The process starts at GT. The GT includes 3 main parts which is the compressor, combustion and the turbine itself. The air is sucked in through the air inlet and then it will be compressed in the compressor. This compressed air will be mixed with the natural gas and ignited in the combustion chamber. The works caused the mechanical energy where it rotates the turbine and drive the generator to generate electric power. The efficiency of GT is 33%. The exhaust gas produced by GT is led to the HRSG, produces the high pressure (HP) and low pressure (LP) steam. This steam is channeled to the dual pressure ST and produces another electric power through its generator. Finally, the steam balance is led to the condenser changing to water and this process is repeated. The efficiency of this plant is 54 % [5].

1.3 Parabolic Trough based Solar Power Plant

This solar power plant consists of a very large parabolic trough concentrator's field in series and parallel solar concentrator, heat exchanger, steam turbine and generator. The solar concentrator task is to focus the solar radiation from the sun. The global solar radiation is the summation of beam and diffuse radiation. Then the Heat Transfer Fluid (HTF) runs through the absorber tube to absorb the concentrated sunlight. By this action, the heat transfer fluid changes to steam where it is led to rotate the turbine and generate electricity on the generator. Then, the steam balance comes out of the turbine and flows to the condenser for the condensation process and return back to the feedwater tank before it pumps to the solar collector to convert it again to steam.

1.4 Problem Statement

Oil & natural gas volatility and price increases as the increasing of population, high demand and the depletion of the earth fossil fuel reserves. The consumption is still increasing since 1982 until now. In 1982 the consumption was 200 billion cubic feet and it kept increasing until in 2002, the consumption of natural gas was 1000 billion cubic feet (Appendix E). Although the supply of natural gas keep increasing but the reserve will only last for another 33 years [6]. After that, there no more natural gas reserves. The dependant on the fossil fuel is still high and keeps increasing year to year around the world where oil still remains as a dominant fuel until 2030. Natural gas is second highest in demand where it keeps increasing and growth faster in absolute term. The effort and development of the renewable energy technologies are still low. Human still prefer to use fossil fuel because of the less awareness about the affect to the global warming (Appendix F).

In the past few months, Malaysia utility sector has certainly seen a huge amount of news, its clear that the Tenaga Nasional Berhad (TNB) has been troubled by the rapid rise of this natural gas for the past few years. The government had no choice but to help it reverse its negative cash flow to meet the capital expenditure yearly the TNB has to raise its electricity tariff by 12% despite this gives negative impact to the public. This is due to the higher payment to PETRONAS as the gas price has been raised [7]. So the alternative action has to be taken to overcome this matter.

The latest disaster that happened in Malaysia was the worst floods in Johor. Normally, at the end of the year, the east of Peninsular Malaysia will experience the monsoon season. However due to the global warming effect, the wind direction has changed to the south, so this caused south of Peninsular Malaysia experienced its worst floods. Global warming is caused by the carbon dioxide, methane and other gases emission from the gas combustion. The carbon dioxide emission keeps increasing around the world and this is a very crucial issue (Appendix G) [8]. The power station sector is counted as the main contributor to this emission which contributes 21.3% (Appendix H). The Kyoto Protocol was introduced in order to stabilize the greenhouse gas concentration in the atmosphere so that it would prevent dangerous interference with the climate system. Malaysia is one of the members and must commit to reduce the emissions of the greenhouse gases [9].

Thus, the integration of solar energy based power system to the existing power plant is needed in order to overcome all this crucial matters. It is needed to diversify and harness the renewable energy due to the government intention not just relies on the fossil fuel which will be depleted in future. The simulation of this new system will relate the new idea to add solar field as an auxiliary part to the existing power plant. This project used the Lumut Power Plant as a reference.

1.5 Objectives

Based on the problem statements, the objectives of this project are:

1. To use a suitable solar energy based technology for energy conversion.
2. To integrate the solar energy collector to an existing electrical power plant for energy conservation and efficiency.
3. To design a suitable simulation software to carry out simulation studies on an integrated electrical power plant for efficient energy management.

The objectives of this new Integrated Solar Combined Cycle Power Plant (ISCCPP) are to increase the plant efficiency while reducing the natural gas consumption in order to cut the production cost. For the initial stage, the research on the Combined Cycle Power Plant (CCPP) has been done. The reference CCPP model is the Lumut Power Plant which is located in Lumut, Perak. The details about the designation and equations are discussed in Chapter 5. The scope of the studies for this project is how to integrate solar energy to the existing power plant. For the solar power plant type, the Kramer Junction in California is used as the reference. This plant uses the parabolic trough collector as the solar collector.

CHAPTER 2

LITERATURE REVIEW

2.1 Combined Cycle Power Plant

Commonly the combined cycle power plant consists of two types of turbine. There is the gas turbine and steam turbine which are to get better efficiency (54%). The reference plant that is being used for this project is the Lumut Power Plant. The plant is using the combination concept of the Brayton Cycle (Appendix B) in gas turbine with the Rankine Cycle in steam turbine. The process flow is start from its major equipment, gas turbine. The air is sucked in through the air inlet and the air will be compressed in the compressor from 1 bar to 12 bar. The compressed air then will be mixed with natural gas (methane, CH_4) and ignites in the combustion chamber. If the natural gas is tripped, the diesel will be used as a back up fuel. The temperature in the turbine (TIT) is at 1100°C. The energy produced in the combustion chamber is used to turn the gas turbine and drive the generator to generate 140MW of electricity.

Then, the exhaust gas produced from the gas turbine is led to the heat recovery steam generator (HRSG) in order to produce high pressure and low pressure steam. The steam produced is then channelled to the dual pressure steam turbine. The steam turbine will drive its generator to produce 230MW of electricity. After that, the steam will be condensed in the condenser. The condensate is collected in the hotwell before condensate extraction pump flow the condensate to the feed water tank. The feedwater tank serves as a buffer in the water steam cycle system. Finally the feedwater pump will supply water to the HRSG and this is circulated again (Appendix C). The total power output generated by this plant is 1950MW which consists of 9 gas turbines and 3 steam turbines (Appendix I) [10].

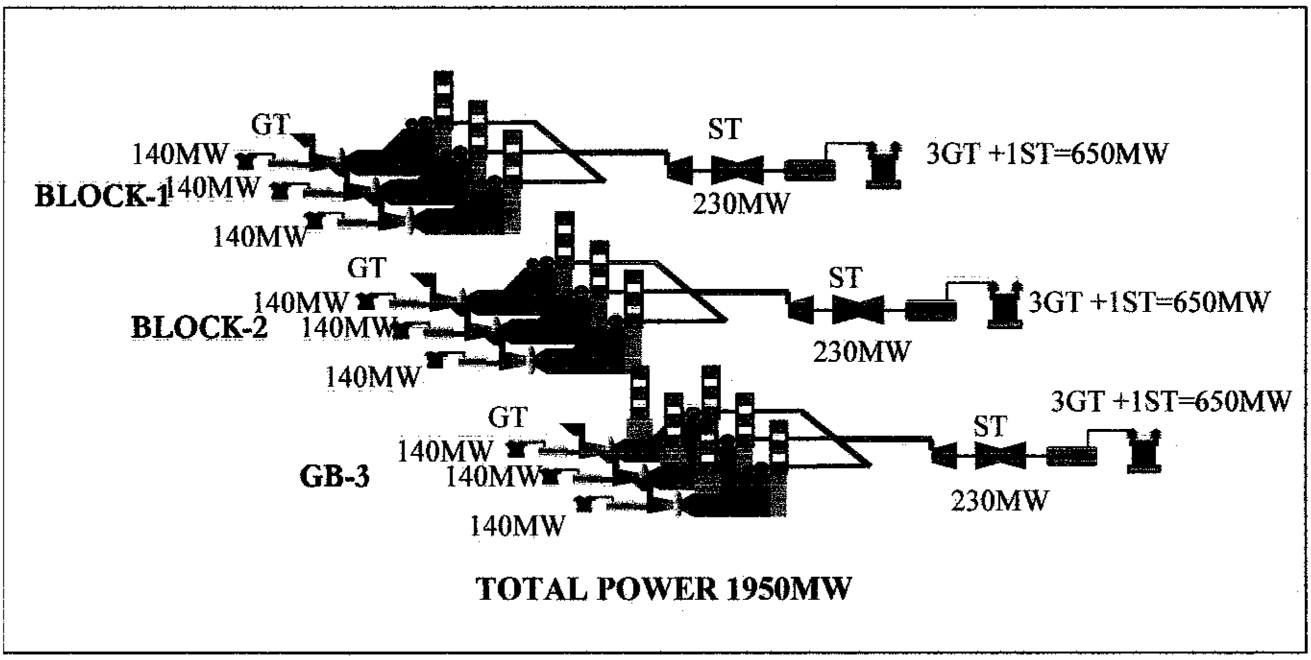


Figure 2.1 Block Diagram of 3 Block CCPP [6]

2.2 Solar Energy

Each day more solar energy falls to the earth than the total amount of energy the earth's approximately 6 billion inhabitants would consume in 26 years. Although every location on earth receives sunlight but the amount received varies greatly depending on the geographical location, season and light. The sun is a sphere intensely hot gas with a diameter of 1.39 x 10^9 m and distance of 1.5 x 10^9m from the earth. By an effective black body temperature of 5777K, the sun is a continuous fusion reactor.

One of the most important process is in which 4 hydrogen atoms combine to form 1 helium atom where the mass of the helium nucleus is less than the four protons (1 hydrogen = protons), mass having lost in the reaction and converted to energy [11]. The reaction is:

$$4\left({}_1H^1 \rightarrow {}_2He^4 + 26.7MeV\right)$$

The solar radiation that can be converted into useful energy lies between 0.3 μm and 3.0 μm [12].The distance between the earth and the sun always varies due to the earth rotating around the sun on its elliptical orbit. Even variation of the distance, not affect the amount of solar radiation that can reaches earth [13].

Although it is not necessary to use this energy, the need to tap the potential of solar energy is crucial of its because various benefits and the current energy need. This solar energy technologies offer a clean, renewable and domestic energy source. In addition, the generating system powered is modular therefore it can be constructed to meet any size necessity and can be enlarged to meet changing energy needs [14].

2.3 Integrated Solar Combined Cycle Power Plant

In an Integrated Solar Combined Cycle Power Plant (ISCCPP), the gas turbine remains like the conventional combined cycle, but it has been a improvement in producing the steam which can be from 2 sides, heat from exhaust gas and solar field. Preheating the feed water and superheating the steam will be performed by the gas turbine exhaust. Higher pressure and temperature of steam can be produce by this solar energy supplement. Steam produced in ISCCPP power plant is 100 bar pressure. These values are higher than steam properties in a conventional combined cycle, thus the efficiency in ISCCPP is more than the combined cycle system [15].

The fuel consumption can be reduced since not much heat is needed from exhaust diffuser. The solar energy will convey the steam to the steam turbine to generate more electricity. So besides helping to reduce the fuel consumption, it also increases the total power generated.

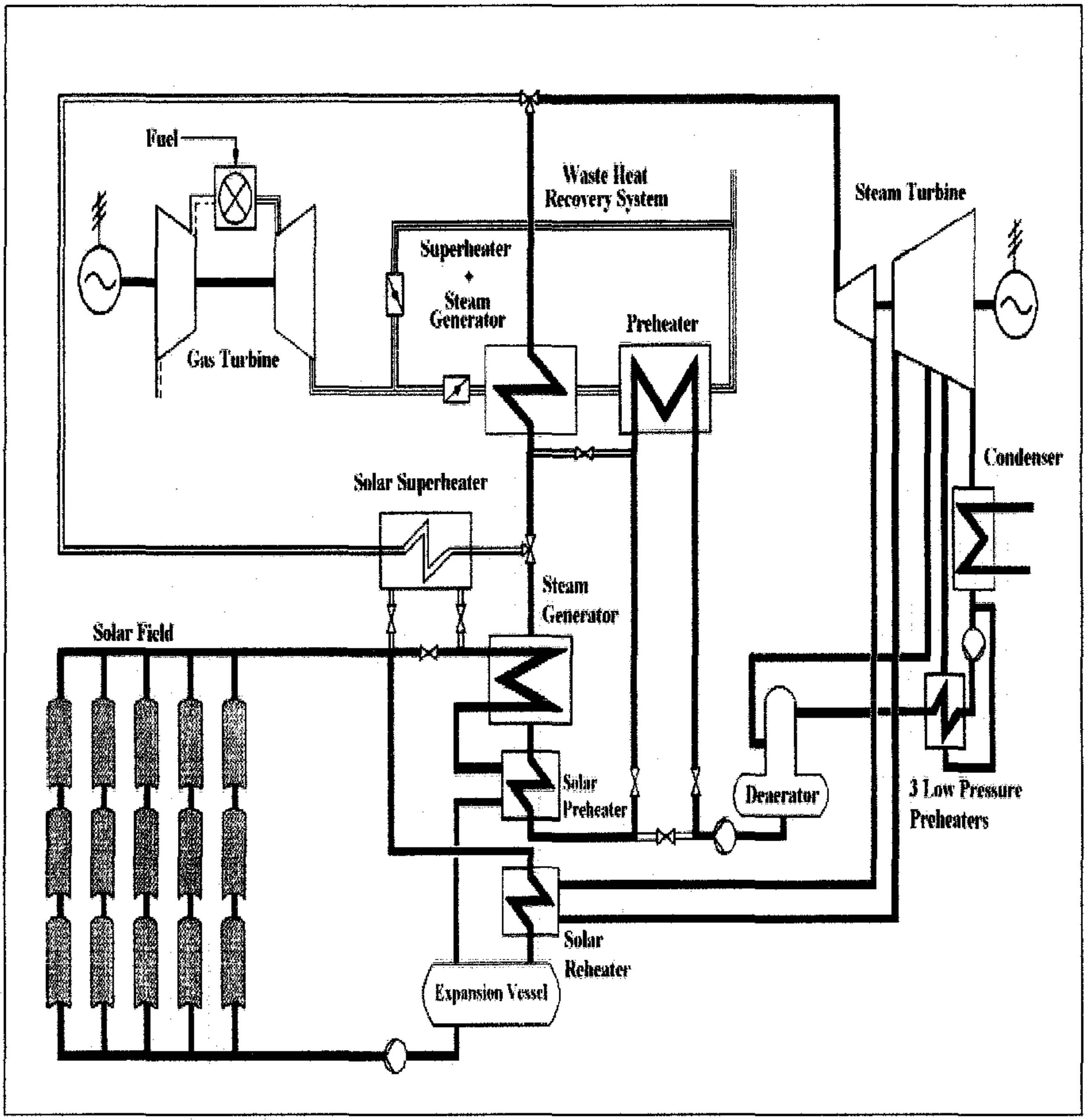


Figure 2.2: Integrated Solar Combined Cycle System [15]

2.4 Types of Solar Collector

The solar collector is the key in a solar energy system. It is also novel technology area that requires new understandings in order to make captured solar energy a viable energy source. The function of the solar collector is to intercepts incoming insolation and changes it into a useable form of energy that can be applied to meet a specific demand.

2.4.1 Parabolic Trough Collector (PTC)

A parabolic trough concentrates incoming solar radiation onto a line running the length of the trough. A tube (receiver) carrying heat transfer fluid is placed along this line, absorbing concentrated solar radiation and heating the fluid inside. The trough must be tracked about one axis, because the surface area of the receiver tube is small compared to the trough capture area. The temperature up to 400°C can be reached without major heat loss [16].

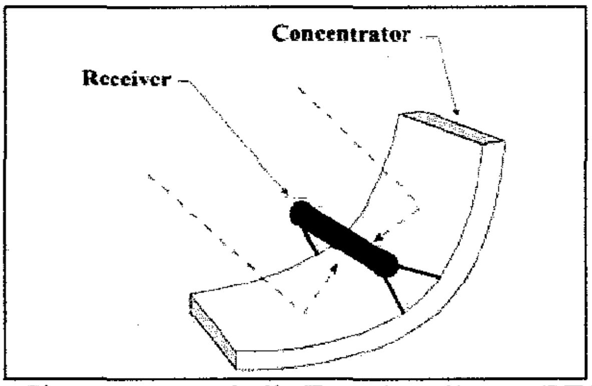


Figure 2.3: Parabolic Trough Collector (PTC)

2.4.2 Compound Parabolic Collector (CPC)

This type of collector is very deep and requires a large concentrator for a given aperture. But the advantage is it can be removed with negligible loss in performance. In addition, the height is shorter by about 50%, so the cost can be reduced. This detailed study on the effect of truncation was carried out [17].

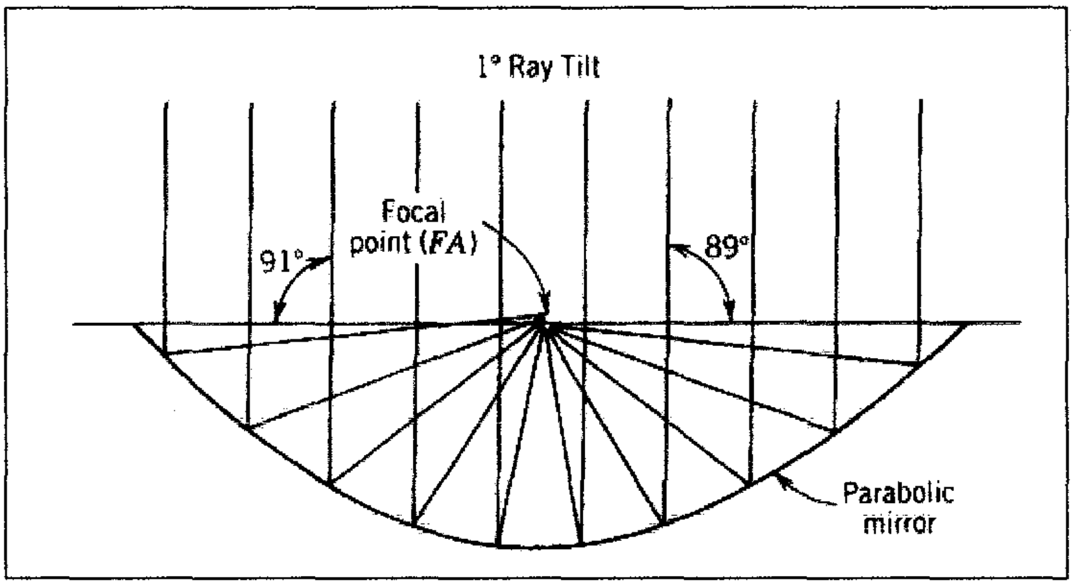


Figure 2.4: off-axis light reflections from parabolic mirror

The light with incidence angle less than one half the acceptance angles will be reflected through the receiver opening and the light with an incidence angle greater than one half will not reflected back to the receiver opening but its will reflected back out through the aperture of the CPC (as shown in Figure 2.4).

