A STUDY OF ALTERNATIVE ENERGY OPTIONS TO MINIMISE HOME LOAD IN COAL POWER PLANTS

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Dissertation submitted in partial fulfillment of the requirements for the degree Master of Engineering

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DECLARATION

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ABSTRACT

Coal fired power plants are one of the main contributors in power generation in the world and it is nearly 40% of global power generation. When considering power generation in Sri Lanka, Puttalam Coal Power Plant is the largest and one and only coal fired power plant. Presently 900 MW is produced by three units of this power plant.

Coal fired power plants consume a considerable amount of energy as the home load. For example, many auxiliary systems such as pumping, cooling, coal handling, compressed air, HVAC and lighting. In the coal fired power plants in Sri Lanka, they account for 90 MW, which results in the supply of only 810 MW to the grid out of the produced 900 MW. The majority of auxiliary systems consist of electric motors as prime movers for pumps, compressors, conveyor belts and coal mills. The electricity generator is coupled with a steam turbine that uses the generated steam in the boilers. This system needs prime movers and that consumes the most amount of electricity, which is generated.

By reducing the home load in an efficient and a strategic manner, the power plant efficiency could be increased and more power can be supplied to the grid. However, the implementation of these changes for a power plant, which has already been constructed and operational, is difficult. Although it is a difficult attempt, it is worthwhile to explore the possibility to implement changes in the existing coal power plants. It could potentially yield positive results and incur savings.

This study has looked into ways to minimise the home load and propose alternative renewable energy options for the coal power plants. The research goes on to develop a method to recommend alternative energy options to address the home load needs of coal power plants. In order to evaluate this method, it has been applied to the Norochcholai power plant and to recommend the most suitable energy option to account for the home load. The results suggest that the developed method provides guidance to practitioners to decide the energy efficiency and renewable energy options to address the home load of coal fired power plants. It is suggested to further develop this method as a computer based software program in the future.

Table of contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

HP	High Pressure
IP	Intermediate Pressure
LP	Low Pressure
HT	High Temperature
LT	Low Temperature
ST	Steam Turbine
TF	Transformer
THA	Thermal Heat Acceptance
TMCR	Turbine Maximum Continuous Rate
BMCR	Boiler Maximum Continuous Rate
CSP	Concentrating Solar Power
BFP	Boiler Feed Pump
EX	Extractions
MPB	Main Power Plock
DCS	Distributed Control System
LHV	Lower Heating Value
NIO	North Indian Ocean
TF	Transformer
WTB	Wind Turbine
PCPP	Puttalam Coal Power Project
EFP	Electric Feed Pump
RE	Reciprocating equipment
CPP	Coal power plant
EES	Engineering Equation Solver

LIST OF APPENDICES

CHAPTER 1 - INTRODUCTION

Electricity power generation is one of most popular and important topic which is being discussed in the present world. When considering the electric power generation, various technologies have been used for it. As examples, hydro power, petroleum based power sources, coal power and nuclear power generation are major techniques related to the electric power generation. In addition, wind power, solar power, tidal wave and geothermal can be seen as minor techniques. Comparatively few advantages and disadvantages can be seen in the use of all these sources. For the selection and successful utilisation of a certain power source, the above mentioned advantages and disadvantages are the main key factors. Therefore in the power generation, cost of a source, availability and extractability of a source are very critical [1].

Among the above major technologies, coal based electric power generation is comparatively a less expensive source to produce power. When compared with hydro power generation, it could be more expensive. Higher number of availability index is inherited to coal than the hydro sources [1]. Coal electric power generation was started in about year 1880 and it has been continuously developed, and also successfully being used until today [2]. It is a strong evidence that shows how far the above factors are applied to coal power generation then to other sources. Therefore, a considerable percentage of world electricity power generation is done, based on coal power plants. It is nearly 40% of global power requirement [3] and it is nearly 985 GW [4]. Therefore whatever the disadvantages are, coal power plants have been utilised adding new technologies and features for a long time. In addition to currently operated coal power plants, large numbers of coal power plants are planned to be installed with new technologies.

The number of operating coal power plants in the present world are about 1220 [4] and over 1200 of plants are planned to be installed [5]. When considering the familiarity of coal electric power generation in Sri Lanka, it is a new experience. The first coal power plant with 300 MW capacity is currently operated at Norochcholai, Puttalam. Another two units with 600 MW total capacity were recently commissioned and grid connected [6]. Meanwhile, an agreement has been signed for a coal power plant with 500 MW capacity at Sampoor, Tricomalee. A new proposal is also being discussed in Sri Lankan power generation sector regarding constructions of two coal power plants in Induruwa area and Hambantota [7]. Based on above facts, the main and strong role of electricity power generation in Sri Lanka as well as in world is done by coal power plants.

Electricity generation in a coal power plant is done based on the theories of thermodynamics and basic arrangement of equipment and operations which are almost similar for every coal power plant. Various power consuming equipment and components can be seen in such a power plant. Among these equipment, cranes for coal loading and reclaiming, conveyor belts for coal transferring, crushers for breaking coal into small particles, pulverisers for grinding coal into powder, various pumps for water pumping, different types fans for boiler air and flue gas system as well as compressors for compressed air and chill water system are involved with power generation[8]. These equipment are supportive for steam generation of boiler and power generation of turbine. These are called auxiliary equipment. Electrically driven motors are commonly used as their prime movers.

During the operation, considerable electric power is consumed by auxiliary equipment. This consumed power is called house load or home load. Required home load of the power plant is taken through its generator produced power output. Very rarely this home load requirement is fulfilled by outside power which is generated by another power plant. Therefore there is a great chance to save energy and money by reducing required home load for auxiliary equipment.

Although home load reduction is expected after introducing a new method, modification cost with respect to the expected power gain could be high. Therefore these facts should be studied deeply. To adjust the above idea for the existing coal power plant, identification of practicable alternative solutions and the ways of using mechanisms should be done.

1.1 Background

Electric power is produced by the turbine coupled electric generator based on the thermodynamic theories. This power output is called as plant generated power output. Certain fraction of plant generated power output is used as the home load of the power plant. In 300 MW Norochcholai coal power plant, nearly 30 MW power out of its generated power output is consumed as home load. Although its plant generated power output is 300 MW [8], grid feeding capacity is nearly 270 MW [8]. Large numbers of auxiliary systems and equipment contribute to this 30 MW home load in Norochcholai power plant.

Coal handling system has several unloading cranes, conveyer belts, coal crushers and pulverisers. This system consumes nearly 1.1 MW from home load. Boiler feed water system has several high capacity pumps such as condensate pumps, booster pumps and main boiler feed pump (BFPs). 2.24 MW, 1.2 MW and 9.6 MW power capacities are respectively consumed by these pumps. It nearly consumes 10.8 MW out of 30 MW plant home load [13].

Sea water pre-treatment plant, desalination plant, reverse osmosis plant and chlorination plant are the main water processing plants and a large number of different types of pumps are involved with these plants [8]. Nearly 1.8 MW power is consumed from home load by these auxiliaries [13]. Furthermore, condenser cooling system requires a water flow with 18 m3/s flow rate [8]. The required water flow for condenser cooling is supplied by two axial pumps with 3.2 MW capacity [13]. In the air and flue gas handling system, several forced draft (FD) and induced draft (ID) fans are used. 1.4 2MW and 2.5 MW powers are respectively consumed by FD fans and ID fans in Norochcholai power plant [13]. A large number of compressors which are attached to the compressed air system and chill water systems consume about 1.75 MW auxiliary power from home load [13]. In addition, the large numbers of small auxiliary components contribute to the home load in Norochcholai coal power plant.

1.2 Motivation

The above discussed main auxiliary systems and their processes support to the functions of steam generation through the boiler and the correct operation of the turbine. Therefore all processes are essentially required and can't be omitted. During the generation of 300 MW power, it takes about 30 MW power as home load. It is 10% of plant generated power output. Even though 30 MW is shown as a small figure, its sensitivity is important when compared with the national power production of a developing country like Sri Lanka. If it is taken through the Sri Lankan national grid, that power is equivalent to half the power capacity of Canyon hydro power plant [15] or it is equivalent to power capacity of 5 or 6 mini hydro plants in Sri Lanka or power capacity of a wind farm with 20 wind towers [15]. Based on all the above facts and characteristics of the home load, its influence to grid power supply is proved without any doubt.

Zeroing the home load is impossible, because it is strongly related with main loop of plant power generation. Any attempt to reduce home load in an efficient and strategic manner is very important. For an example, 3% reduction of home load or reducing by 1 MW gives more benefits. If there is a way to operate the above auxiliary equipment by using alternative power source in a power plant instead of utilising home load through plant generator output, it may minimise the actual home load without interrupting the main loop of power plant. To make it as a valuable motivation, the problem is required to be identified well. It is also necessary to observe the technical and economical aspects of this problem.

1.3 Problem statement

As discussed earlier, home load is catered by the auxiliary power requirement of power plant. The portion of the home load for building lighting and electronic equipment such as computers and displays is very small. Therefore the influence to home load by lighting, computers and displays is negligible. A great portion of the home load is allocated for the main auxiliary systems. A particular auxiliary system could consist of a pump, compressor, fan, crane, conveyor belt, crusher of pulveriser. The common feature of all these auxiliary components is the utilisation of electric motor as its prime mover. This means a great percentage of home load is consumed by electrically driven motors.

When considering the power consumption of auxiliary equipment in a coal power plant, pumps consume a considerable portion of home load. Appling this to the Norochcholai coal power plant, it is nearly 18.5 MW [13]. As a percentage, it is nearly 61.7% of plant house load. See Table 1.1 [13].

Table 1.1 : Home load contribution of auxiliaries in NCPP

Type of equipment	**Total power consumption(MW)**	**As a percentage of home load**
Cranes	0.80	02.67 %
Conveyor belts	1.05	03.50 %
Coal crushers	1.00	03.33 %
Pulverizers	1.35	04.50 %
Pumps	18.50	61.66 %
Fans	4.85	16.17 %
Compressors	1.10	03.67 %

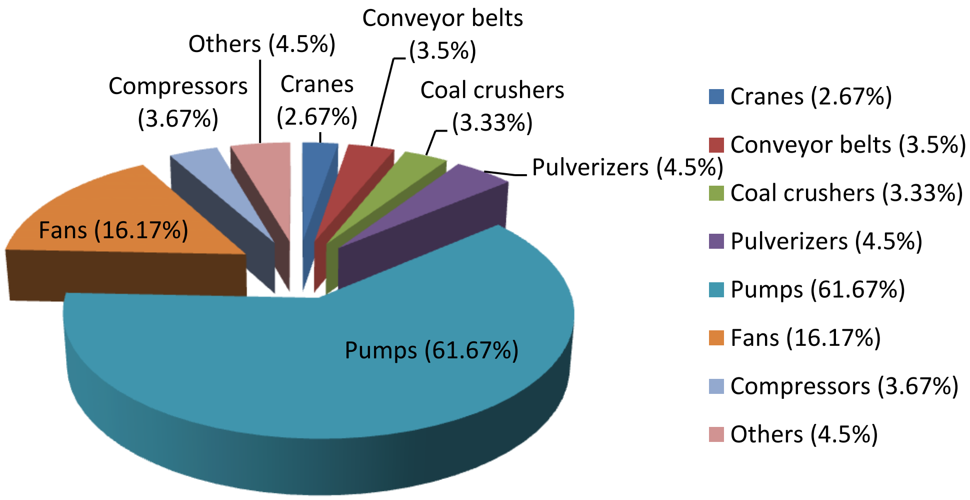


Figure 1.1 : Pie chart for power consumption of auxiliaries in NCPP

Based on the above observations, it is clear that the electric motors of the pumps in auxiliary systems strongly influence to the plant home load.

In considering the power consumption of pumps in a coal power plant, it can be clearly observed that the boiler feed pumps consume massive portion of home load. In applying this to the Norochcholai coal power plant, it is near 9.6 MW [13]. As a percentage, it is nearly 54.87% of load portion of the pumps. also it is nearly 32% of plant house load [13]. See Table 1.2.

Table 1.2 : Home load contribution of pumps in NCPP

Pump	Total power consumption (MW)	As a percentage of load of pumps	As a percentage of home load
Makeup water transfer pump	0.10	00.57 %	00.33 %
Condensate water pumps	0.50	02.86 %	01.67 %
Booster pumps	0.85	04.86 %	02.83 %
Main boiler feed water pumps	9.60	54.86 %	32.00 %
Condenser cooling pumps	2.80	16.0 %	09.33 %
FGD absorber pumps	0.55	03.14 %	01.83 %
Pumps in pre-treatment plant	0.45	02.57 %	01.50 %
Pumps in desalination	0.75	04.29 %	02.50 %
Pumps in RO plant	0.41	02.34 %	01.37 %
Pumps in firefighting system	0.58	03.31 %	01.93 %

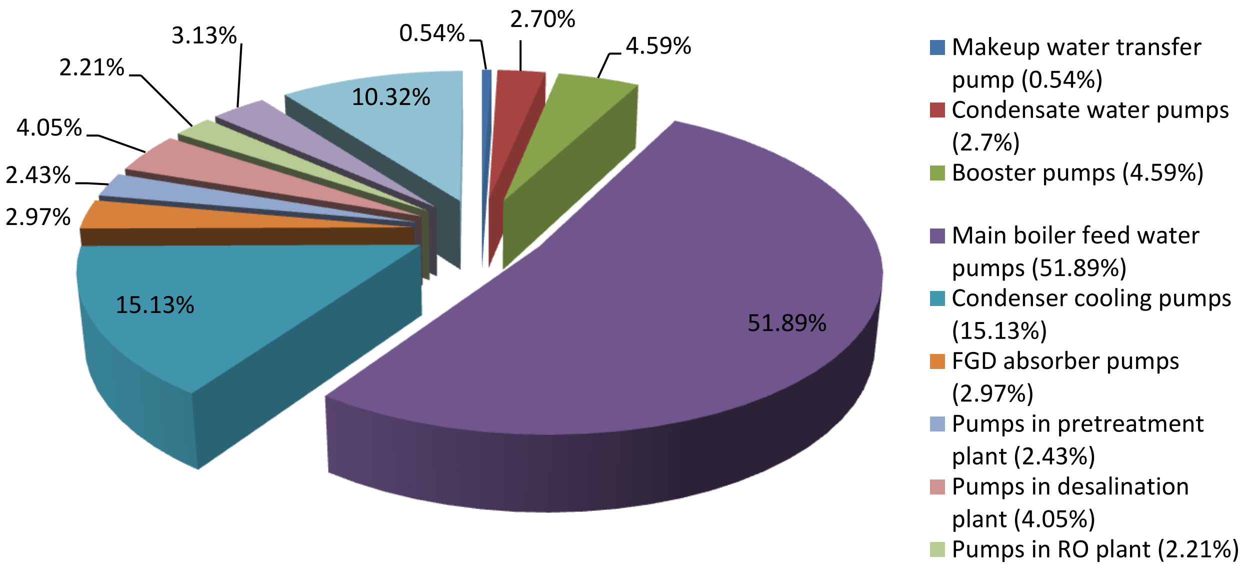


Figure 1.2 : Pie chart for power consumption of pump in NCPP

Based on the above observations, it is very clear that the electric motors of the boiler feed pumps critically influence to the plant home load. Therefore the boiler feed pump is the most important contributor for home load. The criticalness of this contribution is intensified by nature of its operation pattern. In a coal power plant, some pumps are frequently operated. Some of them are used infrequently. When considering the BFPs, they continuously operate over the whole operation time of the power plant. It is clearly proved by the operation patterns of pumps which are summarised in Table 1.3 in applying this to Norochcholai power plant [16]. This continued operation of boiler feed pumps intensifies the influence on plant home load.

Table 1.3 : Pump grading base on influence to home load

Rank	Pump	Power consumption (MW)	Contribution to home load	Operating frequency
01	Main boiler feed water pumps	9.60	32.00 %	Continuously
02	Condenser cooling pumps	2.80	09.33 %	Continuously
03	Booster pumps	0.85	02.83 %	Continuously
04	Pumps in desalination	0.75	02.50 %	Intermittently
05	Pumps in firefighting system	0.58	01.93 %	Continuously

1.4 Aim and objectives

- Aim of the research

A great portion of home load in a coal power plant is consumed by boiler feed pumps. It is a key player of the home load. When introducing an alternative solution to minimise the home load, boiler feed pumps are the most important equipment which takes priority. Also it is very difficult to introduce an alternative solution to the existing coal power plant, because the plant has been constructed and is being operated.

Also the aim is to develop a method to introduce site available alternative energy options for boiler feed pumps to minimise home load in coal power plants

- Key objectives of the research

1. Identify the most popular alternative energy option applicable to coal power plants.

2. Develop a method to introduce most feasible alternative energy option for boiler feed pumps instead of the existing electric motor which is critically contributed to plant home load.
3. Evaluate the developed method applicable to the Norochcholai coal power plant

- Other objectives

1. Identify the alternative power sources related to the coal power plants
2. Identify the ways which can be used to estimate availability and power potential of alternative power source.
3. Study the power extraction ways and transferring techniques related to the alternative power sources in coal power plants.
4. Study the losses, advantages and disadvantages when transferring power applicable to alternative power sources in coal power plant
5. Identify the steps which are used to estimate the cost of implementing for alternative power source.

1.5 Outcomes

1. To develop a method to introduce site available alternative energy options for boiler feed pumps instead of its electric motor .
2. To decide on the most suitable alternative energy option applicable to the Norochcholai coal power plant. .
3. To evaluate the method applicable to the alternative energy sources in Norochcholai coal power plant.
4. To estimate the power gain in Norochcholai coal power plant after introducing suitable alternatives.
5. To calculate the annual power saving, annual financial serving, annual coal serving and payback period after applying method to Norochcholai coal power plant.
6. To estimate the coal saving for future

1.6 Methodology

The method to study the relevant information related to the coal power plants and their alternative energy options, and to carry out a comprehensive literature review. Based on the extracted information through the literature review, a common method is developed to introduce most feasible alternative energy option for boiler feed pumps in coal power plants. The developed method is evaluated by studying cases for the selected few existing coal power plants. Through the case studies, results of method are justified. Outcomes are obtained based on above justifications.

1.7 Introduction to chapters

The first chapter of this study describes the power generation of coal power plants and related home load. The main contributors and key contributor are also highlighted. Alternative energy options and required feasibility factors when introducing are discussed in chapter two. The ability to implement each of the alternatives is checked with information found in various research papers and publications. Chapter three develops a specific method to introduce the most feasible alternative energy option for coal power plants. Developed method in chapter three is evaluated in chapter four using case study related to the Norochcholai coal power plant. The specific results which is obtained through case study is generalised in chapter five. The results of the study are discussed in chapter six and the last chapter is dedicated to present the conclusion about the findings of this study and the recommendations.

CHAPTER 2 - LITERATURE REVIEW

In order to study alternative energy options to minimise home load in coal power plants first and foremost coal fired power generation and characteristics of home load need to be reviewed. Then the method which can be used for their implementation must be studied. For this, many cases are required to be studied by using various sources such as research articles, technical papers, journals and books, although these cases may not be fully applicable to the coal power plants. However some points and information could be extracted by referring to these sources. In addition, the concepts and factors appropriate to coal power plants can be observed by studying other similar cases. The observed factors from these studies are needed to be reviewed in depth. He main points then must be divided in to sub items and they should be discussed with relevance to the topic. Following this procedure will be the entrance to study the minimising losses of home load related the boiler feed pumps in coal power plants.

2.1 Coal fired power generation and home load

Electricity power generation is one of most popular and important topic which is being discussed in the present world. When considering the electric power generation, various technologies have been used for it. In addition to the main equipment, large numbers of auxiliary systems can be seen in a coal power plant. Major auxiliary systems in a coal fired power plant are as below [69].

i. Coal handling system
ii. Boiler feed water system
iii. Raw water processing and condenser cooling system
iv. Flue gas handling and treatment system
v. Compressed air and chill water system

To operate these auxiliary equipment in the power plant, considerable electric power is consumed by relevant motors. This consumed power is called house load or home load. This home load for a particular coal fired power plant is taken as its generator produced power output or as generated power by another power plant [18]. During the generation of the above power, several losses are occurred. For example, if this home load is taken through steam power plant, mechanical losses due to energy conservation in turbine, losses in generator, losses during the power distribution due to transformers and conductors could be seen. Therefore there is a great chance to save energy and money by reducing home load with alternative energy options in the power plant. On an average, the home load of a coal fired power plant is nearly 10% of plant generated power output [10]. If there is a possibility to minimise the home load by at least 1%, considerable power and money can be saved in a coal power plant.

Introducing a solution for a new power plant which has not been constructed is a little easier than introducing it for the existing power plant. When introducing a solution to the existing power plant, many design aspects of the power plant have to be considered. In order to apply the above idea for the existing coal power plants, identification of practicable alternative energy options and the method of using it must be reviewed.

2.2 Design modification aspects

Reviewing the design modification aspects is very important in such a study. Although it may not be exactly similar to this case, several studies have been done in different industries to achieve similar objectives. According to several studies which have been published in many articles, it is imperative that observation and identification of all the alternative energy sources applicable to the location must be taken into consideration before implementing them [86, 87]. Sometimes, observation on alternative energy sources is done separately in the first stage. Then identification of practicable alternatives is done in the second stage [86]. In some cases, both observations and identifications on alternative sources are done in the same stage [87]. In addition to the two aspects, it is required to notify the main alternatives which are involved with the considered site. When compared with the first two aspects, this is not an imperative requirement. Sometimes it will be automatically notified, based on the levels which are going to be observed and identified as alternative sources [86, 87]. The aspect of level of design modification on existing structures is decided by selected alternative power source and its power transferring easiness [88].

When implementing alternative energy sources for existing systems in an industry, required design modification on existing structures is another important aspect [88]. The availability of the alternative sources applicable to the considered industry and its time of operation are critical aspects of design modifications [88]. Further it is highlighted to check the cost involvement when implementing the alternatives, because this aspect will decide the economic feasibility of the implementation [88]. These economic aspects are checked in the last stages [86, 88]. Additionally the availability of alternatives and the implementation cost for each alternative should be separately analysed [88].

There are different opinions on the level of design modifications and the cost of implementations. In addition to the above mentioned design modification aspects, match the site available power potential and the required potential when substituting the existing requirements of the industry [87, 88].

Although the above discussed design modification aspects are not fully matched with the situation of coal power plant, the used methods and concepts which have been expressed to select aspects can be applied to coal power generation industry with appropriate changes. Based on the above concepts, the following design modification aspects have to be studied in depth.

1. Identify all alternative energy option and the most popular alternatives applicable to coal power plants [86, 88].
2. Availability of alternative power source applicable to coal power plants [86, 88].
3. Required level of design changes on the existing power plant [86, 87].
4. Power transferring easiness of each alternative power sources, because level of design modification is governed by power transferring easiness of the alternative source [87, 88].
5. Power potential of alternative sources applicable to the power plant [86, 87, 88].

6. Power extraction method, transferring techniques and their losses related to the alternative power source [88].
7. Implementation cost related to the each alternative power source in power plant [86, 88].

2.3 Alternative power sources

There are two types of alternative power sources which are associated with coal power plants in the world. The alternative power sources are dependent on design parameters of the power plant and geographical location of the plant. Among these types, in-plant alternative sources are decided by design parameters of the power plant. Renewable alternative sources are decided by geographical localisation of the power plant [70].

2.3.1 In-plant alternative power sources

Several in-plant alternative energy options which are associated with thermal power plant have been listed in technical papers [71, 72]. Based on the review of the above articles, in-plant alternative power sources in thermal power plants can be listed as follows.

i. Mechanical power sources
ii. Superheated steam sources
iii. Chemical power sources

2.3.2 Renewable alternative power sources

Many number of renewable energy sources are commonly associated with thermal power plants including coal power plants [73, 74]. These renewable alternative power sources which are associated with power plants are listed below.

i. Wind power
ii. Solar power
iii. Geothermal energy
iv. Hydroelectric power
v. Hydrokinetic power (Sea wave/Tidal)

2.3.3 Main alternative sources in selected coal power plants

Mechanical power and steam sources are the most commonly available in-plant alternative sources in coal power plants. In addition to the above in-plant alternative power sources, wind power, solar power and sea wave energy are the most commonly available renewable alternatives applicable to the thermal power plants [75].

When studying the background of Norochcholai coal power plant in Sri Lanka, Qingshan coal power plant complex in China, Paiton coal power station in Indonesia, Kendal coal power Station in South Africa and Kahalgaon super thermal power station in India, the popularity of available alternatives can be checked. The study of the background of the above power plants is useful to confirm the previously expressed opinions.

Table 2.1 : Summary of main alternatives in some selected CPPs

Power station	In-plant alternatives		Renewable alternatives		
	Mech. power	Steam	Wind	Sea wave	Solar
Norochcholai coal power plant[16]	✓	✓	✓	✓	✓
Qingshan coal power complex[37]	✓	✓	X	X	✓
Paiton coal power station[77]	✓	✓	✓	✓	✓
Kendal coal power Station[78]	✓	✓	✓	X	X
Kahalgaon thermal power station[79]	✓	✓	✓	X	✓

Norochcholai power plant and Qingshan coal power complex have been constructed according to the design of Harbin Turbine Company (HTC) in China [16]. The design of the Paiton coal power station was done by Siemens in Germany [77]. Kendal coal power Station is represented by the designs and technology of Alstom Company in United Kingdom [78]. Kahalgaon thermal power station has been constructed on the designs of Shanghai Power Company in China [79]. These coal power plants are located in different geographical regions. According to reviewed information in Table 2.1 and the expressed opinions in journal of PowerGen Africa-2015, mechanical power and steam source are almost applicable with all coal power plants as in-plant alternative power sources. Among the renewable alternative sources, wind energy, solar energy and sea wave energy are dominant.

2.4 Observations on main alternative sources

As discussed in section 2.3, five main alternative energy sources can be commonly listed. For the successful study of these alternatives, it needs to observe separately their various features such as origination of the source, the available number of sources and common usage of the source applicable to the coal power plants [86].

2.4.1 Mechanical power sources

A few mechanical power sources can be identified in all coal power plants which are operated worldwide. In such a power plant, mechanical power sources are used to rotate the main generator shaft. When considering a coal power plant, the required mechanical power is produced as a result of expansion of steam which is generated by boiler in high pressure and high temperature condition through a steam turbine. This mechanical power is transferred to the main generator and very rarely a small fraction of this power is used to operate an auxiliary generator [72]. When designing a boiler or a steam turbine in a coal power plant, gross power output of a main generator is focused. In addition, the equivalent steam capacity for mechanical torque power of turbine or steam generation capacity in boiler is always higher than the equivalent steam capacity at the requirement of the generator rated output. When Norochcholai coal power plant in Sri Lanka is taken as an example, the required turbine mechanical torque power and boiler steam generation for 300 MW rated power and the maximum ability of producing mechanical torque power in the turbine and boiler steam capacities are shown in Table 2.2 [16].

Table 2.2 : Equivalent torque capacity of the 300 MW NCPP

Designed capacity	Boiler stem generation (T/hrs)	Turbine mechanical torque power (kNm)
@ Rated power	964	1000
@ BMCR	1025	1065

By referring to the data in Table 2.2, a special point can be clearly observed. Some considerable excessive mechanical power is available in a coal power plant and this excessive power can be used as prime mover. This alternative power source is not dependent on geographical location of the power plant [72].

2.4.2 Super-heated steam source

When considering the steam generation in a coal power plant, it is done in the boiler by transferring heat energy which is obtained due to combustion of coal. To increase the energy which is carried by steam entering the turbine and prevent cavitation on the turbine blades due to water droplets of steam, boiler generated steam is required to be super-heated [16]. For that saturated steam is circulated through super heater tube panel of the boiler prior to entering into turbine. Purity and the temperature of steam entering the turbine are increased by above process. Maximum steam generation capacity of the boiler is higher than the equivalent steam generation for plant rated power output [16]. This situation is common for all coal power plants. For example, generated steam flow rates in boiler and flow rates of the turbine entering steam in 300 MW Norochcholai coal power plant are shown in Table 2.3 [16].

There are some particular reasons to produce excessive steam in such a coal power plant. As mentioned earlier, to increase the efficiency of thermal cycle it needs to heat up the feeding water up to certain temperature before entering boiler. This process is called re-generation stage of boiler feed water [16]. For doing re-generation process, boiler feed water is circulated through several heat exchangers which are at different temperature and pressure. One purpose of the above mentioned excessive steam is utilisation as heating source of these heat exchangers. In addition, many steam requirements can be seen in a coal power plant for auxiliary purposes [13]. Although this auxiliary steam component is taken through an auxiliary boiler in the start-up time, during plant normal operation it is taken as a fraction of the boiler excessive steam. Boiler soot blowing and coal mill firefighting are major usages of auxiliary component. In some specially designed power plants, boiler supplies huge excessive steam quantity to other industries which are located outside the power plant. For example, several boilers of Qingshan coal power plant in China supply steam for nearby steal manufacturing factory [37]. When considering the above facts, most of the coal power plants in the world generate considerable excessive steam quantity through the boiler than the requirement of turbine rated steam flow capacity. This excessive steam quantity of a boiler varies from 10% to 20% due to power plant design requirement [16]. Therefore the above mentioned ability of generating excessive super-heated steam in boilers can be seen as an available power source in a coal power plant. This power source does not depend on geographical location of the power plant.

