INTEGRATED SOLAR COMBINED CYCLE SYSTEM (ISCCS)

By

HANIM ABDUL WAHID

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 SOLAR COMBINED CYCLE SYSTEM (ISCCS)

by

Hanim Abdul Wahid

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. Afza Shafie
Project Supervisor

Dr. Balbir Singh Mahinder Singh
Project Co - Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

JUNE 2006

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.

Hanim Abdul Wahid

ACKNOWLEDGEMENT

In the name of Allah the Most Gracious and Merciful, I wish to mention that a large measure of gratitude is owed to the following persons who contributed by way of help, suggestion and criticisms to complete this project:

Dr. Balbir Singh Mahinder Singh (Supervisor)

Dr. Afza Shafie (Supervisor)

A special acknowledgement goes to my parents, Tn. Hj. Abdul Wahid and Pn. Hjh. Noor Ainon who gave their time and support and also to my sister, Hanis and my brother in law, Ruzaini who had helped me in developing the simulation software for this project.

Last but not least, to my close friends who rendered their support at all time.

May God bless them.

ABSTRACT

This project is related to the simulation studies carried out with the possibility of integrating a combined cycle system power plant in Malaysia, with a suitable heat collecting system. The Integrated Solar Combined Cycle System (ISCCS) consists of gas turbine (GT), Heat Recovery Steam Generator (HRSG) and steam generator (ST) with solar field. Solar energy can be considered as an alternative to supplement the ever-decreasing supply of fossil fuels. In year 2002, it was reported that the energy consumption and demand in Malaysia has increased to 1.5% and 9.4% respectively, and energy demand is expected to grow at about 3 % to 4% over the next 20 years. Therefore, the need to ensure continuously sufficient supply of power is vital. The focus of this project is to identify equations to model the operations of combined cycle power plant. Simulations were carried out using Matlab software to increase the power plant efficiency. Initial work carried out at Lumut Power Plant indicated that without using HRSG system, the efficiency of gas turbine is around 33 %, but with HRSG system, the plant's efficiency was improved up to 53 %. Through initial simulations carried out based on local solar insolation data, instantaneous conversion efficiency improved to around 58.7 %. The problem that plagues the implementation is related to the local meteorological conditions. Through this project work, it was discovered that local meteorological conditions, though on the whole is favorable, but cloudiness can distort the efficiency of solar energy based systems. However, with proper planning, this so-called catastrophic effect can be overcome and the measures are reported in this report.

TABLE OF CONTENTS

Contents Page

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

S_R	Absorbed flux
T_a	Ambient temperature
$\tau\ \alpha$	Average value of the transmissivity – absorbptivity product for beam radiation
C	Concentration ratio of the receiver
$\dot{A}_{eff}$	Effective area of the receiver
η_G	Efficiency of GT
η_{PP}	Efficiency of power plant
η_S	Efficiency of ST
$\dot{Q}_R$	Energy balance for parabolic trough
Q_3	Energy for ST
Q_2	Energy from GT
Q_1	Energy from NG
Q_{L2}	Energy loss in the condenser
Q_{L1}	Energy loss in the HRSG
F_R	Heat removal factor
h_f	heat transfer coefficient
T_{f_i}	Inlet temperature
γ_s	Intercept factor
L	Length of the collector
$\dot{m}_{HP}, \dot{m}_{LP}$	Mass flow rate of HP & LP steam
$\dot{m}$	Mass flow rate of NG
I_b	Maximum beam flux
D_o	Outer diameter of receiver tube
U_{LR}	Overall heat loss coefficient
W_{PP}	Power output for power plant

W_1	Power output GT
W_2	Power output ST
F_{RE}	Receiver efficiency factor
C_p	Specific enthalpy drop for GT
C_{HP}, C_{LP}	Specific enthalpy drop for HP and LP
ρ	Specular reflectivity of receiver surface
ΔT	Temperature difference
W	Width of the collector

CHAPTER 1

INTRODUCTION

About 1 x 10^{11} kW of energy would be required with a total power of 10kW need per person for a world population of 10 billion people. Therefore, if the solar irradiance on only 1% of the earth's surface could be converted into useful energy with 10% efficiency, solar energy could provide of all the energy needs for all the people in the world (Goswani *et al.*, 2000).

Currently, the total production capacity of electric power in the world exceeds 3000GW and the component of combined cycle is about 300GW, which amounts to about 10% of the existing capacity. Figure 1.1 shows the various power systems which make up the overall capacity. Steam plants account for about 56% of the capacity, nuclear plants account for about 12%, hydro plants about 20%, combined cycle and gas turbine power plants about 10%, diesel plants about 2%, and renewable energies amount to about a tenth of 1% (Boyce, 2002).

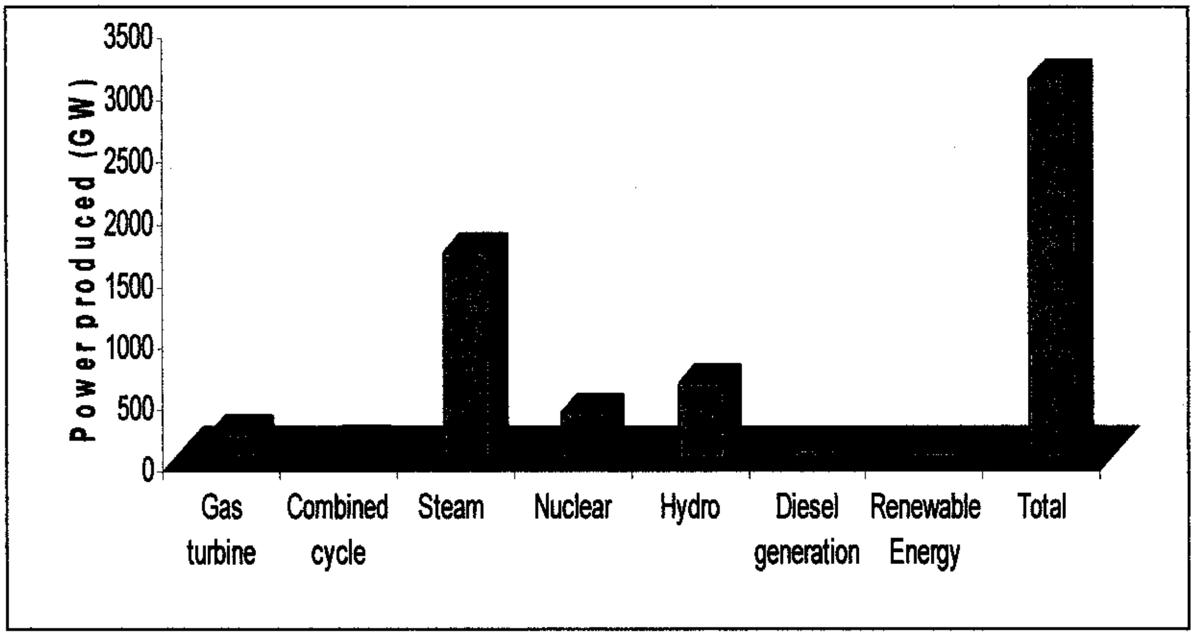


Figure 1.1: World Power Outlook (Boyce, 2002)

Natural gas is the fuel of choice whenever it is available because of its clean burning and its competitive pricing. Whenever oil or natural gas is the fuel of choice, gas turbines and combined cycle plants are the power plants of choice. In Malaysia, there has been tremendous growth of natural gas as fuel for large-scale power generation, with high efficiency combined cycle gas turbine plant being the standard approach for new plant. Currently, 17 power stations in the country are fuelled by gas as against just one plant in 1984. Natural gas usage in power generation has increased from less than 1% in 1984 to 70% in 2002 largely displacing oil (Malaysia Energy Commission, 2005).

In the Ninth Malaysian Plan (2006-2010), it was stated that the overall demand of energy is expected to increase at an average rate of 6.3% per annum during the plan period as shown in Appendix A. The consumption of natural gas in Peninsular Malaysia is expected to increase at an average rate of 4.3% per annum where the power sector is expected to remain the major user of natural gas. With the positive outlook of the national economy, the peak demand for electricity is also expected to grow at an average rate of 7.8% per annum to reach 20087MW in 2010 (refer Appendix B). By the end of 2010, the accumulated installed capacity is expected to increase to 25258 MW.

In an effort to reduce the usage of the fossil fuels, the development and utilization of renewable energy in Malaysia will be further intensified for the five year period of the Ninth Malaysia Plan. New sources of energy such as solar and wind will be developed with the emphasis on utilizing cost-effective technology (EPU, 2006).

1.1 Solar Energy

Solar energy is a very large inexhaustible renewable source of energy. The power from the sun intercepted by the earth is approximately 1.8 x 10^{11}MW, which is thousands times larger than the present consumption rate of all commercial energy sources on the earth. Therefore, solar energy is one of the most promising of the unconventional energy sources that could supply all the present and future needs of the world continuously. Furthermore, solar energy is an environmental clean source of energy and it should be utilised fully as it is free and available in almost all parts of the world.

1.2 Combined Cycle Power Plant (CCPP)

The CCPP consists of gas turbine (GT), Heat Recovery Steam Generator (HRSG) and steam turbine (ST). The process flow of this power plant starts at the GT where air intake is filtered and directed to the compressor. The compressed air and NG mixture is ignited in the combustion chamber, where the resultant mechanical energy drives the generator to produce electrical power. The hot exhaust gases are directed to the HRSG, where superheated steam with high pressure (HP) and saturated steam with low pressure (LP) is produced. HP and LP steam are directed to the dual pressure steam turbine, which drives a generator to produce additional power. This is an energy recovery cycle, where the efficiency of the plant is increased up to 54% (Hanim, 2005).

1.3 Solar Power Plant

The solar power plant consists of large fields of solar collector, series of heat exchanger and a steam turbine. Each solar collector has a linear parabolic-shaped reflector that focuses the sun's direct beam radiation on a linear receiver located at the focus of the parabola. A heat transfer fluid (HTF) is heated as it circulates through the receiver and returns to a series of heat exchangers in the power block where the fluid is used to generate high-pressure superheated steam. The superheated steam is then fed to a conventional reheat steam turbine/generator to produce electricity. The exhaust steam from the turbine is condensed in a condenser and returned to the heat exchangers via condensate and feedwater pumps to be converted back into steam. The steam cooling is provided by cooling towers. After passing through the HTF side of the solar heat exchangers, the cooled HTF is recirculated through the solar field. Based on the nine large commercial-scale solar power plants in Kramer Junction, California Mojave Desert, solar power plant uses large fields of parabolic trough collectors to supply the thermal energy used to produce steam for a Rankine steam turbine and drive a steam generator.

1.4 Problem Statement

The oil & gas are becoming increasingly expensive as the energy consumption and demand in Malaysia increases to 1.5% and 9.4% respectively in the first half of year 2002 and the energy demand is expected to grow at about 3 to 4% over the next 20 years. The rising costs are attributed to the rising demand, limited supply and manipulation at the world market. In Malaysia, it is projected that the supply of fossil fuel will decrease by 17% from the year 1995 to 2005 as indicated in the Eight Malaysia Plan (refer Appendix C) (EPU,1999). Even developed countries like U.S. are looking for alternative sources of energy such as solar energy and the latest is to extract hydrogen gas from water. The experiences of the developed countries in the field of energy has given some indication for developing country like Malaysia to diversify energy policy from fossil fuel to other forms of energy which in this case the solar energy.

As reported by the local press, Tenaga Nasional Berhad (TNB), may get the Malaysian Government approval by December to raise electricity prices by as much as 10%. The company may receive a 2.35 cent per kilowatt - hour increase in the gross rates because of a higher cost of natural gas bought from Petroliam Nasional Berhad (PETRONAS) at a subsidised rate (The Malay Mail, 2005). Furthermore, TNB is also to be said to be currently exploring the use of a technology that would enable coal-fired power plants to use high sulphur coal and save the power industry billions of ringgit in fuel cost (The Star, 2005). However coal being a fossil fuel which is not renewable and will soon be depleted too. This situation applies to all other source of fossil fuel including natural gas.

Thus, there is a need for Malaysia to diversify its energy policy fuel to other forms of alternative energy. Solar energy can be considered as a fine and viable option to minimize the risk of high cost and continuous supply to power generation. In this project, simulation studies were carried out, in an attempt to integrate solar energy related technology with modern combined cycle power plant, also known as Integrated Solar Combined Cycle System (ISCCS). ISCCS is a proven technology and has been implemented at the Kramer Junction (Price, 2003).

1.5 Objectives

Based on the problem statement, the main objective of this project is to carry a simulation study on the possibility of integrating solar direct steam generating system with a current combined cycle system power plant.

In order to achieve this objective, there is a need to carry out a research work on

i. identifying suitable solar energy related technology
ii. weather condition in Malaysia
iii. simulation software for Integrated Solar Combined Cycle System (ISCCS)

The objective of the ISCCS is to reduce the usage of the natural gas and to increase the system efficiency. An initial design has been identified to be incorporated with the current layout of the reference combined cycle power plant which is The Lumut Power Plant. The details of the design are explained in Chapter 5. The scope of studies for this project is summarized in Figure 1.2. The scope of the Combined Cycle Power Plant only comprise of 3 gas turbines and 1 steam turbine which represent 1 block. The main scope of study is to integrate a suitable solar energy related technology to the existing combined cycle system. The most comprehensive reference for solar technology would be the solar power plant in Kramer Junction, California whilst the reference power plant for the combined cycle system would be the Lumut Power Plant in Segari, Malaysia.

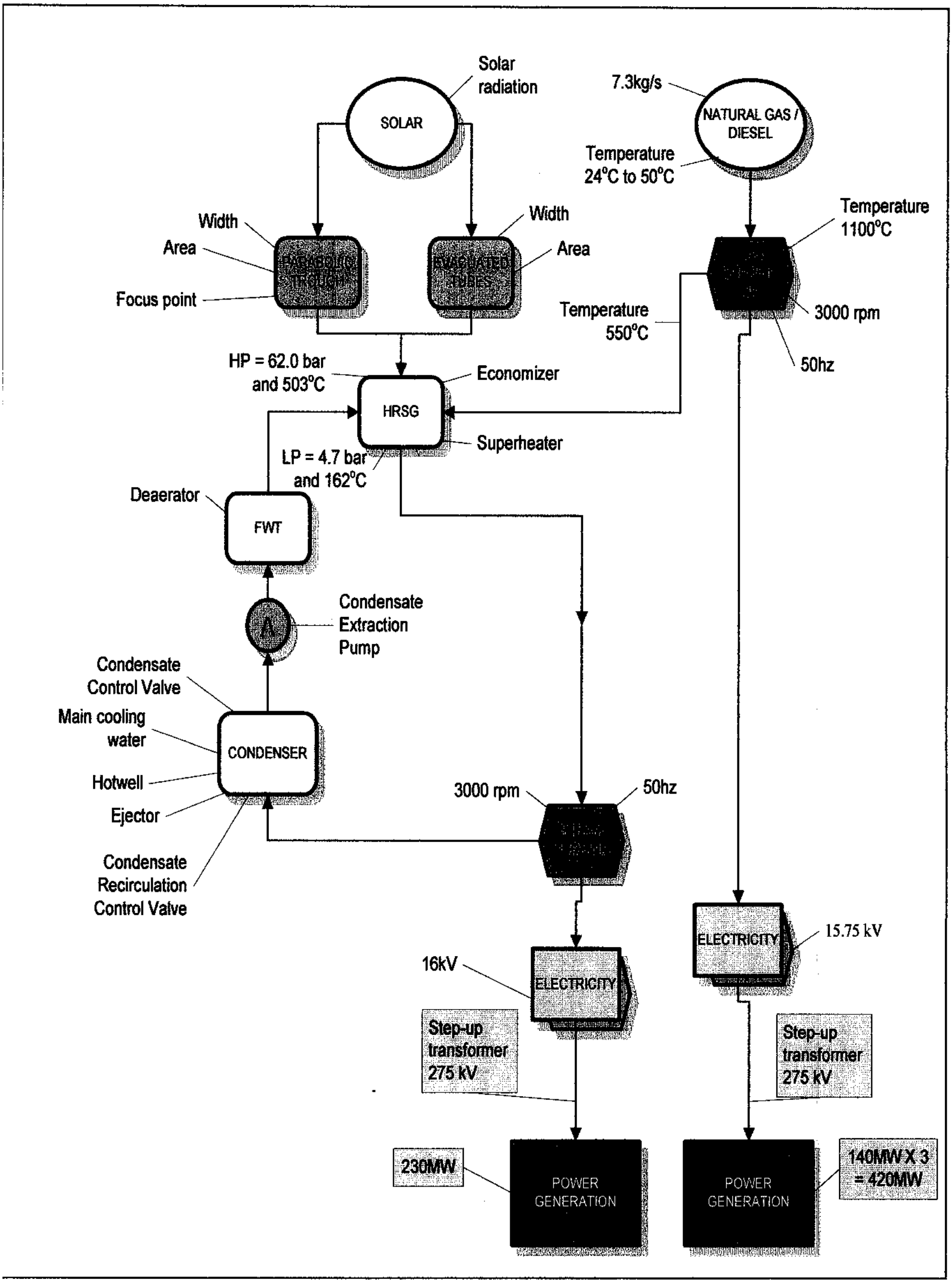


Figure 1.2: Scope of the ISCCS Project

CHAPTER 2

LITERATURE REVIEW

During the Eight Plan period (2001 - 2005), the focus of the energy sector was on the sustainable development of depletable resources and the diversification of energy sources. The policy to reduce dependence on oil resulted in the rapid development and usage of natural gas. However, the use of new and alternative energy sources was encouraged and measures were also undertaken to utilize energy in an efficient manner (EPU, 1999). Sustainable development of energy resources was undertaken during the Eight Plan period. A holistic approach was adopted in promoting the utilization of renewable resources such as biomass, biogas, municipal waste, solar and minihydro. In this regard, a project on the Development of a Strategy for Renewable Energy as the Fifth Fuel was undertaken to assess the renewable energy potential in Malaysia and consider the legal, regulatory and financial framework in order to encourage the utilization of renewable resources (EPU, 1999).