2.5 Meteorological conditions

From the meteorological data that was taken from the Meteorological Department, the conversion into spreadsheet makes it easy to analyses. For example, the graph below shows the hourly solar radiation for day 1 to day 6 from 6a.m till 7p.m.The graph shows that in the morning the radiation is low since there is no sun rise yet. It starts increasing towards the afternoon when the sun has raised fully. The graph shows the highest solar radiation is during 11am-1pm. Towards the evening, the solar radiation starts reducing. At sunset, there is no solar radiation.

The graph shows that the solar radiation is not exactly same for the whole day. This happen because the weather fluctuates. The cloudy condition causes this to happen. The best place to develop the plant is the coastal area where the clouds are less.

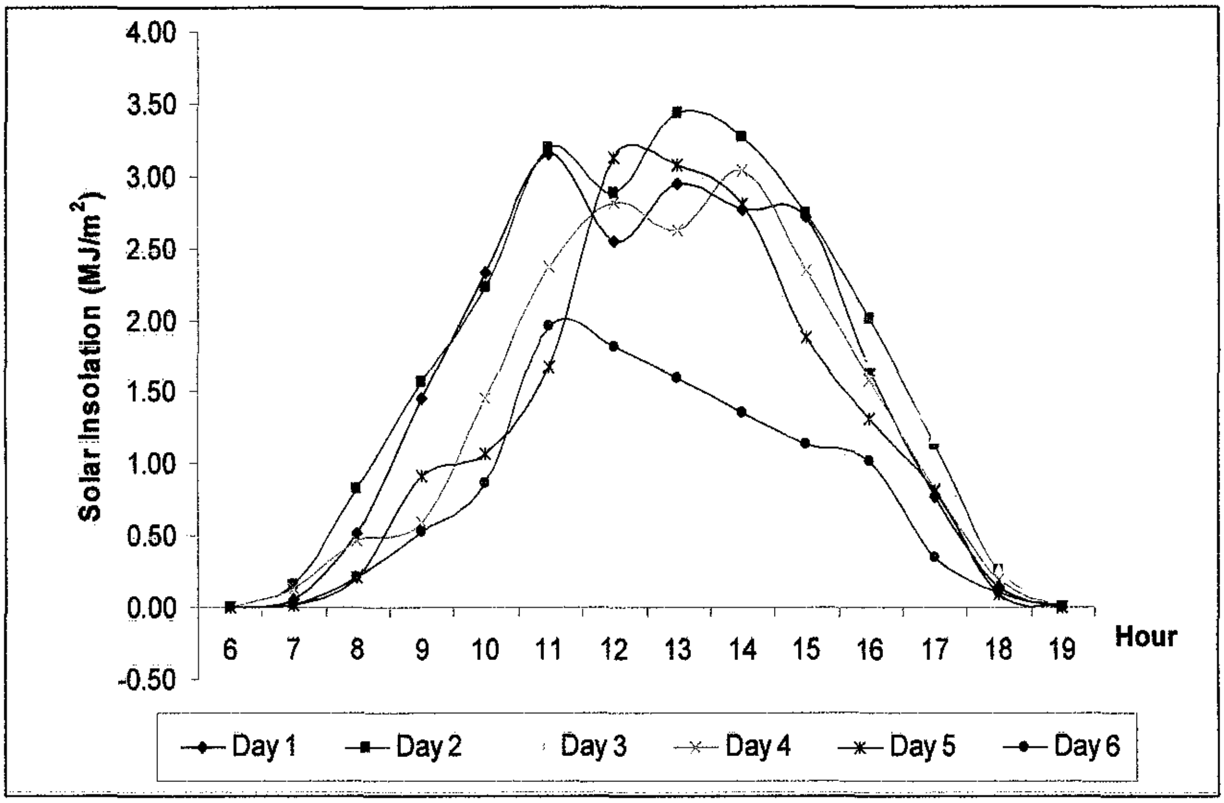


Figure 2.5: The hourly solar radiation for day 1st October to 6th October 2006

CHAPTER 3

THEORY / PROJECT WORK

3.1 Processes in a CCPP

In this section equation for the processes in combined cycle power plant is developed. The heat loss between two plants is in series, where a Brayton cycle is applied the topping plant while the Rankine cycle is in the bottoming plant. All the heat rejected by the topping plant is absorbed by the bottoming one [18].

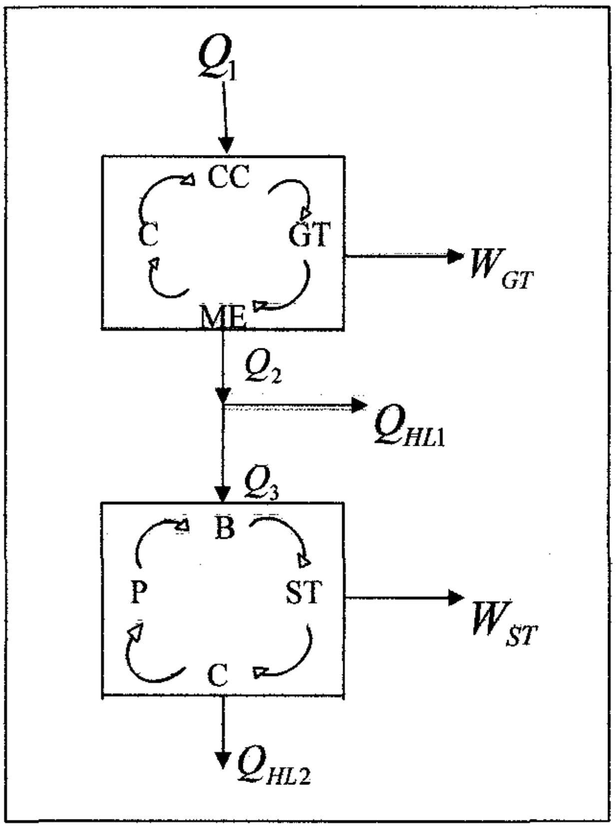


Figure 3.1: Flow diagram of combined cycle power plant

The process flow diagram is shown in Figure 3.1, and all the equations related to the various parameters shown above is given in Figure 3.2:

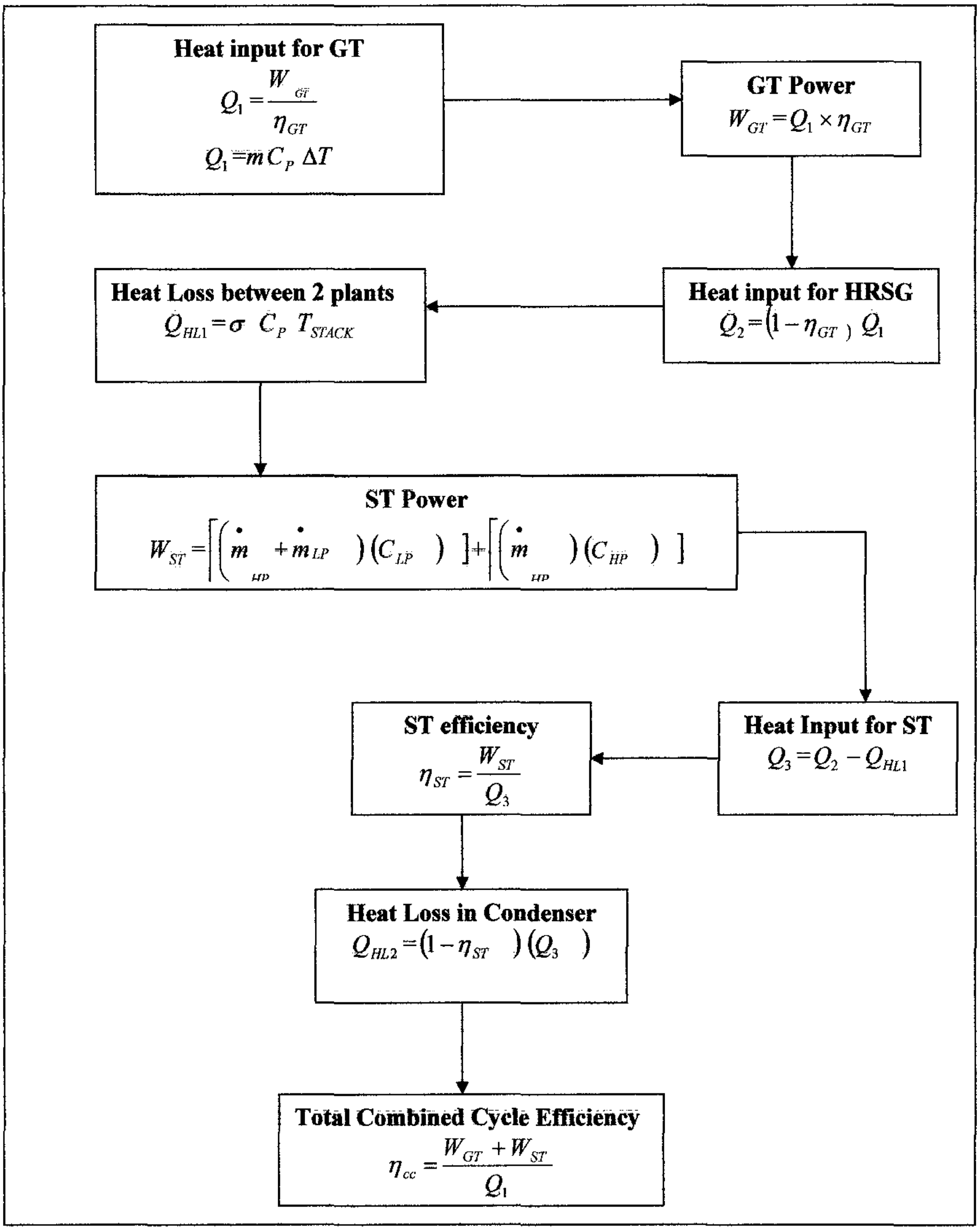


Figure 3.2: Heat energy and output power

3.2 Parabolic Trough Collector related Equations

A parabolic trough collector concentrates incoming solar radiation onto a line running the length of the trough. The highest temperature of 400°C can be reached without major heat loss. After some study and making comparison on the PTC and CPC, the results show better absorb temperature is on the PTC. Therefore, this PTC will be implement to the integration power plant. The basic elements that make up a conventional collector are [17]:

1. The absorber tube located at the focus axis in which the liquid to be heated flows
2. The concentric transparent cover
3. The parabolic concentrator

These calculation below is done by refer to the Sukhatme equations.

- For parabolic trough collector, the useful heat gain is :

$$Q_u = \dot{m}\, C_P \left(T_{fo} - T_{fi}\right)$$

$$= \dot{m}\, C_P \left[\frac{CS}{U_l} + T_a - T_{fi}\right]\left[1 - \exp\left\{-\frac{F_{RF}\,\pi D_O U_l L}{\dot{m} C_P}\right\}\right]$$

$$= F_R A_{eff}\left[S_R - \frac{U_{LR}}{C}\left(T_{fi} - T_a\right)\right] \qquad (3.1)$$

- To get the useful gain, all the parameters should be find first:
  - Absorbed flux, S_R

$$S_R = I_b R_b \left[\rho\gamma(\tau\alpha)_b \left(\frac{D_o}{W - D_o}\right)\right] \qquad (3.2)$$

  - Receiver effective area, A_{eff}

$$A_{eff} = \left(W - D_o\right)L \qquad (3.3)$$

Average velocity of the fluid (water) inside the absorber tube, V_w,

$$V_w = \frac{\dot{m}}{\pi D_i^2 \rho} \tag{3.4}$$

The Reynolds number, Re_w

$$\mathrm{Re}_w = \frac{V_w D_i}{v} \tag{3.5}$$

If Reynolds number is greater than 2000, the flow is turbulent and the heat transfer coefficient can be calculated from the Dittus-Boelter for Nusselt number, Nu_w

$$Nu_w = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \tag{3.6}$$

a. Heat transfer coefficient, h_f,

$$h_f = \frac{Nu_w \times k}{D_i} \tag{3.7}$$

Receiver efficiency factor (Sukhatme, 1996), F_{RF}

$$F_{RF} = \frac{1}{U_{LR}\left(\frac{1}{U_{LR}} + \frac{D_o}{D_i h_f}\right)} \tag{3.8}$$

- Heat removal factor, F_R

$$F_R = \frac{\dot{m}C_p}{\pi F_{RF} D_o U_{LR}}\left[1 - \exp\left\{\frac{\pi F_{RF} D_o U_{LR}}{\dot{m}C_P}\right\}\right] \tag{3.9}$$

- Receiver concentration ratio, C

$$C = \frac{(W - D_o)}{\pi D_o} \tag{3.10}$$

- Overall heat loss coefficient (Mullick & Nanda, 1975), U_{LR}

$$U_{LR} = \left[\frac{1}{C_1(\delta T_1)^{0.25} + \left(\frac{\sigma(\delta T_2)(\delta T_3)}{C_2} \right)} + \left[\left(\frac{D_o}{D_{co}} \right) \left(\frac{1}{C_3} \right) \right] \right]^{-1} \tag{3.11}$$

To calculate the overall heat loss coefficient, there are the need to calculate the temperature constants and coefficient from the correlation of Raithby and Hollands (1975). The constants are:

$$C_1 = \frac{17.74}{(\delta T_2)^{0.4} D_o \left(D_o^{-0.75} + D_{ci}^{-.0.75} \right)} \tag{3.12}$$

$$C_2 = \frac{1}{\varepsilon_p} + \frac{D_o}{D_{ci}} \left(\frac{1}{\varepsilon_c} - 1 \right) \tag{3.13}$$

$$C_3 = h_w + \left(\sigma \varepsilon_c (\delta T_4)(\delta T_5) \right) \tag{3.14}$$

The temperature coefficients are:

$$\delta T_1 = T_{pm} - T_c \tag{3.15}$$

$$\delta T_2 = T_{pm} + T_c \tag{3.16}$$

$$\delta T_3 = T_{pm}^2 + T_c^2 \tag{3.17}$$

$$\delta T_4 = T_c + T_a \tag{3.18}$$

$$\delta T_5 = T_c^2 + T_a^2 \tag{3.19}$$

All the temperature values are expressed in Kelvin and the following equation are used to evaluate the cover temperature, T_c. The temperature of the glass cover, T_c when the T_{pm} is in the range of 333 K< T_{pm} <513 K (Sukhatme, 1996).

$$T_c = T_a + \left[\left(0.04075 \left(\frac{D_o}{D_{ci}} \right)^{0.4} h_w^{-0.67} \left(2 - 3\varepsilon_p + \frac{(6 + 9\varepsilon_p) T_{pm}}{100} \right) \right) (T_{pm} - T_a) \right] \tag{3.20}$$

The Reynolds number for the condition of air, $Re_{(air)}$,

$$Re_{(air)} = \frac{VD}{v} \tag{3.21}$$

Nusselt number for air,

$$Nu_w = C_1 \operatorname{Re}^n \tag{3.22}$$

The heat transfer coefficient between the glass cover and absorber tube,

$$h_w = \frac{Nu_w K_{AIR}}{D_R} \tag{3.23}$$

For Nusselt number of air, the calculation is according to condition in this table:

40<Re<4000	C_1=0.165	n=0.466
4000<Re<40000	C_1=0.174	n=0.618
40000<Re<400000	C_1=0.0239	n=0.805

The outlet temperature of the PTC:

$$T_{fo} = \frac{\dot{Q}_{R(LP)}}{\dot{m} C_p} + T_{fi} \tag{3.24}$$

CHAPTER 4

METHODOLOGY

4.1 Literature review

A review on the fossil fuel pricing is important to prove that the fossil fuel is getting expensive and it is wise for our country to find alternative energy. From the research and study, the most suitable renewable energy is solar energy which is very large inexhaustible in the world. It should be commercialized because it is an environmentally clean source, free and available everywhere. Besides, it is suitable with our country's geographical area and weather. Review on the solar collector and its technology gives the basic idea on how to harness the solar energy for the human benefits.

4.2 Identified problem

In Malaysia, there is no renewable energy power plant. The common plant is the combined cycle power plant in which the main source is the fossil fuel. This is very costly and for the time being it will cause depletion of fossil fuel in Malaysia. This project will improve the power plant generating besides reducing the fuel consumption by harnessing the alternative energy which is solar energy. For this case, the solar energy will be integrated to the existing combined cycle power plant.

4.3 Analyze the Solar Insolation Data

Analyze and re arranged the data that was apply from National Meteorological Department (Appendix D). This data is recorded in hourly global radiation, in MJ/m^2 and for the October and November 2006 radiation in Sitiawan, Perak, Malaysia. This solar radiation data is in text format and had to be re arranged into the spreadsheet so that it is easy to analyze. The bulk of data for 2 months, in October & November 2006 is shown in Figure 5.1

4.4 Develop the theory equations

Develop the equations on both for the combined cycle power plant (CCPP) and integrated solar combined cycle power plant (ISCCPP). This theory equation which is constructed for the CCPP is based on the heat loss flow process between two plants which is show in Figure 3.1.