Table 2.3 : Stem flow conditions in boiler and turbine - NCPP

Operation condition	Boiler stem generation (T/hrs)	Steam flow rate through turbine (T/hrs)
THA*	911.69	845.6
TMCR**	964	893
BMCR***	1025	947

* Thermal Heat acceptance

** Turbine Maximum Continuous Rate

*** Boiler Maximum Continuous Rate

2.4.3 Wind power sources

Wind power sources are different from mechanical power sources and super-heated power sources around a coal power plant. It is directly governed by geographical location of the power plant. For example, wind potential around a power plant depends on its environment. Although excellent wind potential can be seen around a power plant which is located inshore with good wind pattern, the same wind potential cannot be expected around off shore power plants because it is disturbed by forests, buildings and mountains. Further, the yearly time length of wind season is another critical factor for wind potential. Many of the inshore coal power plants such as Norochcholai, Sri Lanka have grate wind potential. Estimated potential of wind in Norochcholai area is in between 500-600 W/m2 [38]. Therefore, when considering alternative power sources around a coal power plant, significant involvement may be given by wind power sources.

2.4.4 Sea waves power sources

This alternative power source also depends on geographical location of the power plant. Although it does not have the ability to use this power source in offshore power plant, there can be great opportunity to use sea waves as alternative power source in power plant which is located onshore. Even though it is not attached with onshore coal power plants, there are several wave power plants and generate electric power by using sea waves. 22.5 MW Energias station in Portugal and Oregon wave power farm in Canada are good examples of this [39]. However this power potential is mainly governed by some factors such as depth of the shore, nature of the waves and annual seasonal conditions. Estimated sea wave power potential in shores near some coal power plants which have been proposed and constructed in Sri Lanka are shown in Table 2.4 [40, 54].

Table 2.4 : Potential of sea wave around coal power plants in Sri Lanka

Power plant	Depth of sea (m)	Power potential (kW/m)	Status
Norochcholai coal power plant	8-12	20	Constructed
Sampoor coal power project	24-28	24	Proposed
Southern coal power project-Mawella	15-18	22	Proposed

2.4.5 Solar energy

This alternative power source is not dependent on the location whether it is in onshore or offshore. It is firmly linked with power plant position on the Earth [41]. Even though it is not jointly operated with a coal power plant, there are several solar energy power plants in the world. 1 MW Feranova CSP Plant in Turkey and 2 MW Keahole Solar Power station in USA are good examples of this [44]. The estimated solar power densities around some coal power plants which have been proposed and constructed in Sri Lanka are shown in Table 2.5 [43].

Table 2.5 : Density of solar energy around coal power plants in Sri Lanka

Power plant	Power density $(kWhm^{-2}/day)$	Status
Norochcholai coal power plant- Puttalam	5-5.5	Constructed
Sampoor coal power project – Tricomalee	5-5.5	Proposed
Southern coal power project- Mawella	4.5-5	Proposed

Estimated solar energy power densities around some coal power plants which are being operated in the world are noted in Table 2.6.

Table 2.6 : Density of solar energy around coal power plants in world context

Power plant	**Power density** [48] $(\boldsymbol{kWhm^{-2}}/\boldsymbol{day})$	**X, Y** [37]
Amravati Thermal Power Station, India [37]	5-5.5	21°01′21″N,77°49′25″E
Beijiang Power Station, China [37]	4-4.5	39°13′08″N,117°55′50″E
Kendal Power Station, South Africa [37]	5.25-5.75	26°05′24″S,28°58′17″E

2.5 Availability of alternative power sources

In attempting to energise the boiler feed pumps by using alternative energy option applicable to the power plant, some of them are common for all power plants and some alternatives are unique for considered power plants. Therefore it needs to individually observe their feasibility to use them as an alternative.

2.5.1 Availability of mechanical power sources

Mechanical power sources are one of the common alternative options which can be seen in any power plant in the world. Some parameters such as capacity of the source and availability of the source differ from plant to plant [16]. This mechanical power source in a power plant can be seen as the output torque of turbine shaft. These turbine systems are operated with some excessive mechanical power. Hence the ability of mechanical power extraction over full time of the turbine operation, availability of the power source is very high. The extractable power capacity is decided by design parameters of the power plant [16].

2.5.2 Availability of super-heated steam sources

Super-heated steam sources are another most common energy source which can be seen in all steam power plants including coal power plants. When considering the coal power plants, two types of superheated steam sources are involved [16].

i. Super-heated steam through start-up boiler
ii. Super-heated steam generation through main boiler

In a steam power plant, the leading steam production is done by main boiler for the purpose of electricity generation. In addition, one or two start-up boilers are used to fulfil unit start-up requirements [13]. Critical auxiliary steam requirements such as bottom heating of main boiler and de-aerator heating at initial start-up stage are accomplished by start-up boiler. After achieving stability of main boiler with certain steam flow rate, start-up boiler is shut down and requirements of auxiliary steam are shared by a fraction of main-steam. The auxiliary steam requirement is of a very small quantity, when compared with the main steam generation [13].

During the process of super-heated steam generation in main boiler, respectively feed water circulated through the economiser panels and the evaporative water walls. Finally it goes through the super heater panels. Conditioned super-heated steam enters into the high pressure turbine. Expanded steam through the HP turbine is called cold-reheated steam. Cold-reheated steam returns to boiler for further heat addition. This process is called as reheating part of the thermal cycle which increases the temperature and keeps the steam quality as recommended by the designer [16]. After energy addition in the boiler, it is called hot-reheated steam. Hot-reheated steam again enters into intermediate pressure turbine. Expanded steam through IP turbine enters into the one or two low pressure turbines. During the above process of super-heated steam generation and circulation through turbines, two main sources can be identified to extract excessive superheated steam [16].

i. Through the outlet of start-up auxiliary boiler
ii. Tapping through the extractions of regenerative heat exchangers

When considering the extracted steam through the first source point, its availability is very low, because this steam source is available only during unit starting time. The availability of second sources is of a comparatively high capacity, because once the boiler system is stabilised after the unit start-up, all tapping points are ready at any time to extract steam. In a coal power plant, several stages with various pressure and temperature conditions are involved to accomplish this regeneration part. Source details for steam extraction with reference to the Norochcholai coal power plant are shown in Table 2.7 [8].

Table 2.7 : Tapping points for regenerative heat exchangers for NCPP

Steam Condition	Stage	Heat exchanger	Tapping Source
Low Pressure & Low Temperature	1	# LP 8	Outlet of LP turbine
	2	# LP 7	Outlet of LP turbine
	3	# LP 6	Inlet of LP turbine
	4	# LP 5	Inlet of LP turbine
High Pressure & High Temperature	5	# HP 4	Outlet of IP turbine
	6	# HP 3	Inlet of IP turbine
	7	# HP 2	Cold Re-heater
	8	# HP 1	Inlet of HP turbine

2.5.3 Availability of wind power

This is an alternative energy source that is dependent on geographical location of the plant and its availability is decided by many other parameters. As it is not fully available energy source over one whole year, continuous power supply cannot be guaranteed.

2.5.4 Availability of sea waves

According to the analysis of the wave energy resource at the European Marine Energy Centre, the amount of energy which is extracted through sea wave is decided by height of the waves [40]. The wave height is dependent on the seasonal wind pattern [47]. Therefore the monsoon pattern is a very important factor to calculate the availability of wave energy in a particular area [47].

2.5.5 Availability of solar energy

Power plants which are located near the Equator have good solar energy intensity. The power plants which are far away from the Equator do not have considerable solar energy intensity, because this source is dependent on geographical location of the power plant [48]. Therefore the availability of the source is governed by seasonal patterns [48]. The solar power is only available during day time. When compared with the operation of the power plant, it operates both day and night. This issue is one of major limitations of solar power availability [44].

2.6 Power extraction methods and transferring techniques

Different types of power extraction methods and transferring mechanisms can be seen in present technology. It is very important to study separately their features with relevant to the each of the sources.

2.6.1 Mechanical power extraction methods and transferring techniques

Several power extraction methods and transferring techniques are used to extract and transmit power from such a mechanical power source. These methods are involved in different applications due to various reasons. Among these methods, mainly three ways of mechanical power extraction can be seen in the world power context [80].

i. By coupled directly to driving shaft.

ii. Using gear mechanisms.

iii. Using belt or chain drives.

- Losses in mechanical power extractions and transferring

Direct coupling method is applied for extracting mechanical energy from high speed rotating shaft. Such a turbine rotor in a power plant is rotated at 3000 rpm. When using direct coupling method for high speed rotor, losses are low [80]. Instead of direct coupling method, gear mechanisms can be used to extract power. Formation of high level of noise and temperature on the system is an unavoidable drawback in this method [45]. Huge friction losses are involved with this due to metal to metal contact with gear teeth. Therefore the overall efficiency is considerably low in this method [45, 80]. In addition, belt driver and chain mechanisms are used to extract energy from rotating shaft [80]. Considerable energy losses occur as slip loss and friction loss respectively. Formation of high level of noise and temperature can be observed when using the chain mechanism [45].

- Advantages and disadvantages of mechanical power extractions and transferring

The usage of direct coupling method is economical. According to the technical point of view, there is a possibility to transfer unnecessary vibration from newly attached equipment, because the relevant equipment is directly coupled with the main turbine. According to the installation manual of Harbin Turbine Company in China, the main turbine rotor is statically and dynamically balanced in factory before site installation [81].Therefore the influence of unexpected vibration which is transferred from the newly linked equipment is not good for the main turbine and its life time. Easy maintenance, low level of fallibility and high level of reliability are other advantages.

Gear mechanisms are suitable for low speed rotors [80]. In economical aspect, initial installation cost as well as maintenance cost is comparatively high. Unwanted vibration from newly attached equipment can pass through the gear mechanisms. It needs several auxiliary systems such as lube oil and cooling system [45, 80]. This technique is not good for high speed applications. Even though the fallibility level is comparatively high, the newly attached equipments can be repaired in an emergency situation without shutting down the main steam turbine [45].

The usage of belt or chain drives are a low cost technique and the relevant technology is simple and common. The ability of maintenance is easy and maintenance cost is very low. Due to the using of belt and chain drives, influence of outside vibration to main turbine rotor is low in this technique [80]. However, high level of fallibility and low energy extraction efficiency are some disadvantages of these techniques. It is difficult to maintain constant speed in driven equipment due to belt slipping [45].

Table 2.8 : Summary of limitations for transferring mechanical power

Mechanism	**Based on technical aspects**		**Based on economic aspects**	
	Advantages	**disadvantages**	**Advantages**	**disadvantages**
Direct coupling	• Easy Maintenance • Low losses • Low Fallibility • High reliability	• Unnecessary vibration transferring • Unable to repair with unit operation	• Low initial cost • Low Maintenance cost	
Gear Mechanism	• Low vibration transferring • Ability to repair with unit operation	• Good for low speed • Need auxiliary systems • High losses • High Fallibility		• High initial cost • High Maintenance cost
Belt/Chain Drives	• Simple technology • Commonly use	• High Fallibility • Low energy extraction rate	• Low initial cost • Low Maintenance cost	

2.6.2 Steam extraction methods and transferring techniques

Four types of methods can be seen in the present applications to extract energy from steam source [81].

i. Utilisation of steam turbine
ii. Shell and tube heat exchangers
iii. Mixed bed type heat exchangers
iv. Metal to metal heat exchangers

The steam piping is used with steam turbine to transfer power. Combination of steam and water piping systems are used with the second and third extraction methods. Combination of steam piping and air duct systems are associated with the fourth method [81].

- Losses in steam extraction and transferring

Many different losses occur when using a steam turbine and steam piping. Pipe flow losses, component losses which are formed during the steam traveling from source to turbine, nozzle loss inside the turbine nozzle box and overall mechanical loss across the turbine can be identified as major losses [81].

In addition, many losses are involved when using the method of shell and tube heat exchangers. As usual, pipe and component losses are added during steam extraction from source to heat exchanger. Furthermore certain level of heat energy loss across the shell can happen although heat exchanger is fully insulated. When considering the mixed bed type heat exchanger, all of the above losses which are involved in shell and tube heat exchanger occur [46, 81].

In this method, huge amount of flashed steam is suddenly formed due to super-heated steam in high pressure and temperature directly mixing with water. This flashed steam accumulates in the heat exchanger. Therefore a certain amount of flashed steam is continuously removed in such a situation for safety purposes. Considerable energy loss occurs by removing flashed steam. Some kind of flashed steam recovering systems have been introduced for the present power plants. Therefore the losses due to flashed steam can be reduced up to a certain level [81].

Metal to metal heat exchanger technique is not commonly utilised in coal power plants. High significance level of loss can be seen due to steam losses when using such type heat exchangers with high pressure and high temperature super-heated steam [46, 81].

- Advantages and disadvantages of steam extraction and transferring

Even though the installation procedures of a steam turbine are a little complicated, using technology for turbine installation is well established in the world [46]. Presently, there is an ability to select and buy steam turbines in a wide capacity range as per the requirement. The efficiency of steam turbines is comparatively at a higher range [46]. Also the energy extraction rate is high. Its installation is not easy. During the operation, many operation parameters are needed to be controlled. Repairing and maintaining procedures are not simple. It needs well trained persons to operate and maintain them. Therefore cost for initial installation, operation and maintenance is considerably high [46, 81].

In the second and third methods, operation and maintenance cost is comparatively low although the initial installation cost is high. Few technical limitations can be seen in these methods. Energy extraction rate is comparatively low. Extracted energy by these methods is absorbed by water. Therefore it needs several complicated energy conversion steps to use it as a convenient power source. The overall efficiency goes down when using such complicated energy conversions [81].

When considering the fourth method, it is not a common technique in power plant industry although the metal to metal heat exchangers are applied as a useful way to extract energy from steam. The main advantage of this method is its ability to transfer the extracted energy into water as well as into air. Energy extraction rate and the efficiency are low. Also the installation cost, operation and maintenance cost are high [46, 81].

Table 2.9 : Summary of limitations for transferring steam

Mechanism	Based on technical aspects		Based on economic aspects	
	Advantages	disadvantages	Advantages	disadvantages
Steam Turbine	• established technology • Wide range of Steam turbines • High energy extraction rate	• Complicated maintenance • Need well trained operator		• High initial cost • High Maintenance cost
Shell & Tube Heat Exchanger	• Well established technology • Simple Maintenance • Low Fallibility	• Low energy extraction rate	• Low Maintenance cost	• High initial cost
Mixed bed Heat exchanger	• Well established technology • Simple Maintenance • Low Fallibility	• Low energy extraction rate	• Low Maintenance cost	• High initial cost
Metal to Metal Heat Exchanger	• Can use with water or air • High energy extraction rate	• Difficult to apply very pressure • High Fallibility		• High initial cost • High Maintenance cost

2.6.3 Wind energy extraction methods and transferring techniques

Different types of wind turbines in various capacities are used in wind energy field. Using a combination of mechanical linkages and a pump or using an electric motor are most common ways for transferring energy which is extracted by wind turbines. There are many practicable limitations when extracting energy through this method [82].

- Losses in wind energy extraction and transferring

Losses occur across the wind turbine are dominant. In addition, several sub losses are added when transferring mechanical energy from wind turbine output to equipment. Among the linking techniques which are applied to transfer energy, belt drives form losses due to slip and chain mechanism form friction loss. If the linked equipment is an electric generator, the overall loss through the generator is additionally added into the previously discussed losses [82].

- Advantages and disadvantages of wind energy extractions and transferring

Mechanically linked wind turbine systems are simple and the cost is low [45, 82]. Required maintenance is minimum and easy. The overall efficiency is very low when using mechanical linkages. Therefore, the efficiency can be increased by coupling an electric generator with wind turbine instead of mechanical linkages. Then again the high initial cost is applied due to complexity of generator installation. The level of reliability for the second method is higher than the first method [82].

Table 2.10 : Summary of limitations for transferring wind energy

Mechanism	**Based on technical aspects**		**Based on economic aspects**	
	Advantages	**disadvantages**	**Advantages**	**disadvantages**
With mechanical linkages	• Common technology • Simple technology • Simple maintenance	• High Fallibility • Low energy extraction rate	• Low initial cost • Low Maintenance cost	
With electrical generator	• Well established • Simple Maintenance • Low Fallibility	• Low energy extraction rate	• Low Maintenance cost	• High initial cost

2.6.4 Sea wave energy extraction methods and transferring techniques

Two main ways are used to extract energy which is stored in sea waves [83].

i. Transferring as mechanical energy
ii. Transferring as electrical energy

In the first method, stored kinetic energy in sea wave is converted in to mechanical energy by using various mechanisms such as pendulum system, oscillating column of water system, power Buoy system and Salter's Duck system[47].This mechanical energy is used to operate some reciprocating equipment like piston pumps. Belt or chain drives, long shaft system, rack and pinion mechanisms are used to transfer the mechanical energy to the relevant equipment after extracting from sea waves [83]. In the second method, the kinetic energy of sea waves is converted into mechanical energy in the same way as the first method. Then the converted mechanical energy is used to generate electricity through a generator. By using conductors, this electricity can be distributed to many of the equipment.

- Losses in wave energy extractions and transferring

In all techniques such as pendulum system, oscillating column of water system, power Buoy system and Salter's Duck system to extract sea wave energy, overall efficiency is at a very low level [47]. Huge friction loss is formed due to the involvement of some reciprocating parts such as pendulums, rack and pinions [47].

- Advantages and disadvantages of wave energy extractions and transferring

Wave energy offers renewability and its environmental friendliness. In addition, there are no considerable advantages in every mechanism which is involved in power extraction through sea waves, because the overall efficiency of all mechanisms is at a very low level. Installation and maintenance are quite difficult. Therefore the installation and maintenance cost in such a sea wave based power stations is rather high [47].

2.6.5 Solar energy extraction methods and transferring techniques

Solar power extractions are divided into two categories such as direct solar power extraction and indirect solar power extraction [84]. Using the direct solar power around a power plant is the most convenient way. Furthermore three main strategies to extract direct solar energy are used in solar power industry. The first strategy is the use of flat-plate collectors. It is a combination of arrays of solar panels arranged in a simple plane and commonly used. The second strategy is the use of focusing collectors. It uses flat-plate collectors with optical devices arranged to maximise the radiation falling on the focus of the collector. This methodology is used in a few scattered areas. The third strategy is the use of passive collectors. In this case, it absorbs radiation and converts it into heat naturally [84].

- Losses in solar energy extractions and transferring

Although the potential of solar energy is high, its rate of extraction is considerably very low. During the solar energy extraction by using the above methodologies, energy is wasted due to several factors such as unwanted heat conversion, photon pass through the solar cells and local recombination of newly created holes as well as electrons [48]. It nearly extracts one third of the total solar energy.

- Advantages and disadvantages of solar energy extractions and transferring

There are three main methodologies to extract solar energy. The flat-plate collector technique is of a low cost when compared with the other two techniques. Since these collectors extract energy individually, energy extracting rate is very low. When considering the focusing collector technique, the efficiency and energy extracting rate area little higher than the first method. Comparatively, using of passive collectors is the most efficient technique for extracting solar energy. However some common features such as low efficiency, low reliability, high initial cost, requirements of higher technology with reference to other alternatives can be identified as disadvantages in all techniques. The low operation and maintenance cost and environment friendliness can be seen as advantages of these techniques [48].

2.7 Power transferring easiness and required design changes

When implementing a particular power source as the solution among the others, it needs to be done carefully, because it is going to implement changes on a power plant which has been constructed and is functioning now. Sometimes, it may be necessary to install new components or uninstall the existing components. In addition, laying new power cables, installing steam or water pipe lines and tapping or connecting pipe for existing systems may be expected. In an exceptional situation, it may have to change the civil structures such as construction of basements for new equipment or re-strengthen the basement.

2.7.1 Power transferring easiness

There are three transmission ways to transmit energy from source to the place where the feed pumps are located [66]. If extracted output is electricity, it uses the various power conductors to transmit power. Also various types of mechanical linkages are used if the extracted output is mechanical energy. Steam or water pipes or air ducts are used to transmit energy if the extracted output is thermal energy[81].The requirement of design changes for the existing power plant can be easily identified through the power transmission way, because the required level of design changes are decided by these energy transmission ways. Extraction methods of the alternatives, extracted energy type of the alternatives and their transmission ways are summarised in Table 2.11 for easy reference.

Table 2.11 : Extracted energy outputs and transmission ways

Power source	Extraction method	Type of extracted energy output	Energy transmission ways
Mechanical power source	Direct couplings	Mechanical	mechanical linkage
	Gear mechanisms	Mechanical	mechanical linkage
	Belt and Chain drives	Mechanical	mechanical linkage
Superheated steam sources	Steam turbine	Heat	Steam Pipe
	Shell & tube Heat exchangers	Heat	Steam / water pipe
	Mixed bed heat exchangers	Heat	Steam / water pipe
	Metal to metal heat exchangers	Heat	Steam pipe/ Air duct
Wind energy source	Wind turbine + reciprocating equipments	Mechanical	mechanical linkage
	Wind turbine + electric generator	Electrical	Power conductors
Sea wave energy	All extraction techniques + reciprocating equipments	Mechanical	mechanical linkage
	All extraction techniques + electric generator	Electrical	Power conductors
Solar energy	All extraction methods	Electrical	Power conductors

Among the power transferring techniques, power transmission by using conductors in a power plant is the easiest way. Using steam piping is not easier than using power conductors. It is easier than power transferring by using mechanical linkages. Power transferring with mechanical linkages is very difficult in an existing power plant [85].

2.7.2 Required level of design changes

Although mechanical linkages can be commonly seen in the world, it includes lots of heavy gadgets such as gear mechanisms, belt drives, chain drives and rack and pinion method [80]. When installing these mechanical linkages, they require huge space. Therefore the utilisation of these types of energy transmissions with mechanical linkages requires many changes on the existing design.

Energy transmissions using steam or water pipe lines or air duct is more convenient than the first way. It also may require some changes on structures, existing pipe line with some design calculations [85].

Comparatively few changes on the existing design are required when energy transmission is done by using power conductors. Power cables can be laid underground or over cable tray. These modifications are easier than the installation of mechanical power transmission systems or piping system in a coal power plant which is already constructed [85].

Table 2.12 : Summary of required modifications on existing design

Energy transmission ways	Nature of required modification	Examples for modifications
Using mechanical linkages	Need critical changes	• Need to be removed disturbances (equipment or structural) in between power source and BFP • New basements for equipments • Need protective enclosures for mechanical moving parts
Using steam pipes / water pipes / air ducts	Need moderate changes	• Steam tapping connections are needed to be installed • Need new hangers and supports • Need thermal insulation for ducts
Using power conductors	Need minor changes	• Only new need cable trays of underground trenches

2.8 Implementation cost of alternatives

Though any alternative may be selected as the solution, it needs to check its economic feasibility when analysing the overall feasibility. Therefore it is necessary to get an idea about the cost involvement when each alternative is used as solution. It can be separated into few sub cost components such as the cost for structural and design changes, the cost of new equipment and the installation cost. Based on the above cost separation, it is easy to study the cost involvement when substituting prime mechanism of the existing boiler feed pumps by each alternative. These studies are very important to decide many economical parameters such as initial cost of the project and the payback period.

Table 2.13 : Summary of implementing cost for mechanical energy source

Method of extraction	**Cost for implementation of mechanical energy sources**		
	Structural/Design changing cost	**New equipment cost**	**Installation cost**
Direct couplings	*This method is not possible for existing power plant (see appendix D)	*This method is not possible for existing power plant (see appendix D)	*This method is not possible for existing power plant (see appendix D)
Gear mechanisms	*New basement for Gear mechanism *New basement for mechanical linkages	*Gear mechanism & its auxiliaries *Mechanical linkages *Protection system for mechanical linkages	*Cost for installing gear mechanism, mechanical linkages and their protection system
Belt and Chain drives	*New basement for mechanical linkages	*Mechanical linkages *Protection system for mechanical linkages	*Cost for installing mechanical linkages and their protection system

Table 2.14 : Summary of implementing cost for superheated steam source

Method of extraction	Structural/Design changing cost	New equipment cost	Installation cost
Steam turbine	*New basement for steam turbine	* Steam turbine & its auxiliaries * Steam piping, supports & hangers * Thermal insulations	*Cost for installing steam turbine, piping, supports & hangers, thermal insulation
Shell & tube heat exchangers	*New basement for heat exchanger	* Heat exchanger & its auxiliaries *Steam piping, supports & hangers *Thermal insulations	*Cost for installing heat exchanger, piping, supports & hangers, thermal insulation
Mixed bed heat exchangers	*New basement for Heat exchanger	* Heat exchanger & its auxiliaries *Steam piping, supports & hangers *Thermal insulations	*Cost for installing heat exchanger, piping, supports & hangers, thermal insulation
Metal to metal heat exchangers	*New basement for Heat exchanger	* Heat exchanger & its auxiliaries *Steam piping, supports & hangers *Thermal insulations	*Cost for installing heat exchanger, piping, supports & hangers, thermal insulation

Table 2.15 : Summary of implementing cost for wind energy

Method of extraction	Structural/Design changing cost	New equipment cost	Installation cost
Wind turbine + reciprocating equipments	*New basement for mechanical linkages	*Mechanical linkages *Protection system for mechanical linkages *Cost for wind turbine	*Cost for installing wind turbine, mechanical linkages and their protection system
Wind turbine + electric generator	*New cable trays and cable trenches	*Power cable and auxiliary equipments *Cost for wind turbine	*Cost for wind turbine *Cost for laying cables & installation cost of auxiliary electric equipment.

Table 2.16 : Summary of implementing cost for sea wave energy

Method of extraction	Structural/Design changing cost	New equipment cost	Installation cost
Extraction techniques + reciprocating equipments	*New basement for mechanical linkages	*Mechanical linkages *Protection system for mechanical linkages *Cost for energy extractor	*Cost for installing energy extractor, mechanical linkages and their protection system
Extraction techniques + electric generator	*New cable trays and cable trenches	*Power cable and auxiliary equipments *Cost for energy extractor	*Cost for installing energy extractor, *Cost for laying & installation for cables and auxiliaries

Table 2.17 : Summary of implementing cost for solar energy

Method of extraction	Cost for introducing solar power		
	Structural/Design changing cost	New equipment cost	Installation cost
3 types Solar collectors	*New cable trays and cable trenches	*Power cable and auxiliary equipments *Cost for solar collector	*Cost for installing solar collector *Cost for laying cables & installation cost for auxiliaries

2.9 Summary of the literature review

All possible alternative energy options applicable to coal power plants in the world have been identified in technical papers and engineering news journals. The different types of alternative energy sources are observed by applying them. Among all the possible alternative energy options applicable to the coal power plants, the most popular and commonly available options may be selected by studying the opinions which have been expressed in technical papers, books and engineering news journals. The correctness of the selected common energy options may be checked from the background of the five selected coal power plants where are located with different designs and different geographical regions.

Although it is not hundred percent equal to coal fired power industry similar researches and case studies which have been carried out in different industries in the world can be reviewed. The design modification aspects involved when selecting the most suitable and feasible alternative energy options for coal power generation should be studied. Based on the study, a conceptual framework can be designed and specific method can be developed. In order to compare and analyse the design modification aspects in qualitative and quantitative manner, the data and information gathered from various technical articles such as engineering news journals, text books, previous project proposals, operation and maintenance manuals of the existing power plants and World Wide Web can be used.

CHAPTER 3 - DEVELOPMENT

As discussed in the literature review, a great portion of home load in a coal power plant is consumed by boiler feed pumps [8]. By introducing an alternative power solution for the existing boiler feed pumps in coal power plant which has been already constructed and operated, many positive outcomes can be obtained. For that, a specific method can be developed by considering all relevant background conditions and parameters in the power plant. Based on identification of literature review, two main in-plant power source and three main renewable energy sources are commonly applicable with all coal power plants [71, 72]. These alternative power sources are taken as variable inputs of the method. In addition, power demand of the boiler feed pumps motor is taken as an invariable input.

The availability of the power source, power transferring easiness, required design changes, power potential of the source and implementation costs are determined by relating them to the variable inputs. Equivalent power potential of alternatives to operate BFPs is determined in relation to the power demand of BFP motor. By matching power potential and equivalent power potential of the source, requirement for BFP power satisfaction is checked.

To select key solutions, the analysis is carried out based on following feasibility factors.

i. Availability of the alternative power source
ii. Required level of design changes
iii. Satisfaction of BFP power requirement
iv. Implementation cost of the source

Then the developed method is evaluated by studying as a case for selected coal power plants. Outcomes of the method are obtained through the justification of selected solutions. The framework of the developed method is shown in Figure 3.1.