Several actions have been undertaken from the TNB side to reinforce the organization's commitment to the Government's Five Fuel Strategy. One of them is with the launching of the gas-fuelled PD1 power plant. TNB has also driven the development of Renewable Energy Power Purchase Agreements (REPPA). Under the agreements, power generated from renewable energy is linked to the National Grid (NST, 2005). Another undertaking which is now on a small scale basis is the use solar power to electrify remote islands and villages throughout Malaysia by means of Solar Hybrid Systems (SHS). Nevertheless, the SHS is in infancy stage and not widely available and furthermore its capacity is very limited.

Until now, there is no large scale use of solar power to generate electricity in this country. Therefore, it is timely that Malaysia which has sunshine almost throughout the year to venture into solar energy and thus the integrated solar combined cycle system is more likely the most suitable alternative in producing electricity.

2.1 Solar Radiation at the Earth's Surface

Solar radiation received at the earth's surface is in an attenuated form. This is because it is subjected to the mechanisms of absorption and scatterings as it passes through the earth's atmosphere. Absorption will occurs in the presence of ozone, water vapor and other gases (like CO_2, NO_2, CO, O_2 and CH_4), while scattering occurs due to all gaseous molecules as well as particulate matter in the atmosphere. The scattered radiation is redistributed in all directions, some going back into space and some reaching the earth's surface. The atmosphere on the earth surface is often classified into two broad types; one is where an atmosphere without clouds and another one is an atmosphere with clouds. Less attenuation will take place in a cloudless sky whereas attenuation will be high in a cloudy sky. Maximum radiation is received on the earth's surface under the condition of cloudless sky. Solar radiation received at the earth's surface (in line with the sun) is known as beam or direct radiation, I_b. Diffuse radiation, I_d occurs when the radiation received at the earth's surfaceis from all parts of the sky's hemisphere (after being subjected scattering in the atmosphere (refer Appendix . Therefore the sum of the beam and diffuse radiation is referred to as global radiation as shown in Equation (2.3) (Sukhatme, 1996).

$$I_{Global} = I_b + I_d \tag{2.3}$$

2.2 Combined Cycle Power Plant (CCPP)

The process flows of the power plant start with its major equipment, gas turbine. Ambient air will be suck from the air intake whereby it will be filtered first before going to the compressor. The inlet air is directed to the 21 stages compressor to be compressed from 1 bar to 12 bar. After that, the compressed air is mixed with natural gas (propane) and ignites in the combustion chamber. The temperature in the combustion chamber is 1100°C. If the natural gas tripped, diesel will be used as a backup fuel. Subsequently, the 5-stages turbine then produces mechanical energy to drive the compressor and air cooled generator to generated 140 MW electric powers. In each block in LPP, there are 3 gas turbines. As the efficiency of GT is around 33%, there will be heat losses. The waste heat which is around 550°C in the form of exhaust gasses of GT, is channelled through the exhaust gas duct to dual pressure Heat Recovery Steam Generator (HRSG). It produces superheated steam in high pressure (HP) cycle and saturated steam in low pressure (LP) cycle. The amount of steam produced depends on the amount of waste heat delivered by GT. HRSG in LPP uses 'Natural Circulation Boilers' that generally have a horizontal gas flow across vertical tubes. Each boiler produces HP steam and LP steam. The pressure of HP steam is at 60 bar and the steam will be drained to a common header through 3 pipelines.

Meanwhile, the remaining exhausts gases will be released to the atmosphere through the stack at about 100°C. Steam produced by the HRSG is directed to the dual pressure steam turbine, which drives a hydrogen-cooled generator to produce addition power. However, during the start-up process of HRSG, the HP-LP bypass will be opened to dump the steam into the condenser. This is due to the low quality steam produced during HRSG start-up. Once the HP steam reaches 62.0 bar and 503°C, while the LP steam reaches 4.7 bar and 162°C, the HP-LP bypass will close automatically.

The steam turbine (ST) is able to produce about 231 MW of electricity. The steam will be condensed in the condenser, which uses seawater as the cooling medium to condense the steam into water. The condensate water is collected in the condenser's hotwell and pumped by condensate extraction pumps (CEP) to the feedwater storage tank (FWT). The FWT serves as a buffer in the water steam cycle. Finally, HP-LP FW pumps will supply water to the HRSG and this water will be circulated again. Each block consists of 3 gas turbines and one steam turbine where the total power generated from 3 gas turbines are 420MW and from steam turbine is 230MW and this total up to 650 MW of electrical power generated for one block. Therefore, the total power generated capacity of Lumut Power Plant which consists of 3 Blocks is 1950 MW.

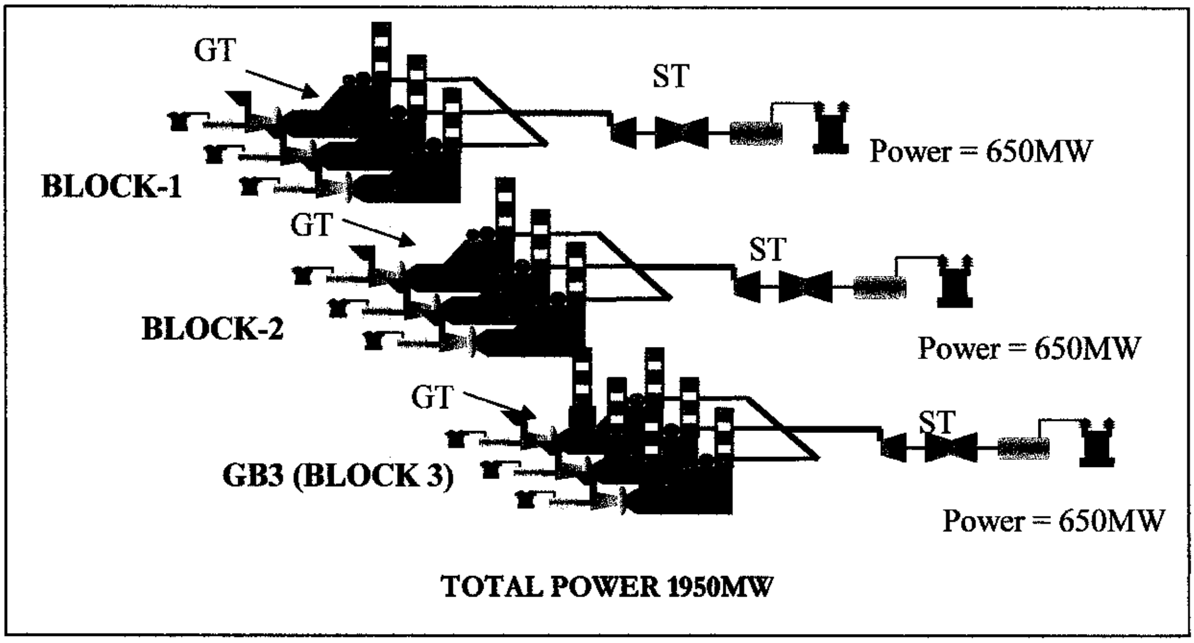


Figure 2.1: The layout of LPP which compromise of 9 GT and 3 ST

2.3 Solar Parabolic Trough Concentrator (PTC)

Parabolic trough power plant was introduced by Frank Schumann and C.V. Boys of U.S in 1912. They constructed a 45 kW solar steam pumping plant for pumping irrigation water from the Nile in Meaeli, Egypt which covered an area of 1,200m^2 (Smith, 1995). Solar parabolic trough collector has a linear parabolic-shaped reflector that focuses the sun's direct beam radiation on to a linear receiver placed along the focus line concentrically. In this simulation work, saturated water is used as the heat transfer fluid (HTF), where direct steam is generated. In solar power plants, the collector field consists of a large field of single-axis tracking parabolic trough solar collectors. The solar field is modular in nature and is composed of many parallel rows of solar collectors aligned on a north-south horizontal axis. Each solar collector has a linear parabolic-shaped reflector that focuses the sun's direct beam radiation on a linear receiver located at the focus of the parabola. The collectors track the sun from east to west during the day to ensure that the sun is continuously focused on the linear receiver. A heat transfer fluid (HTF) is heated as it circulates through the receiver and returns to a series of heat exchangers in the power block where the fluid is used to generate high-pressure superheated steam. The superheated steam is then fed to a conventional reheat steam turbine/generator to produce electricity. The exhaust steam from the turbine is condensed in a condenser and returned to the heat exchangers via condensate and feedwater pumps to be converted back into steam. After passing through the HTF side of the solar heat exchangers, the cooled HTF is re-circulated through the solar field.

At Kramer Junction, the plants can operate at full rated power using solar energy alone if given sufficient solar input. During summer months, the plants can operate for 10 to 12 hours a day at full-rated electric output. During periods of low solar radiation, all plants have been hybrid solar/fossil plants which mean that the power plants have a backup fossil-fired capability that can be used to supplement the solar output during those periods. In the system shown in Figure 2.1, the natural-gas-fired HTF heater is situated in parallel with the solar field, or the gas steam boiler/re-heater located in parallel with the solar heat exchangers. This system provides this capability. The fossil backup can be used to produce electric output during overcast or nighttime periods. It also shows that thermal storage is a potential option that can be added to provide dispatchability (IEA SolarPACES).

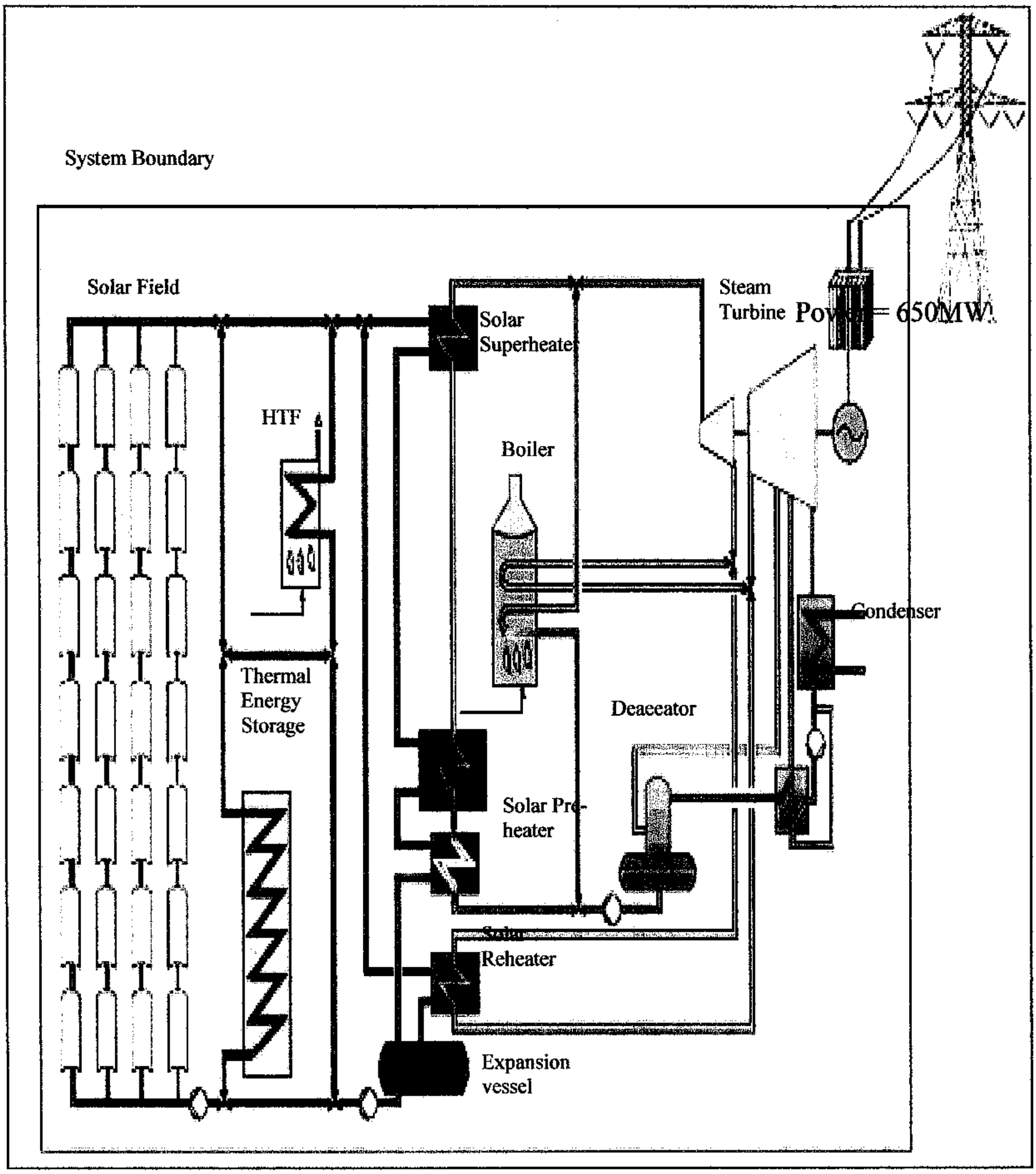


Figure 2.2: Solar Power Plant System (IEA SolarPACES)

2.3.1 Collector Technology

The basic component of the solar field is the solar collector assembly (SCA). Each SCA is an independently tracking parabolic trough solar collector made up of parabolic reflectors (mirrors), the metal support structure, the receiver tubes, and the tracking system that includes the drive, sensors, and controls. The cylindrical parabolic collectors used have their axes oriented north-south. The absorber tube used is made of steel and has a specially developed selective surface. It is surrounded by a glass cover with a vacuum. The collectors heat synthetic oil to a temperature of 400°C with a collector efficiency of about 0.7 for beam radiation. The synthetic oil is used for generating superheated high pressure steam which executes a Rankine Cycle with an efficiency of 38%.

CHAPTER 3

THEORY / PROJECT WORK

In this chapter, the theoretical construction is divided to two parts. Part one will focused on the combined cycle power plant where the simulation theories of gas turbine – steam turbine are constructed. The second part is on the constructions of simulation theories of thermal analysis of the receiver which is the solar parabolic trough collector.

3.1 Combined Cycle Power Plant (CCPP)

The standard cycle for GT and ST are Brayton cycle and Rankine cycle respectively. Unlike the Rankine cycle, Brayton cycle's working fluid does not go through phase changes (Nag, 2002). The CCPP process is as shown in Figure 3.1, where two cyclic power plants are coupled in series. The important equations that needed to carry out simulations are identified and is provided in this section.