Invent the new flow diagram of the integrated solar combined cycle system. From figure below, it shows the new steam turbine being developed by using heat from the parabolic trough collector. The heat radiation from sun mix together with the extra steam that exit form the LP steam turbine. The heat is still being used and to develop another power from new steam turbine.

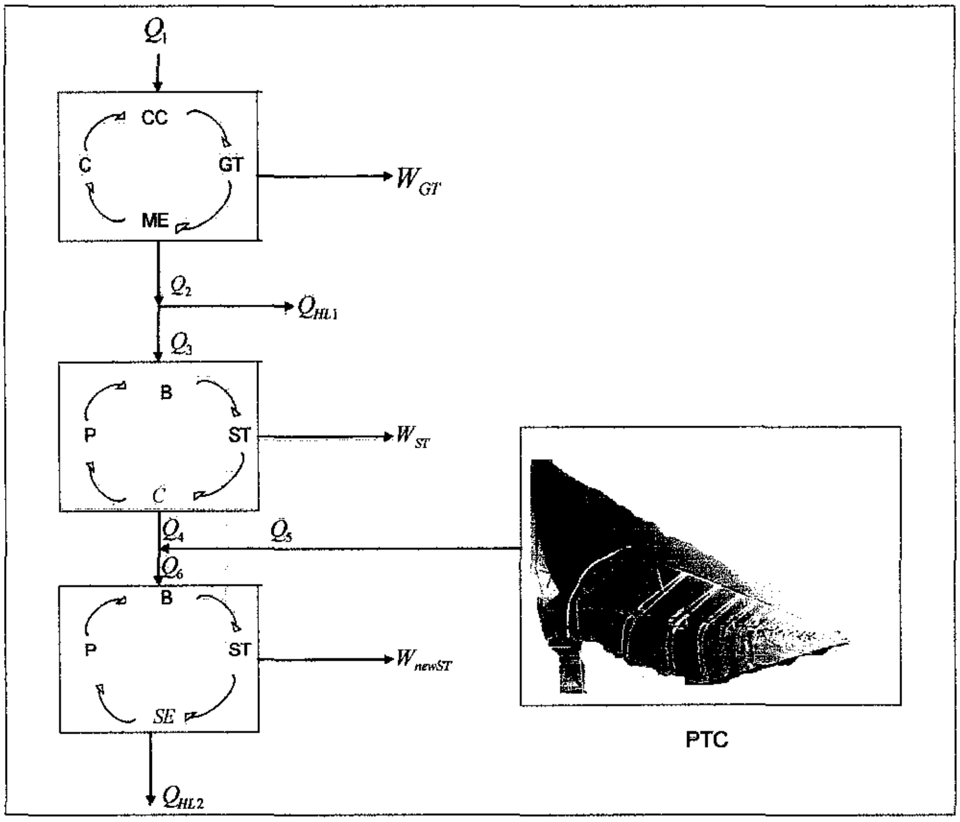


Figure 4.1: Flow diagram of integrated solar combined cycle system

4.5 Analyze the steam specific enthalpy

From the steam table introduce by spirax sarco, the value of specific enthalpy of the steam can be manage in proper manner. The table manages into account so that all the value is compile and arrange properly. This parameter is used for the calculation on the new part where the new steam is being produced.

4.6 Simulation programming

By using the Visual Basic.NET, the Combined Cycle Power Plant (CCPP) and Integrated Solar Combined Cycle Power Plant (ISCCPP) simulation is developed. The simulation needs the power demand and the day as the input, so that it can simulate the total power produced in the GT, ST, and new ST. Therefore, it will calculate the usage of natural gas, the cost and the overall efficiency of the plant (Appendix K & L).

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Design of Integrated Solar Combined Cycle Power Plant

The new design of this ISCCPP is the improvement from the real CCPP layout where the enhancement is on the new solar field. The main parts of this system are Gas Turbine, Steam Turbine, Heat Recovery Steam Generator, Condenser, Feedwater Tank and Solar field. Therefore, by introducing this new solar field the plant can stay away from only depending to the natural gas in producing electricity. The solar field as an auxiliary will assist the plant in producing the electricity and at the same time reducing the natural gas consumption.

In the afternoon, with the high solar radiation, the solar collector will absorb the potential radiation heating the water into steam and producing electricity. So upon this period, the usage of natural gas can be reduce even the same amount of electricity demand is needed. During the night or unfavorable condition, where there is no solar radiation, the plant totally depends on the natural gas.

The designed layout shows the water from feedwater tank flows to the solar field where the solar collector concentrates the solar radiation. With this radiation, the heat then converts the water into saturated steam. This saturated steam is mixed together with the steam and comes out from the LP steam turbine before being channeled into the new steam turbine and producing more electricity in the new generator. The balance steam then flows to the condenser and this process repeated again.

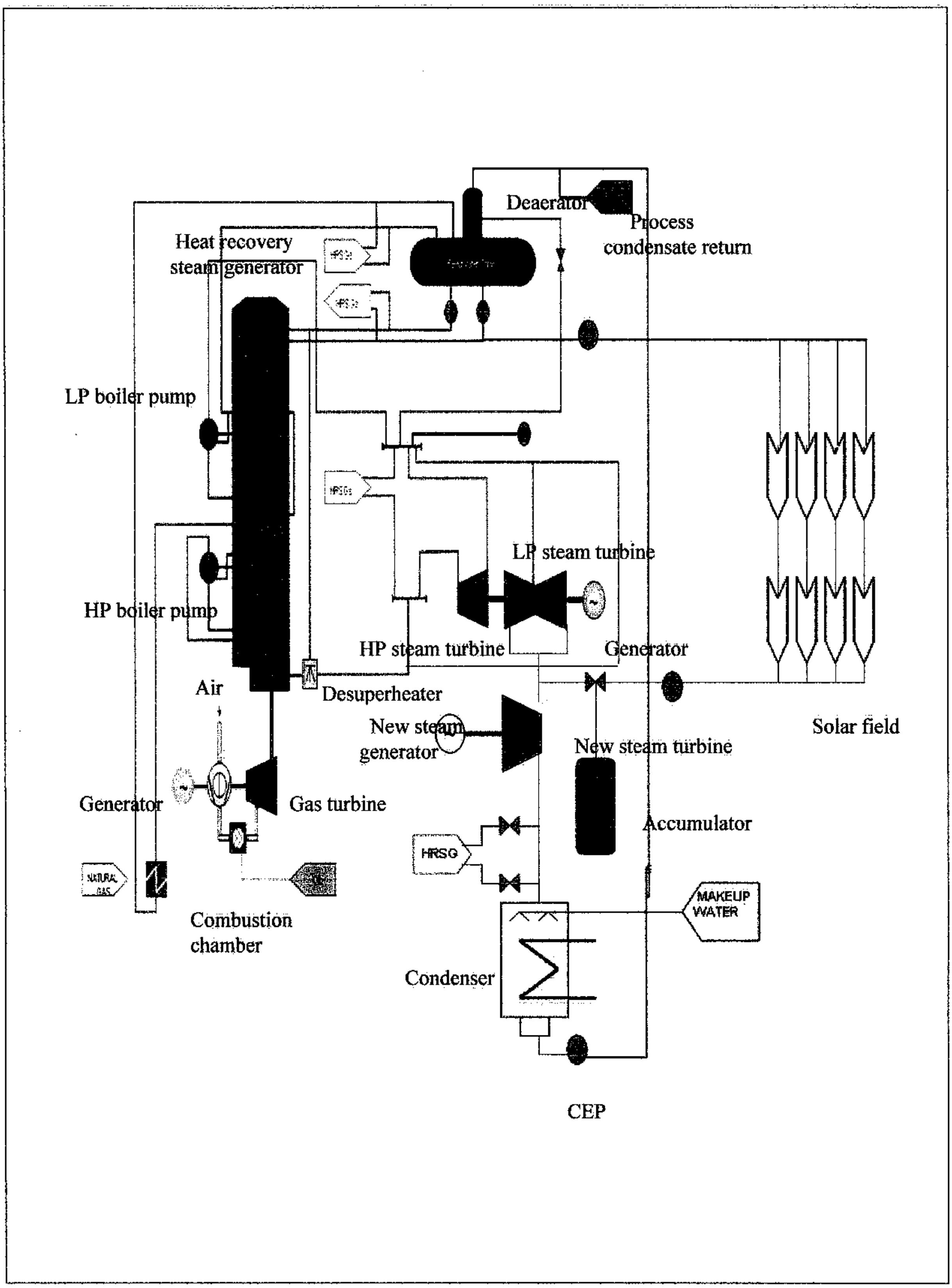


Figure 5.1: Integrated Solar Combined Cycle Power Plant layout

5.2 Solar radiation

This is the data recorded for hourly global radiation in Sitiawan, Perak, Malaysia. The data is in the in MJ/m^2 unit. The simulation development of the PTC that was developed by using VB.NET software, to calculate the exit temperature was done by using this meteorological data as reference.

	Time in hours														Daily Total
Day	6	7	8	9	10	11	12	13	14	15	16	17	18	19	MJ/m²
1	0.00	0.05	0.51	1.45	2.33	3.15	2.55	2.95	2.77	2.71	1.66	0.77	0.14	0.00	21.04
2	0.00	0.16	0.83	1.57	2.23	3.19	2.88	3.44	3.27	2.74	2.01	1.13	0.26	0.00	23.71
3	0.00	0.02	0.41	1.23	1.66	1.35	1.27	1.95	1.76	1.92	1.71	1.19	0.26	0.00	14.73
4	0.00	0.13	0.46	0.59	1.46	2.37	2.82	2.62	3.04	2.34	1.58	0.82	0.2	0.00	18.43
5	0.00	0.01	0.21	0.91	1.07	1.67	3.12	3.08	2.81	1.88	1.31	0.81	0.09	0.00	16.97
6	0.00	0.02	0.21	0.53	0.86	1.95	1.81	1.59	1.35	1.13	1.02	0.35	0.11	0.00	12.06
7	0.00	0.14	0.81	1.43	1.97	2.4	3.12	2.89	1.91	2.35	1.53	0.69	0.2	0.00	19.44
8	0.00	0.04	0.74	1.13	1.93	2.47	2.74	2.25	2.57	2.21	1.58	0.9	0.14	0.00	18.7
9	0.00	0.05	0.68	1.26	2.09	2.28	1.67	0.84	1.25	1.82	1.1	0.59	0.16	0.00	13.79
10	0.00	0.11	0.67	1.25	2.13	2.59	3.15	1.67	2.53	1.94	1.32	0.84	0.15	0.00	18.35
11	0.00	0.07	0.49	1.8	1.25	1.34	0.51	1.09	0.96	0.99	0.67	0.61	0.19	0.00	8.87
12	0.00	0.3	0.59	1.54	2.45	2.32	1.99	2.43	2.74	2.5	1.78	1.03	0.28	0.00	19.95
13	0.00	0.07	0.09	0.13	0.37	0.62	1.17	1.44	1.1	1.27	0.89	0.41	0.13	0.00	7.69
14	0.00	0.07	0.56	1.21	1.9	1.81	1.23	0.47	0.93	1.31	1.18	0.76	0.21	0.00	11.64
15	0.00	0.12	0.66	1.56	1.67	0.9	0.74	1.97	2.15	0.92	1.56	0.7	0.08	0.00	13.03
16	0.00	0.07	0.57	1.28	1.87	2.28	1.94	2.12	2.02	1.41	1.09	0.6	0.11	0.00	15.36
17	0.00	0.07	0.68	1.18	-1.11	-1.11	-1.11	2.46	1.85	1.66	0.9	0.42	0.08	0.00	5.97
18	0.00	0.12	0.55	0.99	1.88	2.27	1.74	0.15	1.33	1.81	1.28	0.68	0.15	0.00	12.96
19	0.00	0.10	0.65	1.39	1.89	2.24	2.73	2.90	2.76	2.19	1.40	0.70	0.07	0.00	19.52
20	0.00	0.08	0.56	1.35	1.83	2.54	3.08	2.29	2.06	1.69	1.34	0.73	0.11	0.00	17.66
21	0.00	0.05	0.23	0.86	1.70	1.62	1.67	2.27	2.64	2.28	1.14	0.51	0.06	0.00	15.09
22	0.00	0.12	0.65	0.70	1.09	2.02	2.16	2.04	2.15	1.41	1.51	0.81	0.21	0.00	14.87
23	0.00	0.16	0.70	1.31	1.88	2.41	2.39	2.64	2.83	2.29	1.53	0.71	0.19	0.00	19.04
24	0.00	0.15	0.66	1.53	2.31	2.82	1.76	2.23	3.11	2.51	1.39	0.11	0.00	0.00	18.66
25	0.00	0.04	0.58	1.25	1.75	2.40	2.28	1.02	0.41	0.15	0.12	0.14	0.02	0.00	10.16
26	0.00	0.05	0.44	1.26	2.10	2.12	1.28	1.59	1.29	1.63	0.89	0.83	0.12	0.00	19.60
27	0.00	0.03	0.56	0.97	1.71	1.76	2.47	2.29	2.53	0.25	0.06	0.07	0.07	0.00	12.77
28	0.00	0.14	0.85	1.79	2.22	2.72	3.56	1.69	3.28	2.74	1.63	0.97	0.07	0.00	21.86
29	0.00	0.22	1.03	1.83	2.57	2.97	1.23	2.34	2.87	2.71	0.84	0.75	0.18	0.00	18.54
30	0.00	0.18	0.69	1.29	2.04	1.41	2.34	3.05	2.85	2.41	1.38	0.79	0.20	0.00	18.53
31	0.00	0.06	0.53	1.53	1.86	1.53	1.88	2.12	1.02	0.35	0.31	0.35	0.07	0.00	11.81
Monthly Total	0.00	3.00	17.85	38.10	52.96	62.41	62.17	63.88	66.14	55.52	37.71	20.77	4.31	0.00	484.82
Monthly Mean	0.00	0.1	0.58	1.23	1.71	2.01	2.01	2.06	2.13	1.79	1.22	0.67	0.14	0	15.68
1	0.00	0.02	0.02	0.17	1.53	2.18	3.20	3.26	2.95	2.41	1.64	0.52	0.04	0.00	17.84
2	0.00	0.13	0.53	0.97	1.69	2.76	2.77	2.65	2.85	1.67	0.98	0.37	0.00	0.00	17.37
3	0.00	0.07	0.91	1.74	2.40	2.78	2.57	3.34	3.06	1.09	0.22	0.04	0.01	0.00	18.23
4	0.00	0.13	0.81	1.67	2.46	3.05	2.52	3.40	2.76	1.53	0.04	0.00	0.00	0.00	18.37
5	0.00	0.09	0.53	1.45	1.65	2.44	2.10	3.28	1.04	2.32	0.54	0.00	0.00	0.00	15.44
6	0.00	0.11	0.81	1.42	2.13	2.47	2.36	2.35	2.96	2.62	2.10	1.00	0.28	0.00	20.61
7	0.00	0.13	0.78	1.67	1.67	2.35	2.97	3.27	2.35	2.30	1.69	1.06	0.07	0.00	20.31
8	0.00	0.20	0.56	0.96	1.30	2.11	3.04	1.67	1.07	1.23	1.60	1.18	0.25	0.00	15.96
9	0.00	0.08	0.79	1.39	1.93	1.58	0.72	1.33	2.73	2.13	0.28	0.21	0.09	0.00	13.25
10	0.00	0.09	0.76	1.60	2.27	1.36	0.81	2.13	3.07	2.84	0.65	0.09	0.05	0.00	16.72
11	0.00	0.07	0.90	1.37	1.96	2.73	2.19	1.62	0.41	0.82	0.28	0.12	0.02	0.00	12.49
12	0.00	0.09	0.52	1.23	2.39	2.64	2.66	1.90	2.77	2.49	0.83	0.00	0.00	0.00	17.52
13	0.00	0.13	0.85	1.58	1.75	0.65	1.84	1.80	0.50	0.21	0.27	0.12	0.10	0.00	8.8
14	0.00	0.11	0.99	1.08	1.75	1.70	2.49	3.10	3.04	2.55	1.72	0.51	0.05	0.00	19.19
15	0.00	0.08	0.38	1.32	1.83	1.18	1.44	2.98	2.87	2.17	0.97	0.08	0.00	0.00	15.3
16	0.00	0.19	0.88	1.70	2.43	3.28	2.04	2.41	1.98	1.07	0.56	0.65	0.20	0.00	17.39
17	0.00	0.10	0.74	1.69	2.40	1.63	1.88	2.25	1.08	1.37	0.58	0.85	0.23	0.00	14.6
18	0.00	0.13	0.84	1.69	2.44	2.98	2.56	2.15	3.17	1.77	1.29	0.88	0.18	0.00	20.38
19	0.00	0.10	0.77	1.66	2.27	2.94	2.53	3.58	2.44	1.49	0.37	0.41	0.11	0.00	18.57
20	0.00	0.06	0.61	1.10	1.83	1.59	0.75	2.71	2.29	2.13	1.42	0.66	0.17	0.00	15.32
21	0.00	0.08	0.54	1.10	1.37	1.47	1.55	2.53	2.75	1.50	1.62	0.96	0.23	0.00	15.7
22	0.00	0.08	0.61	1.46	2.37	3.00	2.08	2.40	2.32	2.22	1.97	1.35	0.30	0.00	20.16
23	0.00	0.10	0.74	1.39	1.93	2.13	1.78	1.64	1.65	1.46	1.00	0.64	0.11	0.00	14.87
24	0.00	0.15	0.89	1.75	1.43	1.29	0.99	1.62	1.32	0.66	0.08	0.00	0.00	0.00	10.18
25	0.00	0.05	0.45	1.03	1.72	2.40	2.91	2.51	2.72	2.01	1.40	0.22	0.28	0.00	17.7
26	0.00	0.07	0.71	1.50	2.05	2.11	2.45	2.85	2.51	2.23	1.44	0.52	0.02	0.00	16.46
27	0.00	0.09	1.04	1.79	2.34	2.32	2.47	3.04	2.02	2.59	0.26	0.00	0.00	0.00	17.96
28	0.00	0.15	0.62	1.57	1.99	2.52	2.40	2.10	2.98	2.29	0.17	0.08	0.07	0.00	16.94
29	0.00	0.13	0.92	1.69	2.49	2.72	3.05	1.42	1.41	2.32	0.69	0.11	0.05	0.00	17
30	0.00	0.16	0.52	0.95	0.96	1.51	1.79	1.83	2.03	1.97	1.58	0.94	0.10	0.00	14.34
Monthly Total	0.00	3.17	21.02	41.68	58.73	65.87	64.91	73.12	67.10	55.46	28.14	13.57	3.01	0.00	495.78
Monthly Mean	0.00	0.11	0.7	1.39	1.96	2.2	2.16	2.44	2.24	1.85	0.94	0.45	0.10	0.00	16.54