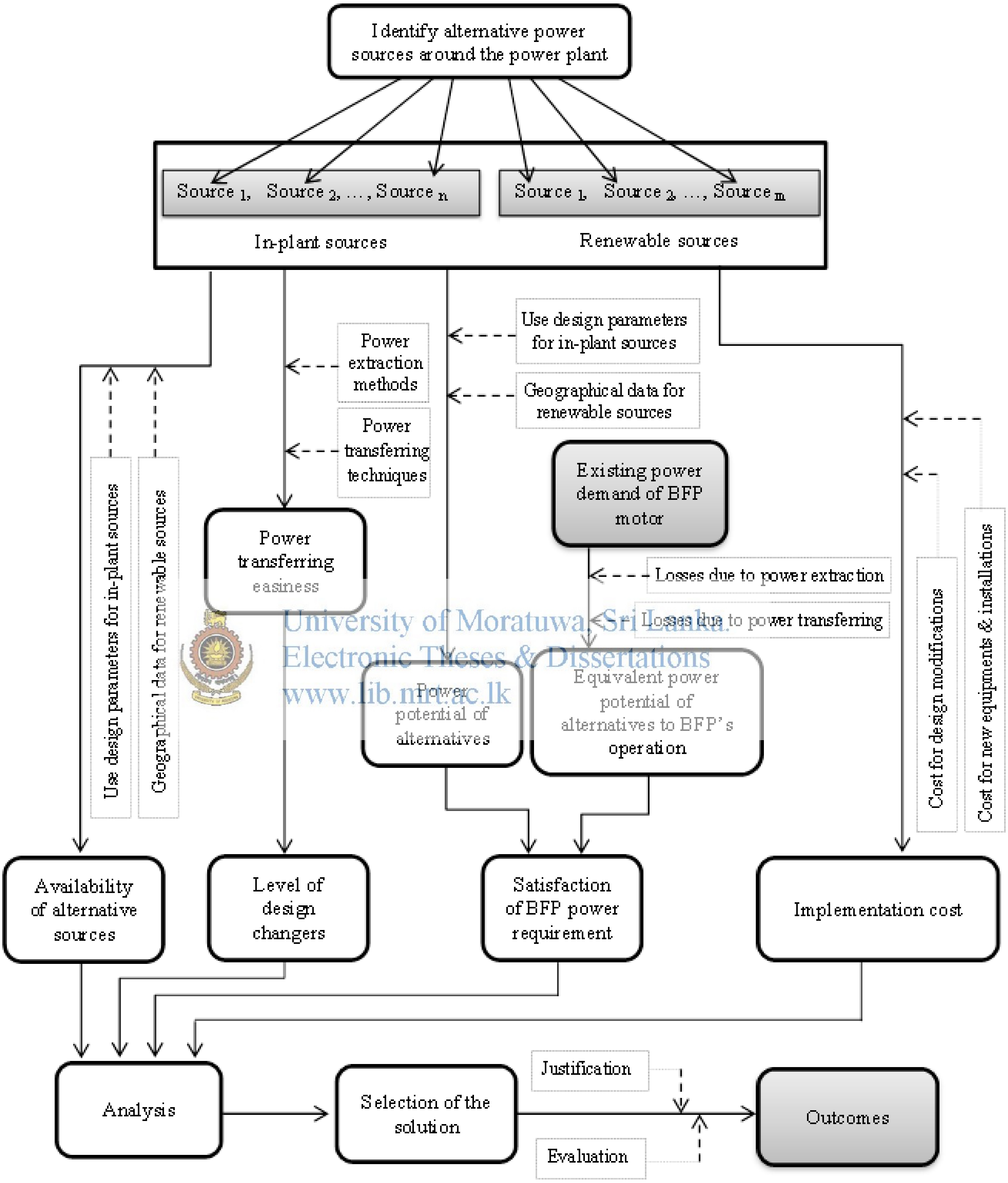


Figure 3.3.1 : Framework of the method

3.1 Identify the alternative power sources applicable to CPP

Based on the results of the literature review, mechanical power, superheated steam, wind energy, sea wave energy, chemical energy and solar energy are the main power sources which can be seen in the operation of the coal power plants [75]. Furthermore these alternative sources are categorised as in-plant power sources and renewable power source [70]. In-plant power sources are decided by design parameters of the power plant and renewable power sources are decided by geographical and environmental factors of the area where the power plant is located.

3.2 Availability of the sources during the plant operation

The availability of the power sources with reference to the power plant operation time is determined. Design parameters of the power plant are used for determining the availability of in-plant power sources. Geographical parameters, environmental factors and the dimensions of the site are used to determine the availability of the renewable energy sources.

3.2.1 Determination the availability for mechanical sources

As studied in literature review, mechanical torque power output of the main turbine shaft is only one power source which can be used practically. The availability of the mechanical power is hundred percent during power plant operation time.

3.2.2 Determination the availability for superheated steam

As studied in the literature review, four steam sources which are extracted through the steam inlet of HP turbine, outlet of HP turbine, Inlet of IP turbine and outlet of IP turbine are dominant. In continuous operation of the power plant, these four extractions have been designed to extract from the main steam path of the steam cycle. Therefore the availability of the steam sources are hundred percent during the stable power plant operation time.

3.2.3 Determination the availability for wind energy sources

As pointed out in the literature review, the availability of wind energy sources is calculated by measuring geographical and environmental factors around the power plant. If not, it is calculated using the previous annual data which have been recorded by a neighbouring institute.

3.2.4 Determination the availability for sea wave energy sources

As mentioned in the literature review, the availability of sea wave energy sources is calculated by measuring or reviewing geographical and environmental factors around the power plant. If not, it is calculated using previous annual data which have been recorded by a neighbouring institute.

3.2.5 Determination the availability for sea solar energy

As pointed out in the literature review, the availability of solar energy is calculated by measuring or reviewing geographical and environmental factors around the power plant. If not, it is calculated using previous annual data which have been recorded by a neighbouring institute.

3.2.6 Summarising the availability of alternative power sources

The availability of the sources is determined by using the most convenient data collection method related to the power plant. It is summarised as mentioned in Table 3.1.

Table 3.3.1 : Summarisation format of availability of alternatives

Power source	Availability (%)	Level
Mechanical power	X_1	(Excellent/Good/Average/Poor/Zero)
Superheated steam	X_2	(Excellent/Good/Average/Poor/Zero)
Wind energy	X_3	(Excellent/Good/Average/Poor/Zero)
Sea wave energy	X_4	(Excellent/Good/Average/Poor/Zero)
Solar power	X_6	(Excellent/Good/Average/Poor/Zero)

3.3 Power transferring easiness

As mentioned in the literature review, easiness of power transferring to BFPs after the extraction of power is dependent on using power extraction method and power transferring technique. In addition, disturbances due to the existing structures and equipment of the power plant which are between power extracted point and BFPs are considered. Then power transferring easiness related to the main alternatives around a coal power plant is qualitatively evaluated.

3.3.1 Easiness of mechanical power transferring

As pointed out in the literature review, mechanical linkages are used for transmission of power, after extracting mechanical power by using all extraction methods. Power transferring with mechanical linkages in a coal power plant which is already constructed is extremely difficult.

3.3.2 Easiness of power transferring related to steam sources

Whatever methods are used to extract energy from steam, as mentioned in the literature review, it is transferred as a heat mass. Full steam piping, combination of steam and water piping or combination of steam and air ducting are used as power transferring techniques and their power transferring easiness is moderate.

3.3.3 Easiness of wind power transferring

As discussed in the literature review, using a wind turbine with mechanical linkages is very difficult to be introduced for constructed and currently operated power plant. Therefore the most suitable power transferring way is by using a generator coupled wind turbine and power conductors. In this case power is transmitted easily.

3.3.4 Easiness of sea wave energy transferring

As pointed out in the literature review, using of power conductors is a more easy transferring technique than the use of mechanical linkages. Therefore power transferring is easy after extracting energy through wave energy extractors.

3.3.5 Easiness of solar power transferring

As mentioned in the literature review, using of power conductors is only one power transferring technique for solar energy. Therefore power transferring related to the solar energy is easy.

3.3.6 Summarising the power transferring easiness of alternatives

Table 3.3.2 : Summary of the power transferring easiness

Power source	Extraction method	Extraction technique	Easiness
Mechanical power	(Direct couplings Gear mechanisms Belt drives Chain drives	Mechanical linkage	Ext. difficult.
Superheated steam	Steam turbine Tube heat exchanger Metal heat exchanger	Steam piping Steam/Water piping Steam pipe/Air duct	Moderate
Wind energy	Wind turbine + Gen.	Power conductors	Easy
	Wind turbine + RE	Mechanical linkage	Ext. difficult.
Sea wave energy	Energy collector +Gen.	Power conductors	Easy
	Energy collector +RE	Mechanical linkage	Ext. difficult.
Solar power	All solar collectors	Power conductors	Easy

3.4 Deciding the level of design changes

When implementing alternatives, the required level of design changes on the existing power plant is dependent on the transferring easiness of relevant transferring technique. According to the literature review, there are three main power transferring techniques are involved with the alternatives. The methodology which decides the level of the brequired design changes with reference to the alternatives and their power transferring easiness is summarised in Table 3.3.

Table 3.3.3 : Summary of required level of design changes

Power source	Power transferring technique	Level of required design changes
Mechanical power	Mechanical linkages	Total design change
Steam sources	Steam piping	Moderate changes
Wind energy	Power conductors	Minor change
Sea wave energy	Power conductors	Minor change
Solar energy	Power conductors	Minor change

3.5 Power potential of alternatives

3.5.1 Potential of mechanical torque power through main turbine shaft

As per the discussion which was done in the literature review, mechanical power potential is calculated by using the manual calculation based on theories or using a developed computer software like Engineering Equation Solver (EES).

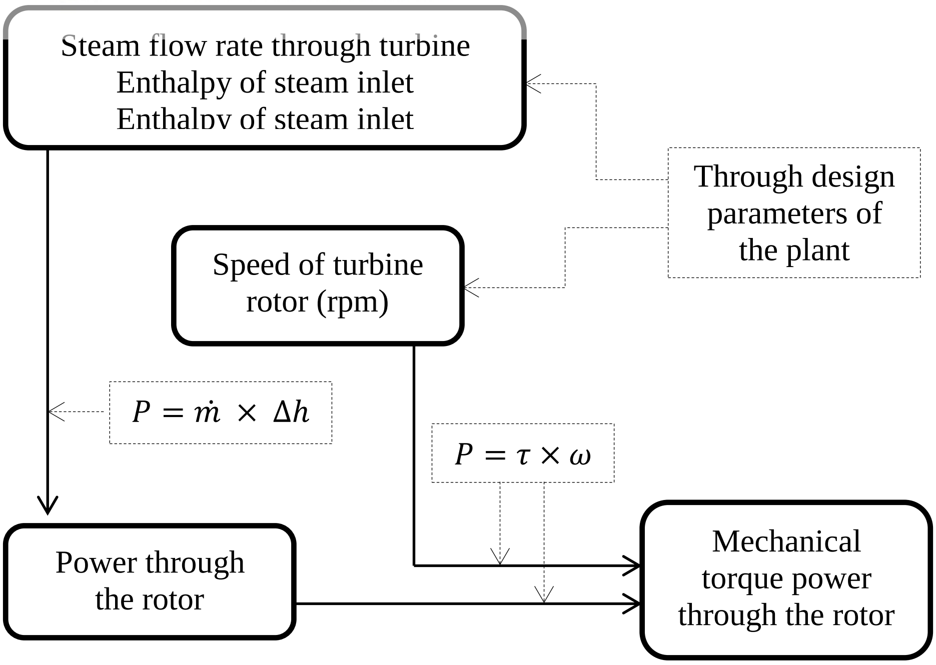


Figure 3.3.2 : Flow of calculations for mechanical source

The methodology applied for calculations and the flow of calculation shown in Figure 3.2 is used to calculate the mechanical power potential through a single turbine shaft. If the power plant has multiple turbine rotors, the total potential is calculated by adding power potential of each shaft after calculating for each shaft separately.

In addition to the calculation flow, three steps in two power conditions are involved to find the excessive torque power through the main turbine rotor.

Step 01- Calculation for total mechanical torque power of combined main turbine shaft at plant rated power condition (@ P_{rated} MW condition).

- P_{rated} MW is obtained by design parameters of the power plant

Step 02- Calculation for total mechanical torque power of combined main turbine shaft without taking power for BFPs from plant home load. (@ P_x MW condition)

- P_{BFPs} MW is component of home load which is consumed by BFPs at rated conditions and P_x MW can be obtained as follows.

$$P_x\ MW = P_{rated}MW - P_{BFPs}MW$$

Step 03- Calculation for excessive mechanical torque power and potential (Torque power potential difference between condition P_{rated} MW and P_x MW)

3.5.2 Potential of steam sources through four steam extractions

As mentioned in the literature review, four main steam extractions are available for process of feed water regeneration in a coal power plant. They are extracted before the main steam entering into HP turbine, cold reheated steam before entering the boiler, hot reheated steam before entering IP turbine and out stream of IP turbine. Excessive steam capacities are calculated as the difference of used steam at the above four locations with reference to the two power conditions which is explained in section 3.5.1. For the steam flow rates across each turbine rotor with reference to the two power conditions are calculated.

As per the discussion which was done in the literature review, these calculations are done manually based on theories or using developed computer software like Engineering Equation Solver (EES). The flow of calculation which is shown in Figure 3.3 is used to calculate the steam flow rate across a single turbine shaft.

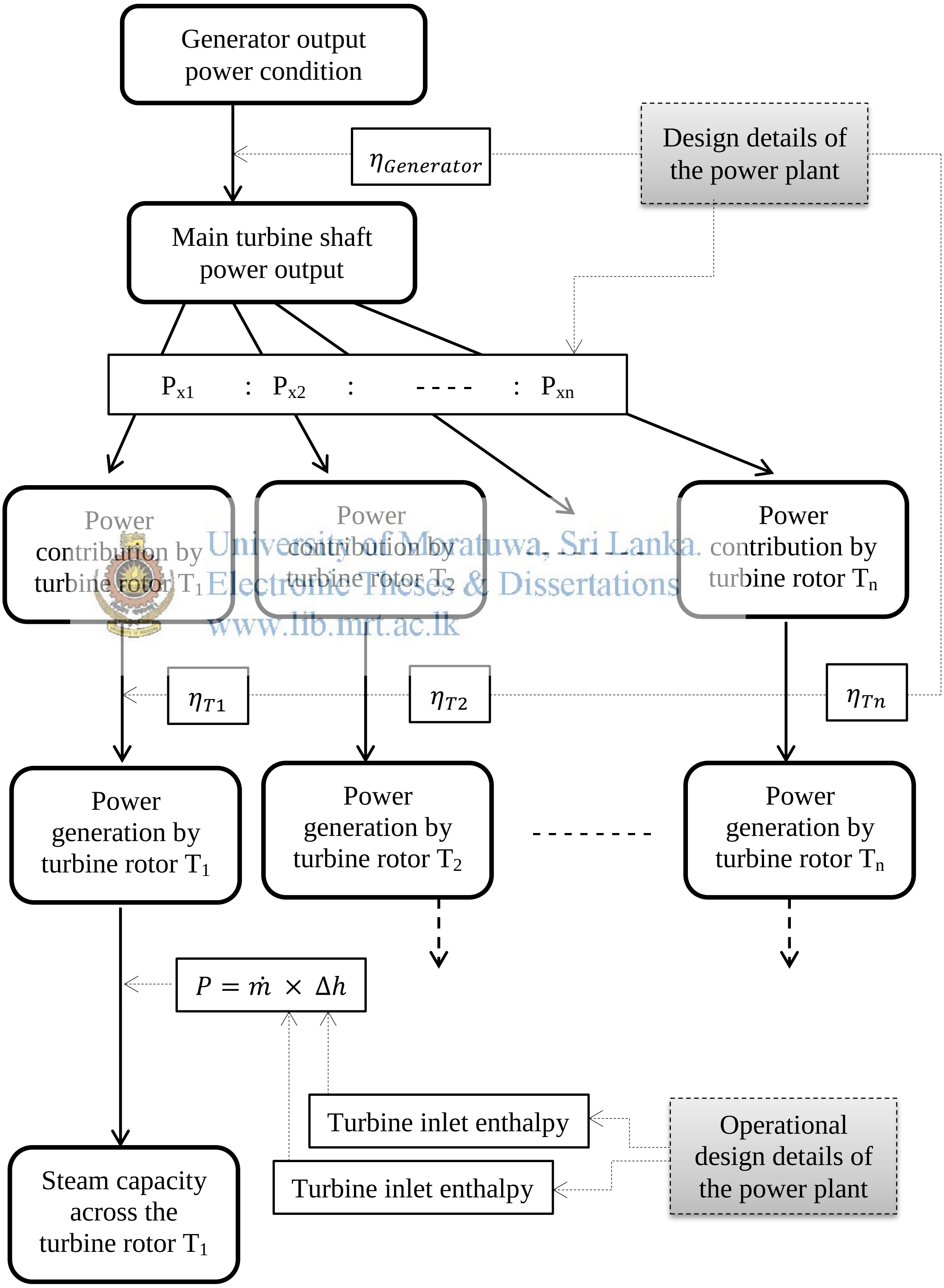


Figure 3.3.3 : Flow of calculation for steam sources

3.5.3 Wind power potential associated to the power plant

As discussed in the literature review, two strategies can be followed to estimate the wind power potential associated with the site of power plant. The first strategy is to do a study by adopting all the steps which are done in a feasibility study for new wind power farm. The second strategy is to check the ability and numbers of wind turbines according to the requirement of blade diameter. For this, the selected wind turbine type which has been practically installed and successfully operated in the neighbouring wind farm is used.

3.5.4 Sea wave energy potential associated to the power plant

According to the studies done in the literature review, potential of wave energy is dependent on the depth of the sea. (See Figure 4.7) By referring to the depth of the sea facing the site and length of the shore, sea wave energy potential is estimated.

3.5.5 Solar energy potential associated to the power plant

As per the literature review, solar energy density is extracted by solar density maps with reference to the considered area. Base on site construction details, area of bear land in power plant is calculated. Then solar energy potential of the site associated to the power plant is calculated.

3.5.6 Summary of power potential in the site of power plant

Table 3.3.4 : Summarisation format for the power potential of alternatives

Alternative power source	**Power potential in the site (MW)**
Mechanical power	$P_{1@site}$
Steam sources	$P_{2@site}$
Wind energy	$P_{3@site}$
Sea wave energy	$P_{4@site}$
Solar energy	$P_{5@site}$

3.6 Existing power demand of BFP motor

As discussed in the literature review, power demand of the existing motor of BFP is decided by BFP as well as its fluid coupler. There the required motor demand is calculated by using the calculation flow which is shown in Figure 3.4.

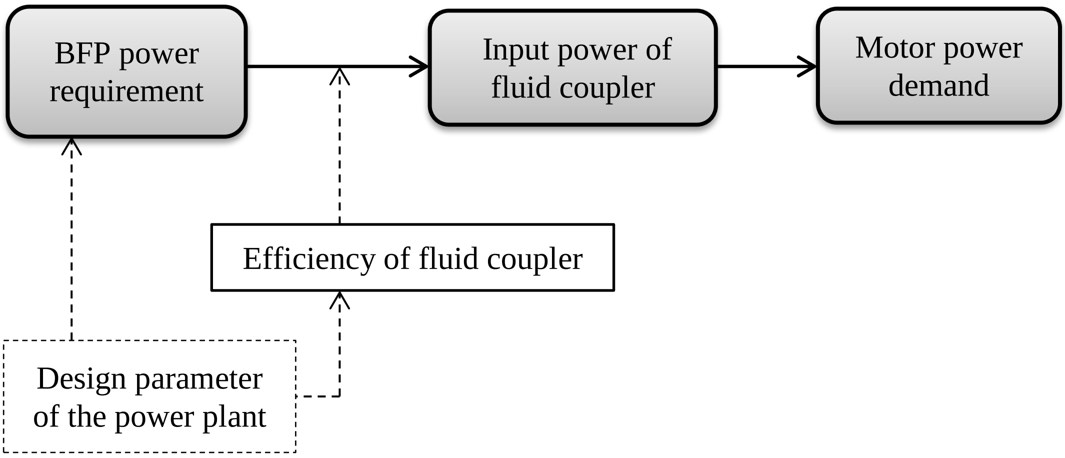


Figure 3.3.4 : Calculation flow for power demand of BFP motor

3.7 Equivalent power potential of alternatives to BFP's operation

Equivalent power potential which is demanded by motor of boiler feed pumps is calculated for each alternative power sources. This equivalent power is much higher than the demanded power by BFP motor, because of several losses are involved in power transferring mechanism between power extraction point and BFP motor. By considering design parameters of the power plant which were discussed in the literature review, equivalent power potential is calculated.

3.7.1 Equivalent mechanical power potential

Equivalent power requirement is definitely higher than the power demand of BFP motor. Any mechanical power extraction method or transferring mechanism discussed in the literature review is used, considerable power losses occur. Therefore to calculate equivalent power potential, calculation flow shown in Figure 3.5 is applied.

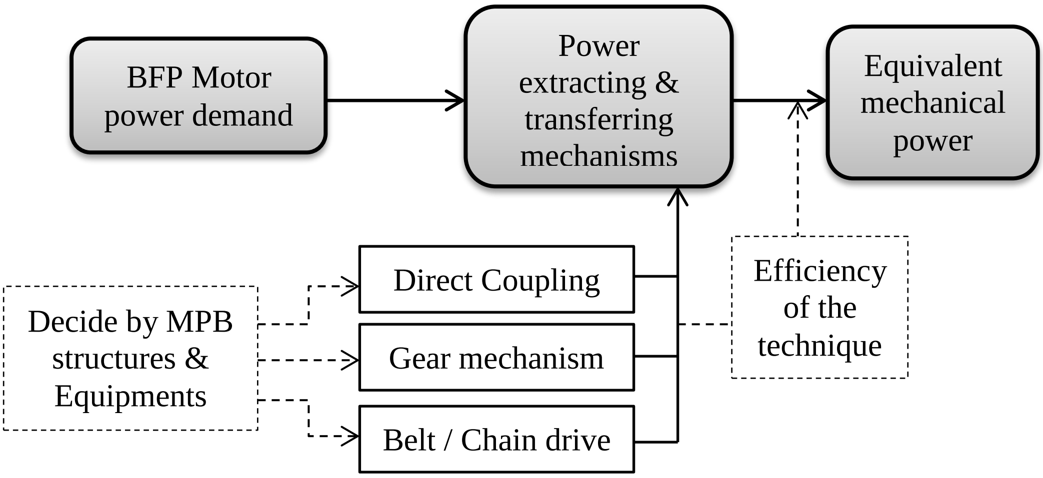


Figure 3.3.5 : Calculation flow of equivalent power for mechanical sources

3.7.2 Equivalent power potential for steam source

Any extraction method or transferring mechanism which was discussed in the literature review is used, considerable power losses occur. Therefore to calculate equivalent power potential calculation for steam sources, the flow shown in Figure 3.6 is applied.

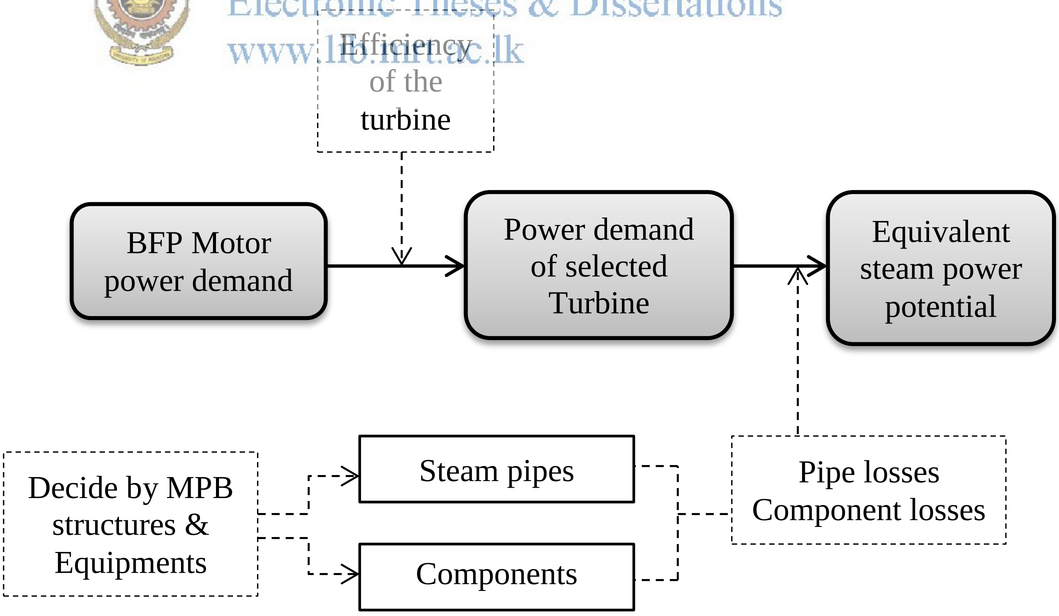


Figure 3.3.6 : Calculation flow of equivalent power for steam sources

3.7.3 Equivalent wind energy potential

To calculate equivalent power potential of wind energy, the calculation flow shown in Figure 3.7 is applied.

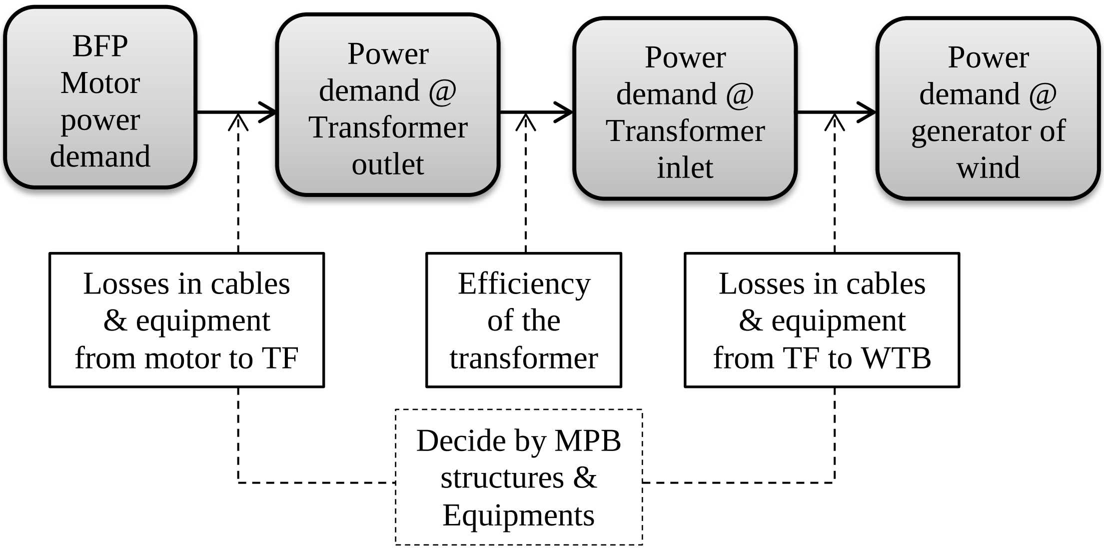


Figure 3.3.7 : Calculation flow of equivalent power for wind energy

3.7.4 Equivalent sea wave energy potential

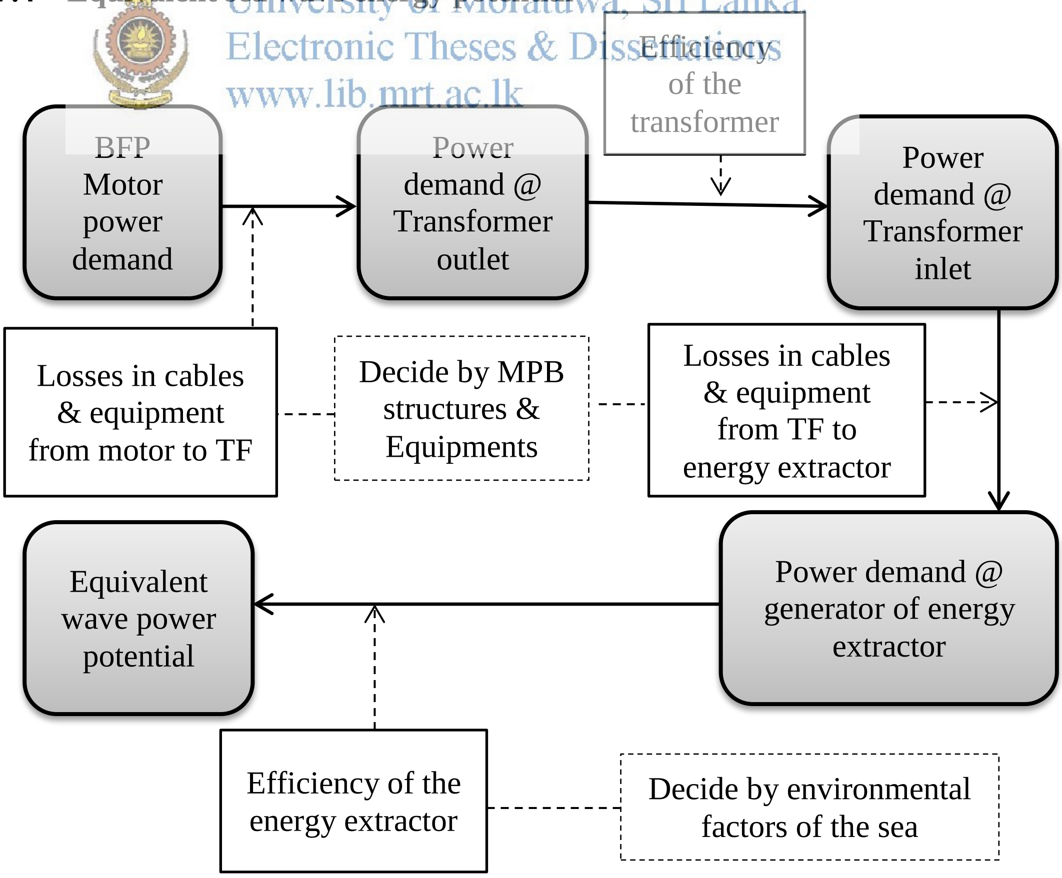


Figure 3.3.8 : Calculation flow of equivalent power for sea wave

To calculate equivalent power potential of sea wave energy, the calculation flow shown in Figure 3.8 is applied.