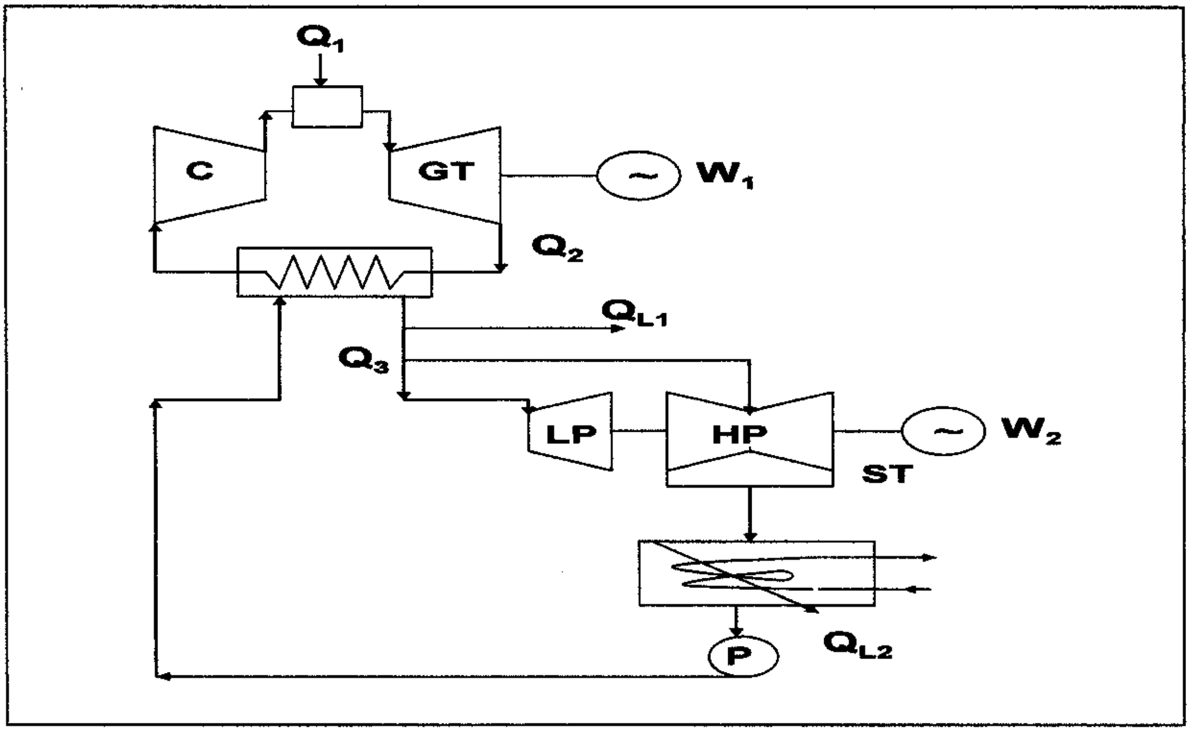


Figure 3.1: Flow diagram of gas turbine – steam turbine power plant

Let η_G and η_S be the efficiency of gas turbine and steam turbine respectively and η_{CC} is the overall efficiency of the combined cycle (Fujii, 1999).

$$Q_1 = \frac{W_1}{\eta_G} = \dot{m}C_p\Delta T \tag{3.1}$$

$$Q_2 = (1 - \eta_G)Q_1 \tag{3.2}$$

Where W_1 is the output power for gas turbine

Output power for steam turbine W_2 is defined in Equation (3.3)

$$W_2 = [(\dot{m}_{HP} + \dot{m}_{LP})(C_{LP})] + [\dot{m}_{HP}(C_{HP})] \tag{3.3}$$

Let Q_{L1} be the heat loss between two plants.

$$Q_{L1} = \omega c_p (T_1 - T_2) \tag{3.4}$$

Therefore,

$$Q_3 = Q_2 - Q_{L1} = Q_1 (1 - \eta_G) - Q_{L1} \tag{3.5}$$

The exhaust energy after being condensed is defined in Equation (3.6).

$$Q_{L2} = (1 - \eta_S)Q_3 \tag{3.6}$$

The overall efficiency of the power plant is as given in Equation (3.7)

$$\eta_{PP} = \frac{W_1 + W_2}{Q_1} \tag{3.7}$$

3.2 Parabolic trough design criteria

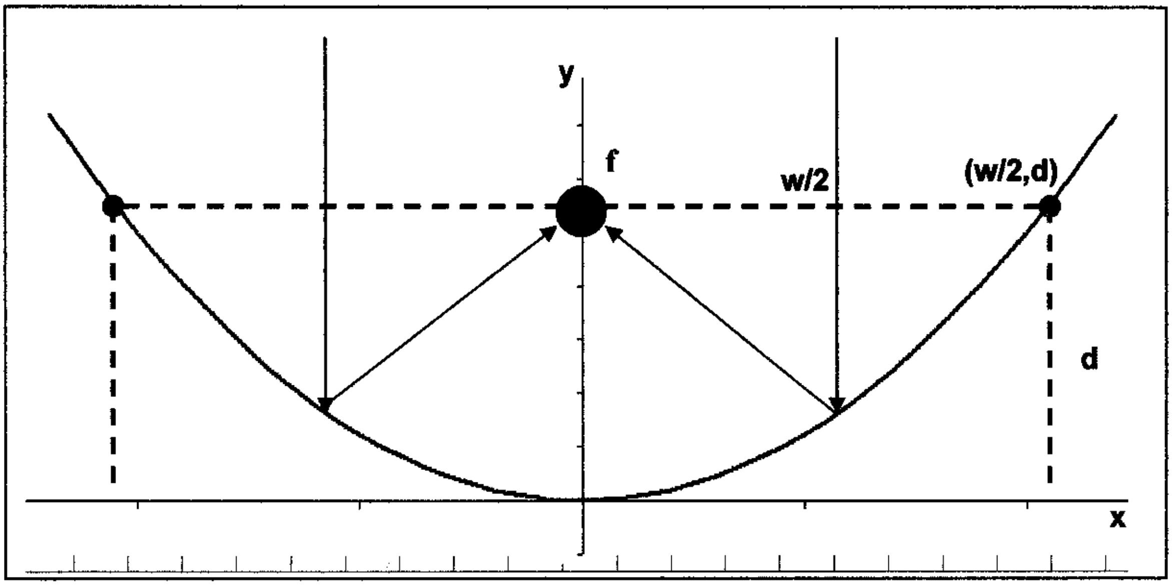


Figure 3.2: Parabolic Trough

From the diagram, the equation of the parabolic trough is,

$$y = ax^2$$

$$a = y / x^2$$

$$= d / (w/2)^2 \qquad (3.8)$$

where; a = arc length, d = depth, w = width

Therefore,

$$a = d / (0.5w)^2 \qquad (3.9)$$

$$y = \frac{d}{(0.5w)^2} x^2 \qquad (3.10)$$

The focus point of the parabolic trough is,

$$f = w^2 / 16d \qquad (3.11)$$

therefore,

$$y = \frac{1}{4f} x^2 \qquad (3.12)$$

3.3 Solar Parabolic Trough Concentrator (PTC)

A PTC can be divided to two main parts. The first part is the concentrator, where parabolic geometry depends on the aperture, *W* and depth, *d*. The other part is the receiver, normally placed along the focus line. The receiver consists of a glass envelope and a circular cylindrical conduit tube, acting as an absorber. The optical analysis is mainly related to the concentrator, which acts as the reflector. The amount of energy intercepted by the receiver strongly depends on the outcome of error analysis and intercepts factor γ_s.

$$S_R = \rho\tau\alpha\gamma_s I_b \tag{3.13}$$

The absorber tube has an inner diameter D_i and an outer diameter D_0 and it has a concentric glass cover of inner diameter D_{ci} and outer diameter D_{co} around it. The cross section of the parabolic trough collector is shown in Figure 3.3

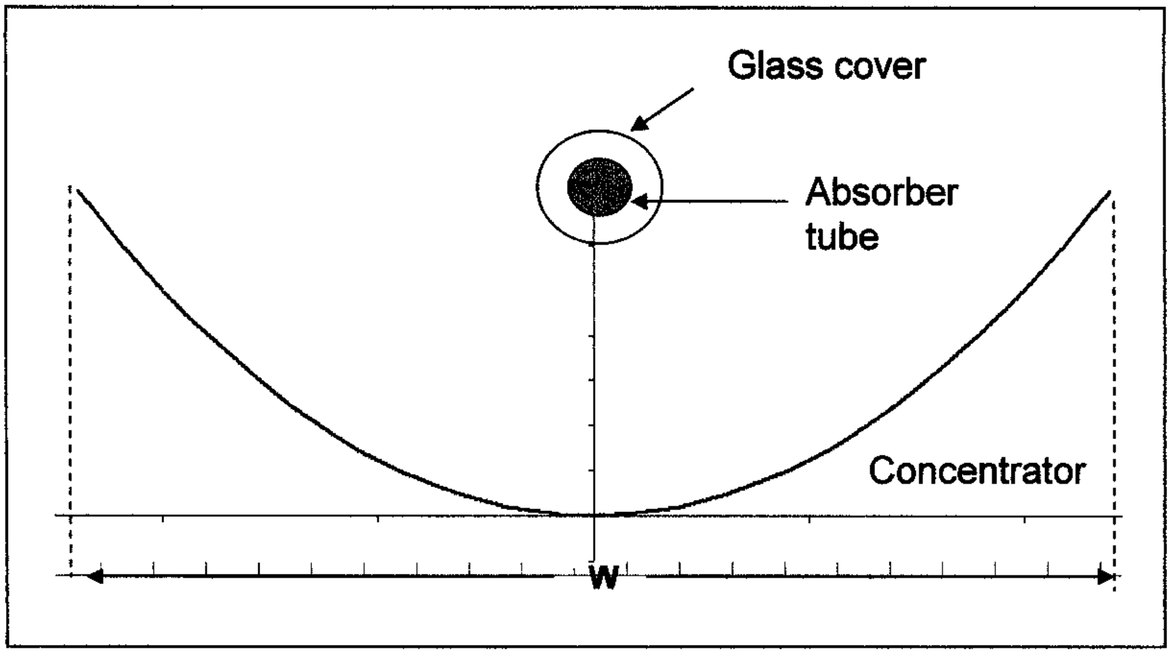


Figure 3.3: Cross section of the parabolic trough collector

The useful heat gain rate is given in equation 3.14 and 3.15.

$$Q_R = \dot{m}C_p(T_{fo} - T_{f_i}) \qquad (3.14)$$

$$Q_R = F_R A_{eff}\left[S_R - \frac{U_{LR}}{C}\left(T_{f_i} - T_a\right)\right] \qquad (3.15)$$

Absorbed flux, S_R is:

$$S_R = I_b R_b\left[\rho\gamma(\tau\alpha)_b + (\tau\alpha)_b\left(\frac{D_o}{W - D_o}\right)\right] \qquad (3.16)$$

Instantaneous efficiency based on beam radiation alone, η_{ib} is defined in Equation (3.17)

$$\eta_{ib} = \frac{Q_R}{I_b R_b W L} \qquad (3.17)$$

Concentration ratio of the receiver, C is

$$C = \frac{(W - D_o)L}{\pi D_o L} \qquad (3.18)$$

The effective are of the receiver is:

$$A_{eff} = (W - D_o)L \qquad (3.19)$$

the heat removal factor, F_R is:

$$F_R = \frac{\dot{m}C_P}{\pi F_{RE} D_o U_{LR}}\left[1 - \exp\left\{\frac{\pi F_{RE} D_o U_{LR}}{\dot{m}C_P}\right\}\right] \tag{3.20}$$

Receiver efficiency factor , F_{RE} is defined by Equation (3.21) (Sukhatme, 1996).

$$F_{RE} = \frac{1}{U_{LR}\left(\frac{1}{U_{LR}} + \frac{D_o}{D_i h_f}\right)} \tag{3.21}$$

heat transfer coefficient h_f is:

$$h_f = \frac{Nu_W \times k}{D_i} \tag{3.22}$$

For Reynolds number greater than 2000, the flow is turbulent and the heat transfer coefficient can be calculated from the Dittus – Boelter equation for Nusselt number.

$$Nu_W = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4} \tag{3.23}$$

The Reynolds number is

$$\mathrm{Re}_W = \frac{VD_1}{v} \tag{3.24}$$

The average velocity of the fluid inside the absorber tube is

$$V_W = \frac{\dot{m}}{\pi D_i \rho} \tag{3.25}$$

The evaluation of the overall heat loss coefficient U_{LR} can be estimated by using the semi – empirical equation developed by Mullick & Nanda (1989).

$$U_{LR} = \left[\frac{1}{C_1(\delta T_1)^{0.25} + \left(\frac{\sigma(\delta T_2)(\delta T_3)}{C_2} \right)} + \left[\left(\frac{D_o}{D_{co}} \right) \left(\frac{1}{C_3} \right) \right] \right]^{-1} \tag{3.26}$$

To calculate the overall heat loss coefficient, there are some other constants and coefficient need to be calculated. They are the temperature coefficients and the constants obtained from the correlation of Raithby and Hollands (1975).

The temperature coefficients are

$$\delta T_1 = T_{rm} - T_c \tag{3.27}$$

$$\delta T_2 = T_{rm} + T_c \tag{3.28}$$

$$\delta T_3 = T_{rm}^2 + T_c^2 \tag{3.29}$$

$$\delta T_4 = T_c + T_a \tag{3.30}$$

$$\delta T_5 = T_c^2 + T_a^2 \tag{3.31}$$

The constants are:

$$C_1 = \frac{17.74}{(\delta T_2)^{0.4} D_o \left(D_o^{-0.75} + D_{ci}^{-0.75} \right)} \tag{3.32}$$

$$C_2 = \frac{1}{\varepsilon_p} + \frac{D_o}{D_{ci}}\left(\frac{1}{\varepsilon_c} - 1\right) \tag{3.33}$$

$$C_3 = h_w + \left(\sigma\varepsilon_c(\delta T_4)(\delta T_5)\right) \tag{3.34}$$

the temperature of the glass cover T_c

$$T_c = T_a\left[\left(0.04075\left(\frac{D_o}{D_i}\right)^{0.4} h_w^{-0.67}\left(2 - 3\varepsilon_p + \frac{(6+9\varepsilon_p)T_{rm}}{100}\right)\right)(T_{rm} - T_a)\right] \tag{3.35}$$

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

$$h_W = \frac{Nu_W K_{AIR}}{D_R} \tag{3.36}$$

The Reynolds number for the condition of air

$$\mathrm{Re}_{(air)} = \frac{VD}{v} \tag{3.37}$$

Nusselt number for air

$$Nu = C_1 \mathrm{Re}^n \tag{3.38}$$

Nusselt number is calculated according to the condition in Table 3.3 below.

Table 3.3: Condition for Nusselt number when Re is known

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 parabolic trough collector T_{fo} is defined by:

$$T_{fo} = \frac{\dot{Q}_R}{\dot{m}C_p} + T_{f_i} \tag{3.34}$$

CHAPTER 4

METHODOLOGY

This project studies the feasibility of integrating solar related technology to the existing combined cycle system. This project shall be executed as follows:

4.1 Literature review

Literature reviews on existing combined cycle system and solar electric generating system. A reviews on the fossil fuels pricing such as the natural gas is also important to prove that the fossil fuel are getting expensive and it is wisely for a developing country such as Malaysia to ventures to other alternative energy like solar energy. Reviews on solar related technology such as solar collectors will give the basic idea on how in harnessing the solar energy.

4.2 Problem identification

Most of the present day power generation in Malaysia is using non-renewable energy. This is very costly and contributes to the depletion of the fossil fuel in Malaysia. This project will prove into alternative energy power generation and in this case, integrating the solar related technology to the existing combined cycle system.

4.3 Analyze Current Existing Combined Cycle Power Plant

The input to the combined cycle system is natural gas. In LPP, the flow rate of the natural gas into the combustion system is 7.3kg/s. Therefore, in one day of operation for one gas turbine is 630,720 kg. This is a lot of natural gas consumption. From the gas turbines, the waste heat are recovered in the HRSG to produced high pressure steam to drives a steam turbine and generator. The output of combined cycle system in LPP is approximately 1950MW.

4.4 Analyze solar energy related technology

Solar power plant is using solar energy as its input to produce steam and drives a steam turbine and generator. There are several means of collecting the solar energy. Solar parabolic trough collector and evacuated tubes collector are the two higher efficiency collectors. For this project solar parabolic trough which is the solar collector field in the successful commercial solar power plant, is being taken into consideration. The collector uses a linear parabolic-shaped reflector that focuses the sun's direct beam radiation on a linear receiver located at the focus of the parabola. The output for the commercial solar power plant in Kramer Junction, California is 30MW for SEGS II through SEGS VII 400 and 80 MW for SEGS VIII and SEGS IX with the output temperature for the collector is about 400°C.

4.5 Construct simulation theories

Construct simulation theories on both combined cycle power plant (CCPP) and parabolic trough collector (PTC). The simulation theories constructed for the CCPP were based on the flow process in Figure 3.1 and Figure 4.1 below.

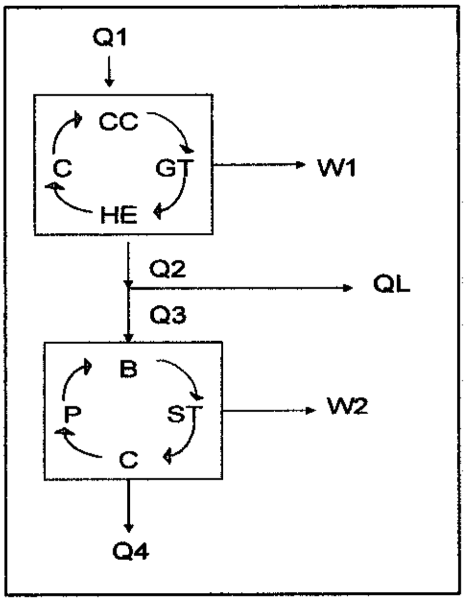


Figure 4.1: Flow diagram of gas turbine – steam turbine power plant

4.6 Integrated Solar Combined Cycle System (ISCCS)

The simulation theories constructed and real time data collected are simulated using MATLAB application. The simulation theories constructed for the ISCCS were based on flow process in Figure 4.2 below. The output power for CCPP and ISCCS are compared and the efficiency of the ISCCS is then determined.