Figure 5.2: The hourly global solar radiation for October & November 2006 in Sitiawan area that was taken form Malaysia Meteorological Department [19]

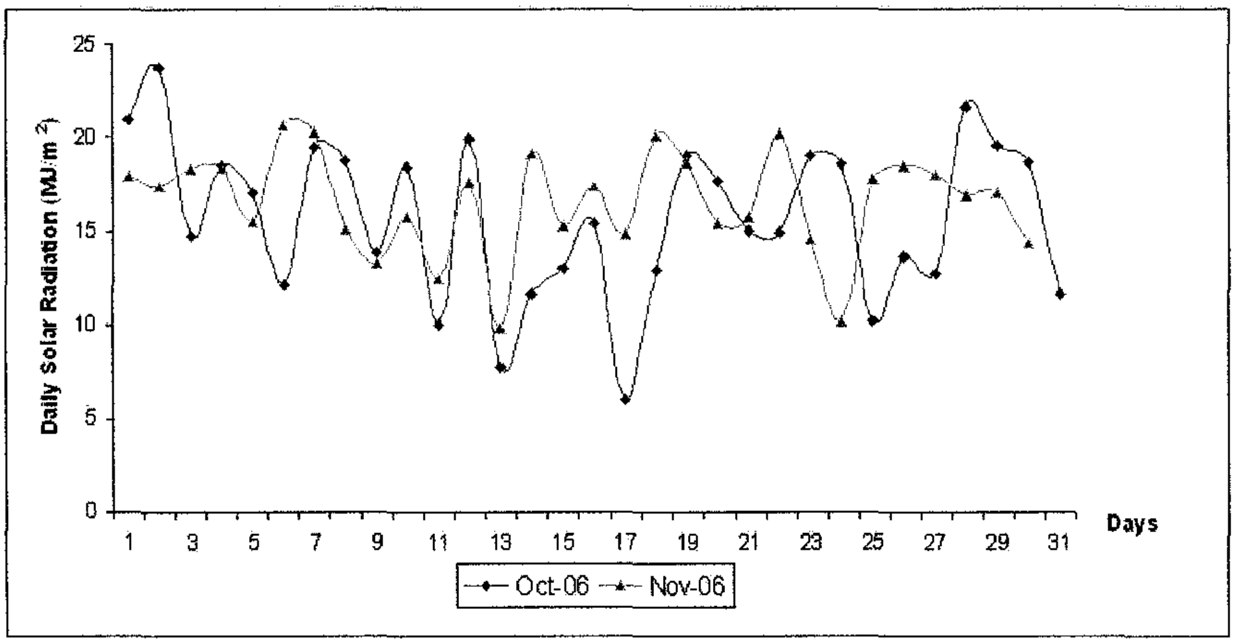


Figure 5.3: The daily solar radiation for October & November 2006 in Sitiawan area

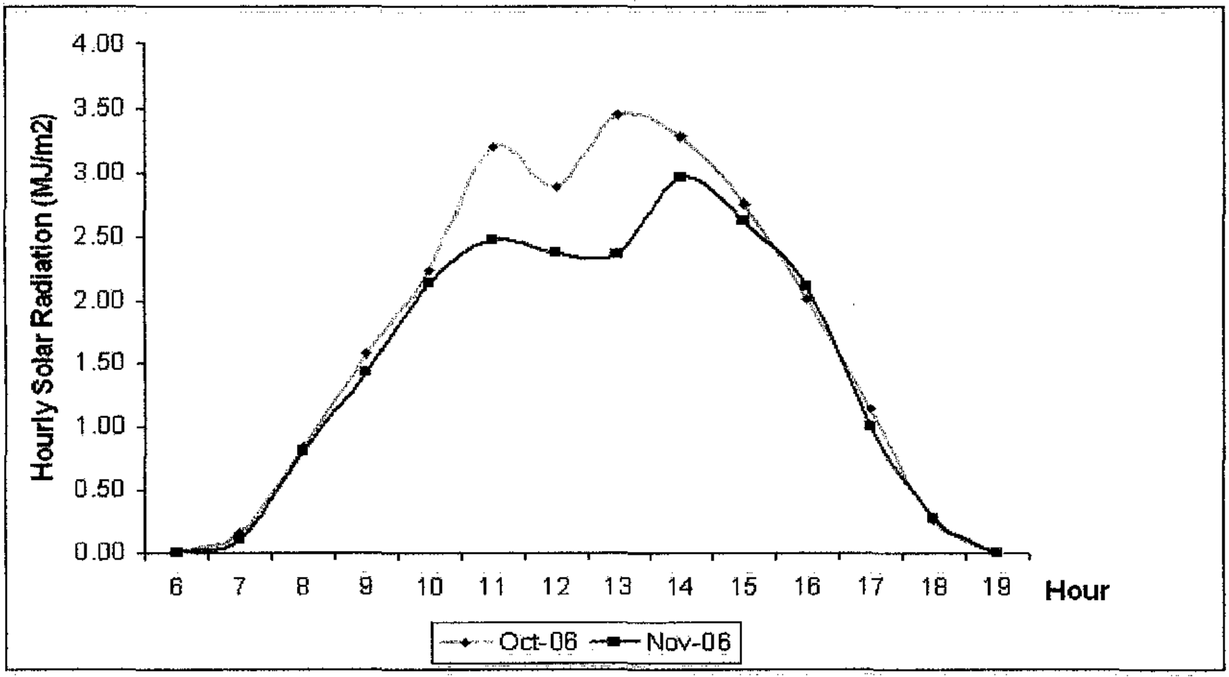


Figure 5.4: The hourly solar radiation for October & November 2006

The $\bar{I}_G$ is the global radiation. The sum of the beam radiation and diffuse radiation is global radiation: $\bar{I}_G = \bar{I}_B + \bar{I}_D$. The Azni-Zain (2002) report shows the trend of diffuse radiation received in Malaysia climate at any area is 30%-40% of the global solar radiation [20]. Figure 4 shows the amount of daily beam radiation and diffuse radiation for the month of October & November 2006 in Sitiawan area.

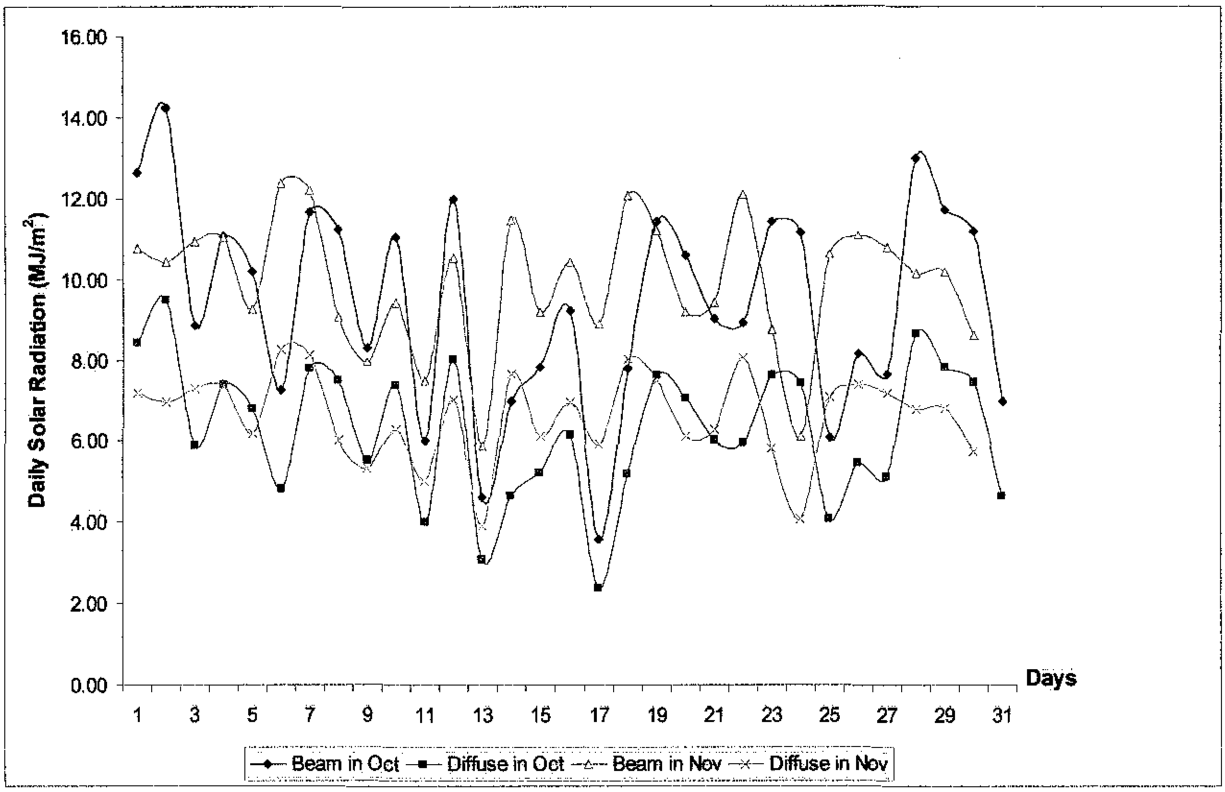


Figure 5.5: The beam and diffuse radiation in daily for October & November 2006

5.3 Combined Cycle Power Plant Simulation

The heat loss between two plants is in series. The air standard for the gas turbine is the Brayton cycle which is in topping plant while the steam turbine is the Rankine cycle is bottoming one. For this kind of plant, all the heat rejected by the topping plant is absorbed by the bottoming one [18].

- Insert all the data for combined cycle parts. All the parameters taken from Lumut Power Plant.

Table 5.1: Basic parameter for gas turbine [10].

Air mass flow	494.5kg/s
Gas/fuel mass flow	7.84kg/s
Outlet gas temperature from GT	550°C + 273K
Power output from G T	132MW
GT efficiency	33%
Enthalpy of the exhaust gas from the GT	1.114kJ/kg
Allowable temperature drop of the exhaust GT	550°C – 107°C + 273K

Table 5.2: Basic parameter for dual pressure steam turbine [10].

HP mass flow	61.7kg/s
LP mass flow	13.9kg/s
HP steam pressure	71 bar
LP steam pressure	5.5 bar
HP steam temperature	520°C + 273K
LP steam temperature	271.5°C + 273K
Outlet LP steam temperature	49°C+273K
Specific enthalpy drop in HP turbine	670kJ/kg
Specific enthalpy drop in LP turbine	570kJ/kg
Condenser pressure	0.057 bar
Specific enthalpy of 100°C steam	2.676kJ/kg

Temperature at the stack	$100^{0}C$ +273K

- Insert all the formula for the heat input, heat loss, power output and efficiency. This calculation is based on the maximum condition.

- **Heat input for GT**

$$Q_1 = \frac{W_{GT}}{\eta_{GT}}$$

$$Q_1 = m C_P \Delta T$$

$$= (494.5 + 7.84)(1.114)(550 - 107 + 273)$$

$$= 1201.95 MW$$

- **GT Power**

$$W_{GT} = Q_1 \times \eta_{GT}$$

$$= 400.65 \times 0.33$$

$$= 396.6 MW$$

- **Heat input for HRSG**

$$Q_2 = (1 - \eta_{GT}) Q_1$$

$$= (1 - 0.33)(400.65)$$

$$= 805.425 MW$$

- **ST Power**

$$W_{ST} = \left[\left(\dot{m}_{HP} + \dot{m}_{LP}\right)(C_{LP})\right] + \left[\left(\dot{m}_{HP}\right)(C_{HP})\right]$$

$$= [(61.7 + 13.9)(570) + (61.7)(670)]$$

$$= 253.293 MW$$

- **Heat loss between two plants**

$$Q_{HL1} = \sigma \; C_P \; T_{STACK}$$

$$= 75.6 \times 2.676 \times 1000 \times 373$$

$$=226.38MW$$

- **Heat loss in condenser**

$$Q_{HL2}=(1-\eta_{ST}\ )(Q_3\ )$$

$$=(1-0.4375\ )(192.97M)$$

$$=325.62MW$$

- **Heat input for ST**

$$Q_3=Q_2-Q_{HL1}$$

$$=268.475-75.46$$

$$=579.045MW$$

- **ST efficiency**

$$\eta_{ST}=\frac{W_{ST}}{Q_3}$$

$$=\frac{253.293}{579.045}$$

$$=43.75\%$$

- **Total combined cycle efficiency**

$$\eta_{cc}=\frac{W_{GT}+W_{ST}}{Q_1}$$

$$=\frac{396.6+253.293}{1201.95}$$

$$=54.07\%$$

Table 5.3: Result of the energy/power output

	POWER
Q_1	$1201.95MW$
Q_2	$805.425MW$
Q_3	$579.045MW$
Q_{HL1}	$226.38MW$

Q_{HL2}	$325.62MW$
W_{GT}	$397MW$
W_{ST}	$253MW$
η_{GT}	33%
η_{ST}	43.75%
η_{cc}	54.07%

5.4 Integrated Solar Combined Cycle Power Plant Simulation

By adding the actual combined cycle power plant with the solar field, the solar radiation can be harnessed to heat the water convert into steam. A parabolic trough collector concentrates incoming solar radiation onto a line running the length of the trough. The highest temperature up to 400°C can be reached without major heat loss. The basic elements that make up a conventional collector are [17]:

Table 5.4: Parabolic Trough Collector specifications [21].

Absorber tube: Inner diameter Outer diameter	 $Di = 0.06m$ $D_o = 0.07m$
Glass cover Inner diameter Outer diameter	 $D_{ci} = 0.12m$ $D_{co} = 0.13m$
Aperture	$W = 6m$
Length	$L = 100m$
Maximum beam flux	$I_b R_b = 750W / m^2$
Global solar radiation	Depends on the original data
Specular reflectivity of receiver surface	$\rho = 0.96$

Intercept factor	$\gamma = 0.96$
Average value of the transmissivity – absorptivity product for beam radiation	$(\tau\alpha)_b = 0.96$
Air: Mean flow velocity Kinematics viscosity Prandlt number Thermal conductivity	 $V_{AIR} = 3m/s$ $v = 16 \times 10^{-6} m^2/s$ $\Pr = 0.701$ $k = 0.0267W/m-k$
Water (fluid) at 200°C: Density Specific heat capacity Kinematics viscosity Thermal conductivity Prandlt number	 $\rho = 863kg/m^3$ $C_p = 2.298kJ/kg-K$ $v = 0.158 \times 10^{-6} m^2/s$ $k = 0.663W/m-K$ $\Pr = 0.93$
Receiver tube emissivity	$\varepsilon_p = 0.96$
Glass cover emissivity	$\varepsilon_c = 0.88$
Stefan-Boltzmann constant	$\sigma = 5.670 \times 10^{-8} W/m^2 - K^4$
Collector inlet mass flow rate LP side	$\dot{m} = 0.8kg/s$
Temperature coefficients:	$T_{pm} = 443K$ $T_a = 303K$ $T_{fi(LP)} = 343K$ $T_{fi(HP)} = 423K$

- From the values in the table, the useful heat gain value can be calculated. This calculation is based on the maximum condition. Start with solve these equations :
  - Absorbed flux, S_R

$$S_R = I_b R_b \left[\rho\gamma(\tau\alpha)_b + (\tau\alpha)_b \left(\frac{D_o}{W - D_o} \right) \right]$$

$=663.552 \text{W/m}^2$

- Receiver effective area, A_{eff}

$$A_{eff} = (W - D_o)L$$

$=593$

- Receiver efficiency factor, F_{RF}

$$F_{RF} = \frac{1}{U_{LR}\left(\frac{1}{U_{LR}} + \frac{D_o}{D_i h_f}\right)}$$

$=0.9852$

- Receiver concentration ratio, C

$$C = \frac{(W - D_o)}{\pi D_o}$$

$=26.97$

- Overall heat loss coefficient, U_{LR}

$$U_{LR} = \left[\frac{1}{C_1(\delta T_1)^{0.25} + \left(\frac{\sigma(\delta T_2)(\delta T_3)}{C_2}\right)} + \left[\left(\frac{D_o}{D_{co}}\right)\left(\frac{1}{C_3}\right)\right]\right]$$

$=12.54 \text{W/m}^2\text{-K}$

∴ **The useful heat gain for LP sides (The highest solar radiation is taken):**

$$Q_{R(LP)} = F_R A_{eff}\left[S_R - \frac{U_{LR}}{C}(T_{fi} - T_a)\right]$$

$=\underline{379.313 \text{kW}}$

- The outlet temperature of the PTC:

$$T_{fo} = \frac{\dot{Q}_{R(LP)}}{\dot{m} C_p} + T_{fi}$$

$$= \frac{379313}{0.8 \times 2298} + 70$$

$$= \underline{289.9^{o}C}$$

o Insert this temperature value into:

$$y = \left(4 * 10^{-15} * T_{fo}^{\ 4}\right) + \left(2 * 10^{-13} * T_{fo}^{\ 3}\right) - \left(4 * 10^{-12} * T_{fo}^{\ 2}\right) + 10T_{fo} + 80$$

$$= 3491.53$$

o Specific enthalpy, C_{LP}:

C_{LP} = 3491.53 kJ/kg-2230 kJ/kg= 1261.5 kJ/kg

o **The new ST**

$$W_{NEW\ ST} = \dot{m}_{LP} \times C_{LP}$$

$$= 46.87 * 1261.5k$$

$$= \underline{59.13\ MW}$$

- Therefore this will add up the value of the power being produced by this plant. The power is produced from 3 gas turbines and 2 steam turbines for 1 block.