3.7.5 Equivalent solar power potential

To calculate equivalent power potential of sea wave energy, the calculation flow shown in Figure 3.9 is applied.

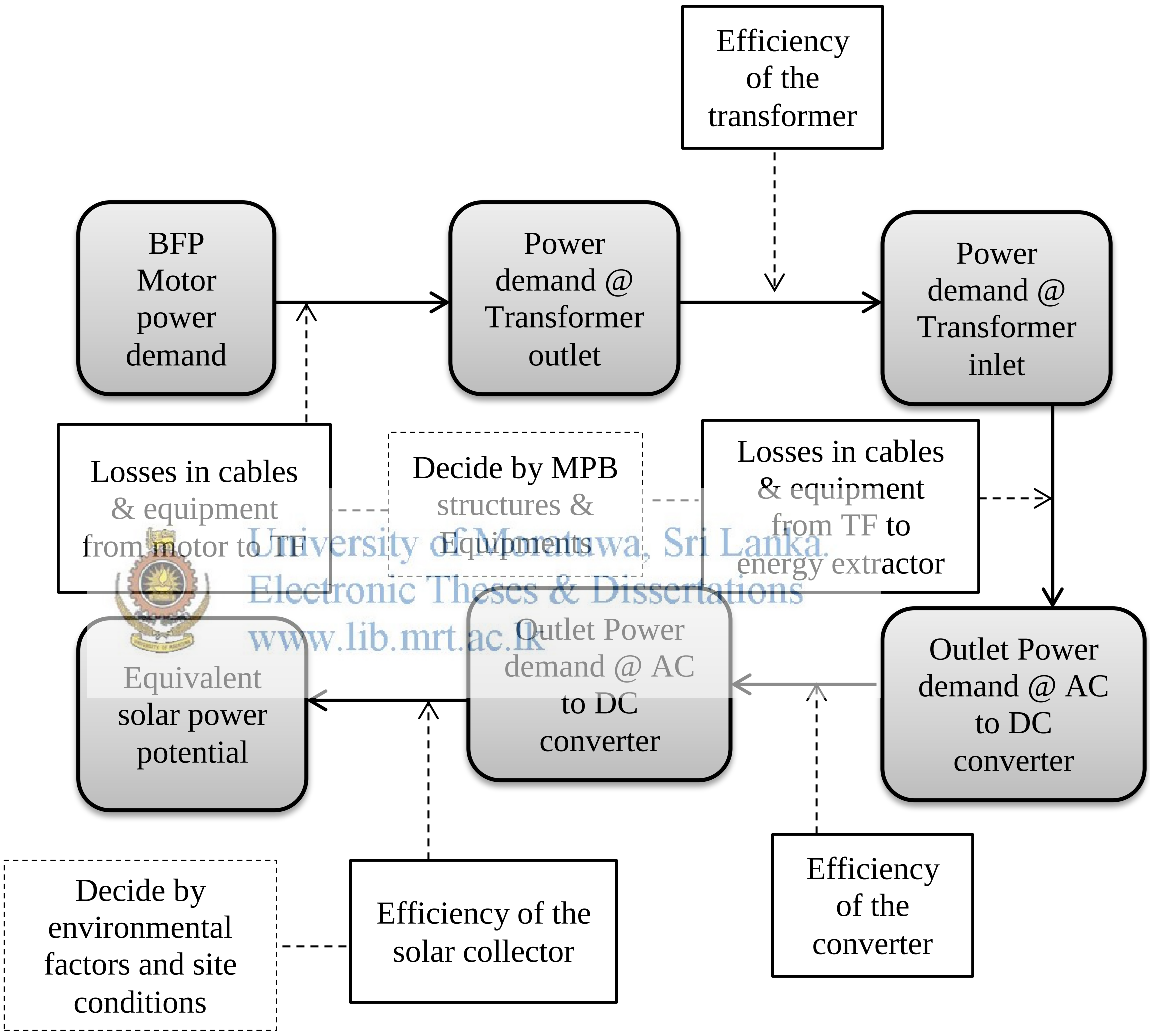


Figure 3.3.9 : Calculation flow of equivalent power for solar energy

3.7.6 Summary for equivalent power potential of alternatives

Table 3.3.5 : Summarisation format for equivalent potential of alternatives

Alternative power source	Power potential in the site (MW)
Mechanical power	$P_{1equivalent}$
Steam sources	$P_{2\ equivalent}$
Wind energy	$P_{3\ equivalent}$
Sea wave energy	$P_{4\ equivalent}$
Solar energy	$P_{5\ equivalent}$

3.8 Satisfaction of BFP power requirement

Satisfaction of BFP power requirement for each source is checked by matching power potential of the source which was discussed in section 3.5 and equivalent power potential of the source which was discussed in section 3.7.

Table 3.3.6 : Summarisation format for BFP power satisfaction

Alternative power source	Power potential in the site (MW)	Power potential in the site (MW)	Satisfactory level ($P_{@site}$ - $P_{equivalent}$)
Mechanical power	$P_{1@site}$	$P_{1equivalent}$	Satisfy/Not satisfy
Steam sources	$P_{2@site}$	$P_{2\ equivalent}$	Satisfy/Not satisfy
Wind energy	$P_{3@site}$	$P_{3\ equivalent}$	Satisfy/Not satisfy
Sea wave energy	$P_{4@site}$	$P_{4\ equivalent}$	Satisfy/Not satisfy
Solar energy	$P_{5@site}$	$P_{5\ equivalent}$	Satisfy/Not satisfy

3.9 Implementation cost

Based on the results of the literature review, implementation cost consists of two cost components. When estimating the implementation cost, both cost components are considered.

3.9.1 Implementation cost for mechanical power sources

When implementing mechanical power source for BFP system in an existing power plant, the cost for the new equipment and cost for design changes are considered as studied in the literature review. The cost for new equipment as well as design modification cost is dependent on site condition of the power plant.

3.9.2 Implementation cost for steam sources

As discussed in the literature review, the cost for relevant steam turbine, steam pipes and auxiliaries are required to be estimated under new equipment. The cost for new basement for steam turbine is estimated under modification cost. Installation cost is calculated separately.

3.9.3 Implementation cost for sea wave energy

The cost for modification, new equipment and their installation can be calculated as a new estimation by adopting all the steps which are done for a new sea wave power station. Otherwise, modification cost inside the power plant is calculated using the steps taken in section 3.9.3. The equipment and installation cost can be simply estimated by using cost estimation of similar previous power projects in the world.

3.9.4 Implementation cost for solar energy

All components related to the implementation cost can be calculated as a new estimation by adopting all the steps taken for a new solar power station. Else, equipment and installation cost can be simply estimated by using cost estimation of similar previous power projects in the world.

3.9.5 Implementation cost for wind energy sources

Modification cost inside the power plant is calculated separately. Because of this, modification is dependent on the existing design of the power plant. The cost for new wind turbines and its installation can be estimated as a new estimation by adopting all the steps which are done for a new wind power farm. Otherwise it is calculated using installation cost data of wind turbines which have been practically installed and successfully operated in the neighbouring wind farm.

3.10 Analysis and selecting solutions

Key solutions are selected by analysing the availability of alternatives, required level of design changes, satisfaction of BFP requirement, by alternatives and implementation cost for alternatives. For this, details related to the above four factors are summarised. The summarised details which are in Table 3.7 are compared qualitatively and quantitatively.

Table 3.3.7 : Overall summarisation format for feasibility factors

Factor **Power source**	**Availability**	**Requirement of design changes**	**Satisfaction of BFP's demand**	**Cost**
Mechanical	Excellent Good Average Poor Zero	Total design changes Moderate changes Minor changes	Satisfied Not satisfied	C_1
Steam	--do--	--do--	--do--	C_2
Wind	--do--	--do--	--do--	C_3
Sea wave	--do--	--do--	--do--	C_4
Solar	--do--	--do--	--do--	C_5

3.11 Evaluation and justification of the solutions

The developed method is evaluated by applying to several coal power plants as case studies. If there are feasible solutions from these power plants according to the developed method, feasibility of solutions may be further justified by considering the following technical and economic factors.

- Grid supply power gain
- Annual power saving
- Annual financial saving
- Payback period
- Annual coal saving

3.12 Obtaining the outcomes

The obtained positive responds of the factors which were discussed in section 3.11 are the outcomes of the developed method.

CHAPTER 4 - CASE STUDY

4.1 Methodology for method evaluation

The developed method is evaluated by using a few cases. Some selected existing coal power plants which were constructed and are currently being operated with electric boiler feed pumps are used for that evaluation. In the scope of this study, Norochcholai coal power plant in Sri Lanka is used for the method evaluation. The required information and data are collected from the most popular alternative energy options using operational and design parameters of the Norochcholai coal power plant and supportive secondary data with relevant to the environment of Norochcholai area. To check some feasibility factors, calculations based on theories are done manually or by using computer software programs. After selecting the feasible solutions, results are justified by studying some technical and economic outcomes such as power gain, annual saving of energy, annual financial saving, payback period and annual coal saving for future.

4.2 Introduction of Norochcholai Coal Power Plant

The Norochcholai coal power plant is the largest and the first coal power plant in Sri Lanka. It is located in Norochcholai on the Kalpitiya Peninsula, approximately 12 km west of the city of Puttalam. Site coordinates - 8.0935613N 79.6392059E [49]. See Figure 4.2.

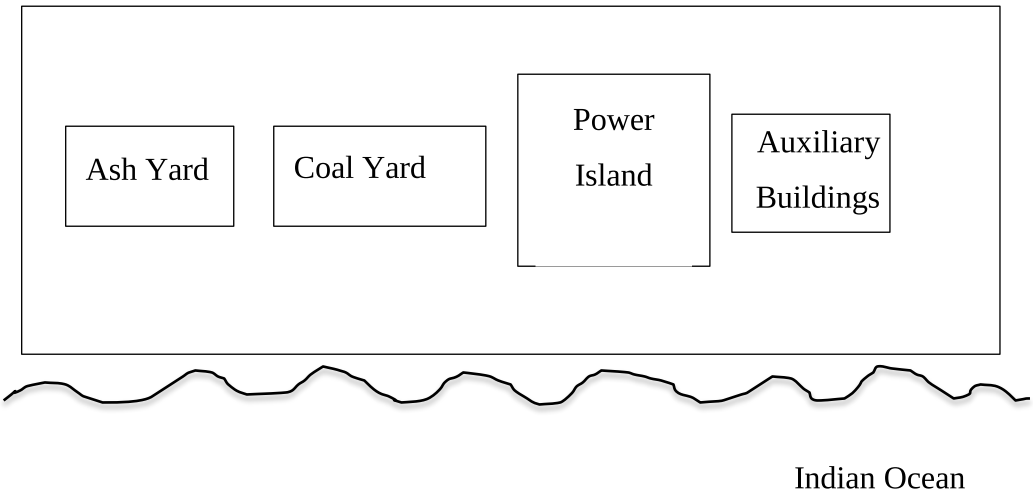


Figure 4.4.1 : Area utilisation of the site for buildings

Site dimensions - Norochcholai coal power plant is spread over large area with facing the Indian Ocean. See the attached drawing in appendix A for site layout of Norochcholai coal power plant. Rough area utilisation of the site is shown by Figure 4.1.

Figure 4.4.2 : Location of Norochcholai coal power plant

Source: http://www.maplandia.com/sri-lanka

4.3 Basic dimensions of the site

- Length of the whole site[51] $= 2100\ \text{m}$
- Width of the whole site[51] $= 420\ \text{m}$
- Area of the whole site (A) $= 2100\ \text{m} \times 420\ \text{m}$

  $= 882{,}000\ \text{m}^2 = 0.882\ \text{km}^2$
- Length of the ash yard[51] $= 450\ \text{m}$
- Width of the ash yard[51] $= 300\ \text{m}$
- Aria of the ash yard (A_1)[51] $= 450\ \text{m} \times 300\ \text{m} = 135{,}000\ \text{m}^2$
- Length of the ash coal[51] $= 600\ \text{m}$
- Width of the ash coal[51] $= 300\ \text{m}$
- Aria of the ash coal (A_2)[51] $= 600\ \text{m} \times 300\ \text{m} = 180{,}000\ \text{m}^2$
- Length of the power island[51] $= 300\ \text{m}$
- Width of the power island[51] $= 350\ \text{m}$
- Aria of the power island(A_3)[51] $= 300\ \text{m} \times 350\ \text{m} = 105{,}000\ \text{m}^2$
- Aria of the auxiliary buildings(A_4)[51] $= 300\ \text{m} \times 300\ \text{m} = 90{,}000\ \text{m}^2$
- Remaining available area in the site $= 882{,}000 - (135{,}000 + 180{,}000 + 105{,}000 + 90{,}000)$

  $= 372{,}000\text{m}^2 = 0.372\ \text{km}^2$
- Length of the site facing to shore[51] $= 2100\ \text{m}$

4.4 Case study based on Norochcholai coal power plant (NCPP)

All variable inputs, invariable inputs and four feasibility factors which are mentioned in method framework (See Figure 3.1) are studied applicable to the 300 MW Norochcholai coal power plant.

4.4.1 Alternative power source related to the NCPP

❖ In-plant alternative power sources

- Mechanical power through main turbine shaft
- Four steam extractions from steam cycle

❖ Renewable power sources

- Wind energy
- Sea wave energy
- Solar energy

4.4.2 Determining the availability of alternatives in NCPP

Source availability with respected to the plant operation time is calculated

➢ Availability of mechanical power

Mechanical power through the turbine main shaft is almost fully available except unit start-up time [16]. Therefore the availability is assumed as 100%.

➢ Availability of steam sources

Superheated steam sources are almost fully available except unit start-up time [16]. Therefore the availability of steam sources are assumed as 100% during the unit stable operation time.

➢ Calculation for wind power availability around Norochcholai area

As studied in literature review, time-based availability is the most famous and commonly using method among the other three methods to calculate wind energy availability [51].

$$Availability = \frac{Wind\ turbine\ operation\ time}{Total\ time\ period}$$

There are few wind farms around the Norochcholai power plant. Therefore the annual wind turbine operation times which are listed in Table 4.1 are taken from these wind farms [52].

Table 4.4.1 : Annual operation hours of wind farms around Norochcholai

Year	Operation time of wind turbines (hrs)		
	Daily Life Energy	**Nirmalapura**	**PowerGen**
2012	7508	--	--
2013	7876	7240	7323
2014	7032	7129	7080

$$Annual\ wind\ availability = \frac{Total\ operation\ hours\ of\ wind\ turbines}{365 \times 24\ h} \times 100$$

Table 4.4.2 : Annual wind availability of wind farms around Norochcholai

Year	Daily Life Energy	Nirmalapura	PowereGen
2012	85.71%	--	--
2013	89.90%	82.65%	83.60%
2014	80.27%	81.38%	80.82%
Avg.	85.29%	82.02%	82.21%

$$\therefore Average\ wind\ availability\ around\ Norochcholai = \frac{85.29\% + 82.02\% + 82.21\%}{3}$$

$$Average\ wind\ availability\ around\ Norochcholai = 83.17\%$$

- Calculation for availability of wave energy around Norochcholai

As mentioned in literature review, capacity of energy which is extracted through sea wave is decided by height of the waves [47]. The height is depended on the seasonal wind patterns [53]. Therefore monsoon patterns, seasonal wind patterns and sea wave height in the sea near Norochcholai area are considered to calculate the availability of wave energy.

- Monsoon period for Norochcholai area is from May to October [54].
- According to the report of Wave run-up estimates at gentle beaches in the northern Indian Ocean, seasonal variation of wind speed and sea wave height are shown in the Figure 4.3.

- According to Figure 4.3, five months in a year around Norochcholai sea area is caught by southwest monsoon season and during the off-season average sea wave height is less than 1m.
- For the practicable wave energy extraction, it is required more than 1m average height of sea waves [47].

$$\therefore Annual\ availability\ of\ sea\ wave\ energy\ in\ Norochcholai = \frac{5\ Months}{12\ Months} \times 100\%$$

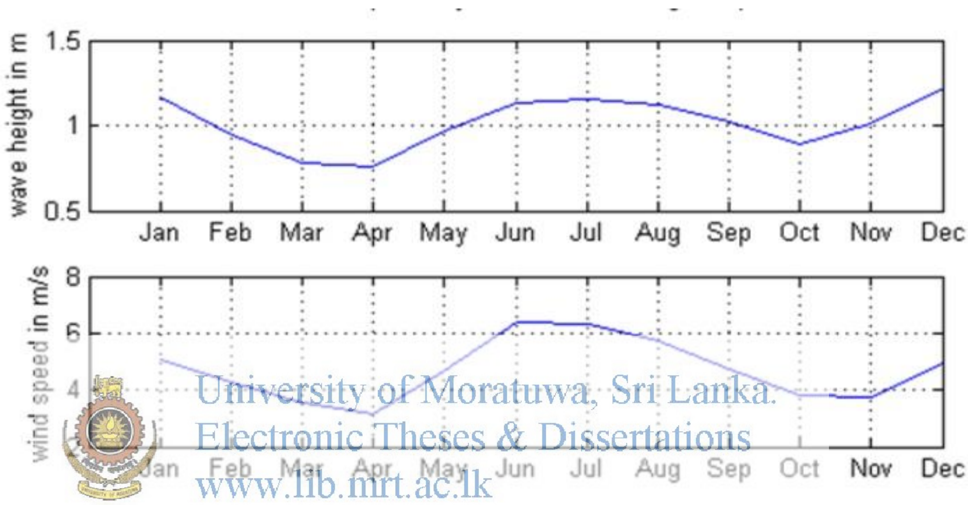


Figure 4.4.3 : Seasonal variation of wind speed and wave height in NIO

Source: http://www.oceandocs.org/bitstream/1834/4557/1/Wave%20runup.pdf

$$Anual\ availability\ of\ sea\ wave\ energy\ in\ Norochcholai = 41.67\%$$

➢ Calculation for availability of solar power around Norochcholai

As mentioned in literature review, annual availability of the solar power source is depended on numbers of the days with clear sky or numbers of sunny days in a year [48]. Puttalam is the most near weather station for Norochcholai area. Therefore collected weather data from Puttalam station are almost equal to Norochcholai area. Past records for numbers of sunny days for Puttalam area shown in the Table 4.3 [55].

Table 4.4.3 : Numbers of sunny days in a year in Puttalam city

Year	**Numbers of sunny days**												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2014	26	26	28	29	30	30	29	28	18	12	15	22	293
2013	28	27	29	29	31	30	28	26	21	16	19	24	308

$$\therefore Day\ time\ solar\ power\ availability = \frac{Sunny\ days\ in\ a\ year}{365} \times 100\%$$

$$Day\ time\ solar\ power\ availability\ in\ 2014 = \frac{293}{365} \times 100\% = 80.27$$

$$Day\ time\ solar\ power\ availability\ in\ 2013 = \frac{308}{365} \times 100\% = 84.38$$

When consider the real availability with reference to the power plant operation time, these percentages are half. Because of the power plant is operated continuously in day time as well as in night time.

$$Real\ time\ solar\ power\ availability = \frac{Availability\ in\ Day\ time}{2}$$

$$\therefore Real\ time\ solar\ power\ availability\ in\ 2014 = \frac{80.27\%}{2} = 40.14\%$$

$$\therefore Real\ time\ solar\ power\ availability\ in\ 2013 = \frac{84.38\%}{2} = 42.19\%$$

$$Average\ solar\ power\ availability = \frac{40.14\% + 42.19\%}{2} = 41.17\%$$

Table 4.4.4 : Availability of power sources in NCPP

Power source	Availability (%)	Level
Mechanical power	100	Excellent
Superheated steam	100	Excellent
Wind energy	83.17	Good
Sea wave energy	41.67	Average
Solar power	41.17	Average

4.4.3 Power transferring easiness in NCPP

❖ Transferring easiness of mechanical power

According to the equipment layout drawing of the main power block (MPB), the main turbine is located at 12.6m level. BFPs are located at 0m level. Many disturbances due to building structures and equipment can be seen between 12.6m level and 0m level [50] (See appendix B). As per the studies which were done in the literature review, mechanical linkages are used to transmit power between the turbine shaft and BFP. Therefore power transferring easiness is extremely difficult when using mechanical linkages with that kind of disturbance.

❖ Transferring easiness for steam sources

As discussed in the literature review, using a steam turbine with steam piping is the most efficient and common way to extract and transfer energy from a steam source. As per the factors which are shown on the general arrangement drawing, power can be transferred with newly designed steam pipe system although structural and equipment disturbances are there. Therefore extracted power through steam sources can be transferred with moderate easiness in the Norochcholai power plant.

- Power transferring easiness from wind sources

  According to the site layout drawing which is attached to appendix A, considerable free area can be identified in the site of Norochcholai power plant. When considering the power transferring easiness based on the literature review, the most suitable way is to use an electric generator coupled with wind turbine and power conductors. Therefore the power transferring of wind energy is easy in relation to Norochcholai power plant.

- Power transferring easiness from sea wave energy

  According to the site layout drawing which is attached to appendix A, western border with 2100 m length of the site of Norochcholai power plant faces to the Indian ocean. When considering the power transferring easiness based on the literature review, the most suitable way is to use an electric generator and wave energy extractor with power conductors. Therefore transferring after power extracting from sea wave energy is easy in relation to the Norochcholai power plant.

- Power transferring easiness from solar energy

  As discussed in the literature review, flat-plate collector method for solar energy extraction is more convenient and suitable for a partially occupied site like of Norochcholai power plant. Power transferring easiness for solar energy is easy due to the use of power conductors.

Table 4.4.5 : Level of power transferring easiness for alternatives in NCPP

Power source	**Power transferring technique**	**Level of easiness**
Mechanical power	Mechanical linkages	Extremely difficult
Steam sources	Steam piping	Moderate
Wind energy	Power conductors	Easy
Sea wave energy	Power conductors	Easy
Solar energy	Power conductors	Easy

4.4.4 Level of required design change in NCPP

❖ Level of required design change when using mechanical linkages

According to the general arrangement drawing of MPB in NCPP (See appendix B), many structures and equipment are affected when power transferring by using mechanical linkages. Therefore it needs a total design change on existing MPB.

❖ Level of required design change when using steam piping

Although new steam piping system is required to newly design, extracted power through steam sources can be transferred with some considerable changes in existing design. No need to change entire design of MPB.

❖ Level of required design change when using power conductors

As discussed in literature review, cable trenches or cable trays are used to lay power conductors. According to the equipment arrangement drawing of MPB in NCPP (See appendix C), there are enough spaces to lay cables with minor modifications

Table 4.4.6 : Required level of changes on MPB in NCPP

Power source	Power transferring technique	Level of design change in MPB
Mechanical power	Mechanical linkages	Total design change
Steam sources	Steam piping	Moderate changes
Wind energy	Power conductors	Minor change
Sea wave energy	Power conductors	Minor change
Solar energy	Power conductors	Minor change

4.4.5 Power potential of alternatives in site of NCPP

- Potential of mechanical torque power through main turbine shaft

The existing BFPs in NCPP are energised by a fraction of the main generator output power. During the generation of 300 MW, which is in power plant rated capacity, 10.78 MW power out of 300 MW is consumed by BFPs [13]. Therefore it needs to calculate the turbine shaft torque at 300 MW as well as at 289.22 MW. Assume that the required 10.78 MW power for BFP energising is not taken through the main generator power output.

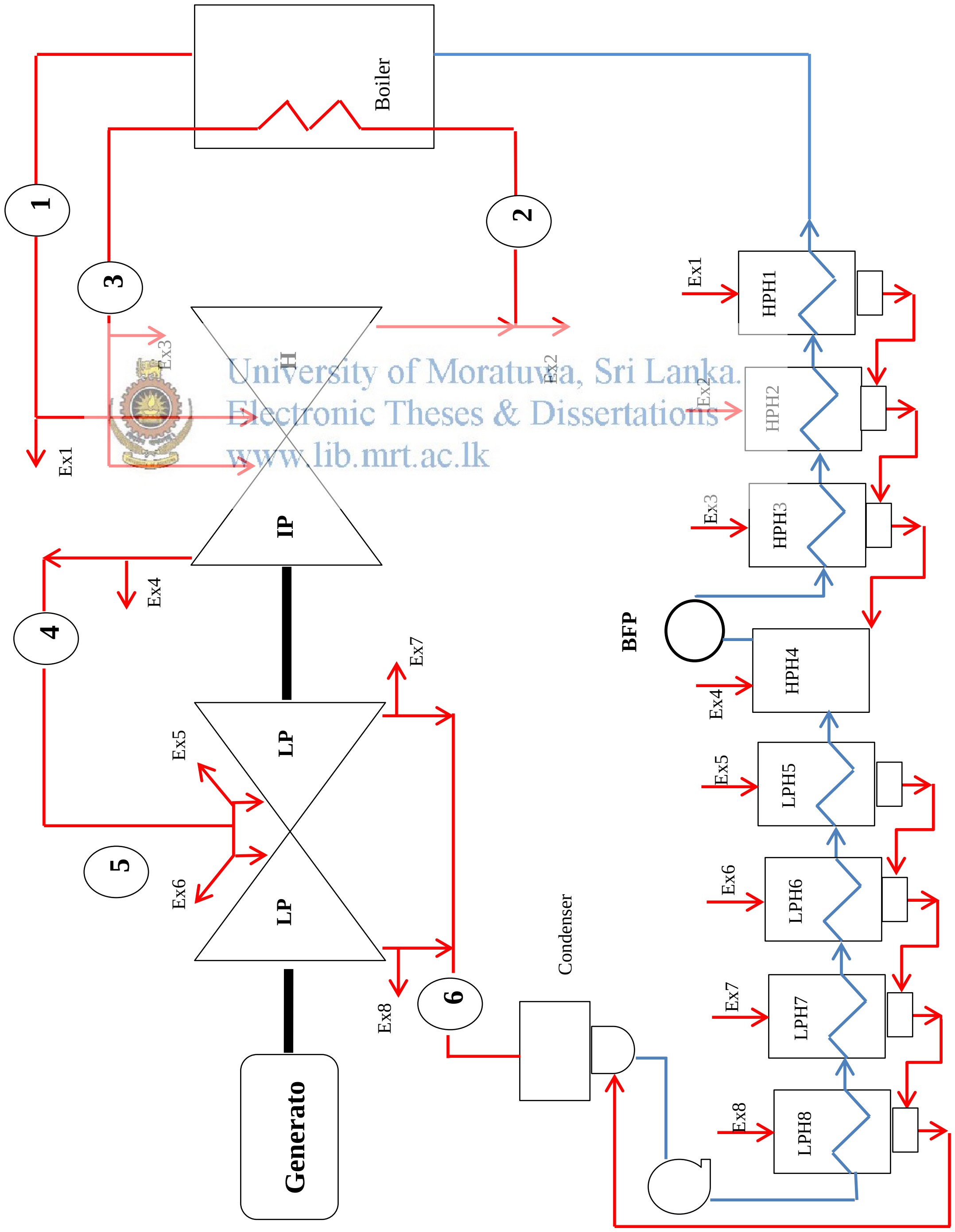


Figure 4.4.4 : Thermal cycle in Norochcholai coal power plant

❖ Operation parameters in Norochcholai power plant at its rated power capacity

- Boiler operation conditions @ 300 MW capacity

$$Boiler\ main\ steam\ pressure = 16.7\ MPa$$

$$Boiler\ main\ steam\ temperature = 538\ ℃$$

- Operational parameters @ 300 MW (plant rated power) related to the point #1 of Figure 4.4 [16].

$$Steam\ flow\ rate\ from\ boiler = \dot{m}_{1@300MW} = 964\ {}^{T}/_{h}$$

$$Enthalpy = h_{1@300MW} = 3396.9\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#1 = \dot{m}_{Ex1} = 71.04\ {}^{T}/_{h}$$

- Operational parameters @ 300 MW (plant rated power) related to the point #2 of Figure 4.4 [16].

$$Cold\ Re-heater\ steam\ flow\ rate\ to\ boiler = \dot{m}_{1@300MW} = 803.75\ {}^{T}/_{h}$$

$$Enthalpy = h_{2@300MW} = 3048.9\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#2 = \dot{m}_{Ex2} = 76.23\ {}^{T}/_{h}$$

- Operational parameters @ 300 MW (plant rated power) related to the point #3 of Figure 4.4[16].