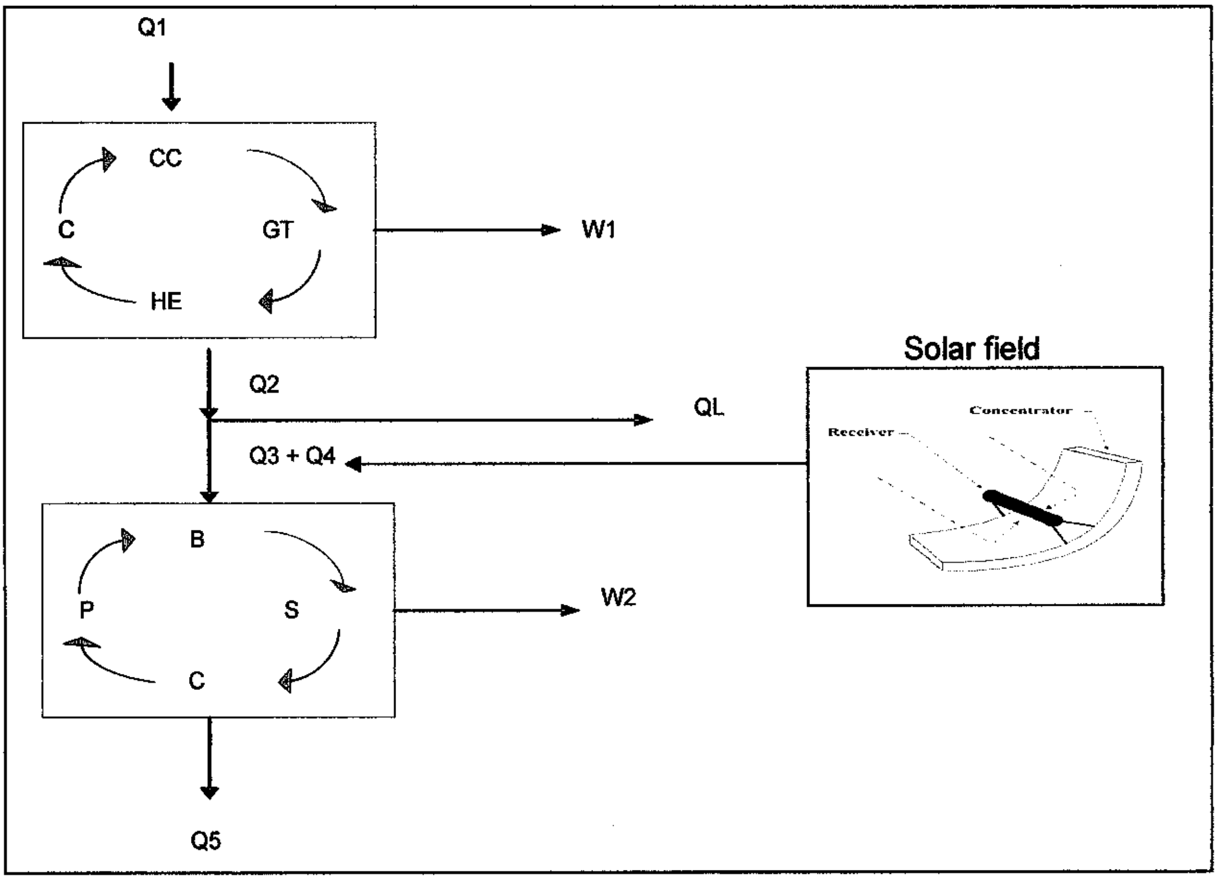


Figure 4.2: Simulation of process flow of ISCCS

4.7 Simulation software of CCPP and ISCCS

Simulation software on the CCPP and ISCCS is developed using Microsoft Visual Basic. The software requires the desired output power as an input data to simulate the required fuel in order to generate the required power. The software also requires the desired type of power plant whether it is CCPP or ISCCS. The flow diagram of the methodology is summarized in Appendix E

CHAPTER 5

RESULTS AND DICUSSION

5.1 Solar Radiation

Some data were taken from the Meteorological Data simulation program. (Balbir, 2004). The data taken from the program are about the records of hourly global radiation for August 2005 with reference to Ipoh city. By using this data, a solar radiation for a particular day can be known. Ipoh has latitude of 4° 34' N and longitude of 101° 06' E. Ipoh which is near to Lumut Power Plant was taken as a reference to show the variation of global radiation in the area. The global radiation data from 6 am to 7 pm for the month of August 2005 were summarized in Figure 5.1

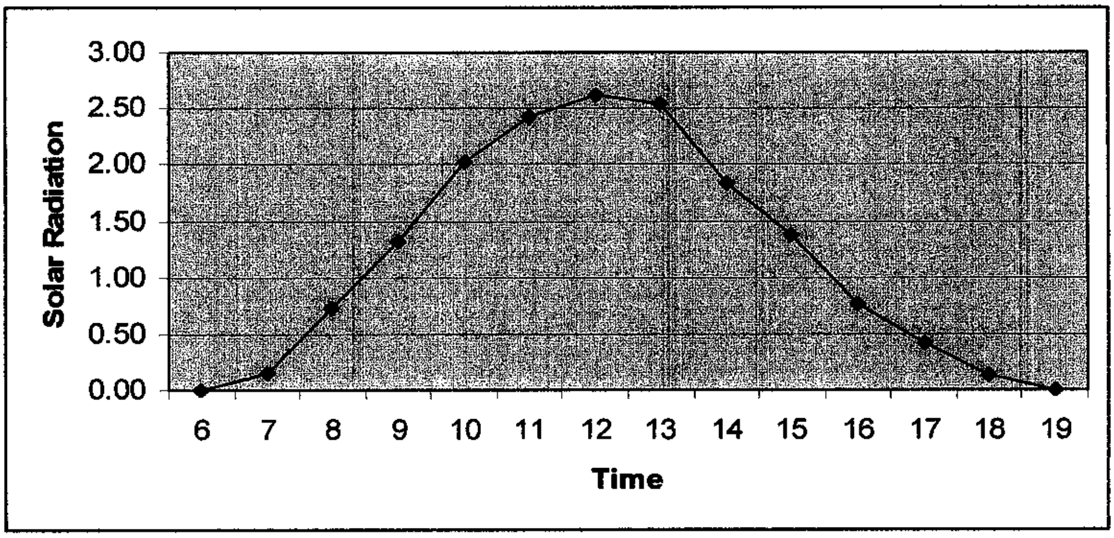


Figure 5.1: Solar radiation vs time for August 2005

From the data and the graph plotted, the peak hours for the highest solar radiation are from 10 am to 2 pm.

5.2 Integrated Solar Combined Cycle System Design

A design layout of an integrated solar combined cycle system diagram based on Lumut power plant combined cycle system can be referred in Figure 5.2.

The Integrated Solar Combined Cycle System is used to integrate solar powered plants with modern combined cycle power plants. The integrated plant consists of a combined cycle plant which includes Gas Turbine, Heat Recovery Steam Generator (HRSG), solar field and Steam Generator. At night or when it is cloudy, the ISCCS operates as a conventional combined cycle plant to generate electricity. When there is enough sunlight, the use of gas turbine is minimized.

The designed diagram shows two solar fields that have been integrated into a combined cycle power plant. Solar Field A is design to produce a superheated high pressure steam for HP side of steam turbine and Solar Field B is for producing a low pressure steam for LP side of steam turbine. The steam produced from the heat collected from both solar field A and B and from the gas turbine exhaust is then channeled to the steam turbine to drive a steam generator.

The specifications used for the parabolic trough solar field is adapted from LS-3 based PTC, implemented at Kramer Junction, California (Price, 2003), while the specification of the CCPP is based on a typical NG power plant in Malaysia. Altogether 3 GTs and 1 ST are used for this simulation studies. The specifications of GT and ST in the CCPP and PTC are summarized in Table 5.1, Table 5.2 and Table 5.3 respectively.

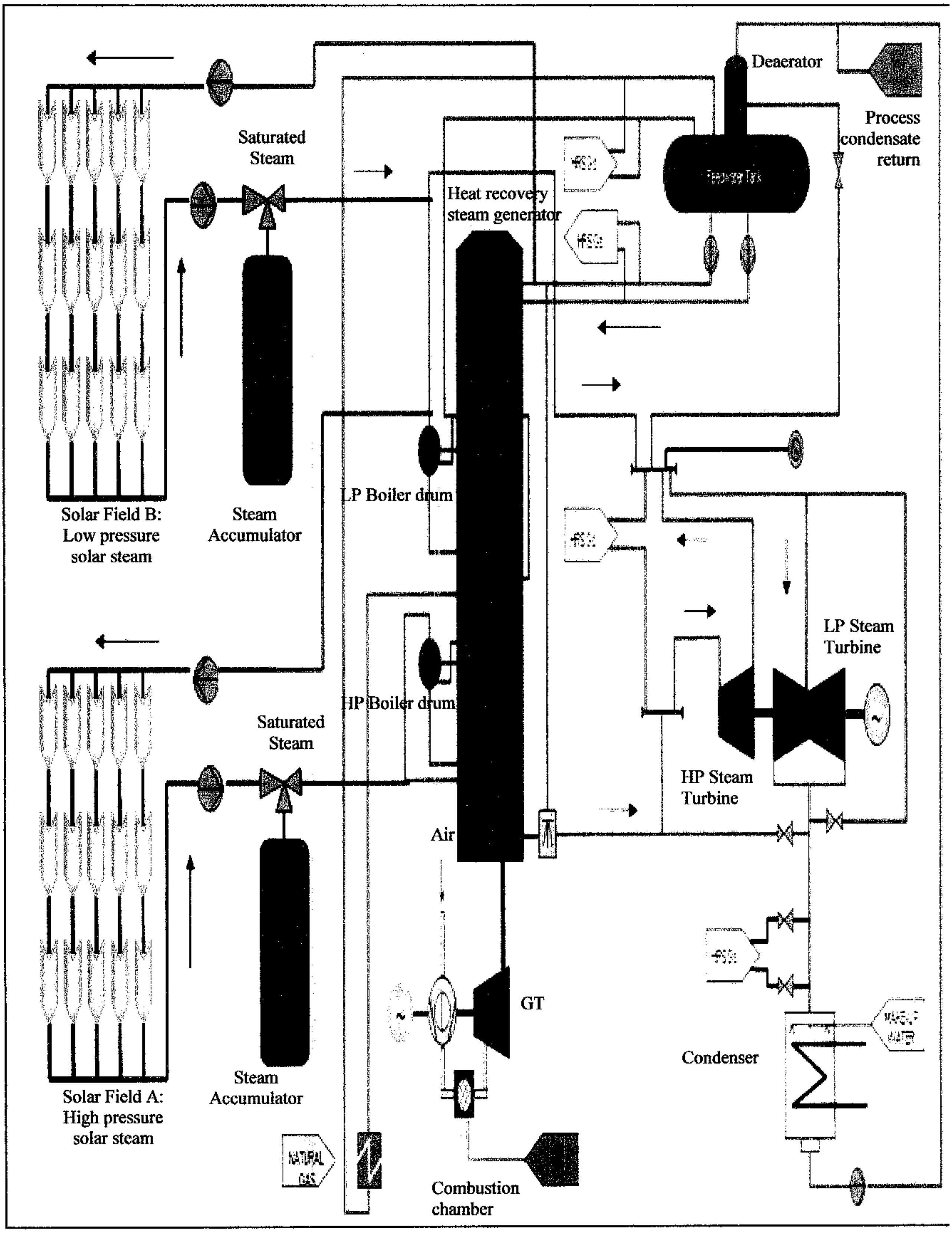


Figure 5.2: Designed INTEGRATED SOLAR COMBINED CYCLE SYSTEM (with LPP as a reference power plant)

5.3 Simulation on Combined Cycle Power Plant

The CCPP consists of 3 GT, 3 HRSG, 1 ST, one condenser and Condensate Extraction pumps (CEP).

Table 5.1: Basic parameters for gas turbine of combined cycle plant

1. Gas inlet temperature to turbine	1100°C
2. Mass flow of air	495kg/s
3. Mass flow of fuel/gas	7.3kg/s
4. Gas outlet temperature from turbine	550°C
5. Electrical power output	140MW
6. Gas turbine efficiency	33%
7. c_p of the exhaust gases from the gas turbine	1.114kJ/kg
8. Allowable temperature drop of the exhaust gases	550°C - 107°C

Table 5.2: Parameters of High Pressure (HP) and Low Pressure (LP) steam for steam turbine

Mass flow of HP steam	61.7kg/s
Mass flow of LP steam	13.9kg/s
Pressure of HP steam	67.2 bar
Pressure of LP steam	5.9 bar
HP steam temperature	506.5°C
LP steam temperature	200°C
Specific enthalpy drop in HP turbines	670kJ/kg
Specific enthalpy drop in LP turbines	570kJ/kg
Condenser pressure	0.068bar
exhausts gases temperature released through the stack	100°C
Specific enthalpy of 100°C steam	2.676kJ/kg

The coding of the simulation on the CCPP can be referred in Appendix F. The results of the simulation are summarized in Table 5.3

Table 5.3: Simulation results for CCPP

Heat Energy	**Power**
Q1	12754MW
Q2	854.54MW
QL1	226.38KW
Q3	854.31MW
QL2	601.02MW
W1	420.89MW
W2	253.293MW
Efficiency of CCPP	52.86%

5.4 Simulation on Solar Parabolic Trough Collector

The parameters of the PTC are summarized in Table 5.4.

Table 5.4: Parabolic trough collector specification

Absorber tube: Inner diameter Outer diameter	$D_i = 0.059m$ $D_o = 0.07m$
Glass cover: Inner diameter Outer diameter	$D_{ci} = 0.118m$ $D_{co} = 0.129m$
Aperture	$W = 5.7m$
Length	$L = 99m$
Maximum beam flux	$I_bR_b = 800W/m^2$
Specular reflectivity of receiver surface	$\rho = 0.95$
Intercept factor	$\gamma = 0.96$
Average value of the transmissivity – absorbptivity product for beam radiation	$(\tau\alpha)_b = 0.96$
Air: Mean flow velocity Kinematics viscosity Prandlt Number Thermal conductivity	 $V_{AIR} = 3m/s$ $v = 16.0 \times 10^{-6} m^2/s$ $Pr = 0.701$ $k = 0.0267$ W/m-K
Working fluid: Water at 200°C Density Specific heat capacity Kinematics viscosity Thermal conductivity Prandlt Number	 $\rho = 863.0 kg/m^3$ $Cp = 4.505$ kJ/kg-K $v = 0.158 \times 10^{-6} m^2/s$ $k = 0.663$ W/m-K $Pr = 0.93$
Receiver tube emissivity	$\varepsilon_p = 0.95$
Glass cover emissivity	$\varepsilon_c = 0.88$
Stefan – Boltzmann constant	$\sigma = 5.670 \times 10^{-8} W/m^2\text{-}K^4$

The simulations on PTC are divided into two parts:

1. Solar Field A: High Pressure (HP) Solar Steam
2. Solar Field B: Low Pressure (LP) Solar Steam

5.4.1 Solar Field A: High Pressure (HP) Solar Steam

The simulation for Solar Field A is based on the parameter in Table 5.5 (L. Valenzuela et al., 2004) and the simulation is based on the peak hour of the solar radiation which is in between 12PM to 1PM

Table 5.5: Input data for PTC Solar Field A

Input	**Data**
Collector inlet mass flow rate	0.75 kg/s
Outlet temperature reference	280 °C – 320 °C
Injection water temperature	150°C
Pressure	30 bar

The results of the simulation of Solar Field A are summarized in Table 5.6

Table 5.6: Simulation results on PTC Solar Field A (HP)

Outlet Temperature	339.5403°C
Collector Efficiency	72.36%
Useful Heat Gain	326.67MW

The simulation coding for Solar Field A can be referred in Appendix G.

5.4.2 Solar Field B: Low Pressure (LP) Solar Steam

The simulation for Solar Field B is based on the parameter in Table 5.7 and the simulation is based on the peak hour of the solar radiation which is in between 12 PM to 1 PM

Table 5.7: Input data for PTC Solar Field B

Input	**Data**
Collector inlet mass flow rate	0.8 kg/s
Injection water temperature	60°C
Pressure	30 bar

The results of the simulation of Solar Field B are summarized in Table 5.8

Table 5.8: Simulation results on PTC Solar Field B (LP)

Outlet Temperature	259.4410°C
Collector Efficiency	77.15%
Useful Heat Gain	348.27MW

The simulation coding for Solar Field B can be referred in Appendix H.