5.5 Simulation on ISCCPP & CCPP

This is the CCPP & ISCCPP simulation window by using Visual Basic.NET. The total power demand and the date of the day is an input in order to simulate this program. By entered these input parameters, all the power output is calculated and shown inside the plant diagram. While the number of GT is being used, total natural gas usage, plant efficiency and the cost of natural gas are display at the bottom of the picture. The current natural gas price that sold by Petronas Gas Berhad is RM0.67/kg while the natural gas usage is 7.84kg/s. All the CCPP output are display in green while the ISCCS outputs are display in blue. All the outputs both from ISCCPP & CCPP are observed. Figure 5.6 shows the total power demand was 650MW on the 30 November 2006. From the simulation, it shows the total power generation on the ISCCPP is lower than CCPP which is 360.55MW. Therefore, the usage of natural gas is less where only 71650.87kg/hour compared to 78833.84kg/hour in the CCPP process. The natural gas cost in ISCCPP just RM 42, 990.52 while the CCPP cost RM 52,818.67. In Figure 5.7, the total demand is

709MW on 30 November 2006. For the CCPP system is not longer available because the total demand is higher than the plant capability while the ISCCPP still can produce at number of power electricity and give the maximum efficiency.

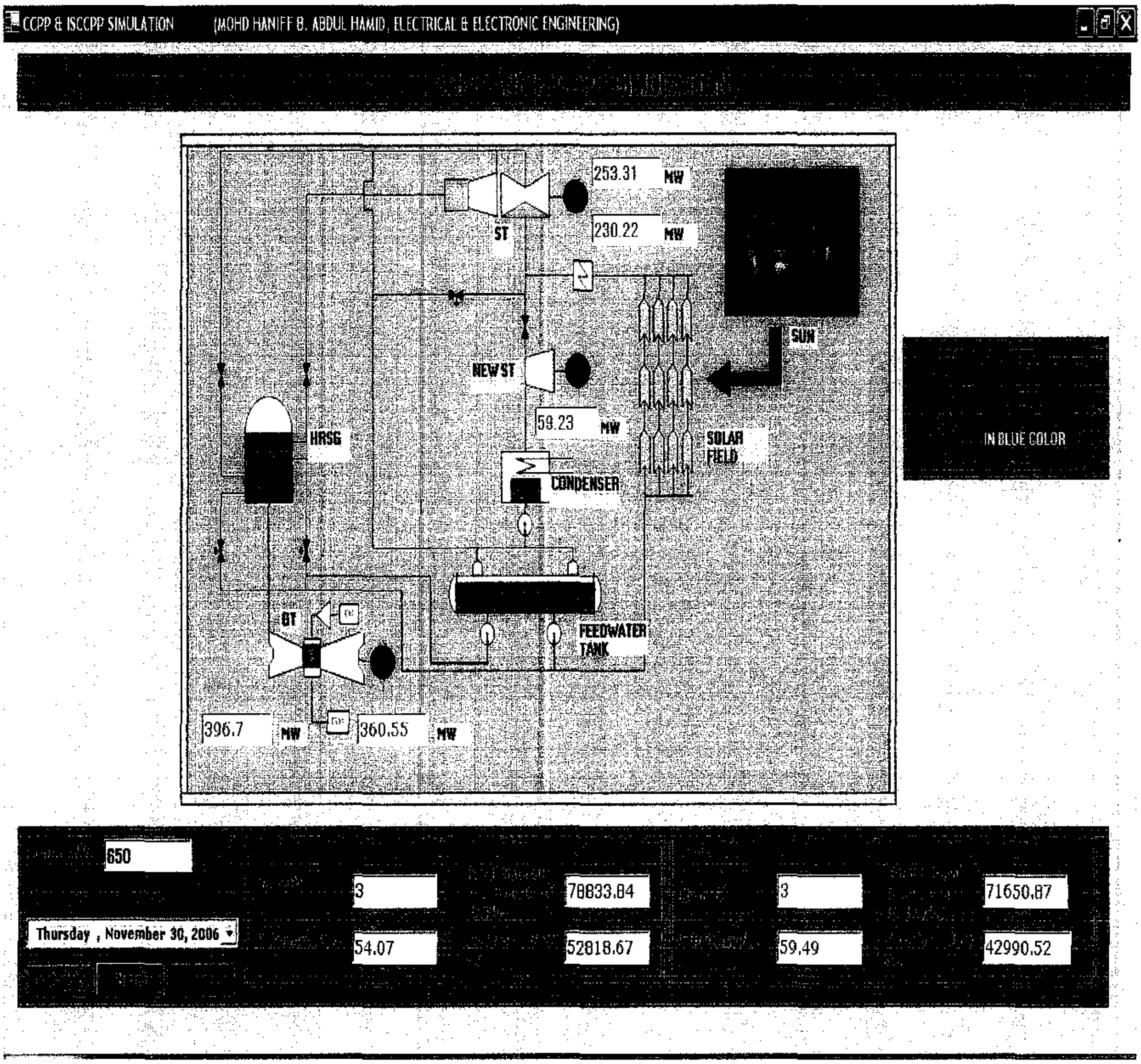


Figure 5.6 Simulations of ISCCPP & CCPP during 650MW demand

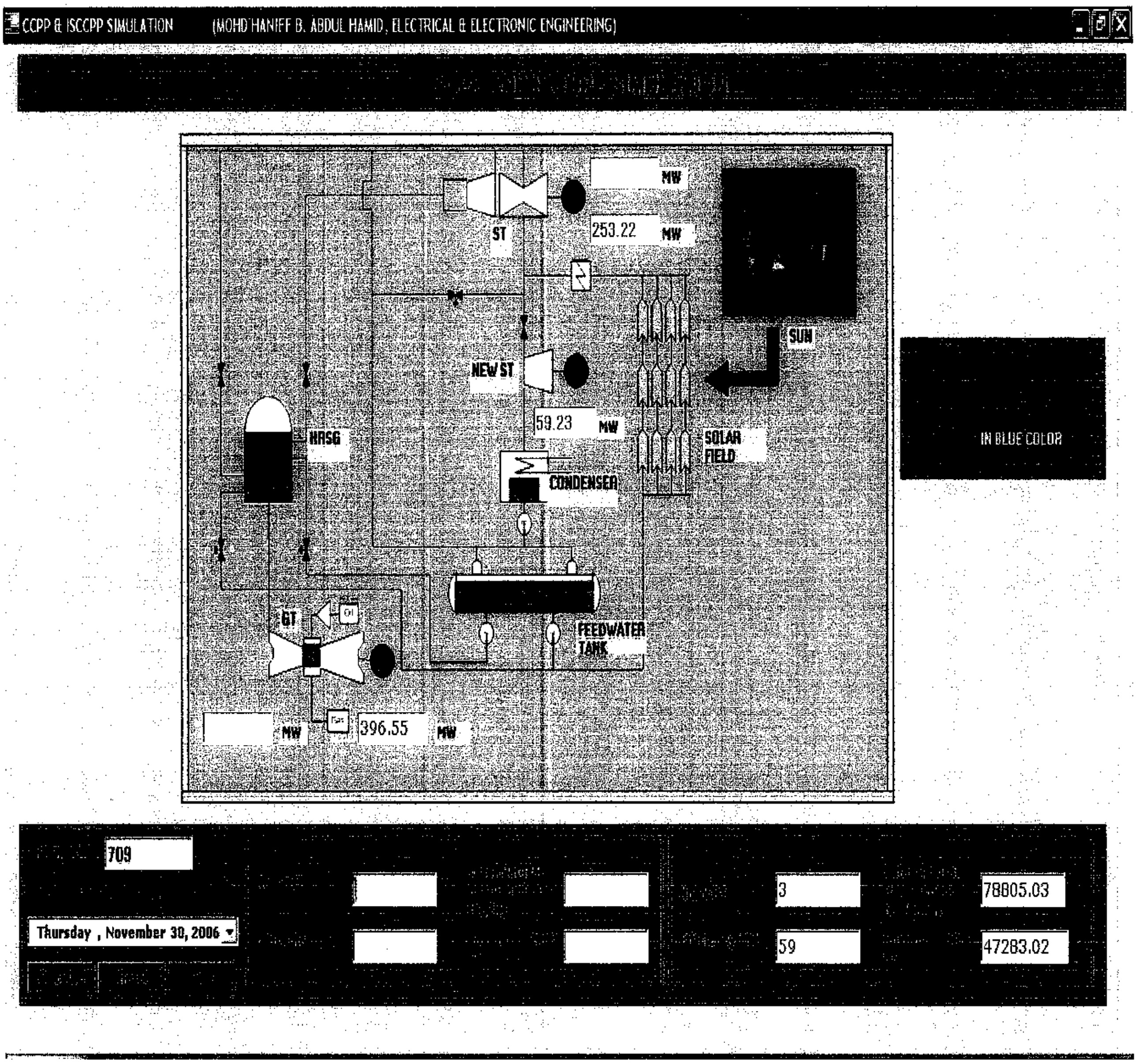


Figure 5.7: Simulation of ISCCPP & CCPP during 709 MW demand

From the simulation, it can be summarized that all the power output on the GT, ST and NEW ST is being counted besides the efficiency on the GT, ST and the full plant.

Table 5.5: The power outputs and the efficiencies

	CCPP	**ISCCPP**
W_{GT}	$397MW$	$397MW$
W_{ST}	$253MW$	$253MW$
$W_{NEW\ ST}$	-	$59MW$
W_{CCPP} / W_{ISCCS}	$650MW$	$709MW$
η_{GT}	33%	33%
η_{ST}	43.75%	54%

The Visual Basic.NET simulate the maximum efficiency of CCPP is 54.07% by using 3 GT and 1 ST at full load. The total power generation is 650MW. On the ISCCPP, the total power generation is 709MW by using 3 GT and 2 ST at full load.

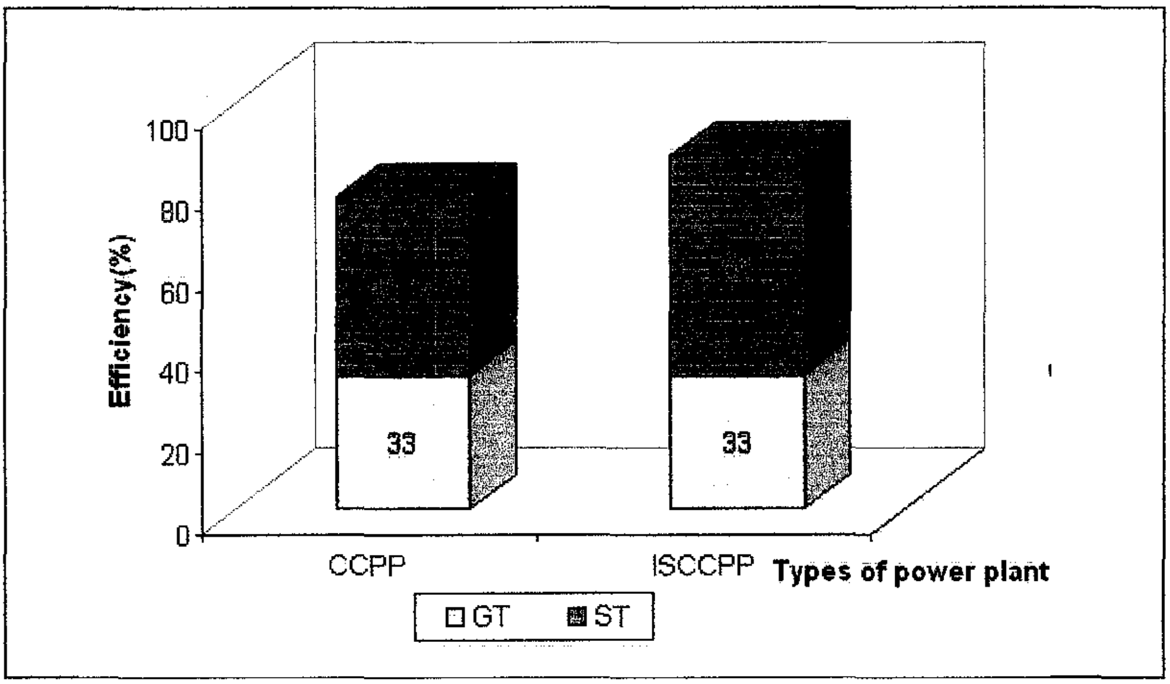


Figure 5.8: The GT, ST efficiency

The total power generation in the 3 operating mode is shown in the table below. As mention earlier, the CCPP is the combination of 3 GT and 1 ST, while the new system ISCCPP is the combination of 3 GT and 2 ST.

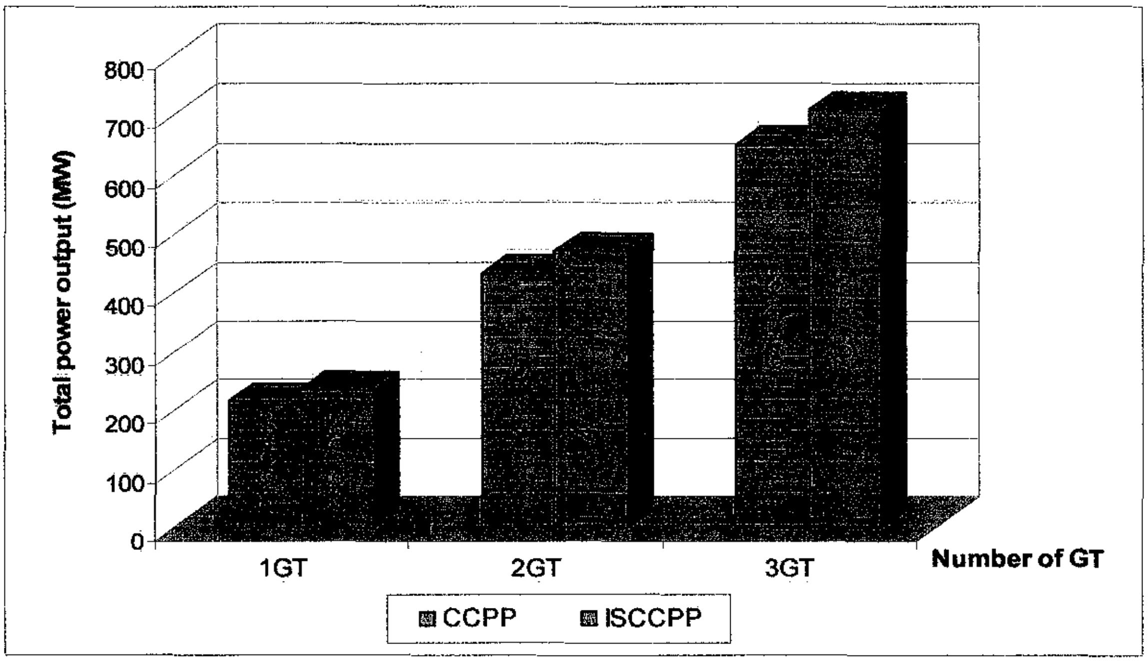


Figure 5.9: Total power output based on the GT's usage

CHAPTER 6

CONCLUSION AND RECOMMENDATION

The ISCCPP is the new way of clean electricity generation. By using the solar energy where the solar radiation captured to be used to heat and convert the water into steam. This steam produced is channeled to the new steam turbine and drive a new generator in order to generate more power output. This new system adds one steam turbine and a generator. In full operation as a result, the plant operates by using 3 GT and 2 ST. This project has approved this new ISCCPP can produce identical or more electrical power than CCPP more clean because of the less usage of natural gas. The ISCCPP can be used as an alternative way in order to extend the reserve of natural gas for the coming years. The solar collector for this system is parabolic trough collector which is the best absorber and is commercialized around the world. Through the simulation, the maximum power output that can be produce by this solar collector during the highest solar radiation is 59.13 MW and gives the total power of the plant to 709MW. Based on this research, the ISCCPP system is inapplicable because of the low solar radiation. The solar collector system is only available from 10am until 3pm daily where there is enough radiation for water heating. Therefore the solar radiation in reference area available just 5 hours which is not well practice in term of optimizing power output for the whole day and the efficiency of power plant. Cloudy and heavy rain is Malaysia weather characteristic. Therefore, there is a need to make research to find another suitable coastal area in Malaysia that can give consistent high solar radiation. To make it more wisely, deep research on the PTC technology has to be done. The improvement on selecting the suitable coating type in a way to increase the reliability of the receiver and expand the concentrator size of aperture and depth of concentrator. The need to execute the solar thermal storage that is useful during the unpredictable weather condition and also during nighttime. The solar radiation during the daytime can be used in the nighttime power generation. Since the reference area is in the coastal area, another source of renewable energy such as wind and tidal energy can be put into account to vary the free source which is available all the time. The solar field implementation cost is not considered in this project due to the time constraint. It is recommended to include the cost in order to influence the feasibility within the budget. This project has achieved its objectives of implementing the ISCCPP which is the enhancement from the CCPP in order to produce higher electricity generation in the clean environmentally condition.

REFERENCES

[1] Natural gas. http://www.naturalgas.org/overview/background.asp. Retrieved on April 20, 2007

[2] Malaysia Department of Environment. < (http://www.doe.gov.my)>. Retrieved on February 2, 2007.

[3] Malaysia Energy Commission. http://www.st.gov.my/SREP.html. Retrieved on March 3, 2007

[4] EPU. (2006). Ninth Malaysia Plan (2006-2010)

[5] Mohd Haniff, A.H. (2006). Industrial Internship Report at Lumut Power Plant. IRC, Universiti Teknologi PETRONAS, Malaysia

[6] Energy Information Administration. http://www.eia.doe.gov. Retrieved on May 1, 2007.