$$Hot\ Re-heater\ steam\ flow\ rate\ from\ boiler = \dot{m}_{3@300MW} = 803.75\ {}^{T}/_{h}$$

$$Enthalpy = h_{3@300MW} = 3535.9\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#3 = \dot{m}_{Ex3} = 31.01\ {}^{T}/_{h}$$

- Operational parameters @ 300 MW (plant rated power) related to the point #4 of Figure 4.4 [16].

$$Steam\ flow\ rate\ of\ IP\ outlet = \dot{m}_{4@300MW} = 733.67\ {}^{T}/_{h}$$

$$Enthalpy = h_{4@300MW} = 3168.7\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#4 = \dot{m}_{Ex4} = 41.12\ {}^{T}/_{h}$$

- Operational parameters @ 300 MW (plant rated power) related to the point #5 of Figure 4.4 [16].

$$Steam\ flow\ rate\ into\ LP\ turbine \quad = \dot{m}_{5@300MW} = 733.67\ {}^{T}/_{h}$$

$$Enthalpy \quad = h_{5@300MW} = 3168.7\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#5 \quad = \dot{m}_{Ex5} = 41.27\ {}^{T}/_{h}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#6 \quad = \dot{m}_{Ex6} = 25.43\ {}^{T}/_{h}$$

- Operational parameters @ 300 MW (plant rated power) related to the point #6 of Figure 4.4 [16].

$$Steam\ flow\ rate\ into\ condenser \quad = \dot{m}_{6@300MW} = 613.25\ {}^{T}/_{h}$$

$$Enthalpy \quad = h_{6@300MW} = 2368.6\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#7 \quad = \dot{m}_{Ex7} = 28.66\ {}^{T}/_{h}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#8 \quad = \dot{m}_{Ex8} = 25.44\ {}^{T}/_{h}$$

<u>Step: 01</u>-Calculation for Mechanical torque of main turbine shaft @ 300 MW (Plant's rated power)

✓ Torque through HP rotor

$$P = \dot{m} \times \Delta h \qquad ;\text{Where } P - \text{power in } kW$$

$$\dot{m} - \text{steam flow rate in kg/s}$$

$$\Delta \text{h} - \text{enthalpy difference in kJ/kg}$$

$$P_{HP@300MW} = (\dot{m}_{1@300\text{MW}} - \dot{m}_{\text{Ex1}}) \times (h_{1@300MW} - h_{2@300MW})$$

$$P_{HP@300MW} = (964 - 71.04) \times \frac{10^3}{60 \times 60}\ {}^{kg}/_{s} \times (3396.9 - 3048.9)\ {}^{kJ}/_{kg}$$

$$P_{HP@300MW} = 86{,}245.05\ kW \ = 86.25\ MW$$

$$P_{HP@300MW} = \tau_{HP@300MW} \times \omega_{@3000rpm}$$

$$86{,}245.05 = \tau_{HP@300MW} \times 3000 \times \frac{2\pi}{60}$$

$$\tau_{HP@300MW} = 274.57\ kNm$$

✓ Torque through IP rotor

$$P_{IP@300MW} = (\dot{m}_{3@300MW} - \dot{m}_{Ex3}) \times (h_{3@300MW} - h_{4@300MW})$$

$$P_{IP@300MW} = (803.75 - 31.0) \times \frac{10^3}{60 \times 60}\ {}^{kg}/_{s} \times (3535.9 - 3168.7)\ {}^{kJ}/_{kg}$$

$$P_{IP@300MW} = 78{,}820.5\ kW = 78.82\ MW$$

$$P_{IP@300MW} = \tau_{IP@300MW} \times \omega_{@3000rpm}$$

$$78{,}820.5 = \tau_{IP@300MW} \times 3000 \times \frac{2\pi}{60}$$

$$\tau_{IP@300MW} = 250.9\ kNm$$

✓ Torque through LP rotors

$$P_{LP@300MW} = (\dot{m}_{4@300MW} - \dot{m}_{Ex5} - \dot{m}_{Ex6}) \times (h_{4@300MW} - h_{6@300MW})$$

$$P_{LP@300MW} = (733.67 - 41.27 - 25.43) \times \frac{10^3}{60 \times 60}\ {}^{kg}/_{s} \times (3168.7 - 2368.6)\ {}^{kJ}/_{kg}$$

$$P_{LP@300MW} = 148{,}197.03\ kW = 148.2\ MW$$

$$P_{LP@300MW} = \tau_{LP@300MW} \times \omega_{@3000rpm}$$

$$148{,}197.03 = \tau_{LP@300MW} \times 3000 \times \frac{2\pi}{60}$$

$$\tau_{LP@300MW} = 471.73\ kNm$$

✓ Total torque output through turbine main shaft @ 300 MW

$$\tau_{turbine@300MW} = \tau_{HP@300MW} + \tau_{IP@300MW} + \tau_{LP@300MW}$$

$$\tau_{turbine@300MW} = 274.57\ kNm + 250.9\ kNm + 471.73\ kNm$$

$$\tau_{turbine@300MW} = 997.2\ kNm$$

❖ Operation parameters in Norochcholai power plant at 289.22 MW power capacity

- Boiler operation conditions @ 289.22 MW capacity

$$Boiler\ main\ steam\ pressure = 16.7\ MPa$$

$$Boiler\ main\ steam\ temperature = 538\ ℃$$

- Operational parameters @ 289.22 MW related to the point #1 of Figure 4.4 [16].

$$Steam\ flow\ rate\ from\ boiler = \dot{m}_{1@289.22MW} = 932.45\ {}^{T}/_{h}$$

$$Enthalpy = h_{1@289.22MW} = 3396.9\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#1 = \dot{m}_{Ex1} = 71.04\ {}^{T}/_{h}$$

- Operational parameters @ 289.22 MW related to the point #2 of Figure 4.4 [16].

$$Cold\ Re - heater\ steam\ flow\ rate\ to\ boiler = \dot{m}_{2@289.22MW} = 785.18\ {}^{T}/_{h}$$

$$Enthalpy = h_{2@289.22MW} = 3048.9\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#2 = \dot{m}_{Ex2} = 76.23\ {}^{T}/_{h}$$

- Operational parameters @ 289.22 MW related to the point #3 of Figure 4.4 [16].

$$Hot\ Reheater\ steam\ flow\ rate\ from\ boiler = \dot{m}_{3@289.22MW} = 778.11\ {}^{T}/_{h}$$

$$Enthalpy = h_{3@289.22MW} = 3535.9\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#3 = \dot{m}_{Ex3} = 31.01\ {}^{T}/_{h}$$

- Operational parameters @ 289.22 MW related to the point #4 of Figure 4.4 [16].

$$Steam\ flow\ rate\ of\ IP\ outlet = \dot{m}_{4@289.22MW} = 705.98\ {}^{T}/_{h}$$

$$Enthalpy = h_{4@289.22MW} = 3168.7\ {}^{kJ}/_{kg}$$

$$Steam\ flow\ rate\ through\ Extraction\ \#4 = \dot{m}_{Ex4} = 41.12\ {}^{T}/_{h}$$

- Operational parameters @ 289.22 MW related to the point #5 of Figure 4.4 [16].

$Steam\ flow\ rate\ into\ LP\ turbine \quad = \dot{m}_{5@289.22MW} = 711.74\ {}^{T}/_{h}$

$Enthalpy \quad = h_{5@289.22MW} = 3168.7\ {}^{kJ}/_{kg}$

$Steam\ flow\ rate\ through\ Extraction\ \#5 \quad = \dot{m}_{Ex5} = 41.27\ {}^{T}/_{h}$

$Steam\ flow\ rate\ through\ Extraction\ \#6 \quad = \dot{m}_{Ex6} = 25.43\ {}^{T}/_{h}$

- Operational parameters @ 289.22 MW related to the point #6 of Figure 4.4 [16].

$Steam\ flow\ rate\ into\ condenser \quad = \dot{m}_{6@289.22MW} = 590.94\ {}^{T}/_{h}$

$Enthalpy \quad = h_{6@289.22MW} = 2368.6\ {}^{kJ}/_{kg}$

$Steam\ flow\ rate\ through\ Extraction\ \#7 \quad = \dot{m}_{Ex7} = 28.66\ {}^{T}/_{h}$

$Steam\ flow\ rate\ through\ Extraction\ \#8 \quad = \dot{m}_{Ex8} = 25.44\ {}^{T}/_{h}$

Step 02:- Calculation for Mechanical torque of main turbine shaft @ 289.22 MW

✓ Torque through HP rotor

$$P_{HP@289.22MW} = (\dot{m}_{1@289.22MW} - \dot{m}_{Ex1}) \times (h_{1@289.22MW} - h_{2@289.22MW})$$

$$P_{HP@289.22MW} = (932.45 - 71.04) \times \frac{10^3}{60 \times 60}\ {}^{kg}/_{s} \times (3396.9 - 3048.9)\ {}^{kJ}/_{kg}$$

$$P_{HP@289.22MW} = 83{,}269.63\ kW = 83.27\ MW$$

$$P_{HP@289.22MW} = \tau_{HP@289.22MW} \times \omega_{@3000rpm}$$

$$83{,}269.63 = \tau_{HP@289.22MW} \times 3000 \times \frac{2\pi}{60}$$

$$\tau_{HP@289.22MW} = 265.05\ kNm$$

✓ Torque through IP rotor

$$P_{IP@289.22MW} = (\dot{m}_{3@289.22MW} - \dot{m}_{Ex3}) \times (h_{3@289.22MW} - h_{4@289.22MW})$$

$$P_{IP@289.22MW} = (778.11 - 31.0) \times \frac{10^3}{60 \times 60}\ {}^{kg}/_{s} \times (3535.9 - 3168.7)\ {}^{kJ}/_{kg}$$

$$P_{IP@289.22MW} = 76{,}205.22\ kW = 76.20\ MW$$

$$P_{IP@289.22MW} = \tau_{IP@289.22MW} \times \omega_{@3000rpm}$$

$$76{,}205.22 = \tau_{IP@289.22MW} \times 3000 \times \frac{2\pi}{60}$$

$$\tau_{IP@289.22MW} = 242.5\ kNm$$

- ✓ Torque through LP rotors

$$P_{LP@289.22MW} = (\dot{m}_{4@289.22MW} - \dot{m}_{Ex5} - \dot{m}_{Ex6}) \times (h_{4@289.22MW} - h_{6@289.22MW})$$

$$P_{LP@289.22MW} = (705.98 - 41.27 - 25.43) \times \frac{10^3}{60 \times 60} \times (3168.7 - 2368.6)\ {}^{kJ}/_{s}$$

$$P_{LP@289.22MW} = 142{,}079.98\ kW = 142.08\ MW$$

$$P_{LP@289.22MW} = \tau_{LP@289.22MW} \times \omega_{@3000rpm}$$

$$142{,}079.98 = \tau_{LP@289.22MW} \times 3000 \times \frac{2\pi}{60}$$

$$\tau_{LP@289.22MW} = 452.25\ kNm$$

- ✓ Total torque output through turbine main shaft

$$\tau_{turbine@289.22MW} = \tau_{HP@289.22MW} + \tau_{IP@289.22MW} + \tau_{LP@289.22MW}$$

$$\tau_{turbine@289.22MW} = 265.05\ kNm + 242.5\ kNm + 452.25\ kNm$$

$$\tau_{turbine@289.22MW} = 959.8\ kNm$$

Step 03:-Calculation for excessive mechanical torque through main turbine shaft

While operating the feed pumps without using power which is generated by the main generator, let's consider how 289.22 MW electricity power is generated as generator unit output power. Although the generator produces 289.22 MW, turbine is capable of operating at plant rated operational conditions. Therefore some excessive mechanical torque power can be expected through the main turbine shaft at 300 MW.

$$Available\ excessive\ torque = \tau_{turbine@300MW} - \tau_{turbine@289.22MW}$$

$$Available\ excessive\ torque = 997.2\ kNm - 959.8\ kNm$$

$$Available\ excessive\ torque = 37.4\ kNm$$

Hence the rotating speed of whole combine turbine shaft is 3000 rpm;

$$Available\ excessive\ mechanical\ torque\ power = \tau_{excessive} \times 3000 \times \frac{2\pi}{60}$$

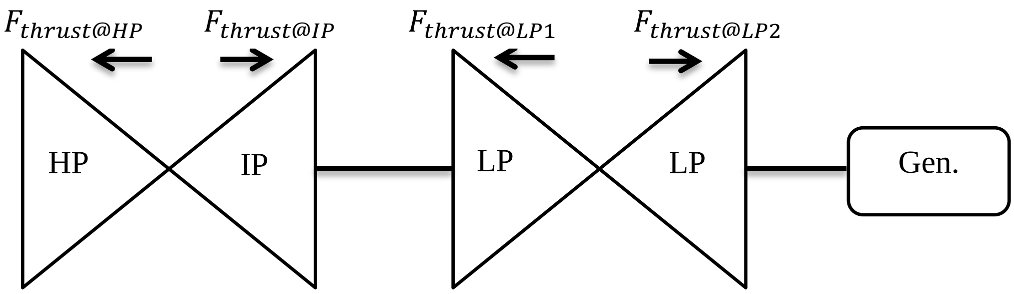
$$Available\ excessive\ mechanical\ torque\ power = 37.4kNm \times 3000 \times \frac{2\pi}{60}$$

$$Available\ excessive\ mechanical\ torque\ power = 11{,}749\ kW = 11.75\ MW$$

- Potential of steam sources through four steam extractions

When the plant is operated on rated operational condition (at 300 MW) and the generator produces 289.22 MW power, some excessive steam quantity due to operation of feed pumps with separate alternative power supply can be expected. Therefore it needs to calculate the required steam capacity for turbines and its power potential for each case. Then the available excessive steam potential can be calculated with reference to 300 MW and 289.22 MW.

Power producing ratio of the combined turbine shaft



$$Power\ ratio\ P_{HP} : P_{IP} : P_{LP1} : P_{LP2} = 0.2410 : 0.2712 : 0.2439 : 0.2439$$

Figure 4.4.5: Thrust force distribution and turbine power ratios

Power extraction in a combined turbine rotors is done by different ratios. In designing of the overall rotor combination, it is designed as much as balancing their thrust forces. See the Figure 4.5. Therefore when extracting power through common shaft with combined turbine rotors, all turbines have unique power ratio which is inherited by design. See the Table 4.7 [16].

Table 4.4.7: Power contribution by turbine stages at various loads

Power ratio	P_{HP}	P_{IP}	P_{LP1}	P_{LP2}
($\pm 5.0\%$)	0.2410	0.2712	0.2439	0.2439
Power @ 150 MW (Half load)	31.15	40.68	36.58	36.58
Power @ 270 MW	65.07	73.22	65.85	65.85
Power @ 300 MW (Rated load)	72.3	81.36	73.17	73.17
Power @ 336 MW (BMCR)	80.976	91.12	81.95	81.95

<u>Step 01</u>:- Calculation for required steam capacities through turbines at 300 MW

- $Efficiency\ of\ main\ electric\ genarator$[16] $= \eta_{Generator} = 99.25\%$
- Efficiency of HP turbine stage[16] $= \eta_{HP} = 95.25\%$
- $Efficiency\ of\ IP\ turbine\ stage$[16] $= \eta_{IP} = 96.9\%$
- $Efficiency\ of\ LP\ turbine\ stages$[16] $= \eta_{LP} = 98.8\%$
- $Overall\ efficiency\ of\ combined\ turbine\ rotor = \eta_{Turbine}$

$$\eta_{Turbine} = \eta_{HP} \times \eta_{IP} \times \eta_{LP}$$

$$\eta_{Turbine} = 95.25\% \times 96.9\% \times 98.8\% = 91.19\%$$

$$\begin{matrix} Generator\ shaft\ inlet\ power \\ @\ rated\ power \end{matrix} = \frac{300\ MW}{\eta_{Generator}} = \frac{300\ MW}{0.9925} = 302.27\ MW$$

$$Power\ extraction\ @300\ MW = P_{HP@300MW} : P_{IP@300MW} : 2 \times P_{LP@300MW}$$

$$= 302.27 \times 0.2410 : 302.27 \times 0.2712 : 2 \times 302.27 \times 0.2439$$

$$= 72.85\ MW : 81.98\ MW : 147.45\ MW$$

- Boiler operation conditions @ 300 MW capacity

$$Boiler\ main\ steam\ pressure^{[16]} = 16.7\ MPa$$

$$Boiler\ main\ steam\ temperature^{[16]} = 538\ ℃$$

- Calculation for required steam capacity through HP turbine

$P = \dot{m} \times \Delta h$; Where P – power in kW

$\dot{m}$ – steam flow rate in kg/s

Δh – enthalpy difference in kJ/kg

$$P_{HP@300MW} = \dot{m}_{HP@300MW} \times (h_{1@300MW} - h_{2@300MW})$$

$$72.85 \times 10^3\ kW = \dot{m}_{HP@300MW} \times (3396.9 - 3048.9)\ {}^{kJ}/_{kg}$$

$$\dot{m}_{HP@300MW} = 211.78\ {}^{kg}/_{s} = 762.24\ {}^{T}/_{h}$$

- Calculation for required steam capacity through IP turbine

$$P_{IP@300MW} = \dot{m}_{IP@300MW} \times (h_{3@300MW} - h_{4@300MW})$$

$$81.98 \times 10^3\ kW = \dot{m}_{IP@300MW} \times (3535.9 - 3168.7)\ {}^{kJ}/_{kg}$$

$$\dot{m}_{IP@300MW} = 223.26\ {}^{kg}/_{s} = 803.72\ {}^{T}/_{h}$$

- Calculation for required steam capacity through LP turbines

$$2 \times P_{LP@300MW} = \dot{m}_{LP@300MW} \times (h_{5@300MW} - h_{6@300MW})$$

$$147.45 \times 10^3\ kW = \dot{m}_{LP@300MW} \times (3168.7 - 2368.6)\ {}^{kJ}/_{kg}$$

$$\dot{m}_{LP@300MW} = 184.29\ {}^{kg}/_{s} = 663.44\ {}^{T}/_{h}$$

Step 02:- Calculation for required steam capacities through turbines at 289.22 MW

$$Generator\ shaft\ inlet\ power\ @\ 289.22\ MW = \frac{289.22\ MW}{\eta_{Generator}} = \frac{289.22\ MW}{0.9925} = 292.19\ \text{MW}$$

$$Power\ extraction\ @289.22MW = P_{HP@289.22MW} : P_{IP@289.22MW} : 2 \times P_{LP@289.22MW}$$

$$= 292.19 \times 0.2410 : 292.19 \times 0.2712 : 2 \times 292.19 \times 0.2439$$

$$= 70.42\ MW : 79.24\ MW : 142.53\ MW$$

- Boiler operation conditions @ 289.22 MW capacity

$Boiler\ main\ steam\ pressure$[16] $= 16.7\ MPa$

$Boiler\ main\ steam\ temperature$[16] $= 538\ ℃$

- Calculation for required steam capacity through HP turbine

$$P_{HP@289.22MW} = \dot{m}_{HP@289.22MW} \times (h_{1@289.22MW} - h_{2@289.22MW})$$

$$70.42 \times 10^3\ kW = \dot{m}_{HP@289.22MW} \times (3396.9 - 3048.9)\ {}^{kJ}/_{kg}$$

$$\dot{m}_{HP@289.22MW} = 200.35\ {}^{kg}/_{s} = 721.26\ {}^{T}/_{h}$$

- Calculation for required steam capacity through IP turbine

$$P_{IP@289.22MW} = \dot{m}_{IP@289.22MW} \times (h_{3@289.22MW} - h_{4@289.22MW})$$

$$79.24 \times 10^3\ kW = \dot{m}_{IP@289.22MW} \times (3535.9 - 3168.7)\ {}^{kJ}/_{kg}$$

$$\dot{m}_{IP@289.22MW} = 210.79\ {}^{kg}/_{s} = 758.84\ {}^{T}/_{h}$$

- Calculation for required steam capacity through LP turbines

$$2 \times P_{LP@289.22MW} = \dot{m}_{LP@289.22MW} \times (h_{5@289.22MW} - h_{6@289.22MW})$$

$$142.53 \times 10^3\ kW = \dot{m}_{LP@289.22MW} \times (3168.7 - 2368.6)\ {}^{kJ}/_{kg}$$

$$\dot{m}_{LP@289.22MW} = 178.14\ {}^{kg}/_{s} = 641.3\ {}^{T}/_{h}$$

Step 03:- Calculation for excessive steam capacities through turbines

$$Excessive\ steam\ capacities\ through\ a\ turbine = \dot{m}_{@300\text{MW}} - \dot{m}_{@289.22\text{MW}}$$

$$\therefore Excessive\ steam\ capacities\ through\ HP\ turbine = \dot{m}_{\text{Ex.steam@HP}}$$

$$\dot{m}_{\text{Ex.steam@HP}} = \dot{m}_{\text{HP@300MW}} - \dot{m}_{\text{HP@289.22MW}}$$

$$\dot{m}_{\text{Ex.steam@HP}} = (211.78 - 200.35)\ {}^{kg}/_{s}$$

$$\dot{m}_{\text{Ex.steam@HP}} = 11.43\ {}^{kg}/_{s}$$

$$\therefore Excessive\ steam\ capacities\ through\ IP\ turbine = \dot{m}_{Ex.steam@IP}$$

$$\dot{m}_{Ex.steam@IP} = \dot{m}_{IP@300MW} - \dot{m}_{IP@289.22MW}$$

$$\dot{m}_{Ex.steam@IP} = (223.26 - 210.79)\ {}^{kg}/_{s}$$

$$\dot{m}_{Ex.steam@IP} = 12.74\ {}^{kg}/_{s}$$

$$\therefore Excessive\ steam\ capacities\ through\ LP\ turbines = \dot{m}_{Ex.steam@LP}$$

$$\dot{m}_{Ex.steam@LP} = \dot{m}_{LP@300MW} - \dot{m}_{LP@289.22MW}$$

$$\dot{m}_{Ex.steam@LP} = (184.29 - 178.14)\ {}^{kg}/_{s}$$

$$\dot{m}_{Ex.steam@LP} = 6.15\ {}^{kg}/_{s}$$

Step 04:- Calculation for power potential of steam sources

Table 4.4.8 : Calculation summary of power potential for steam sources

Steam source	Excessive steam capacity (kg/s)	Enthalpy of source (kJ/kg)	Enthalpy of discharge condition* (kJ/kg)	Power potential of the source(MW) $P = \dot{m} \times \Delta h$
Extraction -1 (Inlet of HPT)	11.43	3396.9	2368.6	11.75
Extraction -2 (Cold Re-heater)	11.43	3048.9	2368.6	7.78
Extraction -2 (Hot Re-heater)	12.74	3535.9	2368.6	14.88
Extraction -2 (Outlet of IPT)	6.51	3168.7	2368.6	5.21

*Assume the steam discharge condition is equal to condenser condition

- Wind power potential associated to the site of NCPP

Wind turbine details of some wind power farms which are operated in Norochcholai area are mentioned in the Table 4.9 [56].

Table 4.4.9 : Wind turbine details of some wind power farms in Norochcholai

Wind farm	Made	Capacity (MW)	Hub height (m)	Rotor diameter (m)
Daily Life Energy	Re-Gen (Germany)	1.5	85	82
Nirmalapura	Re-Gen (Germany)	1.5	88	80
PowerGen	LiteWind	1.25	65	77

As discussed in literature review, longitudinal gap and transverse gap in between tow wind turbine is very important when installing several wind turbines in a wind farm. As a standard, required longitudinal gap and transverse gap are as below [56].

- Longitudinal gap ≥ 2.5 ×Rotor diameter
- Transverse gap ≥ 10 ×Rotor diameter

Assume that the wind turbine type which is used in “Daily Life Energy” wind farm is selected for calculation of site available power potential applicable to Norochcholai power plant;

$$\text{Longitudinal gap between 2 wind turbines} = 2.5 \times 82 \text{ m} = 205 \text{ m}$$

$$\text{Transverse gap between 2 wind turbines} = 10 \times 82 \text{ m} = 820 \text{ m}$$

According to the dimensions of the site in Norochcholai power plant, most suitable placement of these wind turbines are marked in Figure 4.6. Eleven numbers of wind turbines can be installed as fulfilled gap requirements.

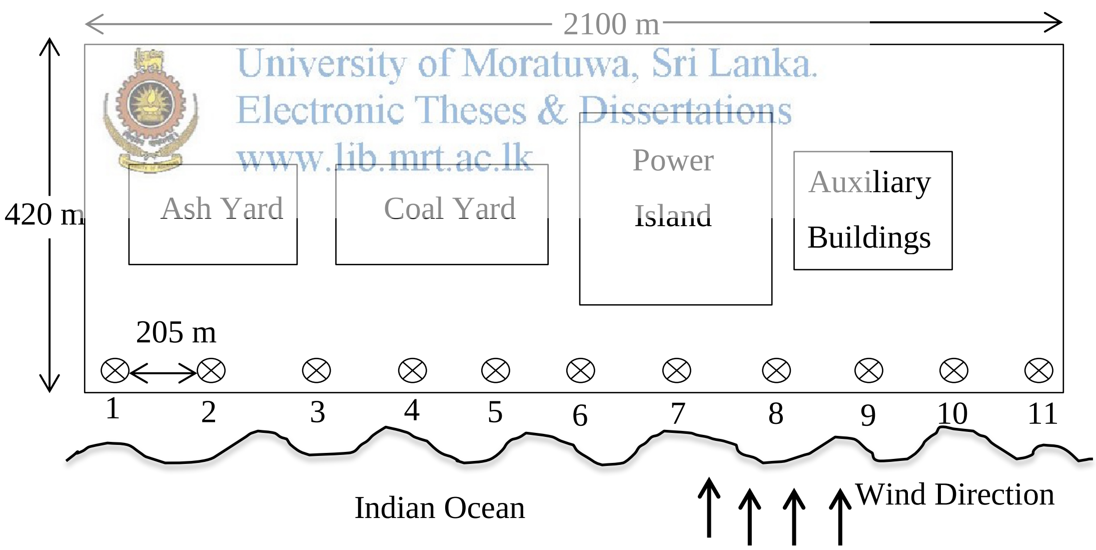


Figure 4.4.6 : Placement of wind turbine in site of Norochcholai power plant

➢ Power potential of sea wave associated to the site of NCPP

According literature review, energy density of sea waves is depended on depth of the sea [40]. See Figure 4.7.

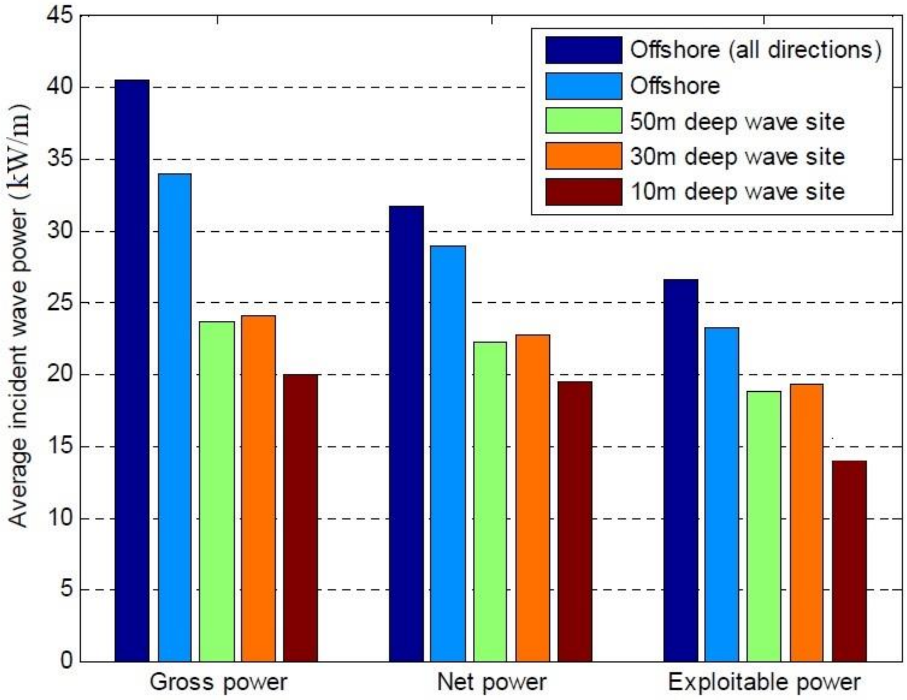


Figure 4.4.7 : Power potential variation with depth of the shore

Source: http://www.aquamarinepower.com/sites/resources

- Sea depth near the Norochcholai power plant is varying from 8 m to 12 m [57]. As an average, 10 m depth can be expected in the sea near the power plant.

$$\therefore\ Exploitable\ power\ @\ 10m\ depth^{[41]} \qquad = 13.5\ {}^{kW}/_{m}$$

- Length of the shore facing to Norochcholai site is 2100 m [50].

$$\therefore\ Exploitable\ power\ near\ the\ Norochcholai\ site = 13.5\ {}^{kW}/_{m} \times 2100\ m$$

$$\therefore\ Exploitable\ power\ near\ the\ Norochcholai\ site = 28{,}350\ kW \quad = 28.35\ MW$$

- Optimal overall efficiency of existing wave power mechanisms is nearly 35% [47].

$$\therefore\ Site\ available\ wave\ power\ potential\ = 28.35\ MW \times \frac{35}{100} = 9.92\ MW$$

➢ Power potential of sea wave associated to the site of NCPP

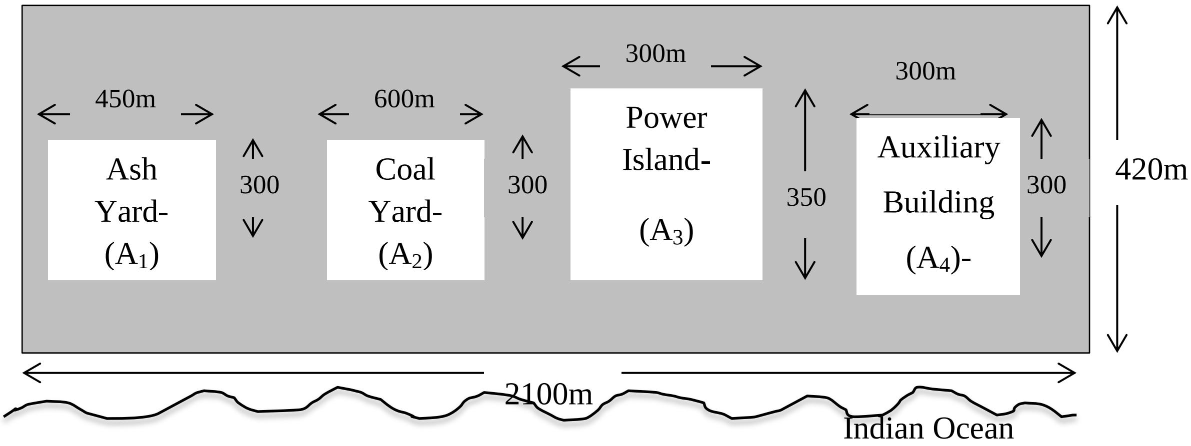


Figure 4.4.8 : Building utilisation in site of Norochcholai power plant

- Effective $area\ for\ installation\ of\ solar\ collectors = A_{Total} - A_1 - A_2 - A_3 - A_4$

$$= 882{,}000\ m^2 - 135{,}000\ m^2 - 180{,}000\ m^2 - 105{,}000\ m^2 - 90{,}000\ m^2$$

$$= 372{,}000\ m^2 = 0.37\ km^2$$

➢ Most suitable solar energy extraction method for locations which are not fully bared as well as area less than 1 km^2 is tilted photovoltaic cells system. Other methods are comparatively required huge area [48].