5.5 Simulation On ISCCS

A miniature of the Combined Cycle power plant has been made for presentation purposes and can be referred in Appendix G and the simulation coding for ISCCS can be referred in Appendix I.

The simulation studies carried out to integrate solar field with a CCPP can be summarized, as represented by block diagrams given in Figure 5.2. Q_1 is the mass flow rate of NG supply, which is around 7.3kg/s for Lumut Power Plant, which is one of Independence Power Producer (IPP), in Malaysia (Hanim, 2005).

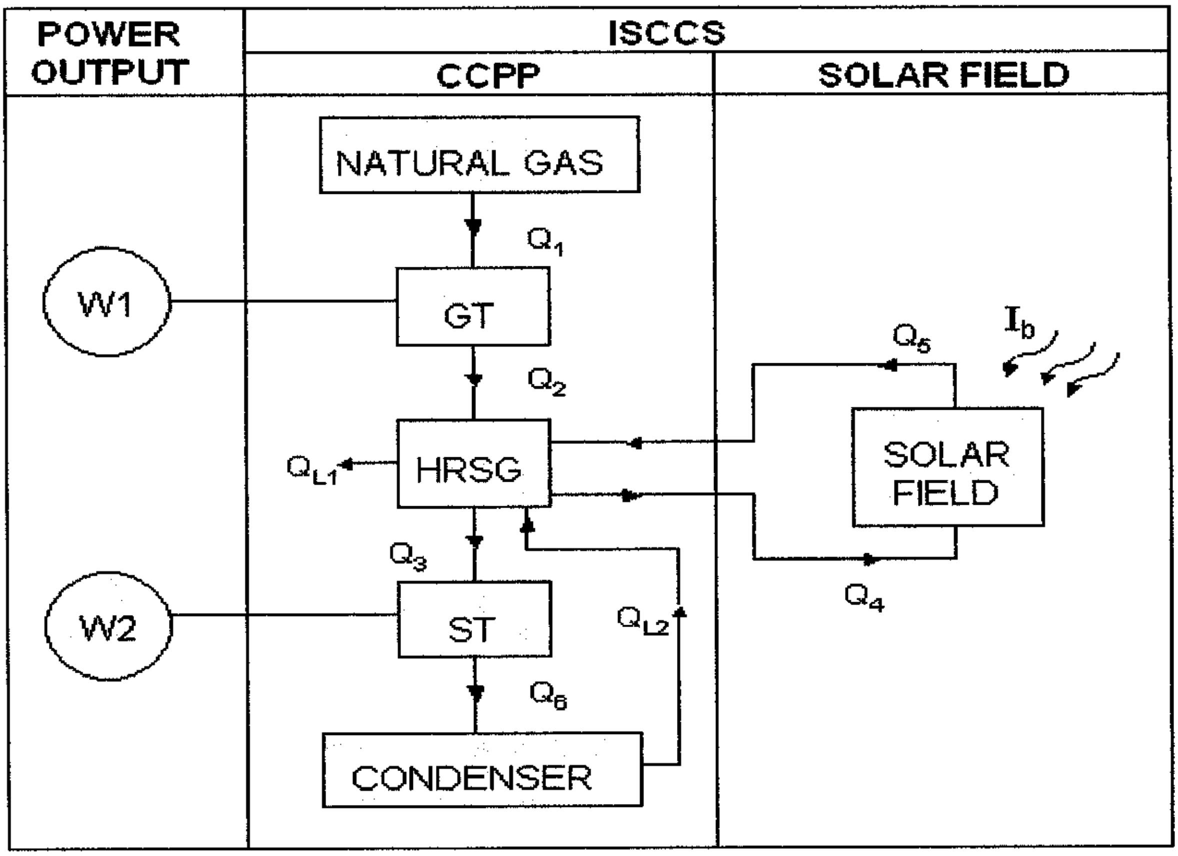


Figure 5.3.: Block diagram of ISCCS, as proposed for an IPP in Malaysia.

The mixture of NG and air is compressed and ignited, where W_1 amount of power is generated. The remaining hot exhaust gases is channelled out to HRSG and passed through a series of heat exchangers, where superheated steam and saturated steam are produced at temperature in the range of 500°C to 510°C and 150°C to 200°C respectively. The remaining exhaust gas is used to preheat steam that will be fed to the PTCs in the solar field. Enhanced energy Q_5, will be fed again to the HP and LP sides of ST together with the superheated steam generated in the HRSG. In ST, power W_2 is generated, and Q_{L2} is re-circulated to the HRSG. The simulation coding for the ISCCS system can be referred in Appendix J.

The CCPP and ISCCS results are shown in Table 5.9 and Figure 5.3.

Table 5.9: The outputs and efficiency of GT and ST for both systems

	CCPP system	**ISCCS system**
W1	420.90 MW	420.90MW
W2	253.29 MW	327.60 MW
W_{pp}	674.19 MW	742.60 MW
η_{GT}	33.0 %	33.0 %
η_{ST}	40.0 %	51.3 %
η_{PP}	52.9 %	58.7 %

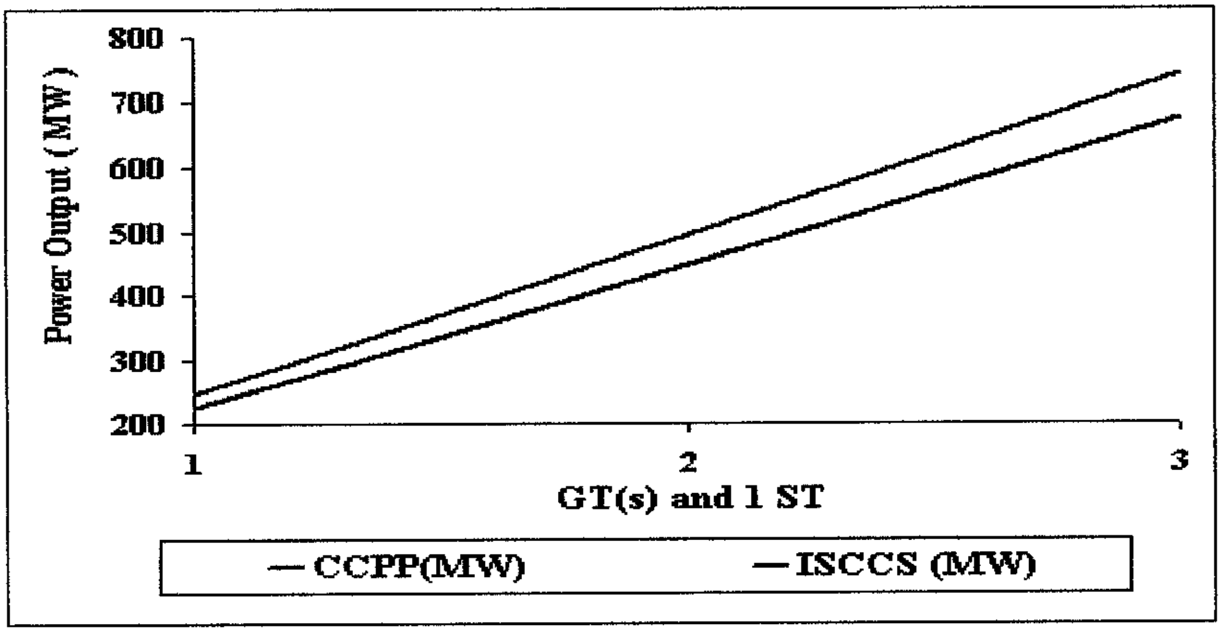


Figure 5.4: Outputs for both systems with different number of GT used and 1 ST.

The calculated value of Q_I is around 1275.435 MW, and hence, the efficiency of the ISCCS power plant is calculated to be around 58.7 %. The efficiency of the ISSCS is higher by 5.8 % as compared to the efficiency of CCPP.

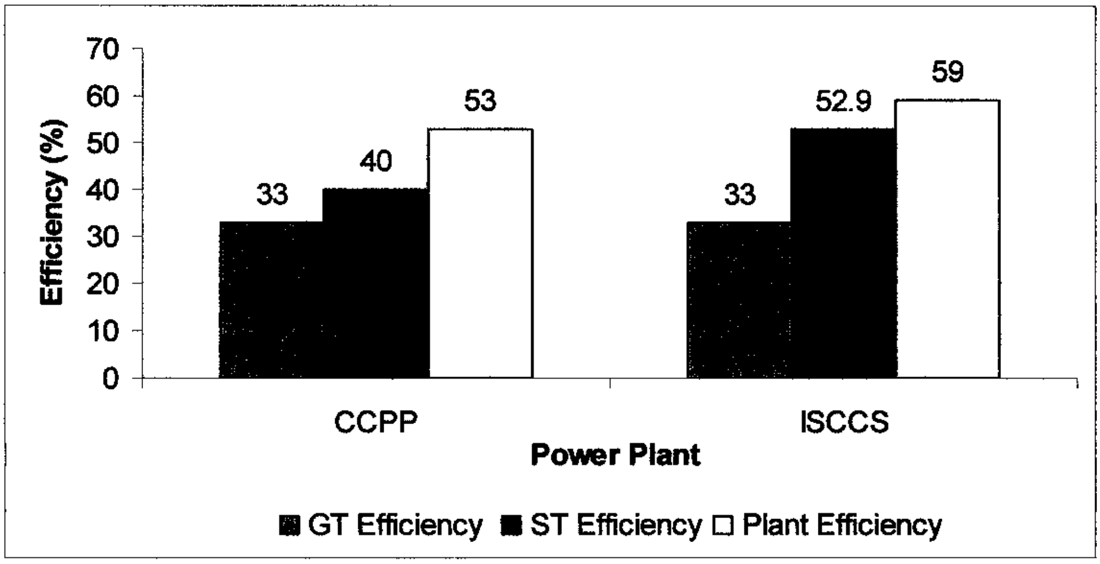


Figure 5.5: Efficiency of GT, ST and the overall efficiency of CCPP and ISCCS.

The increase in the instantaneous efficiency is recorded based on steady-state situation, by integrating a PTC based solar field with constant direct solar radiation value. Solar insolation is transient in nature, and depends on the local meteorological conditions. In Malaysia, clouds are 40 % predominant, with around 10 sunshine hours (Azni-Zain *et al.*, 1991). There are other factors that can be used to strike a balance between the volatility in the local meteorological conditions and the need to seek a viable alternative. The fact that PETRONAS has laid an extensive NG pipeline network throughout the country, which runs along the coastal line, is one such factor. The Lumut IPP is located off the Segari coast, and gets NG supply via this pipeline system. Moreover, the cloud coverage around the coastal area is less dominant. There is also ample supply of seawater, to be processed and used in ST, and PTC field. An additional PTC field can be used to collect and store steam that can be used when meteorological conditions are unfavourable. The energy storage will act as a buffer during periods of low transient weather conditions. This can make even distribution of electricity production and achieve full load operation of the steam cycle at high efficiency (H. Ulf *et al*, 2002).

5.5 Simulation Software of CCPP and ISCCS

The simulation software of CCPP and ISCCS has been developed using Microsoft Visual Basic Software. The layout of the software is as shown in Figure 5.5.

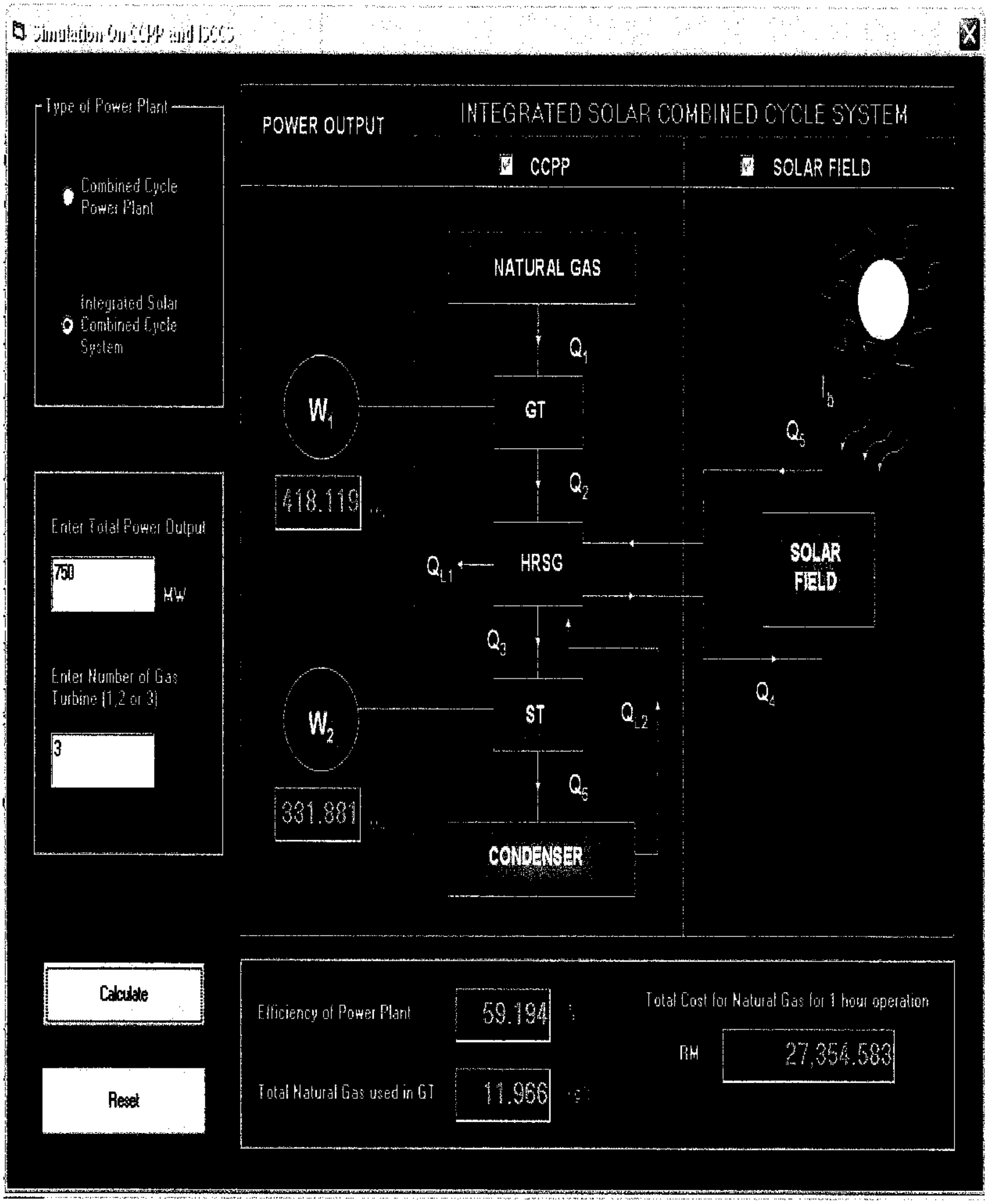


Figure 5.6: Simulation software of CCPP and ISCCS layout

The software requires the desired output power and the number of GT to be used in the plant as the input data to simulate the required fuel in order to generate the required power. The software also requires the desired type of power plant whether it is CCPP or ISCCS. The outcome of the inputs entered will also show the output power of GT and ST. Besides that, it will show the efficiency of the plant. With the known total fuel consumption, the total cost of the Natural gas for an hour operation can be calculated, which in this case, the price for 1 kg of natural is RM 0.63. The cost is also displayed in the software. The utility of this software is to provide an attractive graphical user interface for the simulation studies of the CCPP and ISCCS. The simulation software can also serve as an important item in conducting further innovation and research in the integrated solar combined cycle system.

The simulation coding for the software can be referred in Appendix K.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATION

The ISCCS provides an interesting way of solar electricity generation. The system uses renewable energy which is the solar radiation to make use of the heat to produce high pressure steam. The steam produced is then used to turn a steam turbine and drive another generator to generate electrical power. This will combine with the gas turbine where gas is used as the fuel to drive another generator. This project would show that solar energy can be the most viable alternative source not only to produce cheap electricity but it is also environmental friendly. This situation can only happen by carefully integrating the solar related technology to the combined cycle system. The ISCCS can be considered as a reasonable alternative to the currently used CCPP in Malaysia, and this will certainly prolong the life of NG and provide an opportunity to utilize the daily available solar energy. The best solar collector for ISCCS is the solar parabolic trough which with the right design parameter will contribute up to 326.67 KW of energy. Through the simulations the overall conversion efficiency of the ISCCS is around 58.7% where the total power generated with 3 GT is 752.77 MW. A small pilot plant, can be initiated where other alternative source of renewable energy can also be integrated to further increase the overall efficiency and reliability of modern CCPP. Since the power plants can be suitably located along the coast, wind and wave energy can be used to complement the solar energy systems as well. An additional PTC field can be used to collect and store steam that can be used when meteorological conditions are unfavourable. This project does not include the costing of building and running the ISCCS. It is suggested that a complete research and study on the cost factor which also will influence its viability. It is also useful if another study to look into the shortfall of the solar insolation especially during rainy and cloudy seasons which is typical of Malaysia's weather condition. This project hopefully will benefit the nation as a whole especially in ensuring the stable and continuous supply of power to the ever growing industries and public consumption.