[7] The Star (16 July 2006).Tenaga strikes back. Retrieved on May 3, 2007.

[8] World energy outlook 2006. <http://www.worldenergyoutlook.org/>. Retrieved on May 2, 2007.

[9] Kyoto Protocol. The United Nations Framework Convention on Climate Change <http://unfccc.int/essential_background/convention/background/items/1353.php>. Retrieved on May 1, 2007.

[10] Segari Energy Ventures Sdn. Bhd. Lumut Power Plant (2005)

[11] Tiwari (2000), *Solar Energy Fundamental, Design, Modelling and Applications*, Alpha Science International Ltd. New Delhi.

[12] Garg, H.P. & Prakash, J. (1997). *Solar Energy: Fundamentals and Applications.* New Delhi: Tata McGraw-Hill Publishing Company Limited.

[13] Duffie, J.A. & Beckman, W.A. (1980). *Solar Engineering of Thermal Processes.* New York : John Wiley & Sons.

[14] Ann Chambers (2004), *Renewable Energy in Nontechnical Languange*, PennWell Corporation, Oklahoma.

[15] R. Hosseini, M Soltani, G Valizadeh (December 24.2004), *Technical & Economic Assessment of the Integrated Solar Combined Cycle Power Plant in Iran,* Tehran, Iran.

[16] L. Valenzuela, E. Zarza, M. Berenguel, E.F Camacho (November 14.2006), *Control scheme for direct steam generation in parabolic troughs under recirculation operation mode*, Almeria, Spain

[17] Sukhatme, S.P. (1996). Solar Energy: Principle of Thermal Collection and Storage, Tata Mc Grawhill, New Delhi.

[18] Nag, P.K. (2002). Power Plant Engineering. 2nd Edition. McGraw Hill. Singapore

[19] Sitiawan Global Solar Radiation Data for October & November 2006, Malaysia Meteorological Department.

[20] Azni-Zain, A., Salleh, M.M. & Dalimin, M.N. (1991). Computing The Monthly Average Daily Global and Diffuse Radiation from Sunshine Hours and Clearness Index for Petaling Jaya, West Malaysia. Sains Malaysiana 20(2).p.33-42

[21] Concentrating solar power.http://www.eere.energy.gov retrieved on January 3, 2007.

APPENDICES

Appendix A

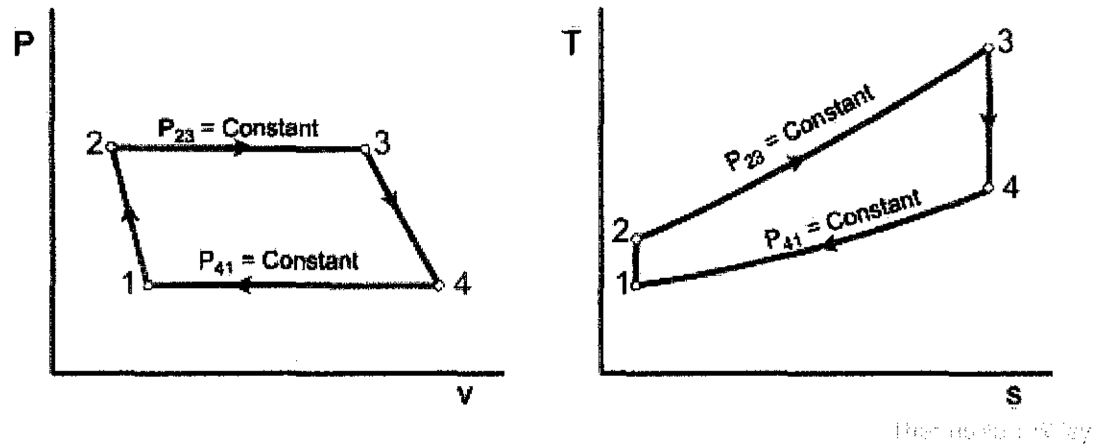
Installed Capacity, Peak Demand and Reserve Margin, 2000-2010

Year	*Generation By System* [1]	*Accumulated Installed Capacity (MW)*	*Peak Demand* [2] *(MW)*	*Reserve Margin* [3] *(%)*
2000	TNB	12,645	9,712	*30.2*
	SESB	785	391	*100.8*
	SESCO	861	554	*55.4*
	Total	**14,291**	**10,657**	***34.1***
2005	TNB	17,622	12,493	*41.1*
	SESB	639	543	*17.7*
	SESCO	956	743	*28.7*
	Total	**19,217**	**13,779**	***39.5***
2010	TNB	22,802	18,187	*25.4*
	SESB	1,100	802	*37.2*
	SESCO	1,356[4]	1,098	*23.5*
	Total	**25,258**	**20,087**	***25.7***

(source: [4])

Appendix B

Simple Brayton Cycle



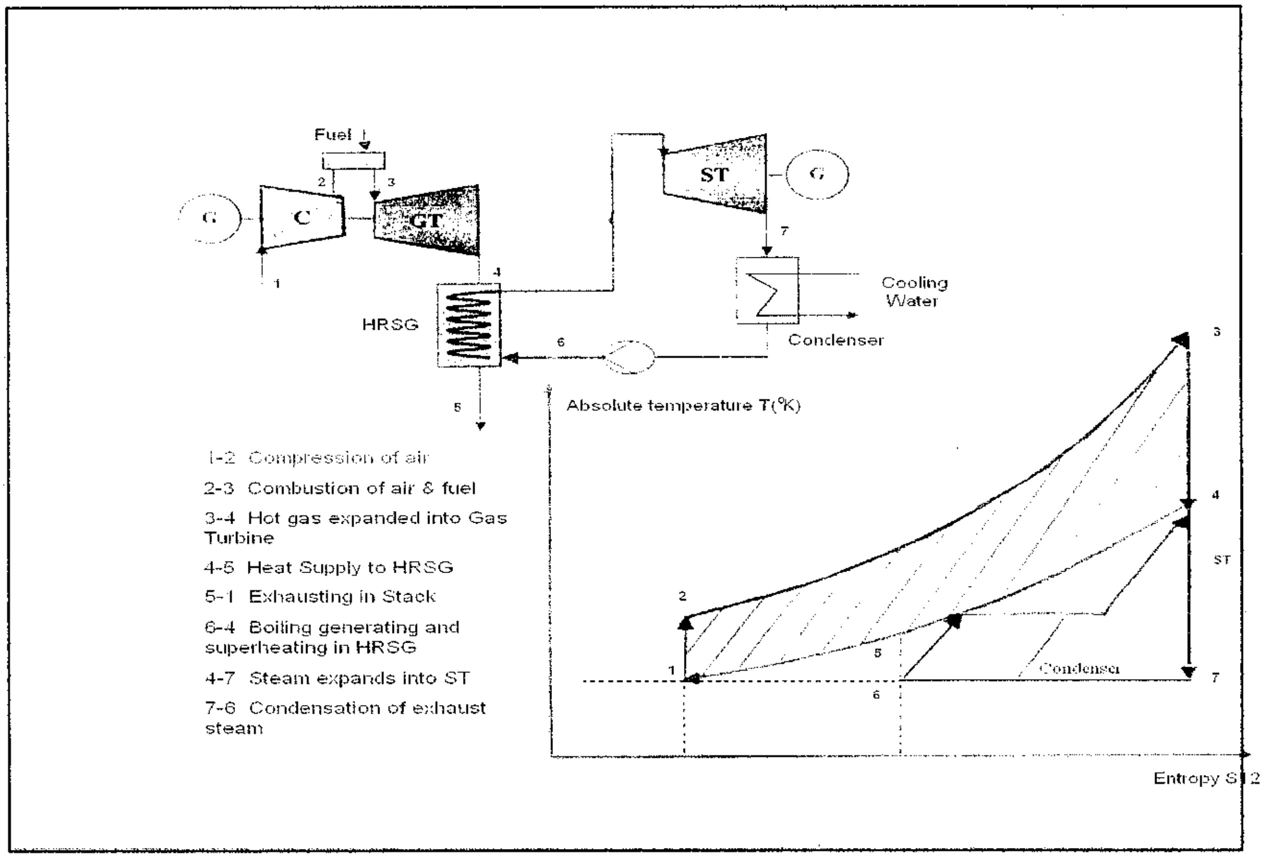
Process Cycles:

1-2	Isentropic Compression by Compressor
2-3	Constant Pressure Heat Addition in Combustion Chamber
3-4	Isentropic Expansion by Turbine
4-1	Heat Sink (Imaginary line)

(source: [10])

Appendix C

Working Principle of Combined Cycle Lumut Power Plant



(source: [10])

Appendix D

Application letter to Malaysia Meteorological Department for request the global solar radiation in Sitiawan area.

UNIVERSITI
TEKNOLOGI
PETRONAS

Dr. Balbir Singh Mahinder Singh
Senior Lecturer, Electrical & Electronic Engineering,
Universiti Teknologi PETRONAS,
Bandar Seri Iskandar,
31750 Tronoh, Perak.

22 Dec 2006

En. Azhar Ishak,
Pengarah Khidmat Komersial
Bahagian Kajiiklim,
Jabatan Meteorologi Malaysia,
Jalan Sultan
46661 Petaling Jaya, Selangor.

Tuan,

Re : Data sinaran suria global purata setiap jam bagi kawasan Sitiawan

Merujuk kepada perkara di atas, saya ingin meminta jasa baik pihak tuan untuk mendapatkan data sinaran suria global purata setiap jam bagi kawasan Sitiawan, bagi tujuan projek tahun akhir pelajar saya. Butiran mengenai pelajar saya adalah seperti berikut :

Nama : Mohd. Haniff bin Abdul Hamid
NRIC : 830503-08-5409
Tajuk projek : Integrated Renewable Energy System for Sustainable Development

Data sinaran suria berkenaan akan digunakan bagi tujuan penyelidikan ini, dan bukannya untuk tujuan komersil. Segala kerjasama dari pihak tuan adalah amat dihargai.

Terima kasih.

Yang benar,

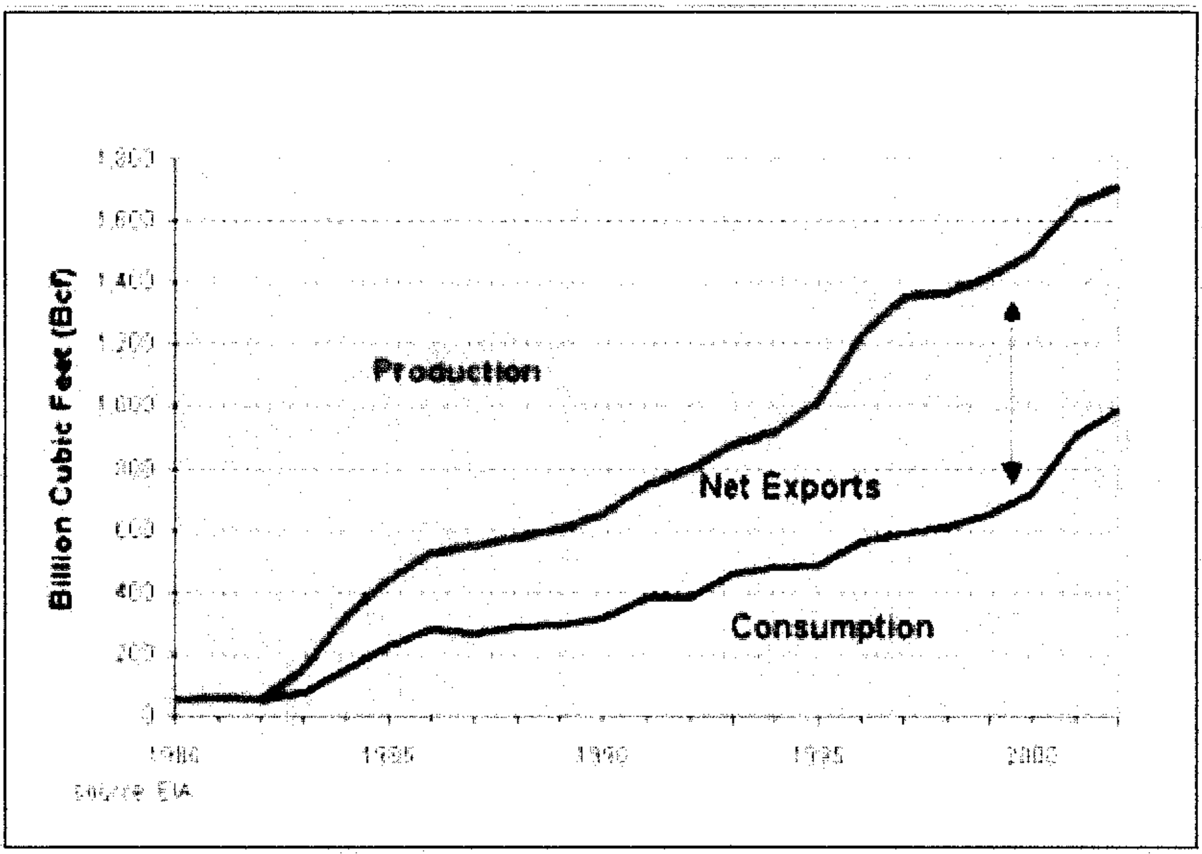
Dr Balbir Singh Mahinder Singh
Senior Lecturer
Electrical & Electronic engineering
Academic Block No. 20 L-3 Room 6
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh,
Perak Darul Ridzuan, MALAYSIA

UNIVERSITI TEKNOLOGI PETRONAS
INSTITUTE OF TECHNOLOGY PETRONAS SDN. BHD.
(Company No: 352875U) Wholly-owned subsidiary of PETRONAS
Bandar Seri Iskandar, 31750 Tronoh, Perak Darul Ridzuan, Malaysia

Tel: 605-3688000 Fax: 605-3654075 D. Lines: HRM 605-3688291 Finance 605-3688283 Library 605-3688486
Public Affairs 605-3688237 Student Services 605-3688409 Academic 605-3688345 Security 605-3688313
Fax: HRM 605-3654075 Finance 605-3654087 Library 605-3667672 Student Services 605-3721286 Academic 605-3654082 Website http://www.utp.edu.my

Appendix E

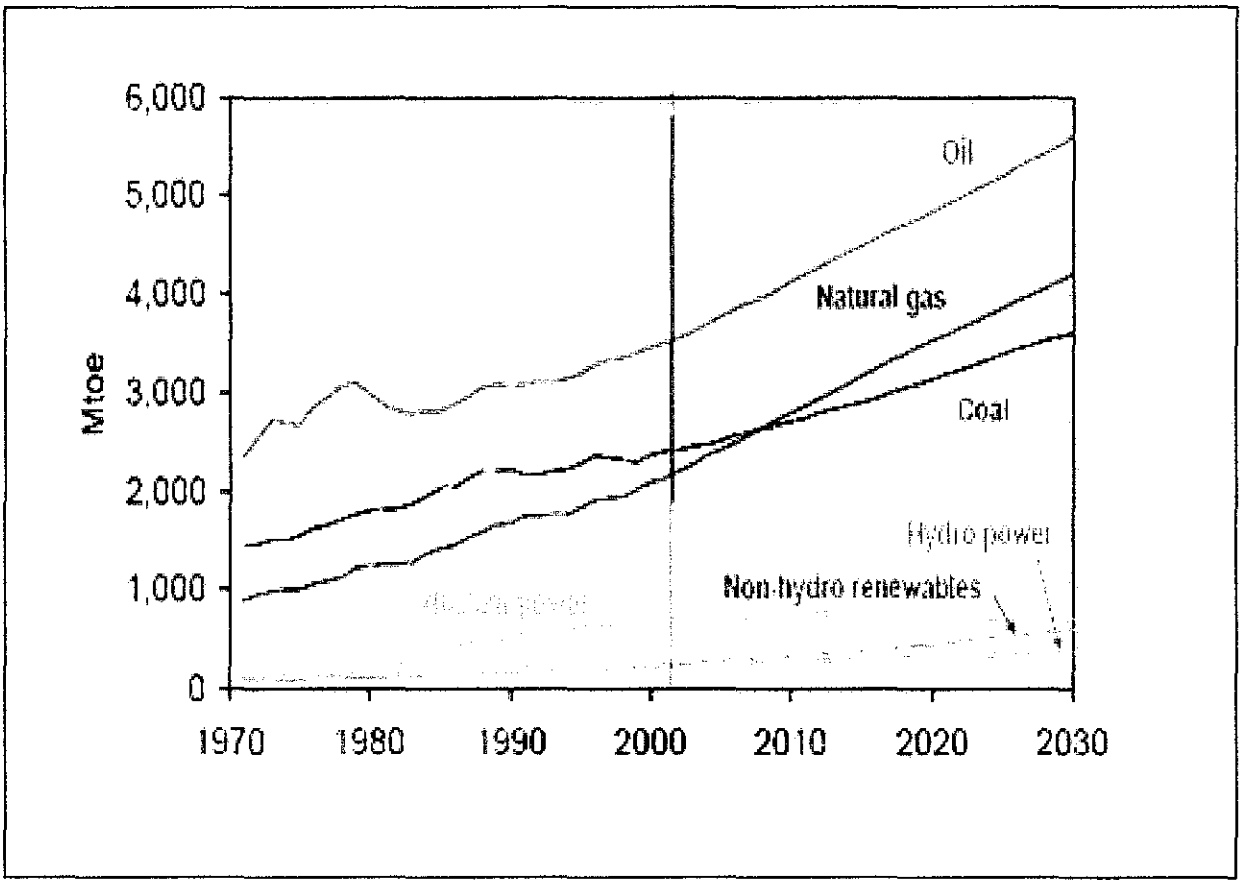
Malaysian Natural Gas Production and Consumption, 1980-2002



(source: [6])