- $Solar\ potential\ at\ latitude^{[44]} = 5.5 - 6.0\ {kWhr}/{\frac{m^2}{day}} = 0.23 - 0.25\ {kW}/{m^2}$

$$Average\ solar\ potential = \frac{0.2 + 0.25\ {kW}/{m^2}}{2} = 0.24\ {kW}/{m^2}$$

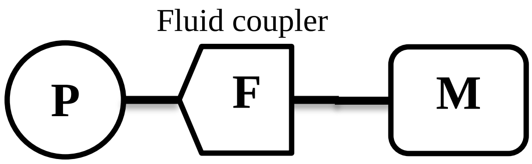
$$= 89{,}280\ kW = 89.28\ MW$$

- Although the general efficiency of photovoltaic cells is around 10% to 12%, it can be increased up to 15% by using solar tracking mechanism [48].

$$\therefore\ Site\ available\ solar\ power\ potential = 89.28\ MW \times \frac{15}{100} = 13.39\ MW$$

4.4.6 Existing power demand of BFP motor in NCPP

- According to the equipment design description, power capacity of 4.87 MW is consumed by 1 BFP at plant rated power condition [13].
- Efficiency of variable speed fluid coupler is 94.1% [14].



$$Required\ power\ for\ BFP\ = 4.87\ MW$$

$$Power\ demand\ by\ BFP\ motor = \frac{Required\ power\ for\ BFP}{Efficiency\ of\ fluid\ coupler} \times 100$$

$$= \frac{4.87\ MW}{94.1} \times 100 = 5.28\ MW$$

4.4.7 Equivalent power potential of alternatives to BFP's operation

- Required equivalent power for mechanical power source

  Due to using of mechanical linkage to power transfer, it is not possible to calculate the equivalent requirement for mechanical power sources in Norochcholai power plant.

- Required power for BFPs through superheated steam sources
  - General equipment arrangement of this method is shown in Figure 4.9.

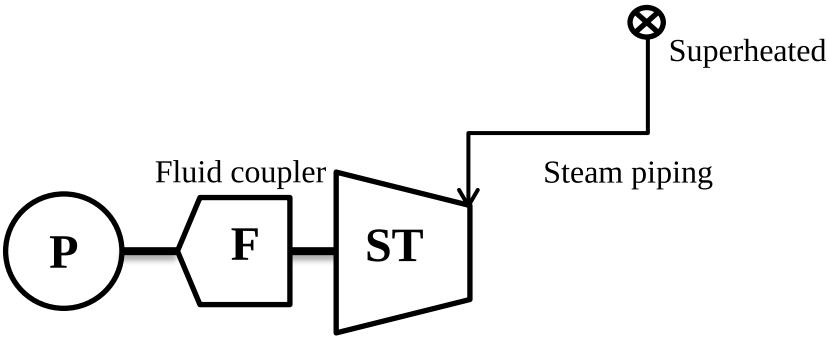


Figure 4.4.9 : Equipment arrangement for BFP operation with steam source

- Industrially available 5 MW turbines and their characteristics are shown in Table 4.10.

Table 4.4.10 : 5 MW turbine and characteristics which are used in industry

Manufacture	Inlet Condition						Efficiency(η)
	Pressure		Unit	Temperature		Unit	
	From	To		From	To		
Kawasaki[23]	31	81	bar(a)				87.5%
Kessels [23]	32	65	bar(a)	380	440	C	84%
	19.5	21	bar(a)	-	336	C	90.8%
Siemens [63]	-	131	bar(a)	-	530	C	96.3%
Marc [23]	-	90	bar(a)	-	500	C	93.5%
GE[65]	-	170	bar(a)	-	565	C	97.8%

- Distance from steam tapping points (under main turbine casing) to boiler feed pump is nearly 35 m. See the drawing (F-5222S-J0201-06) in appendix C.
- If small turbine which is manufactured by General Electric Company is selected as prime mover of feed pump, efficiency of steam turbine is 97.8%. (See Table 4.10)

$$\begin{matrix} Required\ power\ @\ inlet \\ of\ steam\ turbine \end{matrix} = \frac{Required\ power\ for\ Fluid\ coupler}{Efficiency\ of\ steam\ turbine} \times 100$$

$$= \frac{5.28\ MW}{97.8} \times 100 = 5.4\ MW$$

Step 01:- Calculation for required power when using a steam turbine with steam source #1

$$Required\ steam\ rate\ from\ source\ \#1 = \frac{Required\ power\ @\ inlet\ of\ steam\ turbine}{(h_{@source\#1} - h_{@Condenser\ inlet})}$$

$$= \frac{5.4 \times 10^3\ kW}{(3396.9 - 2368.6)\ {}^{kJ}/_{kg}}$$

$$= 5.25\ {}^{kg}/_{s} = 18900\ {}^{kg}/_{hr}$$

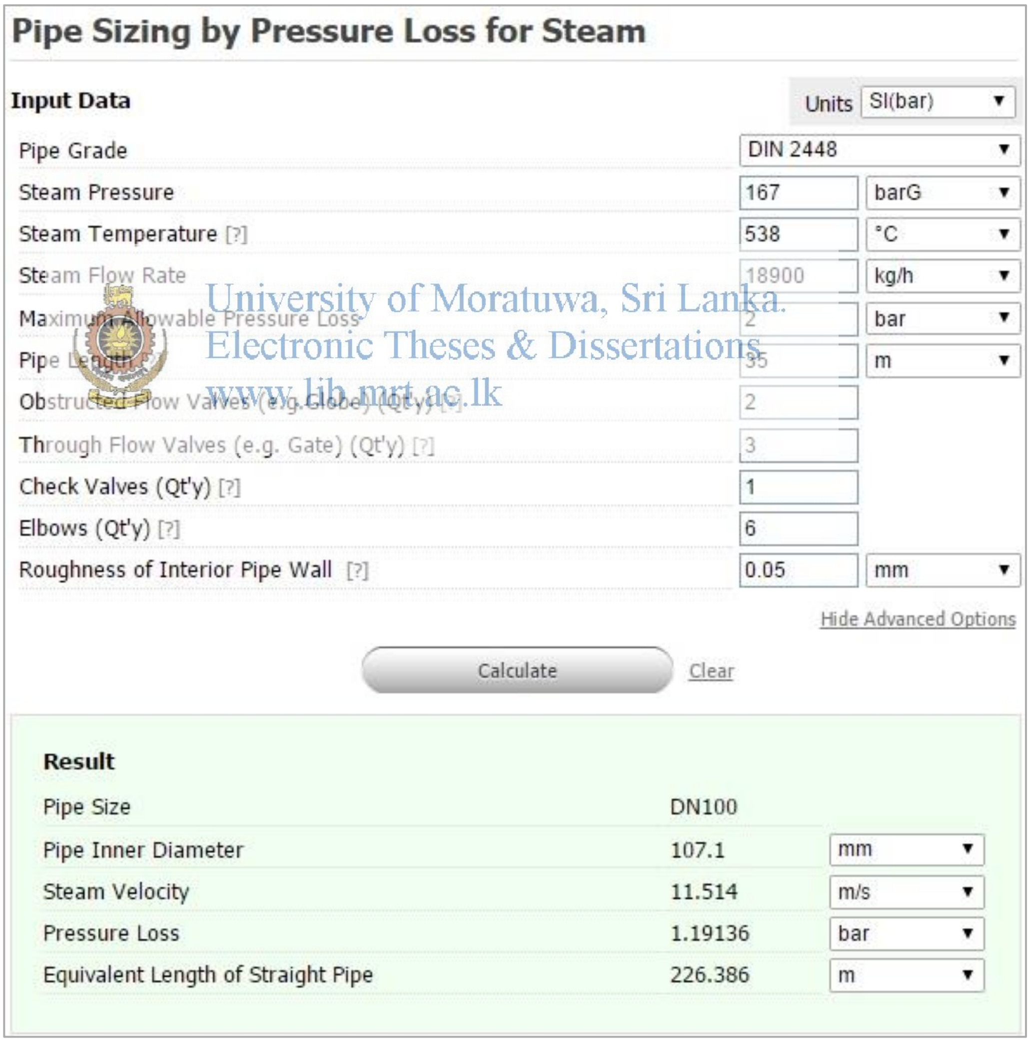


Figure 4.4.10 : Inputs & results for pipe sizing by pressure loss for source #1

- TLV Company in Kakogawa City, Japan has provided a facility for designing pipe and duct system by using engineering calculator [58]. Calculation for pipe sizing by pressure loss is done using TLV engineering calculator and relevant inputs and results are shown in Figure 4.10.
- Pressure loss in steam pipe is 1.19 bars and equivalent power loss is calculated as bellow.

$$Steam\ pressure\ @\ turbine\ inlet = Source\ pressure - pressure\ loss\ in\ pipe$$
$$= 167\ bar - 1.19\ bar$$
$$= 165.81\ bar = 16.58\ MPa$$

$$Equivalent\ power\ loss\ in\ pipe = \dot{m}_{@\ source\#1} \times \left(h_{@16.58MPa,538^oC} - h_{@16.7MPa,538^oC}\right)$$
$$= 5.25\ {}^{kg}/_{s} \times (3398.28 - 3396.9)\ {}^{kJ}/_{kg}$$
$$= 7.25\ kW = 0.007\ MW$$

$$\therefore Required\ power\ for\ 1\ BFP\ @\ source\ \#1 = 5.4\ MW + .007\ MW$$
$$= 5.407\ MW$$

$$\therefore Required\ power\ for\ 2\ BFPs\ @\ source\ \#1 = 5.407\ MW \times 2 = 10.814\ MW$$

<u>Step 02</u>:- Calculation for required power when using a steam turbine with steam source #2

$$Required\ steam\ rate\ from\ source\ \#2 = \frac{Required\ power\ @\ inlet\ of\ turbine}{(\ h_{@source\#2} - h_{@condenser\ inlet})}$$
$$= \frac{5.4 \times 10^3\ kW}{(3048.9 - 2368.6)\ {}^{kJ}/_{kg}}$$
$$= 7.94\ {}^{kg}/_{s} = 28584\ {}^{kg}/_{hr}$$

- Calculation for pipe sizing by pressure loss is done using TLV engineering calculator and relevant inputs and results are shown in Figure 4.11.

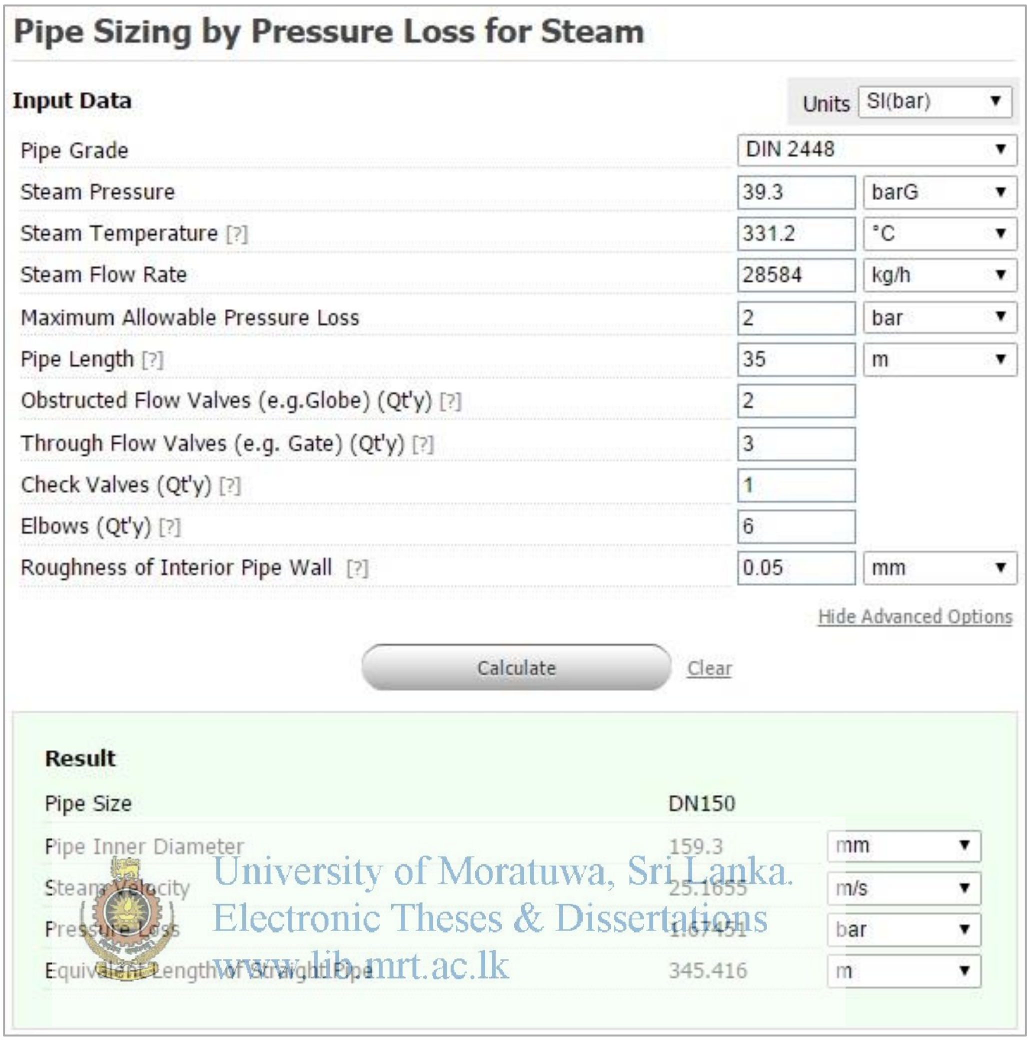


Figure 4.4.11 : Inputs & results for pipe sizing by pressure loss for source #2

- Pressure loss in steam pipe is 1.67 bars and equivalent power loss is calculated as bellow.

$$Steam\ pressure\ @\ turbine\ inlet = Source\ pressure - pressure\ loss\ in\ pipe$$

$$= (39.3\ bar - 1.67\ bar) = 37.63\ bar$$

$$= 3.76\ MPa$$

$$Equivalent\ power\ loss\ in\ pipe = \dot{m}_{@\ source\#2} \times \left(h_{@3.76MPa,331.2^oC} - h_{@3.93MPa,331.2^oC}\right)$$

$$= 7.94\ {}^{kg}/_{s} \times (3053.33 - 3048.9)\ {}^{kJ}/_{kg}$$

$$= 35.17\ kW = 0.035\ MW$$

$$\therefore Required\ power\ for\ 1\ BFP\ @\ source\ \#2 \quad = (5.4\ MW + .035\ MW) = 5.435\ MW$$

$$\therefore Required\ power\ for\ 2\ BFPs\ @\ source\ \#2 \ = 5.435\ MW \times 2 = 10.87\ MW$$

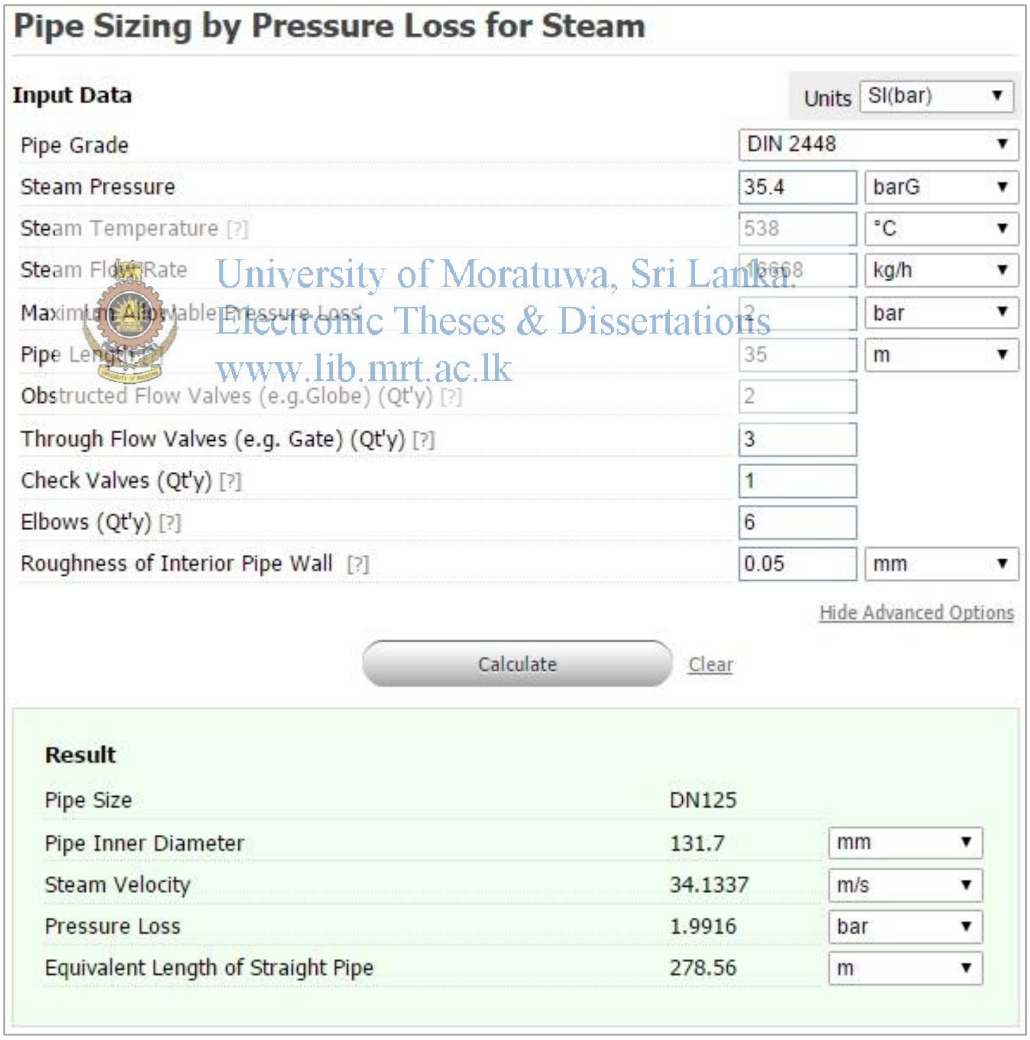
Step 03:- Calculation for required power when using a steam turbine with steam source #3

$$Required\ steam\ rate\ from\ source\ \#3 = \frac{Required\ power\ @\ inlet\ of\ turbine}{(h_{@source\#3} - h_{@condenser\ inlet})}$$

$$= \frac{5.4 \times 10^{3}\ kW}{(3535.9 - 2368.6)\ {}^{kJ}/_{kg}}$$

$$= 4.63\ {}^{kg}/_{s} = 16668\ {}^{kg}/_{hr}$$

- Calculation for pipe sizing by pressure loss is done using TLV engineering calculator and relevant inputs and results are shown in Figure 4.12.



Pipe Sizing by Pressure Loss for Steam

Input Data — Units: SI(bar)

Pipe Grade	DIN 2448	
Steam Pressure	35.4	barG
Steam Temperature [?]	538	°C
Steam Flow Rate	16668	kg/h
Maximum Allowable Pressure Loss	2	bar
Pipe Length	35	m
Obstructed Flow Valves (e.g.Globe) (Qt'y) [?]	2	
Through Flow Valves (e.g. Gate) (Qt'y) [?]	3	
Check Valves (Qt'y) [?]	1	
Elbows (Qt'y) [?]	6	
Roughness of Interior Pipe Wall [?]	0.05	mm

Hide Advanced Options

Calculate Clear

Result

Pipe Size	DN125	
Pipe Inner Diameter	131.7	mm
Steam Velocity	34.1337	m/s
Pressure Loss	1.9916	bar
Equivalent Length of Straight Pipe	278.56	m

Figure 4.4.12 : Inputs & results for pipe sizing by pressure loss for source #3

- Pressure loss in steam pipe is 1.99 bars and equivalent power loss is calculated as bellow.

$$Steam\ pressure\ @\ turbine\ inlet = Source\ pressure - pressure\ loss\ in\ pipe$$

$$= 35.4\ bar - 1.99\ bar$$

$$= 33.41\ bar = 3.34\ MPa$$

$$Equivalent\ power\ loss\ in\ pipe = \dot{m}_{@\ source\#3} \times \left(h_{@3.34MPa,538^oC} - h_{@3.54MPa,538^oC}\right)$$

$$= 4.63\ {}^{kg}/_{s} \times (3537.85 - 3535.9)\ {}^{kJ}/_{kg}$$

$$= 9.03\ kW = 0.009\ MW$$

$$\therefore Required\ power\ for\ 1\ BFP\ @\ source\ \#3 \quad = (5.4\ MW + .009\ MW) = 5.409\ MW$$

$$\therefore Required\ power\ for\ 2\ BFPs\ @\ source\ \#3\ = 5.409\ MW \times 2 = 10.82\ MW$$

Step 04:- Calculation for required power when using a steam turbine with steam source #4

$$Required\ steam\ rate\ from\ source\ \#4 = \frac{Required\ power\ @\ inlet\ of\ turbine}{(h_{@source\#4} - h_{@condenser\ inlet})}$$

$$= \frac{5.4 \times 10^3\ kW}{(3168.7 - 2368.6)\ {}^{kJ}/_{kg}}$$

$$= 6.75\ {}^{kg}/_{s} = 24300\ {}^{kg}/_{hr}$$

- Calculation for pipe sizing by pressure loss is done using TLV engineering calculator and relevant inputs and results are shown in Figure 4.13.

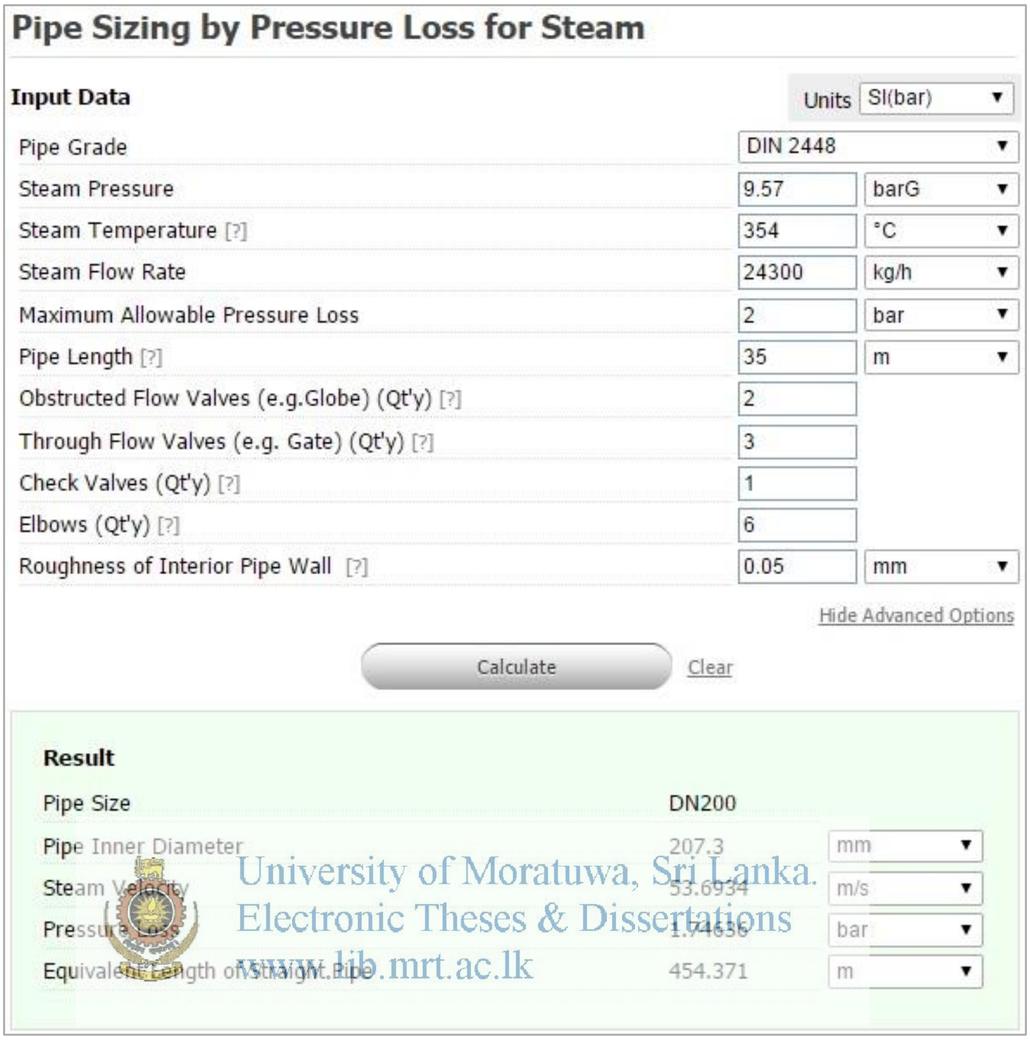


Figure 4.4.13 : Inputs & results for pipe sizing by pressure loss for source #4

- Pressure loss in steam pipe is 1.75 bars and equivalent power loss is calculated as bellow.

$$Steam\ pressure\ @\ turbine\ inlet = Source\ pressure - pressure\ loss\ in\ pipe$$

$$= 9.57\ bar - 1.75\ bar$$

$$= 7.82\ bar = 0.782\ MPa$$

$$Equivalent\ power\ loss\ in\ pipe = \dot{m}_{@\ source\#4} \times \left(h_{@0.782MPa,354^oC} - h_{@0.957MPa,354^oC}\right)$$

$$= 6.75\ {}^{kg}/_{s} \times (3172.13 - 3168.7)\ {}^{kJ}/_{kg}$$

$$\therefore Required\ power\ for\ 1\ BFP\ @\ source\ \#4\ = (5.4\ MW + .023\ MW) = 5.423\ MW$$

$$\therefore Required\ power\ for\ 2\ BFP\ @\ source\ \#4\ = 5.423\ MW \times 2 = 10.85\ MW$$

Step 05:- Summarisation for equivalent required power potential when using steam source with a steam turbine and steam piping

Table 4.4.11 : Required power for operation of 2BFPs from each source point

Superheated steam source	Required power for 2 BFP from source (MW)
Extraction -1 (Inlet of HP turbine)	10.81
Extraction -2 (Cold Re-heater)	10.87
Extraction -2 (Hot Re-heater)	10.82
Extraction -2 (Outlet of IP turbine)	10.85

- Required equivalent power potential for BFP operation through wind power
  - Between the two ways of power transferring, mechanical power extraction mechanisms are difficult to implement for the existing power plant due disturbance of structures and equipment. Therefore the most suitable way is transferring power through conductors.
  - Equipment arrangement of this method is shown in Figure 4.14.