REFERENCES

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.

Balbir, S.M.S. (2004). A Study of an Optimum Parabolic Trough Design for Possible Power Generation in Malaysia. PhD Thesis, Universiti Sains Malaysia.

Becker, H. (1995). Combined Cycle Power Plant Overview, ABB-KWEA: Combined Cycle Power Plant Overview, ABB Power Generation Ltd. Switzerland

Boyce, M. P. (2002). HANDBOOK For Cogeneration and Combined Cycle Power Plants. Asmee Press, New York.

Donovon, L. (1994). Thermodynamics Fundamentals, ABB-KWEA: Combined Cycle Plants, ABB Power Generation Ltd. Switzerland.

EPU. (1999). Support to the Development of a Strategy for Renewable Energy as a Fifth Fuel in Malaysia. Economic Planning Unit, Prime Minister's Department. Kuala Lumpur.

EPU. (2006). Ninth Malaysia Plan (2006 – 2010)

Fujii, T. (1999). Steam Power Plants for Practical Use. In *Steam Power Engineering*. p.103-107. United Kingdom : Cambridge University Press.

Goswani, U. D., Kreith, F. & Kreider, J. F. (2000). Principle of Solar Engineering. 2nd edition. Tangler & Francis, U.S.

Hanim, A.W. (2005). *Industrial Internship Report at Lumut Power Plant*. IRC, Universiti Teknologi PETRONAS, Malaysia.

IEA SolarPACES. (2005). Technology Characterization Solar Parabolic Trough. Implementing Agreement 2002, at http:// www.solarpaces.org

Valenzuela, L. et al. (2004). Control Concept for direct Steam generation in parabolic troughs at http://www.sciencdirect.com

Malaysia Energy Commission. (2005). at http://www.st.gov.my/Overview.php

Nag, P.K. (2002). *Power Plant Engineering*. 2^{nd} edition. Mc Graw Hill. Singapore

NST. (2005). Renewed interest in renewable energy. Port Dickson. (23rd August 2005)

Price, H. (2003). Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecasts. Prepared under Subcontract No. LAA-2-32458-01, National Renewable Energy Laboratory, U.S.

Sukhatme, S. P. (1996). *Solar Energy: Principles of Thermal Collection and Storage*, Tata Mc Grawhill, New Delhi, 1999.

Smith, C. (1995). History of Solar Energy: Revisiting Solar Power's Past. The Solar Energy Newsletter July 1995 at http://www.solarenergy.com/info_history.html

The Malay Mail. (2005). TNB may get Govt nod to up power prices by 10pc. Kuala Lumpur. (16th August 2005)

The Star. (2005). TNB in talks with firm to save fuel costs. Kuala Lumpur. (5th May 2005)

Ulf, H., Michael, G. & Dave, K. (2002). Overview on Thermal Storage Systems. Workshop on Thermal Storage for Trough Power Systems. FLABEG Solar International GmbH at http:// ww.eere.energy.gov

Appendix A

Final Commercial Energy Demand by Sector

Source	Petajoules			% of Total			Average Annual Growth Rate (%)	
	2000	*2005*	*2010*	*2000*	*2005*	*2010*	*8MP*	*9MP*
Industrial[1]	477.6	630.7	859.9	*38.4*	*38.6*	*38.8*	5.7	*6.4*
Transport	505.5	661.3	911.7	*40.6*	*40.5*	*41.1*	5.5	*6.6*
Residential and Commercial	162.0	213.0	284.9	*13.0*	*13.1*	*12.8*	5.6	*6.0*
Non-Energy[2]	94.2	118.7	144.7	*7.6*	*7.3*	*6.5*	4.7	*4.0*
Agriculture and Forestry	4.4	8.0	16.7	*0.4*	*0.5*	*0.8*	*12.9*	*15.9*
Total	**1,243.7**	**1,631.7**	**2,217.9**	***100.0***	***100.0***	***100.0***	**5.6**	***6.3***

(source: EPU, 2006)

Appendix B

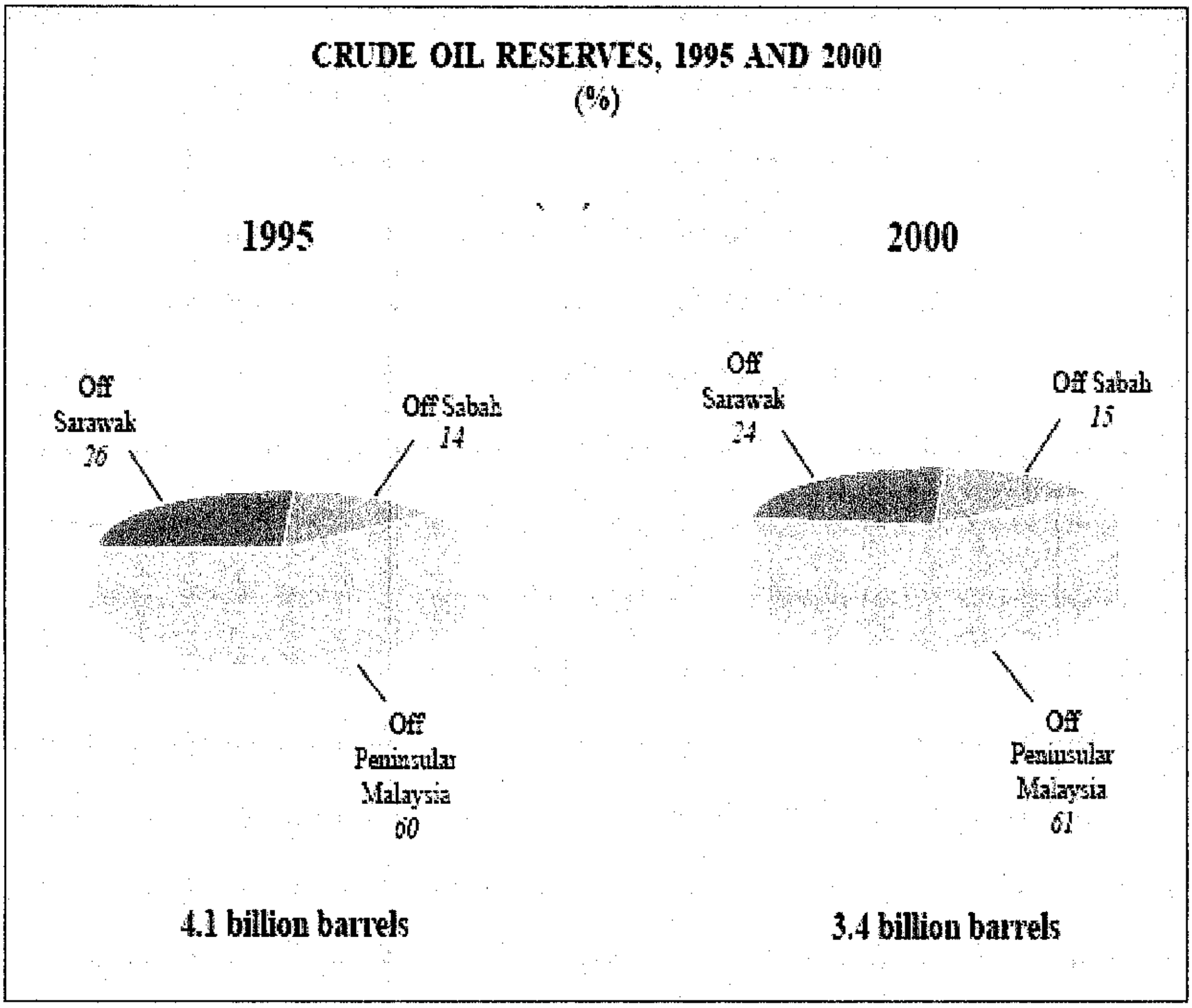
Installed Capacity, Peak Demand and Reserve Margin, 2000 - 2010

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: EPU, 2006)

Appendix C

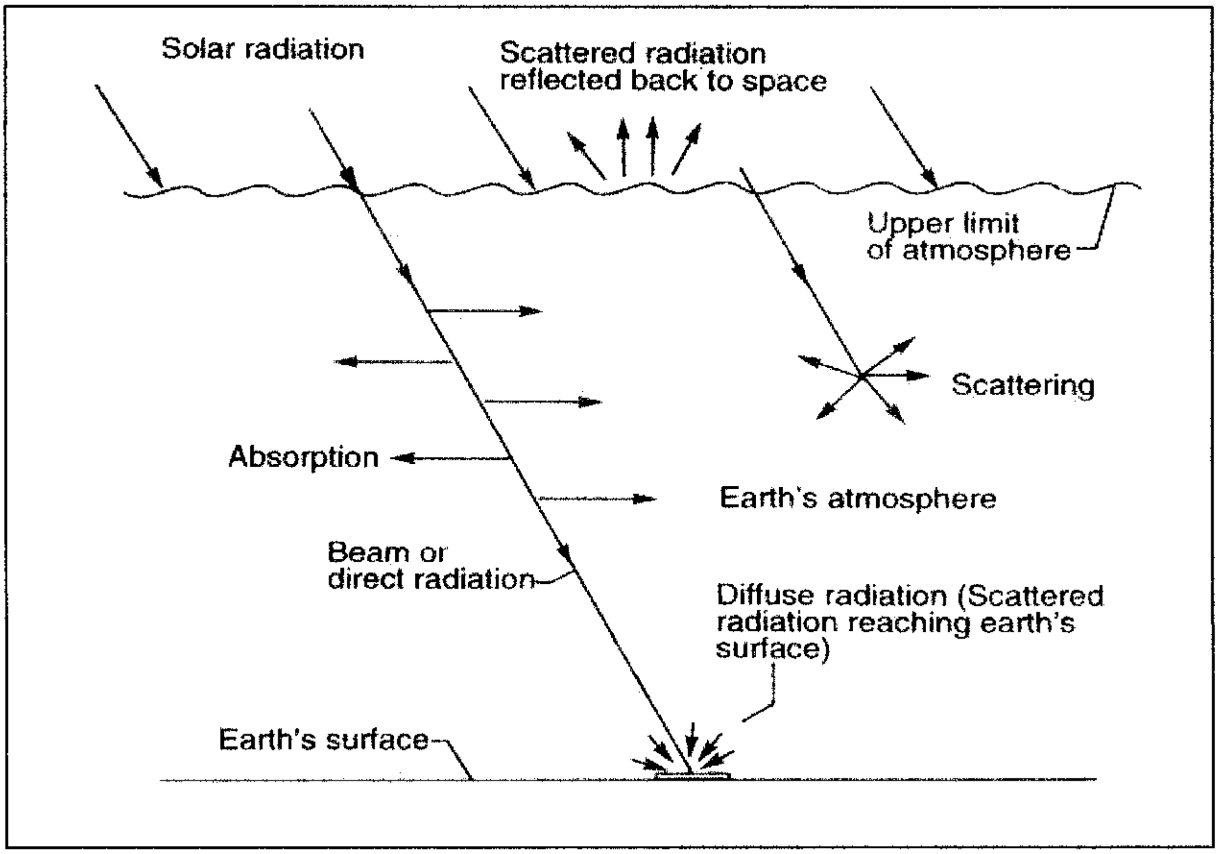
Crude Oil Reserve in Malaysia (1995 and 200)



(source: EPU. 1999)

Appendix D

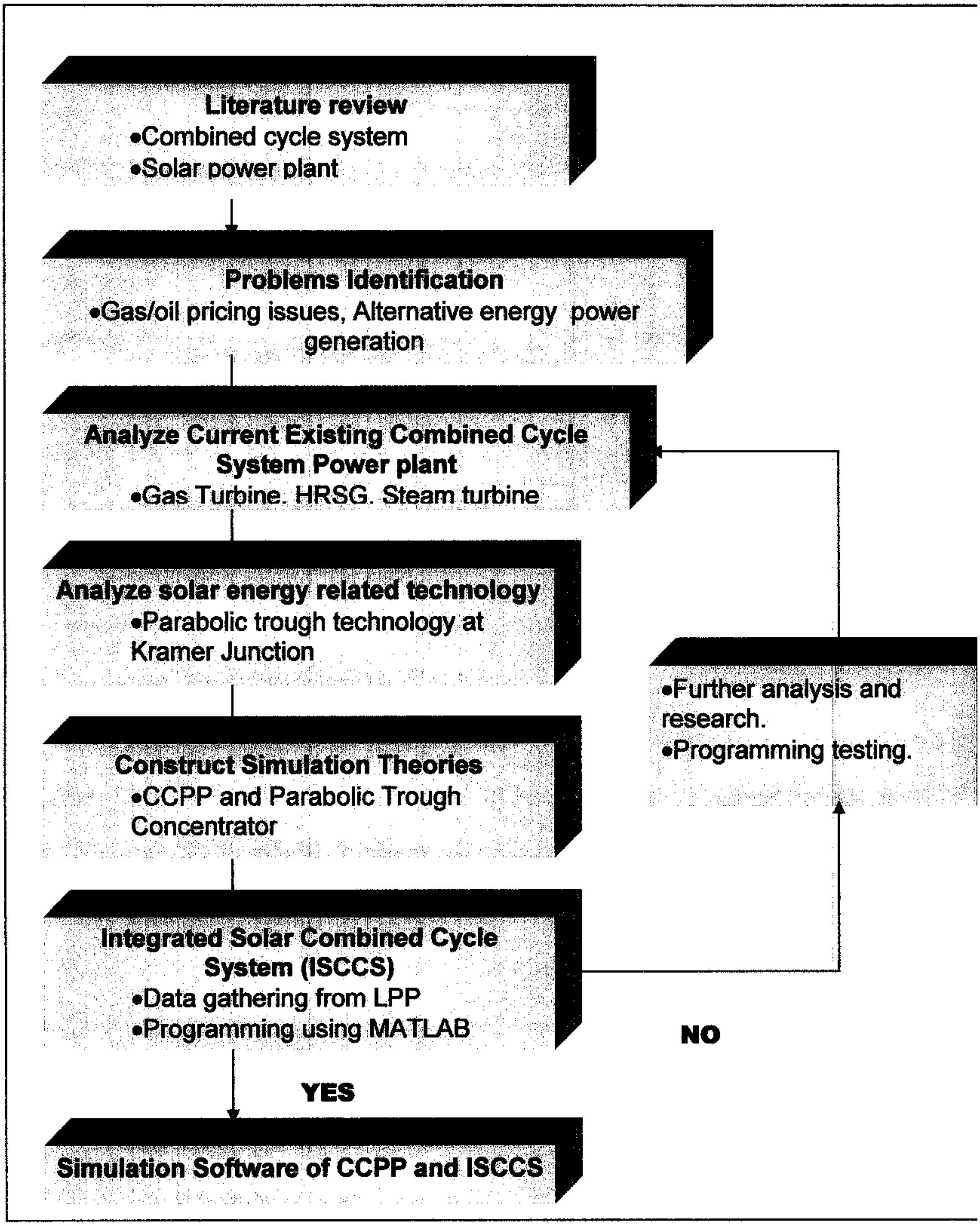
Schematic representation of (i) Mechanism of Absorption and Scattering, and (ii) Beam and Diffuse Radiation Received at the Earth's Surface



(source: Sukhatme, 1996)

Appendix E

The flow diagram of the methodology of ISCCS project



Appendix F

Simulation Coding for CCPP

```
%gas turbine
%number of gas turbine(s)
n = 1;
%mass flow air
mair = 495;
%mass flow of fuel/gas
mgas = 0.0001;
%gas outlet from turbine
To = 572;
%Temperature drop
Td = (To - 111);
%Cp for exhaust gas
Cpgas = 1.836;
%gas turbine efficiency
ngt = 0.33;

%steam turbine
mhp = 61.7*1000;
mlp = 13.9*1000;
Cphp = 670;
Cplp = 570;
Text = 100 + 273;
Cpext = 2.676;

%heat balance equations
%Power output for GT
Q1 = ((mair + mgas)*Cpgas*Td*n)*1000
W1 = Q1*ngt

%Power output for ST
Q2 = (1-ngt)*Q1
W2 = (((mhp + mlp)* Cplp)+(mhp*Cphp))*n

% Loss at HRSG
QL1 = ((mhp+mlp)*Cpext*Text*n)/1000

%heat in HRSG
Q3 = Q2 - QL1

%efficiency of ST
nst = W2/Q3

%loss at condenser
QL2 = (1-nst)*Q3

%efficiency of power plant
npp = (W1 + W2)/Q1

Wpp = W1 + W2
```