Appendix F

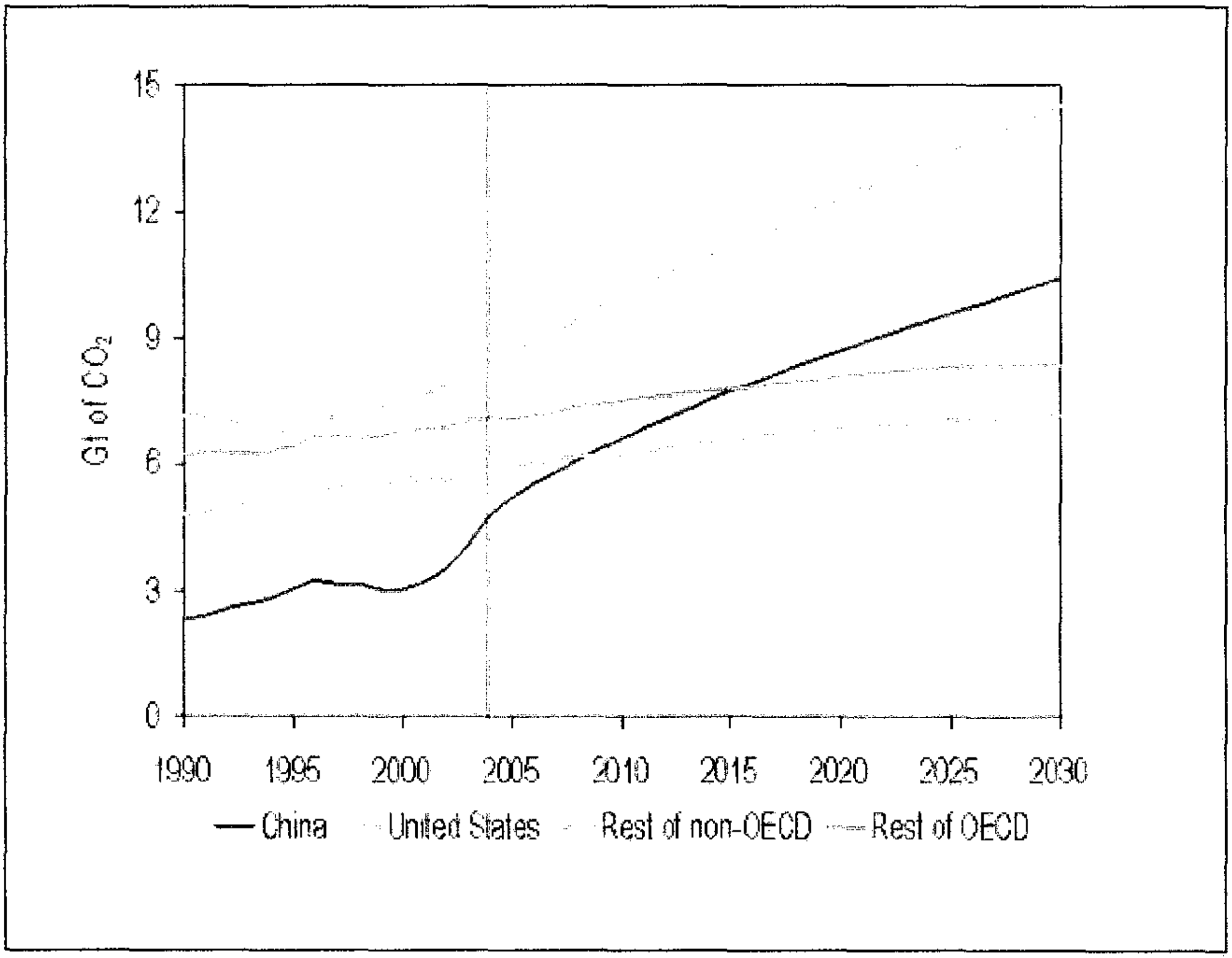
World Primary Energy Demand



(source: [8])

Appendix G

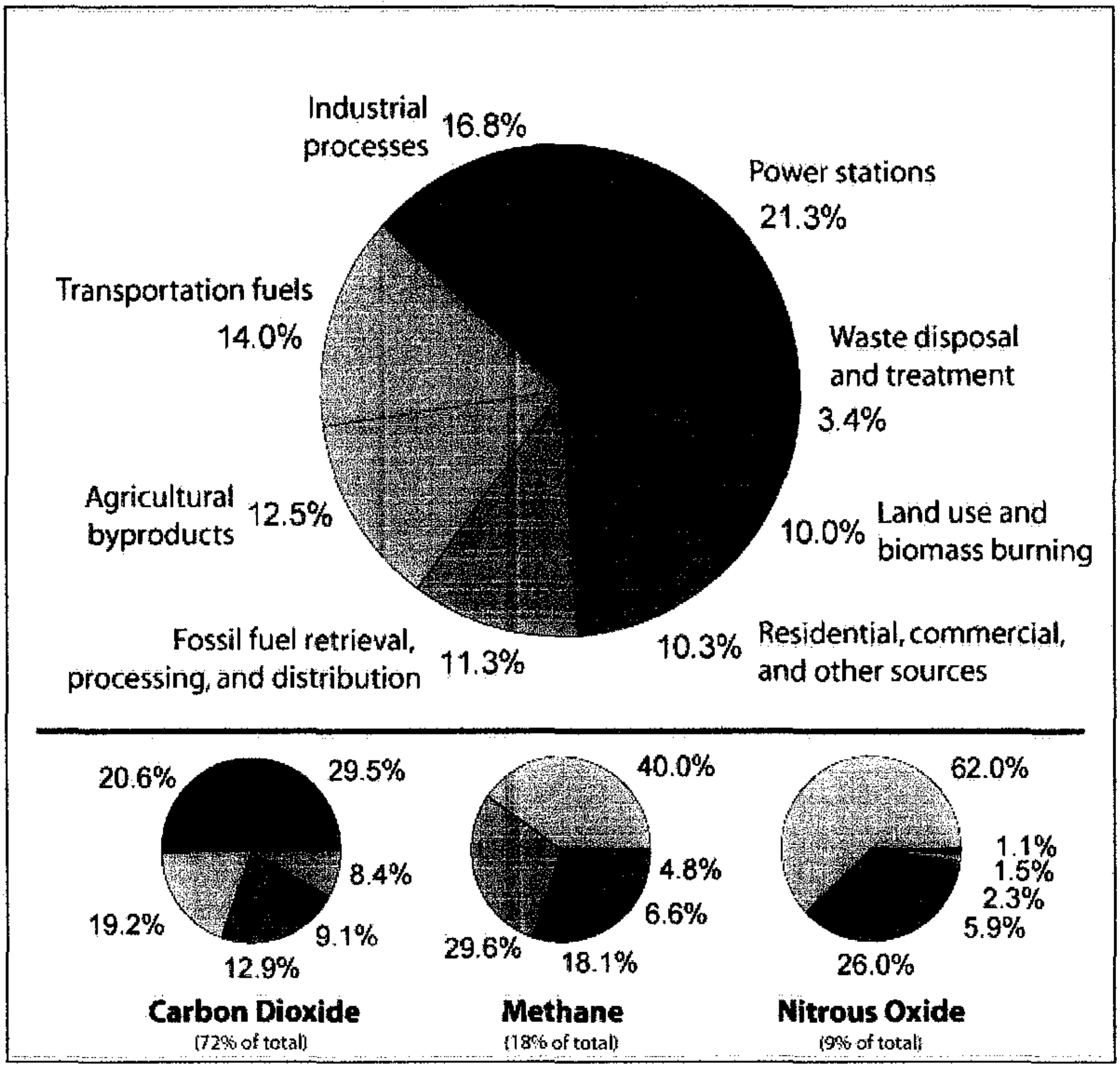
CO_2 Emissions Trends in the Reference Scenario, 1990 - 2030



(source: [8])