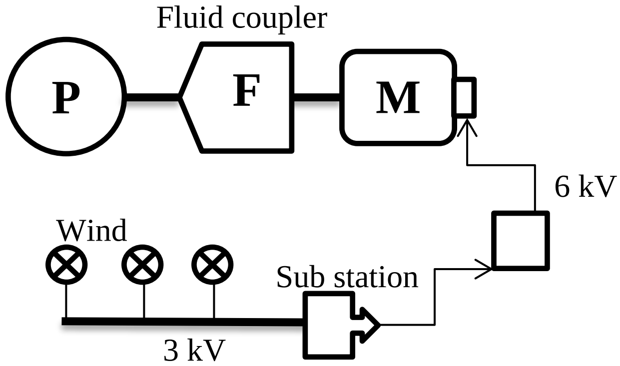


Figure 4.4.14 : Equipment arrangement for BFP operation with wind source

- Efficiency of motor of BFP in NCPP is 98% [13].
- Efficiency of step-up transformer is 98.7% [13].

$$\therefore Required\ power\ for\ motor = \frac{Required\ power\ for\ Fluid\ coupler}{Efficiency\ of\ motor} \times 100$$

$$Required\ power\ for\ motor = \frac{5.28\ MW}{98} \times 100 = 5.39\ MW$$

- Most appropriate place for substation near the 7th wind tower which is mentioned in Figure 4.6 due to closeness to the power island.
- By using online electric loss calculator which is facilitated by Photovoltaic & solar electricity design company, power losses from wind turbines to transformer as well as power losses from transformer to motor can be calculated [60].

✓ If the wind turbine type which is used in "Daily Life Energy" wind farm is selected, output parameters of generator are shown in Table 4.12.

Table 4.4.12 : Output parameter for generator of Re-Gen wind turbine

Parameter	Value	Unit
Power supply type	3 phase AC	--
Voltage	3000	V
Current	340	A
Power factor	0.85	--
Power	1500000	W

✓ Parameters of supplied power for motor of BFP are shown in Table 4.13.

Table 4.4.13 : Parameter of supplied power to BFP motors in Norochcholai

Parameter	Value	Unit
Power supply type	3 phase AC	--
Voltage	6000	V
Current	610	A
Power factor	0.85	--
Power	5390000	W

✓ Required length of cables from substation to motor is nearly 500 m. See Figure 4.6.

✓ Armed 3 core copper cables with 400 mm^2 are selected [61].

Step 01:- Calculation for power losses from motor to transformer

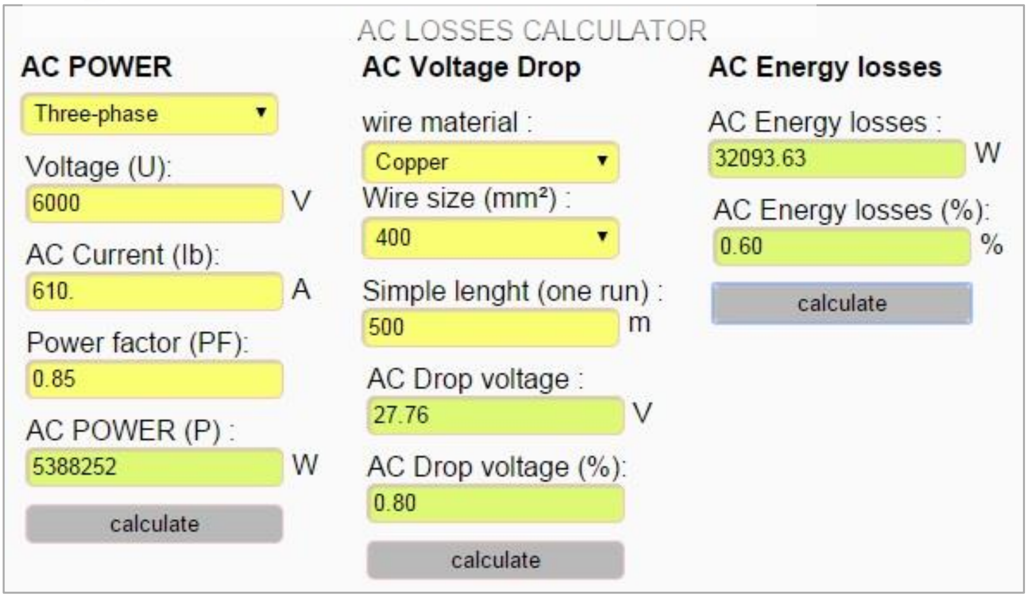


Figure 4.4.15 : Screen shot of loss calculator for cabling from motor to TF

Calculation for power losses from motor to transformer is done using electric loss calculator [60] and relevant inputs and results are shown in Figure 4.15.

$$\therefore Power\ losses\ from\ motor\ to\ transformer = 32093.63\ W = 0.032\ MW$$

Step 02:- Calculation for power losses through the transformer

$$Power\ losses\ @\ transformer = Operating\ power\ through\ TF \times \frac{(100 - \eta_{Tf})}{100}$$

$$= (5.39\ MW + 0.032\ MW) \times \frac{(100 - 98.7)}{100}$$

$$= 5.42\ MW \times 0.013 = 0.07\ MW$$

Step 03:- Calculation for power losses from transformer to wind turbines

Required length of cables, cable size and calculated percentages of power losses from each wind turbines to substation are summarised in Table 4.14. Estimating the cable lengths is done base on Figure 4.6 and relevant power losses are calculated using electric loss calculator [60].

Table 4.4.14 : Summary of cable details and percentage losses from TF to WTB

Wind turbine	Required cable length (m)	Cable size (mm^2)*	Percentage of power loss (%)**
1	1280	300	2.27
2	1075	240	2.38
3	870	150	3.08
4	665	120	2.94
5	460	120	2.04
6	255	120	1.13

Wind turbine	Required cable length (m)	Cable size (mm^2)*	Percentage of power loss (%)**
7	50	120	0.22
8	255	120	1.13
9	460	120	2.04
10	665	120	2.94
11	870	150	3.08

*Armed 3 core copper cables are selected[61]

** Electric loss calculator [60]

$$\text{Transformer } power\ input = 5.42\ MW + 0.07\ MW = 5.5\ MW$$

- Assume that the 5.42 MW is equally given by 11 wind towers.

$$\text{Power } supply\ to\ transformer\ \ by\ 1\ wind\ turbine = \frac{5.5\ MW}{11} = 0.5\ MW$$

- Power losses from transformer to each wind turbines are calculated using electric loss calculator and calculated power losses are summarised in Table 4.15.

Table 4.4.15 : Summary of losses in each cable from TF to WTB

Wind turbine	1	2	3	4	5	6	7	8	9	10	11	Total
Power Loss (MW)	0.03	0.04	0.05	0.04	0.03	0.02	0	0.02	0.03	0.04	0.05	0.35

$$\therefore Power\ losses\ from\ motor\ to\ transformer \quad = 0.35\ MW$$

- Required $power\ for\ 1\ BFP\ by\ wind\ turbines \ = (5.39 + 0.032 + 0.07 + 0.35) MW$

  $= 5.84\ MW$

- Required $power\ for\ 2\ BFP\ by\ wind\ turbines \ = 5.84\ MW \times 2 = 11.68\ MW$

- Required equivalent power potential for BFPs through sea wave energy
  - Energy transferring ways are almost same to the application which is used for energy transferring in wind power sources.
  - As usual, mechanical power extraction mechanisms are difficult to implement for existing power plant due disturbance of structures and equipment. Except cabling from generator of sea wave energy extractor to transformer, all other equipment and cable selections are equal to previous case.
  - Assume that the output voltage of generator is stepped-up directly to 6 KV.
  - Equipment arrangement of this method is shown in Figure 4.16.

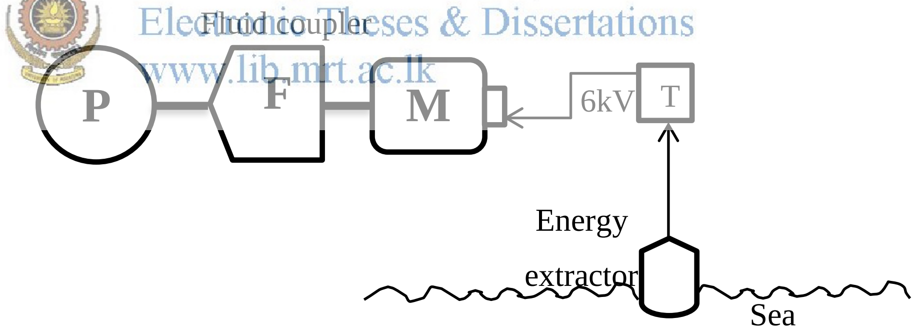


Figure 4.4.16 : Equipment arrangement for BFP operation with Sea wave energy

Required $power\ for\ 1\ BFP\ from\ sea\ waves \ = (5.39 + 0.032 + 0.07) MW$

$= 5.5\ MW$

$$\therefore Required\ power\ for\ 2\ BFP\ from\ sea\ waves \ = 5.5\ MW \times 2 = 11\ MW$$

➢ Required equivalent power potential for BFP operation through solar energy

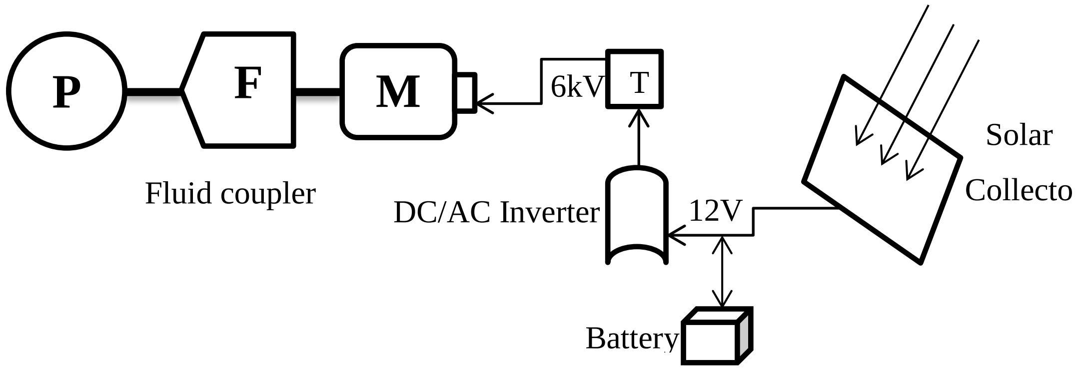


Figure 4.4.17 : Equipment arrangement for BFP operation with solar power

In this mechanism, all equipment from BFP to transformer is almost similar to the previously discussed equipment arrangement. Therefore 5.5 MW power can be taken as the input requirement for the transformer. The general equipment arrangement of this method is shown in Figure 4.17.

- Efficiency of DC to AC converter is 97.5% [48]

$$Power\ loss\ @\ inverter = supply\ power\ to\ TF \times \frac{(100 - \eta_{Inverter})}{100}$$

$$= 5.5\ MW \times \frac{(100 - 97.5)}{100} = 0.14\ MW$$

$$Required\ power\ for\ 1\ BFP\ from\ solar\ source = 5.5\ MW + 0.14\ MW$$

$$= 5.64\ MW$$

$$\therefore Required\ power\ for\ 2\ BFP\ from\ solar\ source = 5.64\ MW \times 2 = 11.28\ MW$$

4.4.8 Satisfaction of BFP power requirement

Table 4.4.16 : Summary of BFP power satisfaction in NCPP

Power source		Site available power potential (MW)	Required power potential for BFP (MW)	Satisfactory Level
Mechanical Power sources		11.75	----	----
Super-heated steam sources	Extraction -1	11.75	10.814	Satisfied
	Extraction -2	7.78	10.87	Not enough
	Extraction -3	14.88	10.82	Satisfied
	Extraction -4	5.21	10.85	Not enough
Wind power source		16.5	11.68	Satisfied
Sea waves		9.92	11	Not enough
Solar power		13.39	11.28	Satisfied

4.4.9 Implementation cost related to the alternatives in NCPP

- Implementation cost for mechanical source

  Due to using of mechanical linkage to power transfer, it is extremely difficult to transfer power. It needs total design change on MPB in NCPP. Therefore implementation cost mechanical sources are not estimated.

- Implementation cost for superheated steam sources
  - Details of selected steam turbine.

  If the SST-060 steam turbine of AFA series which is manufactured by Siemens Power Company is selected as the prime moving steam turbines for Norochcholai coal power plant, relevant technical specifications of the pump are mention in Table 4.17 [63].

Table 4.4.17 : Technical specifications of SST-060 ST by Siemens

Specification	Value	Unit
Type	Compact set	
Length	2.5	m
Width	1.5	m
Height	2.5	m
Overall weight	22.4	T
Max. power output	6	MW
Operating pressure range	13.1-17	MPa
Operating temperature range	530-548	^{o}C

<u>Step 01</u>: - Cost calculation for new basements

- Applied load for the basement is approximately 22.5 T
- Required detentions for basement = 2.75 m X 1.75 m X 0.9 m with premix concrete class S3-122 and reinforcement class EN 10138-4 [68].
- Cost for class S3-122 premixed concrete = 43,875 US$/m3 [64].
- Cost for reinforcement class EN 10138-4 = 60,000 US$/m3 [64].

$$Volume\ of\ basement = 2.75\ m \times 1.75\ m \times 0.9\ m = 4.33\ m^3$$

$$\therefore Cost\ for\ premixed\ concrete = 4.33\ m^3 \times 43,875\ {US\$}/{m^3}$$

$$= US\$\ 0.19\ M$$

$$\therefore Cost\ for\ reinforcement \quad = 4.33\ m^3 \times 60{,}000\ {}^{US\$}/_{m^3}$$

$$= US\$\ 0.2\ 6\ M$$

$$Total\ cost\ for\ 1\ basement \quad = US\$\ 0.19\ M + US\$\ 0.26\ M$$

$$= US\$\ 0.45\ M$$

Step 02: - Cost calculation for new equipments

- Approximate cost for 5 MW steam turbine set is US$ 1,000,000 [65].

  $$\therefore Cost\ for\ 2 \times 5\ MW\ steam\ tubines = US\$\ 1{,}000{,}000 \times 2 = US\$\ 2M$$

- According to the technical agreement of 3X300 MW Puttalam coal power project, cost estimation of steam and water piping is given per meter length. This cost figures are included cost of pipe material, cost of pipe component (bends, valves, drains and air vents etc.), cost of pipe hangers and supports as well as the cost of the thermal insulation materials. Details of cost estimation for steam and water piping are shown in the Table 4.18 [64].

Table 4.18 : Cost estimation details for steam and water piping in PCPP

Item/Pipe	Unit cost (US$/m)	Units (m)	Total cost (US$ M)
Main steam	52,480	108	5.66
Hot re-heater steam	58,750	120	7.05
Cold re-heater steam	62,300	94.5	5.88
HP bypass steam	42,450	12	0.50
HP/HT extraction steam	27,715	155	4.29
LP/LT extraction steam	19,650	270	5.30

Item/Pipe	Unit cost (US$/m)	Units (m)	Total cost (US$ M)
LP bypass steam	34,350	23.2	0.79
Gland sealing steam	08,500	335	2.84
Auxiliary steam	13,255	415	5.50
Feed water	45,510	278	12.65
De-superheating spray	06,700	390	2.61
Condensate water	32,665	315	10.28

All identified steam sources are extracted through same high pressure and high temperature extractions which are used to heat up regenerative heaters. Therefore the condition of extracted steam for new steam turbine is almost equal to the conditions which are supplied to the regenerative heaters. Based on this circumstance, cost of new steam piping is assumed that similar to rates of cost of HP/HT extraction piping.

$$\therefore Cost\ for\ steam\ piping = Length\ of\ pipe^{[66]} \times Unit\ cost\ rate$$

$$Cost\ for\ steam\ piping = 2 \times 35\ m \times 27{,}715\ {}^{US\$}/_{m} = US\$\ 1.94\ M$$

$$\therefore Total\ implementation\ cost\ = 2 \times C_{Basement} + 2 \times C_{ST} + 2 \times C_{Steam\ piping}$$

$$Total\ implem.cost\ for\ steam\ sources = US\$\ 0.89\ M + US\$\ 2M + US\$\ 1.94\ M$$
$$= US\$\ 4.83\ M$$

- Implementation cost for wind energy sources

  <u>Step 01</u>: - Cost estimation for set of complete wind turbine

  For collection easiness of cost data, equipment and installation cost for complete set of wind turbine can be considered as lump cost. Because there are many wind farms have been installed in Norochcholai area and easily these cost can be found out through their project reports.

- WindForce Energy privet limited has 5 wind farms around Norochcholai area and cost for wind turbines for each wind farms are shown in Table 4.19.

Table 4.4.19 : Cost details of turbines in wind farms around Norochcholai

Wind frame	Turbine capacity(MW)	Numbers of turbines	Cost for wind turbines as lump (US$)	Cost for 1 turbine (US$)
Daily Life Energy	1.5	8	25.000 MM	3.125 MM
Nirmalapura	1.5	7	21.875 MM	3.125 MM
PowerGen	1.25	7	18.228 MM	2.604 MM
Seguwantivu	0.8	12	20.004 MM	1.667 MM
Vidatamunai	0.8	13	22.087 MM	1.699 MM

Source: Project cost forecasting report, 2013, WindForce Energy (Pvt) Limited, Sri Lanka

$$\therefore Required\ power\ for\ 2BFPs\ from\ wind\ turbines = 11.68\ MW$$

- If the wind turbine type which is used in "Daily Life Energy" wind farm is selected,

$$Required\ numbers\ of\ wind\ turbines = \frac{11.68\ MW}{1.5\ MW} = 7.78 \approx 8$$

$$\therefore Lump\ cost\ for\ wind\ turbines = US\$\ 3.125\ M \times 8$$

$$= US\$\ 25\ M$$

Step 02: - Cost for 12.5 MW / 6 kV step-up transformer

- Approximate cost for 12.5 MW / 6 kV step-up transformer is US$ 950,000 [65].

<u>Step 03</u>: - Cost for Cabling from transformer to wind turbines

- According to the agreement of 3X300 MW Puttalam coal power project, cost estimation of armed 3 core power cabling is scheduled per meter length. This cost figures are included cost of cable, cost of electric auxiliary equipment (cable lug and isolators etc.), and cost of cable laying. Details of cost estimation for power cabling are shown in the Table 4.20 [64].

Table 4.4.20 : Cost estimation details for power cabling - PCPP

Cable Size (mm^2)	Power cabling cost (US$/m)	
	With cable trenches	**With cable trays**
95	192.3	189.5
120	244.6	239.8
150	310.2	299.7
185	388.7	370.2
240	513.2	480.5
300	652.8	600.0
400	896.0	800.0

- As per the previous calculation 8 numbers of wind turbines are required to supply 11.68 MW.
- Assume the cable trays are used to lay cables
- Location selection for wind turbines related to the Figure 4.6 and power cabling cost from wind turbines to transformer are calculated and summarised in the Table 4.21.

Table 4.4.21 : Summary of the cost for power cabling from WTB to TF

Turbine	Turbine Location	Cable size (mm^2)	Length of cable (m)	Unit cost for cabling (US$/m)	Cabling cost (US$)
1	#3	150	870	299.7	260,782
2	#4	120	665	239.8	159,466
3	#5	120	460	239.8	110,307
4	#6	120	255	239.8	61,149
5	#7	120	050	239.8	11,990
6	#8	120	255	239.8	61,149
7	#9	120	460	239.8	11,0307
8	#10	120	665	239.8	15,9466
				$\boldsymbol{Sub\ total = C_{WT-TF}}$	934,617

<u>Step 03</u>: - Cost for Cabling from transformer to BFPs

$$\text{Cabling } cost\ from\ transformer\ to\ motor\ of\ \ BFP = 800\ ^{US\$}/_{m} \times 500\ m$$

(3 Core, Armed 400 mm^2 cable)

$$= US\$\ 0.4\ M$$

$$\therefore Cabling\ cost\ for\ 2\ Motors = US\$\ 0.4\ M\ \times 2 = US\$\ 0.8\ M$$

Step 04: - Calculation for total implementation cost for wind sources

$$\text{Total } cost\ to\ implimet\ wind\ energy \quad = C_{WT} + C_{WT-TF} + C_{TF} + C_{TF-Motor}$$

$$\therefore Total\ impl.cost -\ wind\ energy \ = US\$(25\ M + 0.93\ M\ + 0.95\ M\ + 0.8\ M\ )$$

$$= US\$\ 27.68\ M$$

$$\therefore Cost\ involvement\ from\ transformer\ to\ motor = C_{TF} + C_{TF-Motor}$$

$$= US\$(0.95\ M + 0.8\ M) = US\$\ 1.75\ M$$

- According to the report of wave power conversion systems for electrical energy production, installation cost of wave energy extractor is 600,000 €/MW [47].

$$\therefore Cost\ for\ extractor = 600{,}000\ {}^{€}/_{MW} \times 11\ MW\ = €\ 6.6\ \text{M}$$

- According to the rates of currency exchange on 07th May 2015,

$$\therefore Cost\ for\ extractor\ in\ USS\$ = 9.32\ \text{M}$$

$$Total\ cost\ to\ implimet\ wave\ energy \quad = C_{Extractor} + [C_{TF} + C_{TF-Motor}]$$

$$= US\$(9.32\ M + 1.75\ M\ )$$

$$= US\$\ 11.07\ M$$

- Implementation cost for solar energy sources
  - According to the report of The Economics of Solar Electricity which was prepared by Erin Baker, Meredith Fowlie, Derek Lemoine, and Stanley Reynolds, installation costs for solar power generation related to the different sites are noted in Table 4.22 [67].

Table 4.4.22 : Installation cost of few solar projects in USA

Location	Panel Orientation	Installed cost (US$/W)
Boston, MA	South- West	6.1
Trenton, NJ	South- West	5.9
Tucson, AZ	South- West	5.2
San Francisco, CA	South- West	6.4

- If the average installed cost of the above sites are taken as the installation cost of solar collector and its auxiliaries, cost for transformer and the cost for the power cabling from transformer to BFP motor are the same as the cost for wind energy and sea wave energy.

$$Average\ installed\ cost\ for\ PV\ collectors = \frac{(6.1 + 5.9 + 5.2 + 6.4)}{4}\ US\$/_W$$

$$= 5.9\ US\$/_W$$

$$\therefore Cost\ for\ solar\ collector\ installation = C_{Solar\ Colle.} = 5.9\ US\$/_W \times 11.28 \times 10^6$$

$$= US\$\ 66.55\ M$$

$$Cost\ involvement\ from\ transformer\ to\ motor = C_{TF} + C_{TF-Motor}$$

$$= US\$(0.95\ M + 0.8\ M) = US\$\ 1.75\ M$$

$$\therefore Total\ cost\ to\ implimet\ solar\ energy = C_{Solar\ Colle.} + [C_{TF} + C_{TF-Motor}]$$

$$= US\$(66.55\ M + 1.75\ M)$$

$$= US\$\ 68.3\ M$$

Table 4.4.23 : Summary of implementation cost in NCPP

Energy source	Implementation cost (US$)
Mechanical Power sources	N/A
Super-heated steam sources with steam turbine	4.83 M
Wind power source + Generator	27.68 M
Sea waves + Generator	11.07 M
Solar power	68.30 M

4.5 Analysing the alternative sources in applicable to the NCPP

There are several alternative power sources such as mechanical power, superheated steam sources, wind power, sea wave energy and solar power sources related to the site of Norochcholai coal power plant which have been identified. When analysing the solutions, it needs to check the feasibility of each alternative source. For this, the previously studied feasibility factors are used. It is more expedient to compare each of the power sources with reference to the discussed feasibility factors in quantitative or qualitative manner.

Table 4.4.24 : Comparison of feasibility factors of alternative power sources

Factor / Power source	Availability	Requirement of design changes	Satisfaction of BFP's demand	Cost (US$)
Mechanical	Excellent	Total design change	- - -	- - -
Steam Ex#1	Excellent	Moderate changes	Satisfied	4.83 M
Steam Ex#2	Excellent	Moderate changes	Not enough	4.83 M
Steam Ex#3	Excellent	Moderate changes	Satisfied	4.83 M
Steam Ex#4	Excellent	Moderate changes	Not enough	4.83 M
Wind	Good	Minor change	Not enough	27.68 M
Sea wave	Average	Minor change	Satisfied	11.07 M
Solar	Average	Minor change	Satisfied	68.30 M

4.6 Selecting the suitable solution for NCPP

The key solution for Norochcholai power plant is selected based on summarised feasibility factors which are mentioned in Table 4.24. When considering the mechanical power sources, power transmission is very difficult although its availability is much higher. Furthermore it needs total design change of the power plant. In the case of utilisation of steam source as an alternative solution, its availability is almost 100% and easiness of power transmission is not difficult as mechanical sources. Even though the potential of some steam extractions are not enough to fulfil the demand of BFPs, extraction #1 and #3 fulfil the demand. Design modification on the power plant in relation to the utilisation of steam sources is not required for total design changes. It needs moderate changes. The most important thing is the requirement of low implementation cost. When considering the wind energy sources, its level of power transmission easiness and requirements for design changes are favourable although it does not fulfilled the demand of BFPs and also the availability of it is not very high. The implementation coast is also a little higher than the cost for utilisation of steam sources or sea wave sources.

Good favourable levels for some feasibility factors such as the easiness of power transmission, requirement of design changes and ability to fulfil the demand of BFPs related to the sea wave power can be seen. Its availability is not at high level, because the BFPs in coal power plant are continuously operated. Therefore the availability of the source is very important. When considering the solar power, its availability is very low although some feasibility factors such as the easiness of power transmission, requirement of design changes and ability to fulfil the demand of BFPs are favourable. The implementation cost for solar power source is comparatively high.

By considering all of the above facts, extraction of steam source #1 and #3 are the most suitable solutions to substitute the electrically operated boiler feed system in the site of Norochcholai power plant.

4.7 Evaluation and justification of the study

Although the steam sources have been selected as the most suitable solution, it is necessary to justify its outcomes and benefits separately for steam extraction #1 and steam extraction #3. To justify the outcomes, it needs a mathematical evaluation in accordance with the Norochcholai power plant.

4.7.1 Argument of the evaluation

- When operating the plant at 300 MW (at plant rated power), 271.8 MW power is supplied to the national grid. 10.78 MW power out of 28.2 MW home load is consumed by motors of boiler feed pumps.
- Therefore 17.42 MW of 28.2MW is consumed by all other auxiliary equipments and 17.42 MW power can be considered as constant at plant rated condition.

- If the grid power requirement does not vary for a certain time period, 271.8 MW power should be supplied by the power plant.
- If the 10.78 MW required power for BFP does not taken from plant generated power and grid power requirement is not vary, simultaneously plant should be de-loaded by 10.78 MW. The boiler operation in out of plant rated condition is a disadvantage financially.
- Therefore during the boiler operation in rated power conditions (at 300 MW), there is some possibility to extract excessive steam through extractions of the turbine, because of the electricity generation by generator is done with lack of 10.78 MW power. Although the generator power output is changed in to 289.22 MW in this scenario, grid connected 271.8 MW power or 17.42 MW power of other auxiliary equipment is not changed
- On this condition, four steam extraction sources have been identified. Source at extraction #1 and extraction #3 satisfy the power requirement of introduced steam turbine of the BFP. This can be clearly identified from Table 4.25.

Table 4.4.25 : Summary of extra steam capacities at 289.22 MW

Steam Source	Available steam capacity (kg/s)	Required steam capacity for BFP (kg/s)	Extra steam capacity (kg/s)
Extraction #1 (Inlet of HPT)	11.43	10.5	0.93
Extraction #3 (Hot Re-heater)	12.74	9.6	3.14

When boiler operates at 300 MW, the generator produces 289.22 MW Power with extractable steam flow of 11.43 kg/s at extraction #1 or steam flow of 12.74 kg/s at extraction #3. These steam flows not only fulfil, but also exceeds the requirement of relevant steam turbine. Extra steam capacities of 0.93 kg/s and 3.14 kg/s are respectively available during these extractions. This extra steam amount can be directly dropped into the condenser. Since the dropping of live steam into condenser is an energy waste, there are two ways which can be applied to take exactly 10.5 kg/s or 9.6 kg/s steam flows through the selected extractions [16].

i. De-loading the boiler with respect to the extra steam capacity of 0.93 kg/s or 3.14 kg/s from boiler rated capacity to little lower capacity.
ii. Increasing the generator output from 289.22 MW to little higher power

As discussed earlier, operation of the boiler in an out rated condition courses considerable economic disadvantages. Therefore increasing the load a little is the only possible way. But there are some limitations to this because it may not be a considerable load increase with respect to the extra steam capacities. Sometimes the power may be negligible. Therefore a further assessment of these results is required although the feed pumps are fully energised by steam sources available at the site. If there is no further gain between the two methodologies of boiler feed pumps energisation, changing the existing mechanism may be a useless attempt.