Appendix G

Simulation Coding for Solar Field A: High Pressure Solar Steam

```
%solar parabolic trough for HP side

%outer diameter = Do
%inner diameter = Di
%outer diameter glass cover = Dco
%inner diameter glass cover = Dci
Do = 0.07;
Di = 0.059;
Dci = 0.118;
Dco = 0.129;
Trm = 443;
Ta = 30+273;
Tfi =150+273;
Tfm = 423;

%colector specification
m = 0.75;
W = 5.7;
L = 99;

%solar radiation
IbRb = 800;
p = 0.95;
y = 0.96;
tab = 0.96;

%air
Vair = 3;
vair = 16.0*(10^(-6));
Prair = 0.701;
kair = 0.0267;

%water (working fluid)
pw = 863.0;
Cpw = 2298;
vw = 0.158*(10^(-6));
kw = 0.663;
Prw = 0.93;
%Receiver tube emissivity = Ep
Ep = 0.95;
%Glass cover emissivity = Ec
Ec = 0.88;
%Q = Stefan-Boltzmann constant
Q = 5.670*(10^(-8));

%Reynolds number for air
Reair = (Vair*Dco)/vair;

%Nusselt number for air
if Reair > 400 && Reair < 4000
           C1n = 0.165;
           n = 0.466;
           Nuair = C1n*(Reair^n);

elseif Reair > 4000 && Reair < 40000
           C1n = 0.174;
           n =0.618;
           Nuair = C1n*(Reair^n);
```

```
else Reair > 40000 && Reair < 400000
            C1n = 0.239;
            n = 0.805;
            Nuair = C1n*(Reair^n);
end

%heat transfer coefficient
hwair = (Nuair*0.0267)/Dco;

%Glass cover temperature Tc
Tc = Ta + (((0.04075*((Do/Dci)^0.4))*(hwair^(-0.67))*(2-(3*Ep)
     +(((6+(9*Ep))*Trm)/100)))*(Trm-Ta));

%temperature coefficients
T1 = Trm-Tc;
T2 = Trm+Tc;
T3 = (Trm^2)+(Tc^2);
T4 = Tc+Ta;
T5 = (Tc^2)+(Ta^2);

%constants
C1 = 17.74/((T2^0.4)*(Do*((Do^(-0.75))+(Dci^(-0.75)))));
C2 = (1/Ep)+(Do/Dci)*((1/Ec)-1);
C3 = hwair+(Q*Ec*T4*T5);

%overall heat loss coefficient
ULR = ((1/((C1*(T1^0.25))+((Q*T2*T3)/C2)))+((Do/Dco)*(1/C3)))^(-1);

%working Fluid
%Average vlocity
Vw = m/(pi*(Di^2)*pw);

%Reynolds number for water
Rew = (Vw*Di)/vw;

%Nusselt number for water
if Rew > 200
            Nuw = 0.023*(Rew^0.8)*(Prw^0.4);

else
            Nuw = 3.66;

end

%Heat transfer coefficient
hf = (Nuw*kw)/Di;

%Receiver efficiency factor
FRE = 1/(ULR*((1/ULR)+(Do/(Di*hf))));

%heat removal factor
FR = ((m*Cpw)/(pi*Do*L*ULR))*(1-exp(-((FRE*pi*Do*L*ULR)/(m*Cpw))));

%Effective are
Aeff = (W-Do)*L

%Absorbed Flux
S = IbRb*p*y*tab;

%Concentration ratio
```

```
C = (W-Do)/(pi*Do);

%Heat gain
QR = FR*Aeff*(S-((ULR/C)*(Tfi-Ta)))

%Outlet temperature
delT=(QR/(m*Cpw));
Tfo =delT +Tfi
Tfo_celcius = Tfo - 273
Thp = Tfo_celcius*1.819

%Instantaneous collector efficiency
nib = QR/(IbRb*W*L)
```

Appendix H

Simulation Coding for Solar Field B: Low Pressure Solar Steam

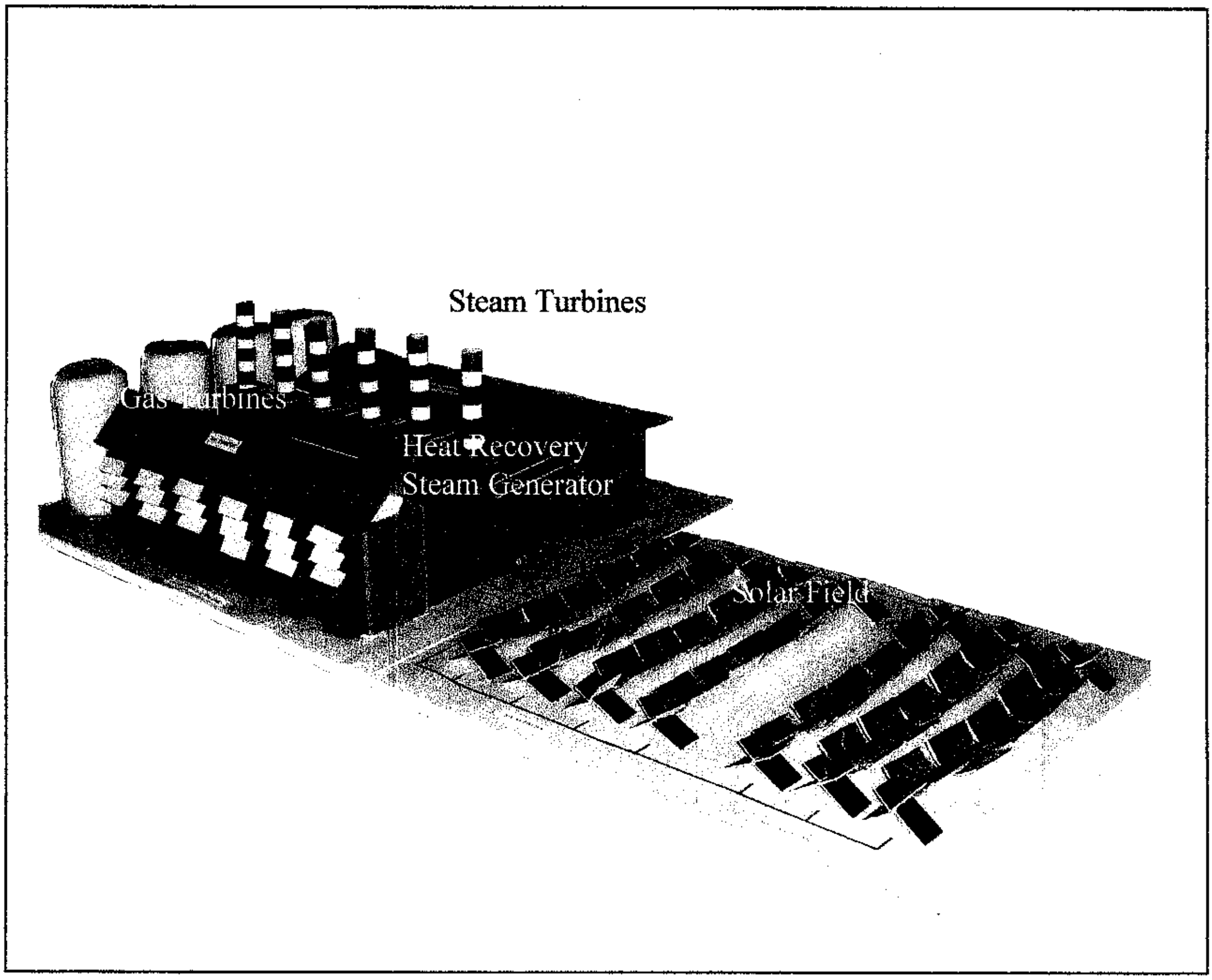
```
%solar parabolic trough for LP side

%outer diameter = Do
%inner diameter = Di
%outer diameter glass cover = Dco
%inner diameter glass cover = Dci
Do = 0.07;
Di = 0.059;
Dci = 0.118;
Dco = 0.129;
Trm = 443;
Ta = 30+273;
Tfi =70+273;
Tfm = 423;

%colector specification
m = 0.8;
W = 5.7;
L = 99;

%solar radiation
IbRb = 800;
p = 0.95;
y = 0.96;
tab = 0.96;

%air
Vair = 3;
vair = 16.0*(10^(-6));
Prair = 0.701;
kair = 0.0267;

%water (working fluid)
pw = 863.0;
Cpw = 2298;
vw = 0.158*(10^(-6));
kw = 0.663;
Prw = 0.93;
%Receiver tube emissivity = Ep
Ep = 0.95;
%Glass cover emissivity = Ec
Ec = 0.88;
%Q = Stefan-Boltzmann constant
Q = 5.670*(10^(-8));

%Reynolds number for air
Reair = (Vair*Dco)/vair;

%Nusselt number for air
if Reair > 400 && Reair < 4000
           C1n = 0.165;
           n = 0.466;
           Nuair = C1n*(Reair^n);

elseif Reair > 4000 && Reair < 40000
           C1n = 0.174;
           n =0.618;
           Nuair = C1n*(Reair^n);
```

```
else Reair > 40000 && Reair < 400000
            C1n = 0.239;
            n = 0.805;
            Nuair = C1n*(Reair^n);
end


%heat transfer coefficient
hwair = (Nuair*0.0267)/Dco;

%Glass cover temperature Tc
Tc = Ta + (((0.04075*((Do/Dci)^0.4))*(hwair^(-0.67))*(2-(3*Ep)
     +(((6+(9*Ep))*Trm)/100)))*(Trm-Ta));

%temperature coefficients
T1 = Trm-Tc;
T2 = Trm+Tc;
T3 = (Trm^2)+(Tc^2);
T4 = Tc+Ta;
T5 = (Tc^2)+(Ta^2);

%constants
C1 = 17.74/((T2^0.4)*(Do*((Do^(-0.75))+(Dci^(-0.75)))));
C2 = (1/Ep)+(Do/Dci)*((1/Ec)-1);
C3 = hwair+(Q*Ec*T4*T5);

%overall heat loss coefficient
ULR = ((1/((C1*(T1^0.25))+((Q*T2*T3)/C2)))+((Do/Dco)*(1/C3)))^(-1);

%working Fluid
%Average vlocity
Vw = m/(pi*(Di^2)*pw);

%Reynolds number for water
Rew = (Vw*Di)/vw;

%Nusselt number for water
if Rew > 200
            Nuw = 0.023*(Rew^0.8)*(Prw^0.4);

else
            Nuw = 3.66;

end

%Heat transfer coefficient
hf = (Nuw*kw)/Di;

%Receiver efficiency factor
FRE = 1/(ULR*((1/ULR)+(Do/(Di*hf))));

%heat removal factor
FR = ((m*Cpw)/(pi*Do*L*ULR))*(1-exp(-((FRE*pi*Do*L*ULR)/(m*Cpw))));

%Effective are
Aeff = (W-Do)*L;

%Absorbed Flux
S = IbRb*p*y*tab;
```

```
%Concentration ratio
C = (W-Do)/(pi*Do);

%Heat gain
QR = FR*Aeff*(S-((ULR/C)*(Tfi-Ta)))

%Outlet temperature
delT=(QR/(m*Cpw));
Tfo =delT +Tfi;
Tfo_celciuslp = Tfo - 273
Tlp = Tfo_celciuslp*1.162

%Instantaneous collector efficiency
nib = QR/(IbRb*W*L)
```

Appendix I

Miniature of ISCCS



Appendix J

Simulation Coding for ISCCS

```
%ISCCS

%gas turbine(GT)
%number of gas turbine(s)
numgt = 1;
%mass flow air
mair = 495;
%mass flow of fuel/gas
mgas = 7.3;
%gas outlet from turbine
To = 572;
%Temperature drop
Td = (To - 111);
%Cp for exhaust gas
Cpgas = 1.836;
%gas turbine efficiency
ngt = 0.33;

%Power output for GT
Q1 = ((mair + mgas)*Cpgas*Td*numgt)*1000;
W1 = Q1*ngt
%...................................................
%solar parabolic trough (SOLAR FIELD)

%outer diameter = Do
%inner diameter = Di
%outer diameter glass cover = Dco
%inner diameter glass cover = Dci
Do = 0.07;
Di = 0.059;
Dci = 0.118;
Dco = 0.129;

%ambient temperature, receiver mean temperature
Trm = 443;
Ta = 30+273;
Tfm = 423;

%colector specification
W = 5.7;
L = 99;

%solar radiation
IbRb = 800;
p = 0.95;
y = 0.96;
tab = 0.96;

%air
Vair = 3;
vair = 16.0*(10^(-6));
Prair = 0.701;
kair = 0.0267;

%water (working fluid)
pw = 863.0;
Cpw = 2298;
vw = 0.158*(10^(-6));
kw = 0.663;
Prw = 0.93;
```

```
%Receiver tube emissivity = Ep
Ep = 0.95;
%Glass cover emissivity = Ec
Ec = 0.88;
%Q = Stefan-Boltzmann constant
Q = 5.670*(10^(-8));

%Reynolds number for air
Reair = (Vair*Dco)/vair;

%Nusselt number for air

if Reair > 400 && Reair < 4000
     C1n = 0.165;
     n = 0.466;
     Nuair = C1n*(Reair^n);

elseif Reair > 4000 && Reair < 40000
     C1n = 0.174;
     n =0.618;
     Nuair = C1n*(Reair^n);

else Reair > 40000 && Reair < 400000
     C1n = 0.239;
     n = 0.805;
     Nuair = C1n*(Reair^n);
end

%heat transfer coefficient
hwair = (Nuair*0.0267)/Dco;

%Glass cover temperature Tc

Tc = Ta + (((0.04075*((Do/Dci)^0.4))*(hwair^(-0.67))*(2-(3*Ep)+(((6+(9*Ep))
     *Trm)/100)))*(Trm-Ta));

%temperature coefficients
T1 = Trm-Tc;
T2 = Trm+Tc;
T3 = (Trm^2)+(Tc^2);
T4 = Tc+Ta;
T5 = (Tc^2)+(Ta^2);

%constants
C1 = 17.74/((T2^0.4)*(Do*((Do^(-0.75))+(Dci^(-0.75)))));
C2 = (1/Ep)+(Do/Dci)*((1/Ec)-1);
C3 = hwair+(Q*Ec*T4*T5);

%overall heat loss coefficient
ULR = ((1/((C1*(T1^0.25))+((Q*T2*T3)/C2)))+((Do/Dco)*(1/C3)))^(-1);
%.....................................................................
%working Fluid for HP (SOLAR FIELD HP)

%solar parabolic trough for HP side
Tfi =150+273;
m = 0.75;

%Average vlocity
Vw = m/(pi*(Di^2)*pw);
```

```
%Reynolds number for water
Rew = (Vw*Di)/vw;

%Nusselt number for water
if Rew > 200
     Nuw = 0.023*(Rew^0.8)*(Prw^0.4);

else
     Nuw = 3.66;

end

%Heat transfer coefficient
hf = (Nuw*kw)/Di;

%Receiver efficiency factor
FRE = 1/(ULR*((1/ULR)+(Do/(Di*hf))));

%heat removal factor
FR = ((m*Cpw)/(pi*Do*L*ULR))*(1-exp(-((FRE*pi*Do*L*ULR)/(m*Cpw))));

%Effective are
Aeff = (W-Do)*L;

%Absorbed Flux
S = IbRb*p*y*tab;

%Concentration ratio
C = (W-Do)/(pi*Do);

%Heat gain
QR = FR*Aeff*(S-((ULR/C)*(Tfi-Ta)))

%Outlet temperature
delT=(QR/(m*Cpw));
Tfo =delT +Tfi;
Tfo_celcius = Tfo - 273

%Instantaneous collector efficiency
nib = QR/(IbRb*W*L);
%.....................................................
%working Fluid for LP (SOLAR FIELD LP)

%solar parabolic trough for LP side
Tfilp =70+273;
mlp = 0.8;

%Average vlocity
Vwlp = mlp/(pi*(Di^2)*pw);

%Reynolds number for water
Rewlp = (Vwlp*Di)/vw;

%Nusselt number for water
if Rewlp > 200
     Nuwlp = 0.023*(Rewlp^0.8)*(Prw^0.4);

else
     Nulp = 3.66;
```

```
end

%Heat transfer coefficient
hf = (Nuwlp*kw)/Di;

%Receiver efficiency factor
FRElp = 1/(ULR*((1/ULR)+(Do/(Di*hf))));

%heat removal factor
FRlp = ((mlp*Cpw)/(pi*Do*L*ULR))*(1-exp(-((FRElp*pi*Do*L*ULR)/(mlp*Cpw))));

%Effective are
Aefflp = (W-Do)*L;

%Absorbed Flux
Slp = IbRb*p*y*tab;

%Concentration ratio
Clp = (W-Do)/(pi*Do);

%Heat gain
QRlp = FRlp*Aefflp*(Slp-((ULR/Clp)*(Tfilp-Ta)))

%Outlet temperature
delTlp=(QRlp/(mlp*Cpw));
Tfolp =delTlp +Tfilp;
Tfo_celciuslp = Tfolp - 273

%Instantaneous collector efficiency
niblp = QRlp/(IbRb*W*L);
%.........................................................
%steam turbine (ST)

msthp = 61.7*1000;
mstlp = 13.9*1000;
Text = 100 + 273;
Cpext = 2.676;

%temperature for HP
Thp = Tfo_celcius*1.819

%temperature for LP
Tlp = Tfo_celciuslp*1.162
%...................................................................
%enthalpy

%when the temperature is Thp = 617.6238 degree celcius
Chp= (-7E-06*Thp^4) + (0.0202*Thp^3) - (21.083*Thp^2) + (12118*Thp) + (515802)

%when the temperature is Tlp = 301.4704 degree celcius
Clp = (0.0023*Tlp^3) - (3.5249*Tlp^2) + (4074*Tlp) + (2E+06)

%enthalpy drop
Cphp = (Chp - 2.758*(10^6))/1000
Cplp = (Clp - 2.275*(10^6))/1000
%..................................................................

%Power output for ST
Q2 = (1-ngt)*Q1
W2 = (((msthp + mstlp)* Cplp)+(msthp*Cphp))*numgt
```

```
% Loss at HRSG
QL1 = ((msthp+mstlp)*Cpext*Text*numgt)/1000

%heat in HRSG
Q3 = Q2 - QL1

%efficiency of ST
nst = W2/Q3

%loss at condenser
QL2 = (1-nst)*Q3
%.........................................................
%POWER PLANT (ISCCS)

%efficiency of power plant
npp = (W1 + W2)/Q1

%power plant output
Wpp = W1 + W2
```