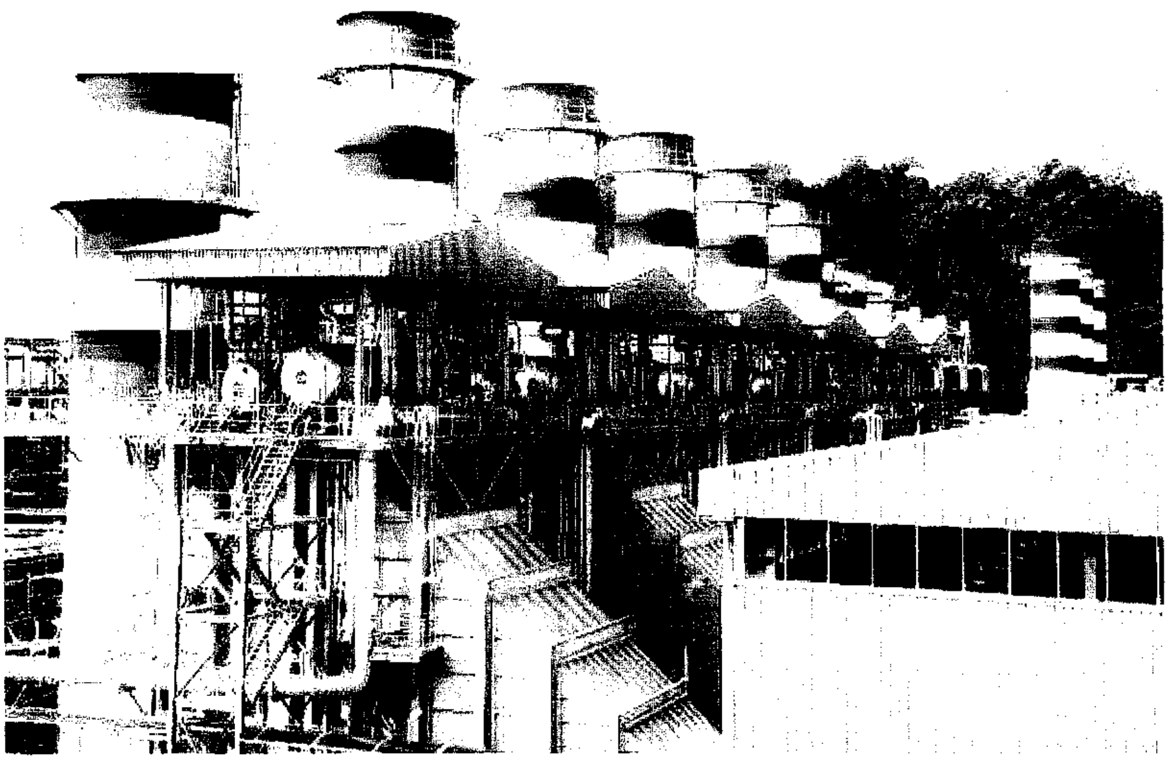
Appendix H

Annual Greenhouse Gas Emissions by Sector



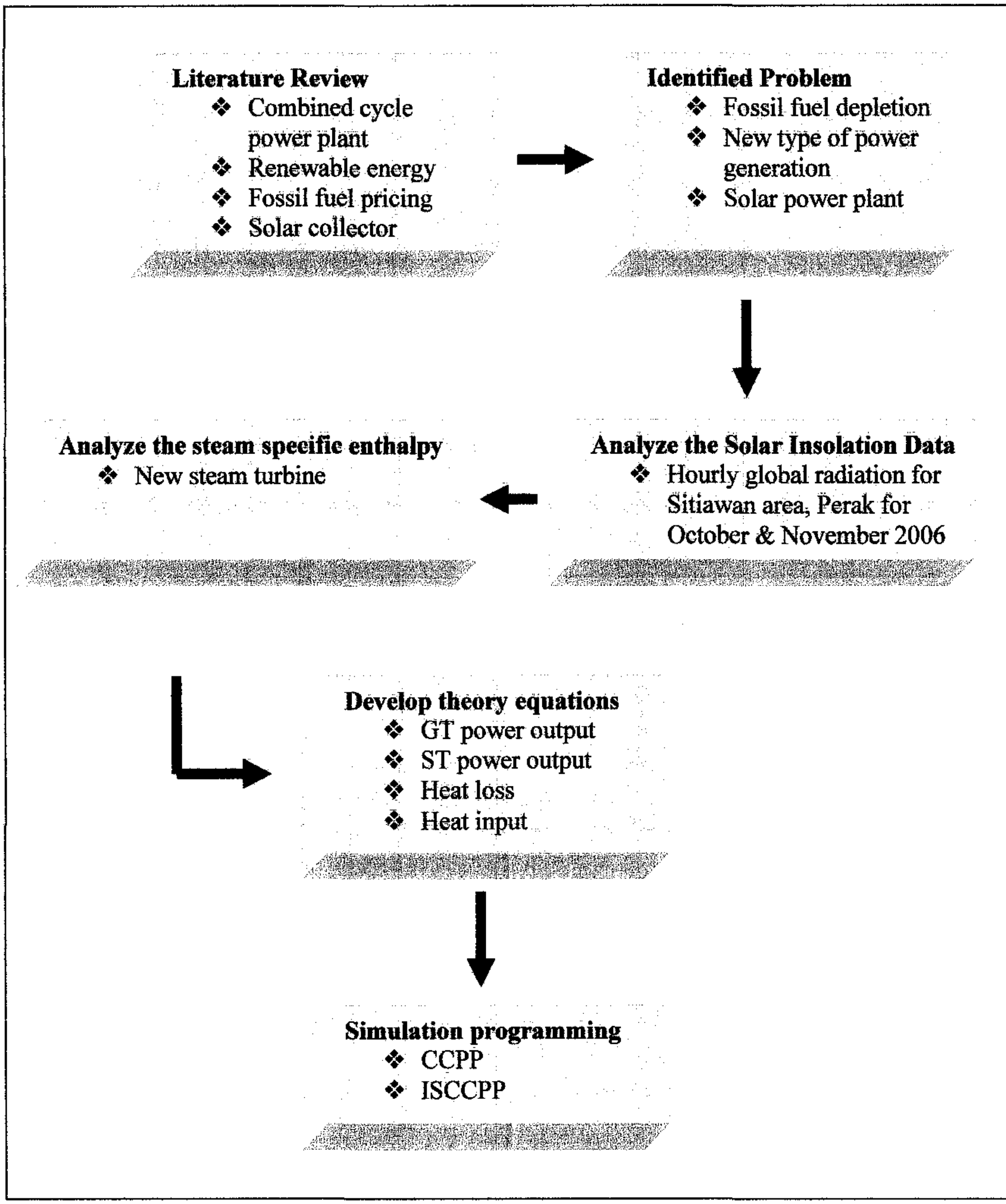
Appendix I

Lumut Power Plant View



Appendix J

The Flow Diagram of the Methodology



Appendix K

Simulation Coding for CCPP

```
Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        TextBox2.Visible = False
        clear()

        Label3.Enabled = True
        Label3.Visible = True
        Label6.Visible = True
        Label7.Visible = True
        Label8.Visible = True
        Label6.Enabled = True
        Label7.Enabled = True
        Label8.Enabled = True
        txtGT.Visible = True
        txtST1.Visible = True
        txtEfficiency.Visible = True
        txtNaturalGasGT.Visible = True
        txtNGcost.Visible = True
        TextBox1.Visible = True

    End Sub


    Private Sub btnCalculate_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs)

        If txtMW.Text <= 99 Then
            MsgBox("Insert value more than or equal to 100")
            clear()
        ElseIf txtMW.Text >= 710 Then
            MsgBox("Insert value less than or equal to 710")
            clear()
        Else



            Count_WgtWstEfficiency_NaturalGas()
            dummyNo_ofGT()
            calculateNoGTISCCPP()
            countISCCSPP()
            calculateNewST_ISCCSPP()
            calculateGT_ST_ISCCPP()
            Count_WgtWstEfficiency_NaturalGas_forISCCPP()
        End If

    End Sub

    Private Sub dummyNo_ofGT()
        Dim read As Double
```

```
        read = txtMW.Text
        If read <= 216.6455 Then
            TextBox1.Text = 1
            Label3.Visible = True
            TextBox1.Visible = True


        ElseIf read >= 216.6456 And read <= 433.291 Then

            TextBox1.Text = 2
            Label3.Visible = True
            TextBox1.Visible = True

        ElseIf read >= 433.292 And read <= 650 Then

            TextBox1.Text = 3
            Label3.Visible = True
            TextBox1.Visible = True

        ElseIf read >= 651 And read <= 710 Then
            'txtGT.Text = ""
            txtST1.Text = ""
            txtEfficiency.Text = ""
            txtNaturalGasGT.Text = ""
            txtNGcost.Text = ""
            TextBox1.Text = "No longer applicable, The maximum value
allow for this CCPP only until 650"
            Label3.Visible = True
            TextBox1.Visible = True

        End If

    End Sub


    Private Sub btnReset_Click(ByVal sender As System.Object, ByVal e
As System.EventArgs)
        clear()
    End Sub
    Private Sub clear()

        txtMW.Text = ""
        TextBox1.Text = ""
        txtEfficiency.Text = ""
        txtNaturalGasGT.Text = ""
        txtNGcost.Text = ""
        TextBox3.Text = ""
        txtEfficiencyISCCPP.Text = ""
        txtNaturalGasGT_ISCCPP.Text = ""
        txtNGcost_ISCCPP.Text = ""
        txtGT.Text = ""
        txtGT_ISCCPP.Text = ""
        txtST1.Text = ""
        txtST_ISCCPP.Text = ""
        txtNewST1.Text = ""

    End Sub
```

```
    Private Sub btnExit_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs)
        Close()
    End Sub
    ''''''''''''''''''''''''''
    Public Sub Count_WgtWstEfficiency_NaturalGas()
        Dim a As Double
        Dim b As Double
        Dim wgt As Double
        Dim wst As Double
        Dim efficiencyGT As Double
        Dim q1 As Double
        Dim Efficiency As Double
        Dim TotalNaturalgas As Double
        Dim NGCost As Single

        a = txtMW.Text
        wgt = (0.6103 * a)
        wst = (0.3897 * a)

        txtGT.Text = Format(wgt, "###.##")
        txtST1.Text = Format(wst, "###.##")
        If wgt >= 60 And wgt <= 69.99 Then
            efficiencyGT = 0.241

        ElseIf wgt >= 70 And wgt <= 79.99 Then
            efficiencyGT = 0.254


        ElseIf wgt >= 80 And wgt <= 89.99 Then
            efficiencyGT = 0.267


        ElseIf wgt >= 90 And wgt <= 99.99 Then
            efficiencyGT = 0.279


        ElseIf wgt >= 100 And wgt <= 109.99 Then
            efficiencyGT = 0.254


        ElseIf wgt >= 110 And wgt <= 119.99 Then
            efficiencyGT = 0.305


        ElseIf wgt >= 120 And wgt <= 129.99 Then
            efficiencyGT = 0.317


        ElseIf wgt >= 130 And wgt <= 132.99 Then
        efficiencyGT = 0.33


        ElseIf wgt >= 133 And wgt <= 139.99 Then
            efficiencyGT = 0.178
```

```
ElseIf wgt >= 140 And wgt <= 159.99 Then
    efficiencyGT = 0.19

ElseIf wgt >= 160 And wgt <= 169.99 Then
    efficiencyGT = 0.203

ElseIf wgt >= 170 And wgt <= 179.99 Then
    efficiencyGT = 0.216

ElseIf wgt >= 180 And wgt <= 189.99 Then
    efficiencyGT = 0.228

ElseIf wgt >= 190 And wgt <= 199.99 Then
    efficiencyGT = 0.241

ElseIf wgt >= 200 And wgt <= 209 Then
    efficiencyGT = 0.254

ElseIf wgt >= 210 And wgt <= 219.99 Then
    efficiencyGT = 0.267

ElseIf wgt >= 220 And wgt <= 229.99 Then
    efficiencyGT = 0.279

ElseIf wgt >= 230 And wgt <= 239.99 Then
    efficiencyGT = 0.292

ElseIf wgt >= 240 And wgt <= 249.99 Then
    efficiencyGT = 0.305

ElseIf wgt >= 250 And wgt <= 259 Then
    efficiencyGT = 0.317

ElseIf wgt >= 260 And wgt <= 264.99 Then
    efficiencyGT = 0.33

ElseIf wgt >= 265 And wgt <= 269.99 Then
    efficiencyGT = 0.088

ElseIf wgt >= 270 And wgt <= 279.99 Then
    efficiencyGT = 0.187

ElseIf wgt >= 280 And wgt <= 289.99 Then
```

```
    efficiencyGT = 0.198

ElseIf wgt >= 290 And wgt <= 299.99 Then
    efficiencyGT = 0.209

ElseIf wgt >= 300 And wgt <= 309.99 Then
    efficiencyGT = 0.22

ElseIf wgt >= 310 And wgt <= 319.99 Then
    efficiencyGT = 0.231

ElseIf wgt >= 320 And wgt <= 329.99 Then
    efficiencyGT = 0.242

ElseIf wgt >= 330 And wgt <= 339.99 Then
    efficiencyGT = 0.253

ElseIf wgt >= 340 And wgt <= 349.99 Then
    efficiencyGT = 0.264

ElseIf wgt >= 350 And wgt <= 359.99 Then
    efficiencyGT = 0.275

ElseIf wgt >= 360 And wgt <= 369.99 Then
    efficiencyGT = 0.286

ElseIf wgt >= 370 And wgt <= 379.99 Then
    efficiencyGT = 0.297

ElseIf wgt >= 380 And wgt <= 389.99 Then
    efficiencyGT = 0.308

ElseIf wgt >= 390 And wgt <= 397.99 Then
    efficiencyGT = 0.33

Else
    txtEfficiency.Text = ""
    txtNaturalGasGT.Text = ""
    txtNGcost.Text = ""

End If
q1 = (wgt / efficiencyGT)
Efficiency = ((wgt + wst) / q1) * 100
txtEfficiency.Text = Format(Efficiency, "###.##")
TotalNaturalgas = ((((q1 * 1000000) * 0.01453) / (1114 * 716))
* 3600)
```

```
txtNaturalGasGT.Text = Format(TotalNaturalgas, "###.##")
NGCost = TotalNaturalgas * 0.67
txtNGcost.Text = Format(NGCost, "###.##")
''''''''''''''''
Label6.Visible = True

txtGT.Visible = True
txtST1.Visible = True
txtEfficiency.Visible = True
txtNaturalGasGT.Visible = True
Label7.Visible = True
Label8.Visible = True
txtNGcost.Visible = True

End Sub
```

Appendix L

Simulation Coding for ISCCPP

```
Private Sub Form1_Load(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles MyBase.Load
        TextBox2.Visible = False
        clear()

        Label11.Enabled = True
        Label11.Visible = True
        Label17.Visible = True
        Label26.Visible = True
        Label25.Visible = True
        Label17.Enabled = True
        Label26.Enabled = True
        Label25.Enabled = True
        Label11.Visible = True
        txtGT_ISCCPP.Visible = True
        txtST1_ISCCPP1.Visible = True
        txtEfficiencyISCCPP.Visible = True
        txtNaturalGasGT_ISCCPP.Visible = True
        txtNGcost_ISCCPP.Visible = True
        TextBox3.Visible = True


    End Sub


    Private Sub btnCalculate_Click(ByVal sender As System.Object, ByVal
e As System.EventArgs)

        If txtMW.Text <= 99 Then
            MsgBox("Insert value more than or equal to 100")
            clear()
        ElseIf txtMW.Text >= 710 Then
            MsgBox("Insert value less than or equal to 710")
            clear()
        Else

            Count_WgtWstEfficiency_NaturalGas()
            dummyNo_ofGT()
            calculateNoGTISCCPP()
            countISCCPP()
            calculateNewST_ISCCPP()
            calculateGT_ST_ISCCPP()
            Count_WgtWstEfficiency_NaturalGas_forISCCPP()
        End If


    Private Sub countISCCPP()
        If txtMW.Text >= 100 And txtMW.Text <= 236.3555 Then
```

```
        TextBox3.Text = 1
    ElseIf txtMW.Text >= 236.3555 And txtMW.Text <= 472.2711 Then
        TextBox3.Text = 2
    ElseIf txtMW.Text >= 472.2711 And txtMW.Text <= 710 Then
        TextBox3.Text = 3
    End If
End Sub
Private Sub calculateNewST_ISCCPP()
    Dim Qr As Double
    Dim Tfo As Double
    Dim y As Double
    Dim Clp As Double
    Dim newST As Single
    Dim GTvalue As Double
    Dim gto As Single
    Dim newVar As Single

    TextBox2.Text = DateValue(DateTimePicker1.Value)
    If TextBox2.Text = DateValue("October-1-2006") Then
        Qr = (588.1374 * (606.7815 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-2-2006") Then
        Qr = (588.1374 * (654.336 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-3-2006") Then
        Qr = (588.1374 * (365.323 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-4-2006") Then
        Qr = (588.1374 * (540.06 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-5-2006") Then
        Qr = (588.1374 * (502.4654 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-6-2006") Then
        Qr = (588.1374 * (320.3482 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-7-2006") Then
        Qr = (588.1374 * (539.6898 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-8-2006") Then
        Qr = (588.1374 * (522.363 - 18.613274))

    ElseIf TextBox2.Text = DateValue("October-9-2006") Then
        Qr = (588.1374 * (366.7968 - 18.613274))


    ElseIf TextBox2.Text = DateValue("October-10-2006") Then
        Qr = (588.1374 * (516.465 - 18.613274))
```

```
ElseIf TextBox2.Text = DateValue("October-11-2006") Then
    Qr = (588.1374 * (226.3449 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-12-2006") Then
    Qr = (588.1374 * (531.9476 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-13-2006") Then
    Qr = (588.1374 * (220.078 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-14-2006") Then
    Qr = (588.1374 * (282.0096 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-15-2006") Then
    Qr = (588.1374 * (307.8144 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-16-2006") Then
    Qr = (588.1374 * (429.097 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-17-2006") Then
    Qr = (588.1374 * (97.32 - 18.613274))

ElseIf TextBox2.Text = DateValue("October=18=2006") Then
    Qr = (588.1374 * (338.412 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-19-2006") Then
    Qr = (588.1374 * (542.27 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-20-2006") Then
    Qr = (588.1374 * (497.3 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-21-2006") Then
    Qr = (588.1374 * (450 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-22-2006") Then
    Qr = (588.1374 * (400.712 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-23-2006") Then
    Qr = (588.1374 * (532.334 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-24-2006") Then
    Qr = (588.1374 * (543.376 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-25-2006") Then
    Qr = (588.1374 * (295.3 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-26-2006") Then
```

```
    Qr = (588.1374 * (369.1 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-27-2006") Then
    Qr = (588.1374 * (405.87 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-28-2006") Then
    Qr = (588.1374 * (597.57 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-29-2006") Then
    Qr = (588.1374 * (541.54 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-30-2006") Then
    Qr = (588.1374 * (519.7824 - 18.613274))

ElseIf TextBox2.Text = DateValue("October-31-2006") Then
    Qr = (588.1374 * (322.929 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-01-2006") Then
    Qr = (588.1374 * (572.5 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-02-2006") Then
    Qr = (588.1374 * (530.473 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-03-2006") Then
    Qr = (588.1374 * (561.81 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-04-2006") Then
    Qr = (588.1374 * (579.51 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-05-2006") Then
    Qr = (588.1374 * (472.966 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-06-2006") Then
    Qr = (588.1374 * (548.905 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-07-2006") Then
    Qr = (588.1374 * (549.643 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-08-2006") Then
    Qr = (588.1374 * (384.123 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-09-2006") Then
    Qr = (588.1374 * (384.123 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-10-2006") Then
    Qr = (588.1374 * (460.063 - 18.613274))
```

```
ElseIf TextBox2.Text = DateValue("November-11-2006") Then
    Qr = (588.1374 * (358.687 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-12-2006") Then
    Qr = (588.1374 * (547.431 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-13-2006") Then
    Qr = (588.1374 * (248.832 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-14-2006") Then
    Qr = (588.1374 * (539.321 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-15-2006") Then
Qr = (588.1374 * (459.6941 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-16-2006") Then
Qr = (588.1374 * (486.974 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-17-2006") Then
Qr = (588.1374 * (391.1271 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-18-2006") Then
Qr = (588.1374 * (438.6816 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-19-2006") Then
Qr = (588.1374 * (562.1761 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-20-2006") Then
Qr = (588.1374 * (416.5632 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-21-2006") Then
Qr = (588.1374 * (411.771 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-22-2006") Then
Qr = (588.1374 * (530.473 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-23-2006") Then
Qr = (588.1374 * (390.39 - 18.613274))


ElseIf TextBox2.Text = DateValue("November-24-2006") Then
Qr = (588.1374 * (269.476 - 18.613274))

ElseIf TextBox2.Text = DateValue("November-25-2006") Then
Qr = (588.1374 * (526.05 - 18.613274))
```

```
    ElseIf TextBox2.Text = DateValue("November-26-2006") Then
    Qr = (588.1374 * (523.469 - 18.613274))

    ElseIf TextBox2.Text = DateValue("November-27-2006") Then
    Qr = (588.1374 * (544.85 - 18.613274))


    ElseIf TextBox2.Text = DateValue("November-28-2006") Then
    Qr = (588.1374 * (526.418 - 18.613274))


    ElseIf TextBox2.Text = DateValue("November-29-2006") Then
    Qr = (588.1374 * (494.347 - 18.613274))


    ElseIf TextBox2.Text = DateValue("November-30-2006") Then
    Qr = (588.1374 * (663.552 - 18.613274))

    End If
    GTvalue = 1.1768
    Tfo = ((Qr / 1723.5) + 70) * GTvalue
    y = (4 * 10 ^ (-15) * Tfo ^ (4)) + (2 * 10 ^ (-13) * Tfo ^ (3))
   - (4 * 10 ^ (-13) * Tfo ^ (2)) + 10 * Tfo + 80
    Clp = y - 2230
    newST = (46.87 * Clp) / 1000
    If TextBox3.Text = 1 Then
        newVar = newST / 3
    ElseIf TextBox3.Text = 2 Then
        newVar = newST * 2 / 3
    Else
        newVar = newST
    End If

    txtNewST1.Text = Format(newVar, "###.##")

End Sub

Private Sub calculateGT_ST_ISCCPP()
    Dim MWValue As Double
    Dim B As Double
    Dim newST As Double
    Dim GT As Single
    Dim ST As Single
    MWValue = txtMW.Text
    newST = txtNewST1.Text
    B = MWValue - newST
    GT = 0.6103 * B
    txtGT_ISCCPP.Text = Format(GT, "###.##")
    ST = (0.3897 * B)
    txtST_ISCCPP.Text = Format(ST, "###.##")

End Sub
Private Sub Count_WgtWstEfficiency_NaturalGas_forISCCPP()

    Dim wgt As Double
    Dim wst As Double
```

```
Dim efficiencyGT As Double
Dim q1 As Double
Dim Efficiency As Double
Dim TotalNaturalgas As Double
Dim NGCost As Single
Dim newST As Single
Dim try1 As Single
Dim temptry1 As Single

try1 = 0

wgt = txtGT_ISCCPP.Text
wst = txtST_ISCCPP.Text
newST = txtNewST1.Text

try1 = txtGT.Text
''''''''''''''''''''''''''''

If try1 >= 60 And try1 <= 69.99 Then
    efficiencyGT = 0.241

ElseIf try1 >= 70 And try1 <= 79.99 Then
    efficiencyGT = 0.254

ElseIf try1 >= 80 And try1 <= 89.99 Then
    efficiencyGT = 0.267

ElseIf try1 >= 90 And try1 <= 99.99 Then
    efficiencyGT = 0.279

ElseIf try1 >= 100 And try1 <= 109.99 Then
    efficiencyGT = 0.254

ElseIf try1 >= 110 And try1 <= 119.99 Then
    efficiencyGT = 0.305

ElseIf try1 >= 120 And try1 <= 129.99 Then
    efficiencyGT = 0.317

ElseIf try1 >= 130 And try1 <= 132.99 Then
    efficiencyGT = 0.33

ElseIf try1 >= 133 And try1 <= 139.99 Then
    efficiencyGT = 0.178

ElseIf try1 >= 140 And try1 <= 159.99 Then
    efficiencyGT = 0.19

ElseIf try1 >= 160 And try1 <= 169.99 Then
    efficiencyGT = 0.203

ElseIf try1 >= 170 And try1 <= 179.99 Then
    efficiencyGT = 0.216

ElseIf try1 >= 180 And try1 <= 189.99 Then
    efficiencyGT = 0.228
```

```
ElseIf try1 >= 190 And try1 <= 199.99 Then
    efficiencyGT = 0.241

ElseIf try1 >= 200 And try1 <= 209 Then
    efficiencyGT = 0.254

ElseIf try1 >= 210 And try1 <= 219.99 Then
    efficiencyGT = 0.267

ElseIf try1 >= 220 And try1 <= 229.99 Then
    efficiencyGT = 0.279

ElseIf try1 >= 230 And try1 <= 239.99 Then
    efficiencyGT = 0.292

ElseIf try1 >= 240 And try1 <= 249.99 Then
    efficiencyGT = 0.305

ElseIf try1 >= 250 And try1 <= 259 Then
    efficiencyGT = 0.317

ElseIf try1 >= 260 And try1 <= 264.99 Then
    efficiencyGT = 0.33

ElseIf try1 >= 265 And try1 <= 269.99 Then
    efficiencyGT = 0.088

ElseIf try1 >= 270 And try1 <= 279.99 Then
    efficiencyGT = 0.187

ElseIf try1 >= 280 And try1 <= 289.99 Then
    efficiencyGT = 0.198

ElseIf try1 >= 290 And try1 <= 299.99 Then
    efficiencyGT = 0.209

ElseIf try1 >= 300 And try1 <= 309.99 Then
    efficiencyGT = 0.22

ElseIf try1 >= 310 And try1 <= 319.99 Then
    efficiencyGT = 0.231

ElseIf try1 >= 320 And try1 <= 329.99 Then
    efficiencyGT = 0.242

ElseIf try1 >= 330 And try1 <= 339.99 Then
    efficiencyGT = 0.253

ElseIf try1 >= 340 And try1 <= 349.99 Then
    efficiencyGT = 0.264

ElseIf try1 >= 350 And try1 <= 359.99 Then
    efficiencyGT = 0.275

ElseIf try1 >= 360 And try1 <= 369.99 Then
    efficiencyGT = 0.286
```

```
    ElseIf try1 >= 370 And try1 <= 379.99 Then
        efficiencyGT = 0.297

    ElseIf try1 >= 380 And try1 <= 389.99 Then
        efficiencyGT = 0.308


    ElseIf try1 >= 390 And try1 <= 397.99 Then
        efficiencyGT = 0.33

    ElseIf try1 >= 398 Then
        try1 = 397.99
        txtGT.Text = ""
        efficiencyGT = 0.33

    Else
        efficiencyGT = 0.33
        q1 = (wgt / efficiencyGT)
        Efficiency = ((wgt + wst + newST) / q1) * 100
        txtEfficiencyISCCPP.Text = Format(Efficiency, "###.##")
        TotalNaturalgas = ((((q1 * 1000000) * 0.01453) / (1114 *
   716)) * 3600)
        txtNaturalGasGT_ISCCPP.Text = Format(TotalNaturalgas,
   "###.##")
        NGCost = TotalNaturalgas * 0.67
        txtNGcost_ISCCPP.Text = Format(NGCost, "###.##")

    End If

    q1 = (wgt / efficiencyGT)
    Efficiency = ((wgt + wst + newST) / q1) * 100
    txtEfficiencyISCCPP.Text = Format(Efficiency, "###.##")
    TotalNaturalgas = ((((q1 * 1000000) * 0.01453) / (1114 * 716))
   * 3600)
    txtNaturalGasGT_ISCCPP.Text = Format(TotalNaturalgas, "###.##")

    NGCost = TotalNaturalgas * 0.67
    txtNGcost_ISCCPP.Text = Format(NGCost, "###.##")

End Sub
```