Appendix K

Simulation Coding for Simulation Software of CCPP and ISCCS

```
Option Explicit

Dim intMair As Integer
Dim intTo As Integer
Dim intTd As Integer
Dim dblCpgas As Double
Dim dblNgt As Double
Dim dblMhp As Double
Dim dblMlp As Double
Dim intCphp As Integer
Dim intCplp As Integer
Dim dblW2 As Double
Dim dblw1 As Double
Dim dblq1 As Double
Dim dblGas As Double
Dim dblCost As Double
Dim dblEff As Double

Private Sub btnCalculate_Click()
If optCCPP.Value = False And optISCCS.Value = False Then
  MsgBox "Please select the 'Type of Power Plant' in order to proceed with the calculation", vbOKOnly,
"validation error"
  Exit Sub
End If

  If txtPwrOutput.Text = "" Or Not IsNumeric(txtPwrOutput.Text) Then
     MsgBox "Invalid value for Output Power."
     txtPwrOutput.SetFocus
     Exit Sub
  End If
  If txtNoOfGT.Text = "" Or Not IsNumeric(txtNoOfGT.Text) Then
     MsgBox "Invalid value for No of GT. Number of GT must be either 1, 2 or 3"
    txtNoOfGT.SetFocus
     Exit Sub
  End If
  If CInt(txtNoOfGT.Text) < 1 Or CInt(txtNoOfGT.Text) > 3 Then
     MsgBox "Number of GT must be either 1, 2 or 3"
     txtNoOfGT.Text = ""
     txtNoOfGT.SetFocus
     Exit Sub
  End If

  If optCCPP.Value = True And CInt(txtNoOfGT.Text) = 1 And CDbl(txtPwrOutput.Text) < 230 Then
     MsgBox "Number of Power Output must be greater or equal 230"
     txtPwrOutput.Text = ""
    txtPwrOutput.SetFocus
     Exit Sub
  End If

  If optCCPP.Value = True And CInt(txtNoOfGT.Text) = 2 And CDbl(txtPwrOutput.Text) < 446 Then
     MsgBox "Number of Power Output must be greater or equal 446"
     txtPwrOutput.Text = ""
    txtPwrOutput.SetFocus

     Exit Sub
  End If
```

```
    If optCCPP.Value = True And CInt(txtNoOfGT.Text) = 3 And CDbl(txtPwrOutput.Text) < 669 Then
        MsgBox "Number of Power Output must be greater or equal 669"
        txtPwrOutput.Text = ""
         txtPwrOutput.SetFocus
        Exit Sub
    End If

    If optISCCS.Value = True And CInt(txtNoOfGT.Text) = 1 And CDbl(txtPwrOutput.Text) < 249 Then
        MsgBox "Number of Power Output must be greater or equal 249"
        txtPwrOutput.Text = ""
       txtPwrOutput.SetFocus
        Exit Sub
    End If

    If optISCCS.Value = True And CInt(txtNoOfGT.Text) = 2 And CDbl(txtPwrOutput.Text) < 498 Then
        MsgBox "Number of Power Output must be greater or equal 498"
        txtPwrOutput.Text = ""
       txtPwrOutput.SetFocus

        Exit Sub
    End If

    If optISCCS.Value = True And CInt(txtNoOfGT.Text) = 3 And CDbl(txtPwrOutput.Text) < 747 Then
        MsgBox "Number of Power Output must be greater or equal 747"
        txtPwrOutput.Text = ""
         txtPwrOutput.SetFocus
        Exit Sub
    End If

If optCCPP.Value Then
        CalcCCPP CDbl(txtPwrOutput), CInt(txtNoOfGT)
    Else
        CalcISCCS CDbl(txtPwrOutput), CInt(txtNoOfGT)
    End If

End Sub

Sub CalcCCPP(dblWpp As Double, intNoOfGT As Integer)
    intMair = 495
    intTo = 572
    intTd = intTo - 111
    dblCpgas = 1.836
    dblNgt = 0.33
    dblMhp = 61.7 * 1000
    dblMlp = 13.9 * 1000
    intCphp = 670
    intCplp = 570

    dblW2 = (((dblMhp + dblMlp) * intCplp) + (dblMhp * intCphp)) * intNoOfGT
    dblw1 = (dblWpp * 10 ^ 6) - dblW2
    dblq1 = dblw1 / dblNgt
    dblGas = (dblq1 / (dblCpgas * intTd * intNoOfGT * 1000)) - intMair
    dblCost = dblGas * intNoOfGT * 3600 * 0.635
    dblEff = (dblw1 + dblW2) / dblq1

    txtGas.Text = CStr(FormatNumber((dblGas) * intNoOfGT, 3))
```

```
    txtEff.Text = CStr(FormatNumber((dblEff * 100), 3))
    txtCost.Text = CStr(FormatNumber((dblCost), 2))
    txtW1.Text = CStr(FormatNumber(dblw1 / (10 ^ 6), 3))
    txtW2.Text = CStr(FormatNumber(dblW2 / (10 ^ 6), 3))
End Sub

Sub CalcISCCS(dblWpp As Double, intNoOfGT As Integer)
    Dim dblDo As Double
    Dim dblDi As Double
    Dim dblDci As Double
    Dim dblDco As Double
    Dim dblW As Double
    Dim dblP As Double
    Dim dblY As Double
    Dim dblTab As Double
    Dim dblPrair As Double
    Dim dblKair As Double
    Dim dblPw As Double
    Dim dblVw As Double
    Dim dblKw As Double
    Dim dblPrw As Double
    Dim dblEp As Double
    Dim dblEc As Double
    Dim dblQ As Double
    Dim dblVair As Double
    Dim dblReair As Double
    Dim dblCln As Double
    Dim dblN As Double
    Dim dblNuair As Double
    Dim dblHwair As Double
    Dim dblM As Double
    Dim dblVew As Double
    Dim dblRew As Double
    Dim dblNuw As Double
    Dim dblHf As Double
    Dim dblULR As Double
    Dim dblTc As Double
    Dim dblT1 As Double
    Dim dblT2 As Double
    Dim dblT3 As Double
    Dim dblT4 As Double
    Dim dblT5 As Double
    Dim dblC1 As Double
    Dim dblC2 As Double
    Dim dblC3 As Double
    Dim dblPi As Double
    Dim dblFRE As Double
    Dim dblFR As Double
    Dim dblAeff As Double
    Dim dblS As Double
    Dim dblC As Double
    Dim dblQR As Double
    Dim dblTfo As Double
    Dim dblTfo_celcius As Double
    Dim dblMlp As Double
```

```
Dim dblVewlp As Double
Dim dblRewlp As Double
Dim dblNuwlp As Double
Dim dblHflp As Double
Dim dblFRElp As Double
Dim dblFRlp As Double
Dim dblSlp As Double
Dim dblClp As Double
Dim dblQRlp As Double
Dim dblTfolp As Double
Dim dblTfo_celciuslp As Double
Dim dblThp As Double
Dim dblTlp As Double
Dim dblAefflp As Double

Dim dblChp As Double

Dim dblCphpst As Double
Dim dblCplpst As Double

Dim intCpw As Integer
Dim intL As Integer
Dim intTa As Integer
Dim intTfi As Integer
Dim intTfm As Integer
Dim intTrm As Integer
Dim intVeair As Integer
Dim intTfilp As Integer
Dim intIb As Integer

dblDo = 0.07
dblDi = 0.059
dblDci = 0.118
dblDco = 0.129

intTrm = 443
intTa = 30 + 273
intTfm = 423
dblW = 5.7
intL = 99

intIb = 800
dblP = 0.95
dblY = 0.96
dblTab = 0.96
intVeair = 3
dblVair = 16 * (10 ^ (-6))
dblPrair = 0.701
dblKair = 0.0267
dblPw = 863
intCpw = 2298
dblVw = 0.158 * (10 ^ (-6))
dblKw = 0.663
dblPrw = 0.93
dblEp = 0.95
dblEc = 0.88
```

```
dblQ = 5.67 * (10 ^ (-8))

dblReair = (intVeair * dblDco) / dblVair

If dblReair > 400 And dblReair < 4000 Then
  dblCln = 0.165
  dblN = 0.466
  dblNuair = dblCln * (dblReair ^ dblN)
  ElseIf dblReair > 4000 And dblReair < 40000 Then
    dblCln = 0.174
    dblN = 0.618
    dblNuair = dblCln * (dblReair ^ dblN)
    ElseIf dblReair > 40000 And dblReair < 400000 Then
    dblCln = 0.239
    dblN = 0.805
    dblNuair = dblCln * (dblReair ^ dblN)
  End If

dblHwair = (dblNuair * 0.0267) / dblDco

dblTc = intTa + (((0.04075 * ((dblDo / dblDci) ^ 0.4)) * (dblHwair ^ (-0.67)) * (2 - (3 * dblEp) + (((6 + (9 * dblEp)) * intTrm) / 100))) * (intTrm - intTa))

dblT1 = intTrm - dblTc
dblT2 = intTrm + dblTc
dblT3 = (intTrm ^ 2) + (dblTc ^ 2)
dblT4 = dblTc + intTa
dblT5 = (dblTc ^ 2) + (intTa ^ 2)

dblC1 = 17.74 / ((dblT2 ^ 0.4) * (dblDo * ((dblDo ^ (-0.75)) + (dblDci ^ (-0.75)))))
dblC2 = (1 / dblEp) + (dblDo / dblDci) * ((1 / dblEc) - 1)
dblC3 = dblHwair + (dblQ * dblEc * dblT4 * dblT5)

dblULR = ((1 / ((dblC1 * (dblT1 ^ 0.25)) + ((dblQ * dblT2 * dblT3) / dblC2))) + ((dblDo / dblDco) * (1 / dblC3))) ^ (-1)

'HP
intTfi = 150 + 273
dblM = 0.75
dblPi = 3.14159

dblVew = dblM / (dblPi * (dblDi ^ 2) * dblPw)
dblRew = (dblVew * dblDi) / dblVw

If dblRew > 200 Then
  dblNuw = 0.023 * (dblRew ^ 0.8) * (dblPrw ^ 0.4)
Else
  dblNuw = 3.66
End If

dblHf = (dblNuw * dblKw) / dblDi
dblFRE = 1 / (dblULR * ((1 / dblULR) + (dblDo / (dblDi * dblHf))))
dblFR = ((dblM * intCpw) / (dblPi * dblDo * intL * dblULR)) * (1 - Exp(-((dblFRE * dblPi * dblDo * intL * dblULR) / (dblM * intCpw))))
dblAeff = (dblW - dblDo) * intL
dblS = intIb * dblP * dblY * dblTab
```

```
dblC = (dblW - dblDo) / (dblPi * dblDo)
dblQR = dblFR * dblAeff * (dblS - ((dblULR / dblC) * (intTfi - intTa)))
dblTfo = (dblQR / (dblM * intCpw)) + intTfi
dblTfo_celcius = dblTfo - 273

'LP
intTfilp = 70 + 273
dblMlp = 0.8
dblPi = 3.14159

dblVewlp = dblMlp / (dblPi * (dblDi ^ 2) * dblPw)
dblRewlp = (dblVewlp * dblDi) / dblVw

If dblRewlp > 200 Then
  dblNuwlp = 0.023 * (dblRewlp ^ 0.8) * (dblPrw ^ 0.4)
Else
  dblNuwlp = 3.66
End If

dblHflp = (dblNuwlp * dblKw) / dblDi
dblFRElp = 1 / (dblULR * ((1 / dblULR) + (dblDo / (dblDi * dblHflp))))
dblFRlp = ((dblMlp * intCpw) / (dblPi * dblDo * intL * dblULR)) * (1 - Exp(-((dblFRElp * dblPi * dblDo *
intL * dblULR) / (dblMlp * intCpw))))
dblAefflp = (dblW - dblDo) * intL
dblSlp = intIb * dblP * dblY * dblTab
dblClp = (dblW - dblDo) / (dblPi * dblDo)
dblQRlp = dblFRlp * dblAefflp * (dblSlp - ((dblULR / dblClp) * (intTfilp - intTa)))
dblTfolp = (dblQRlp / (dblMlp * intCpw)) + intTfilp
dblTfo_celciuslp = dblTfolp - 273

intMair = 495
intTo = 572
intTd = intTo - 111
dblCpgas = 1.836
dblNgt = 0.33
dblMhp = 61.7 * 1000
dblMlp = 13.9 * 1000
intCphp = 670
intCplp = 570

dblThp = dblTfo_celcius * 1.819
dblTlp = dblTfo_celciuslp * 1.162

dblChp = (-7 * (10 ^ (-6)) * dblThp ^ 4) + (0.0202 * dblThp ^ 3) - (21.083 * dblThp ^ 2) + (12118 * dblThp)
+ (515802)
dblClp = (0.0023 * dblTlp ^ 3) - (3.5249 * dblTlp ^ 2) + (4074 * dblTlp) + (2 * (10 ^ 6))

dblCphpst = (dblChp - 2.758 * (10 ^ 6)) / 1000
dblCplpst = (dblClp - 2.275 * (10 ^ 6)) / 1000

dblW2 = (((dblMhp + dblMlp) * dblCplpst) + (dblMhp * dblCphpst)) * intNoOfGT
dblw1 = (dblWpp * (10 ^ 6)) - dblW2
dblq1 = dblw1 / dblNgt
dblGas = (dblq1 / (dblCpgas * intTd * intNoOfGT * 1000)) - intMair
dblCost = dblGas * intNoOfGT * 3600 * 0.635
dblEff = (dblw1 + dblW2) / dblq1
```

```
 txtGas.Text = CStr(FormatNumber((dblGas) * intNoOfGT, 3))
 txtEff.Text = CStr(FormatNumber((dblEff * 100), 3))
 txtCost.Text = CStr(FormatNumber((dblCost), 2))
 txtW1.Text = CStr(FormatNumber(dblw1 / (10 ^ 6), 3))
 txtW2.Text = CStr(FormatNumber(dblW2 / (10 ^ 6), 3))

End Sub

Private Sub btnReset_Click()
 txtEff.Text = ""
 txtGas.Text = ""
 txtNoOfGT.Text = ""
 txtPwrOutput.Text = ""
 txtCost.Text = ""
 txtW1.Text = ""
 txtW2.Text = ""
 optCCPP.Value = False
 optISCCS.Value = False
 chkCCPP.Value = 0
 chkSolar.Value = 0

End Sub

Private Sub cmdGoToGraph_Click()
frmGraph.Show
End Sub

Private Sub Form_load()
optCCPP.Value = False
optISCCS.Value = False

End Sub

Private Sub Label12_Click()

End Sub

Private Sub optCCPP_Click()
chkCCPP.Value = 1
chkSolar.Value = 0
lblTitle.Caption = "COMBINED CYCLE POWER PLANT"

End Sub

Private Sub optISCCS_Click()
chkCCPP.Value = 1
chkSolar.Value = 1
lblTitle.Caption = "INTEGRATED SOLAR COMBINED CYCLE SYSTEM"
End Sub
```