4.7.2 Evaluation of the outcomes - reference to the steam extraction #1

It is considered that there is no further extra steam availability at extraction #1. Available steam capacity of 10.5 kg/s exactly fulfils the requirement of steam turbine of BFPs. Therefore the amount of 0.93 kg/s steam flow is involved with further power increase to more than 289.22 MW. If $x\ MW$ is considered as the new power output of the main generator, power gain through the main turbine can be calculated with reference to the extra steam quantity of 0.9 kg/s.

$$\dot{m}_{\mathrm{HP@300MW}} - \dot{m}_{HP@xMW} = 10.5\ ^{kg}/_{s}$$

$$211.78\ ^{kg}/_{s} - \dot{m}_{\mathrm{HP@}xMW} = 10.5\ ^{kg}/_{s}$$

$$\therefore \dot{m}_{\mathrm{HP@}xMW} = 201.28\ ^{kg}/_{s}$$

That means, 201.28 kg/s rate of steam flow is expanded through the HP rotor.

$$\begin{matrix} \textit{Power through} \\ \text{HP turbine} \end{matrix} = \begin{matrix} \text{Steam flow rate} \\ \text{through HP turbine} \end{matrix} \times \begin{matrix} \text{Enthalpy difference} \\ \text{through HP turbine} \end{matrix}$$

Except the steam flow rate of turbine inlets, other parameters are not changed in the boiler. Because of the boiler is operated continuously at rated condition.

∴ Boiler operation conditions; [16]

$$Main\ steam\ pressure = 16.7\ MPa$$
$$Main\ steam\ temperature = 538\ ℃$$

According to the Figure 4.4, inlet and outlet of the HP turbine are represented by point 1 and point 2 respectively.

$$\therefore\ h_{1@xMW} = 3396.9\ {}^{kJ}/_{kg} \quad \& \quad h_{2@xMW} = 3048.9\ {}^{kJ}/_{kg}$$

$$P_{HP@xMW} = 213.66\ {}^{kg}/_{s} \times (3396.9 - 3048.9)\ {}^{kJ}/_{kg}$$

$$P_{HP@xMW} = 70786.25\ kw = 70.78\ MW$$

Due to 95.25% efficiency of HP rotor; [16]

$$\begin{matrix} Output\ power \\ of\ the\ HP\ turbine \end{matrix} = \begin{matrix} Operating\ power \\ through\ HP\ turbine \end{matrix} \times \begin{matrix} Efficiency\ of \\ HP\ rotor \end{matrix}e$$

$$P_{HP@xMW(out)} = P_{HP@xMW} \times \eta_{HP}$$

$$P_{HP@xMW(out)} = 70.78\ MW \times 0.9525$$

$$P_{HP@xMW(out)} = 70.29\ MW$$

Power ratio of combined rotor shaft; [16]

$$P_{HP} : P_{IP} : P_{LP1} : P_{LP2} = 0.2410 : 0.2712 : 0.2439 : 0.2439$$

∴ Turbine power ratios when generator producing $x\ MW$ power,

$$P_{HP@xMW(out)} : P_{IP@xMW(out)} : P_{LP@xMW(out)} = 0.2410 : 0.2712 : 2 \times 0.2439$$

$$70.29MW : P_{IP@xMW(out)} : P_{LP@xMW(out)} = 0.2410 : 0.2712 : 0.4878$$

$$\frac{70.29\ MW}{P_{IP@xMW(out)}} = \frac{0.2410}{0.2712} \quad \& \quad \frac{70.29\ MW}{P_{LP@xMW(out)}} = \frac{0.2410}{0.4878}$$

$$\therefore P_{IP@xMW(out)} = 79.1\ MW$$

$$\therefore P_{LP@xMW(out)} = 142.27\ MW$$

Overall power output of the turbine is a combination of individual power output of the HP, IP and LP rotors.

$$Turbine\ overall\ power\ output = P_{HP@xMW(out)} + P_{IP@xMW(out)} + P_{LP@xMW(out)}$$

$$P_{Overall\ output\ @xMW} = 70.29\ MW + 79.1\ MW + 142.27\ MW$$

$$P_{Overall\ output\ @xMW} = 291.66\ MW$$

Generator is directly coupled to the main turbine shaft.

$$\therefore\ P_{Overall\ output\ @xMW} = P_{input\ to\ Gen}$$

$$P_{input\ to\ Gen} = 291.66\ MW$$

Due to 99.25% efficiency of the generator; [16]

$$\begin{matrix} Output\ power \\ of\ the\ Generator \end{matrix} = \begin{matrix} Input\ power \\ of\ Generator \end{matrix} \times \begin{matrix} Efficiency\ of \\ Generator \end{matrix}$$

$$P_{xMW} = P_{input\ to\ Gen} \times \eta_{Generator}$$

$$P_{yMW} = 291.66\ MW \times 0.9925 = 289.47\ MW$$

4.7.3 Evaluation of the outcomes - reference to the steam extraction #3

It is considered that there is no further extra steam availability at extraction #3. The available steam capacity of 9.6 kg/s exactly fulfils the requirement of steam turbine of BFPs. Therefore the amount of 3.4 kg/s steam flow is involved with further power increase to more than 289.22 MW. If $y\ MW$ is considered as the new power output of the main generator, power gain through the main turbine can be calculated with reference to the extra steam quantity of 3.4 kg/s.

$$\dot{m}_{\mathrm{IP@300MW}} - \dot{m}_{\mathrm{IP@yMW}} = 9.6 \; {kg}/{s}$$

$$223.26 \; {kg}/{s} - \dot{m}_{\mathrm{IP@yMW}} = 9.6 \; {kg}/{s}$$

$$\therefore \dot{m}_{\mathrm{IP@yMW}} = 213.66 \; {kg}/{s}$$

That means, 213.66kg/s rate of steam flow is expanded through the IP rotor.

$$\begin{matrix} \textit{Power through} \\ \text{IP turbine} \end{matrix} = \begin{matrix} \text{Steam flow rate} \\ \text{through IP turbine} \end{matrix} \times \begin{matrix} \text{Enthalpy difference} \\ \text{through IP turbine} \end{matrix}$$

$$P_{IP@yMW} = \dot{m}_{IP@yMW} \times \left(h_{3@yMW} - h_{4@yMW}\right)$$

Except the steam flow rate of turbine inlets, other parameters are not changed in the boiler, because the boiler is operated continuously at rated condition.

∴ Boiler operation conditions; [16]

$$Main\ steam\ pressure \quad = 16.7\ MPa$$
$$Main\ steam\ temperature = 538\ ℃$$

According to the Figure 4.4, inlet and outlet of the IP turbine are represented by point 3 and point 4 respectively.

$$\therefore \; h_{3@yMW} = 3535.9 \; {kJ}/{kg} \quad \& \quad h_{3@yMW} = 3168.7 \; {kJ}/{kg}$$

$$P_{IP@yMW} = 213.66 \; {kg}/{s} \times (3535.9 - 3168.7) \; {kJ}/{kg}$$

$$P_{IP@yMW} = 79886.32 \; kw = 79.89 \; MW$$

Due to 96.9% efficiency of IP rotor; [16]

$$\begin{matrix} Output\ power \\ of\ the\ IP\ turbin \end{matrix} = \begin{matrix} Operating\ power \\ through\ IP\ turbine \end{matrix} \times \begin{matrix} Efficiency\ of \\ IP\ rotore \end{matrix}$$

$$P_{IP@yMW(out)} = P_{IP@yMW} \times \eta_{IP}$$

$$P_{IP@yMW(out)} = 79.89\ MW\ \times 0.969$$

$$P_{IP@yMW(out)} = 79.24\ MW$$

Power ratio of combined rotor shaft; [16]

$$P_{HP} : P_{IP} : P_{LP1} : P_{LP2} = 0.2410 : 0.2712 : 0.2439 : 0.2439$$

∴ Turbine power ratios when generator producing y MW power,

$$P_{HP@yMW(out)} : P_{IP@yMW(out)} : P_{LP@yMW(out)} = 0.2410 : 0.2712 : 2 \times 0.2439$$

$$P_{HP@yMW(out)} : 79.24\ MW : P_{LP@yMW(out)} = 0.2410 : 0.2712 : 0.4878$$

$$\frac{P_{HP@yMW(out)}}{79.24\ MW} = \frac{0.2410}{0.2712} \quad \& \quad \frac{P_{LP@yMW(out)}}{79.24\ MW} = \frac{0.4878}{0.2712}$$

$$\therefore P_{HP@yMW(out)} = 70.41\ MW$$

$$\therefore P_{LP@yMW(out)} = 142.53\ MW$$

Overall power output of the turbine is a combination of individual power output of the HP, IP and LP rotors.

$$Turbine\ overall\ power\ output = P_{HP@yMW(out)} + P_{IP@yMW(out)} + P_{LP@yMW(out)}$$

$$P_{Overall\ output\ @yMW} = 70.41\ MW + 79.24\ MW + 142.53\ MW$$

$$P_{Overall\ output\ @yMW} = 292.18\ MW$$

Generator is directly coupled to the main turbine shaft.

$$\therefore P_{Overall\ output\ @yMW} = P_{input\ to\ Gen}$$

$$P_{input\ to\ Gen} = 292.18\ MW$$

Due to 99.25% efficiency of the generator; [16]

$$\begin{matrix} Output\ power \\ of\ the\ Generator \end{matrix} = \begin{matrix} Input\ power \\ of\ Generator \end{matrix} \times \begin{matrix} Efficiency\ of \\ Generator \end{matrix}$$

$$P_{yMW} = P_{input\ to\ Gen} \times \eta_{Generator}$$

$$P_{yMW} = 292.18\ MW \ \times 0.9925 = 289.98\ MW$$

4.7.4 Justification of the solutions

As per the calculations which were done for the two instances, there are some power gains when operating the plant at its rated conditions. In the other round, the boiler usually generates the same capacity under the same conditions. Therefore the required fuel rate or coal supplying rate does not change. In addition, extra energy or money is not required. This scenario is the same to the case when operating power plant is operated with electrically driven feed pumps. Because, the power capacity of grid supplying is 271.8 MW and home load requirement of 17.42 MW for other auxiliary equipment do not change. The only thing that changes is the generator produced power without 10.78 MW capacity which was previously used for the motor of BFPs. Instead, a steam capacity of 10.5 kg/s through extraction #1 or a steam capacity of 9.6 k g/s through extraction #3 is used for steam turbines attached BFPs. According to the above calculation, some quantity of power gain is available beyond the expected generation of 289.22 MW in each case. This improvement can be easily understood by referring to Tables 4.26 and 4.27.

Table 4.4.26 : Grid supplied power after implementing new solution

	Used Steam Source	Generator power output (MW)	Home load(MW)	Grid Supplied power (MW)
Case-1	Extraction #1 (Inlet of HPT)	289.47	17.42	272.05
Case-2	Extraction #3 (Hot Re-heater)	289.98	17.42	272.56

Table 4.4.27 : Power gain after implementing new solution

	Grid Supplied power (MW)		Power gain (MW)
	With implementation of steam turbine for BFPs	**With existing motor of BFPs**	
Case-1	272.05	271.8	0.25
Case-2	272.56	271.8	0.76

It can be clearly observed that, some quantity of power gain in each of cases. Therefore it needs some technical and economical evaluation such as power saving, financial saving and payback period on each of case to discuss the feasibility of implementations. Sometimes, considerable financial gain cannot be achieved even though some power saving is obtained. It may take a long time to payback and to recover the cost of implementation. Therefore it is essential to discuss these technical and economic terms.

- Calculation of annual power saving for case #1

$$Annual\ power\ saving = Power\ gain \times 24 \times 365 \times Plant\ factor$$

According to the design specifications of 300 MW Norochcholai coal power plant, expected plant factor is 88% [16].

$$\therefore Annual\ power\ saving = 0.25 \times 10^3 \times 24 \times 365 \times 0.88\ kwhr$$

$$\therefore Annual\ power\ saving = 1{,}927{,}200.00\ kWhrs = 1{,}927.2\ MWhrs$$

- Calculation of annual power saving for case #3

$$Annual\ power\ saving = Power\ gain \times 24 \times 365 \times Plant\ factor$$

According to the design specifications of 300 MW Norochcholai coal power plant, expected plant factor is 88% [16].

$$\therefore Annual\ power\ saving = 0.76 \times 10^3 \times 24 \times 365 \times 0.88\ kwhr$$

$$\therefore Annual\ power\ saving = 5{,}858{,}688.00\ kWhrs = 5{,}858.7\ MWhrs$$

- Calculation of annual financial saving for case #1

$$\therefore Annual\ Finan.saving\ \ = Annual\ power\ saving \times Unit\ gene.cost$$

According to the 2013 annual report of energy purchasing and distribution by Ceylon Electricity Board, unit generation cost at300 MW Norochcholai coal power plant is 8.00 LKR/kWhrs [18].

$$\therefore Annual\ Financial\ saving = 1{,}927{,}200.00\ kWhrs \times 8.00\ {}^{LKR}/_{kWhr}$$

$$\therefore Annual\ Financial\ saving = 15{,}417{,}600.00\ {}^{LKR}/_{year}$$

- Calculation of annual financial saving for case #3

$$\therefore Annual\ Financial\ saving = Annual\ power\ saving \times Unit\ generation\ cost$$

According to the 2013 annual report of energy purchasing and distribution by Ceylon Electricity Board, unit generation cost at300 MW Norochcholai coal power plant is 8.00 LKR/kWhrs [18].

$$\therefore Annual\ Financial\ saving = 5{,}858{,}688.00\ hrs \times 8.00\ {}^{LKR}/_{kWhr}$$

$$\therefore Annual\ Financial\ saving = 46{,}869{,}504.00\ {}^{LKR}/_{year}$$

US$ 4.83 M is required to introduce a steam turbine driven boiler feeding system for the existing coal power plant which is being operated with electric motor. According to the currency exchange rates on 07th May 2015, it is nearly 603,750,000.00 LKR.

- Calculation of payback time for case #1

$$Payback\ period = \frac{Implementation\ cost}{Annual\ Financial\ saving}$$

$$\therefore Payback\ period = \frac{603{,}750{,}000.00\ LKR}{15{,}417{,}600.00\ {}^{LKR}/_{year}}$$

$$Payback\ period = 39.16\ years \approx 39\ years$$

- Calculation of payback time for case #3

$$\therefore Payback\ period = \frac{603{,}750{,}000.00\ LKR}{46{,}869{,}504.00\ {}^{LKR}/_{year}}$$

$$Payback\ period = 12.88\ years \approx 12\ years$$

- Calculation of coal saving for case #1

$$Coal\ requirement\ for\ generating\ 300\ MW\ [16] = 100\ {}^{T}/_{hrs}$$

$$Required\ coal\ quantity\ for\ 1\ MWhrs = 0.33\ {}^{T}/_{MWhrs}$$

$$Annual\ power\ saving = 1{,}927.2\ MWhrs$$

$$Annual\ coal\ saving = Annual\ power\ saving \times 0.33\ {}^{T}/_{MWhrs}$$

$$Annual\ coal\ sa = 1{,}927.2\ MWhrs \times 0.33\ {}^{T}/_{MWhrs}$$

$$Annual\ coal\ saving = 636.3\ {}^{T}/_{year}$$

- Calculation of coal saving for case #3

$$Coal\ requirement\ for\ generating\ 300\ MW\ [16] = 100\ {}^{T}/_{hrs}$$

$$Required\ coal\ quantity\ for\ 1MWhrs = 0.33\ {}^{T}/_{MWhrs}$$

$$Annual\ power\ saving = 5{,}858.7\ MWhrs$$

$$Annual\ coal\ saving = Annual\ power\ saving \times 0.33\ {}^{T}/_{MWhrs}$$

$$Annual\ coal\ saving = 5{,}858.7 MWhrs \times 0.33\ {}^{T}/_{MWhrs}$$

$$Annual\ coal\ saving = 1952.9\ {}^{T}/_{year}$$

39 years and 12 years payback times are respectively required for recovering the investment on implementation of each case. In addition, to fulfil the technical feasibility of a solution, it is an imperative need to get a decision based on economic factors such as payback time and return of investment. The overall lifetime of coal power plant is 30 years [18]. Therefore solution in case #1 can be avoided although all other technical factors are satisfactory. The solution which was discussed in case #3 is the only solution which fulfils both technical and economic factors.

4.8 Outcomes of the implementation

When using #3 extraction steam as alternative energy option in Norochcholai power plant, grid supply is gained by 0.76 MW power capacity with the same unit operation in rated condition. This gain proves that the home load is minimised by 0.76 MW.

Table 4.4.28 : Outcomes of the study with related to #3 extracted steam

Factor	Outcome
Grid supply power gain	0.76 MW
Annual power saving	5,858.7 MWhrs
Annual financial saving	LKR 46.9 M
Payback period	12 years
Annual coal saving	1,952.9 T

CHAPTER 5 - CASE GENERALISATION

During the case study in Norochcholai Coal Power Plant, all outcomes were calculated based on plant's rated load condition. This kind of coal power plant can operates beyond its rated load conditions. That that times, these outcomes may be changed according to it operated load conditions. To make the outcomes more general, it requires calculating relevant achievements with some range of load conditions beyond the rated load of a power plant.

As the first step of case generalisation, history of generated power output of one unit of Norochcholai Coal Power Plant was extracted for certain period through DCS. Generated power out of unit 2 from September 1st, 2014 to December 28th, 2015 was weekly averaged and plotted. See Figure 5.1

According to the load variation which is shown in the graph on Figure 5.1, it can be observed some specific load conditions which were plant operated. These load conditions are 300 MW (Plant rated condition), 285 MW, 270 MW, 240 MW, 200MW, 180 MW, 150 MW (Half load condition), 140 MW and 130MW. The main outcomes which describe in section 4.8 were calculated for each load conditions. For easiness of calculations, a dedicated programme was created by using EES based on the equations and conditions which are met on developed method in chapter 3. EES code of the programme is attached in appendix D.

The main outcomes with reference to the each load conditions which are extracted trough developed EES programme is summarised in Table 5.1. In addition to the results which were obtained in above mentioned specific load conditions in Table 5.1, there can be operated a coal power plant in different power condition in its operation time. To obtain the results in each load condition, main five outcomes were separately plotted against operation conditions of the power plant.

Variation of grid supplied power gain, variation of annual power saving, variation of annual financial saving, variation of payback period and variation of annual coal saving with reference to the operation condition of the power plant are respectively shown in Figure 5.2, Figure 5.3, Figure 5.4, Figure 5.5 and Figure 5.6 as graphs.

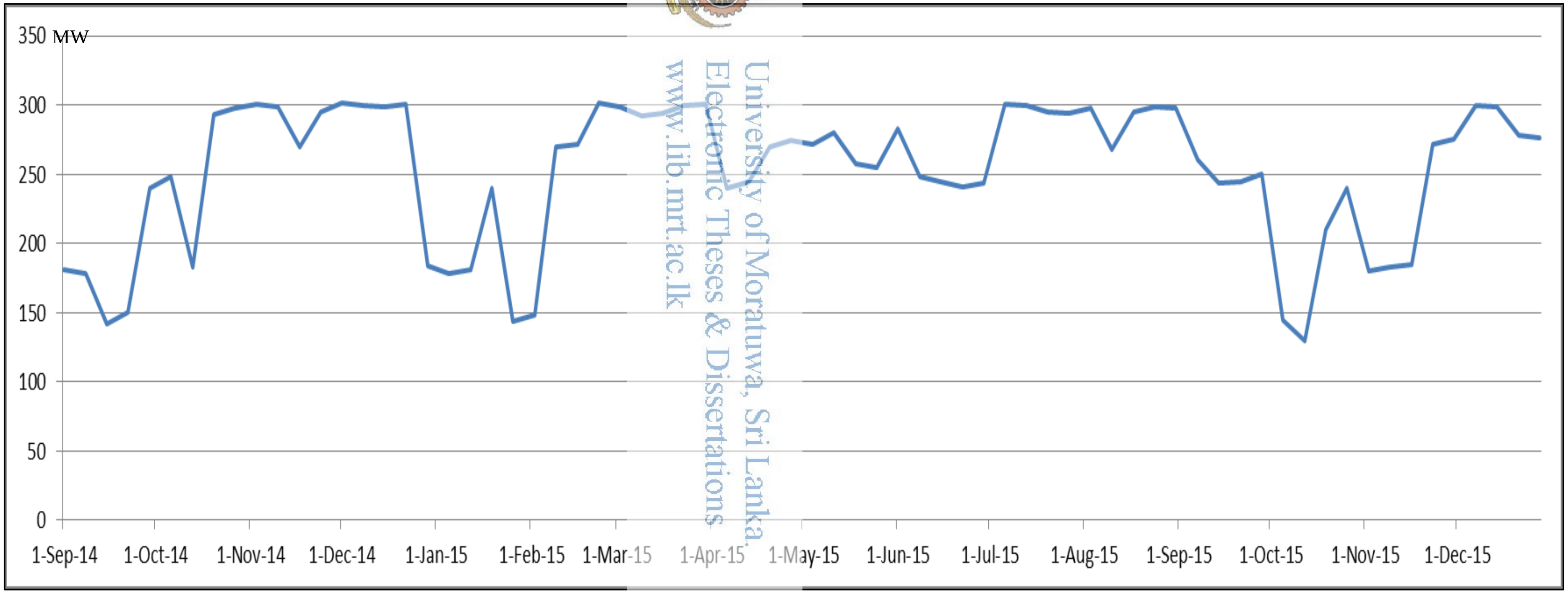


Figure 5.1: Average operated power in LVPS unit 2 from September, 2014 to December, 2015

Table 5.1: Outcomes at mostly operated power condition in LVPS unit 2

Outcomes	Mostly operated power condition in MW								
	130	140	150	180	200	240	270	285	300
Grid supplied power gain (MW)	0.31	0.37	0.41	0.3	0.45	0.55	0.66	0.72	0.76
Annual power saving (MWhrs)	2389.73	2852.26	3160.61	2312.64	3200.00	4239.85	5087.82	5550.35	5858.70
Annual financial saving (LKRM)	19.13	22.83	23.30	18.51	25.20	33.94	40.73	44.43	46.90
Payback period (Years)	29.4	24.0	21.3	26.0	20.0	15.5	13.2	12.6	12.0
Annual coal saving (T)	796.58	950.75	1053.54	770.88	1000.20	1413.28	1695.94	1850.12	1952.90

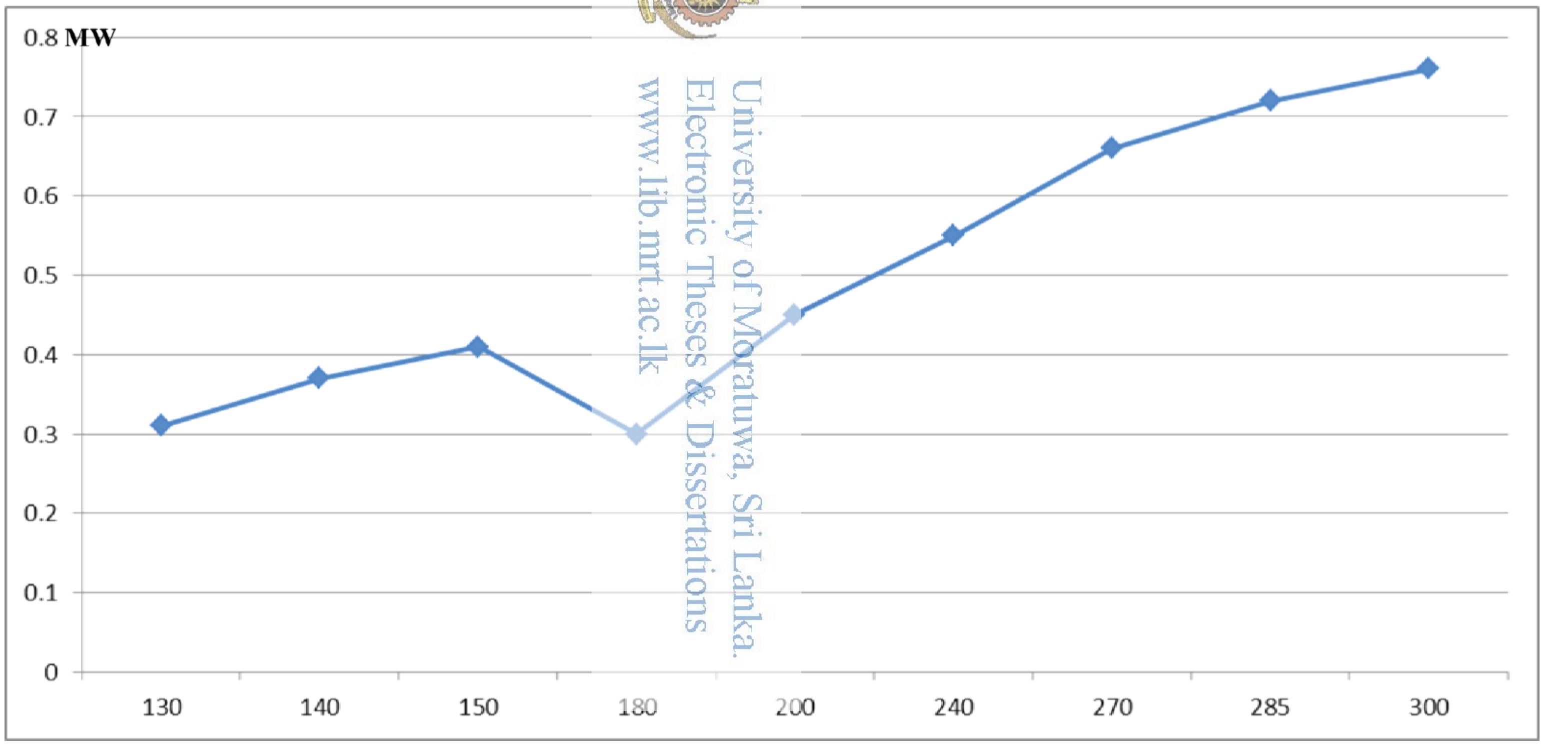


Figure 5.2: Grid supply power gain Vs Operated Power Conditions

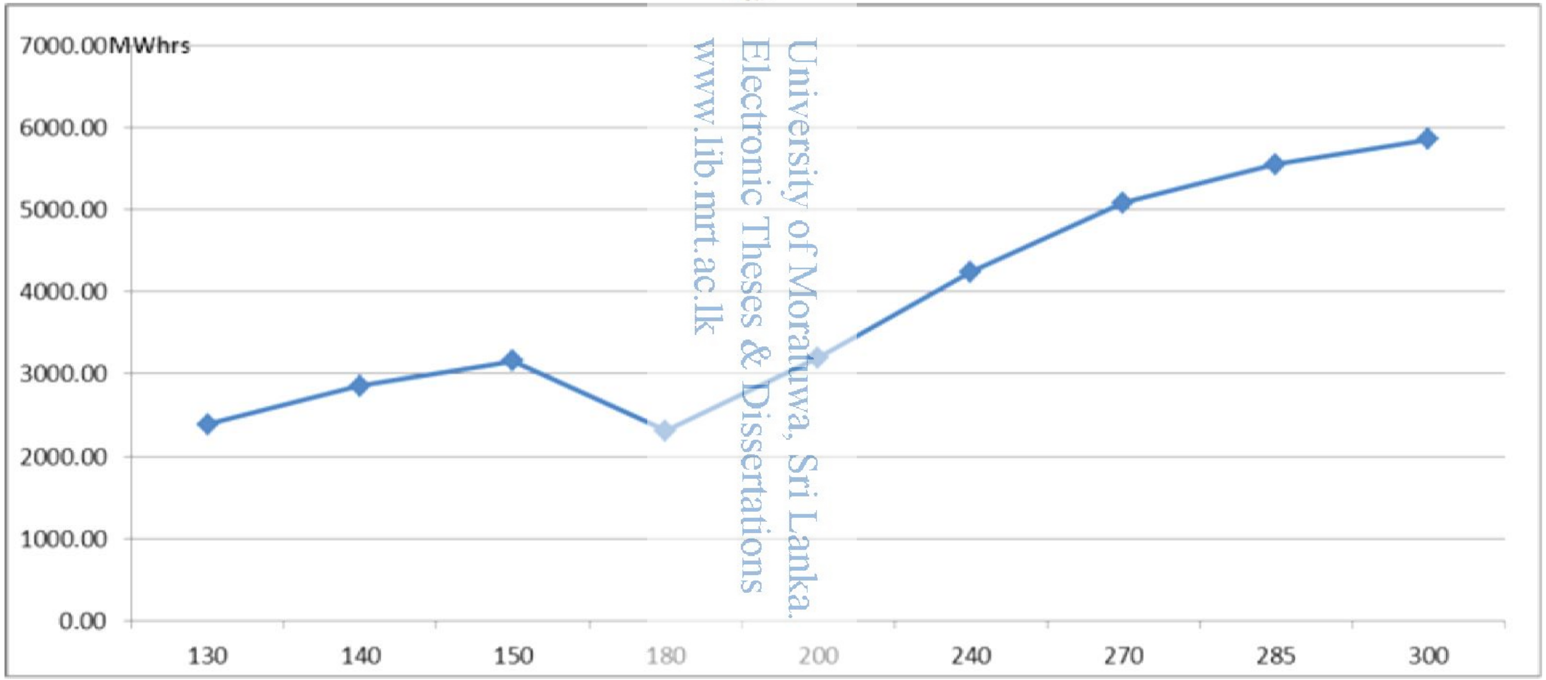


Figure 5.3: Annual power saving Vs Operated Power Conditions

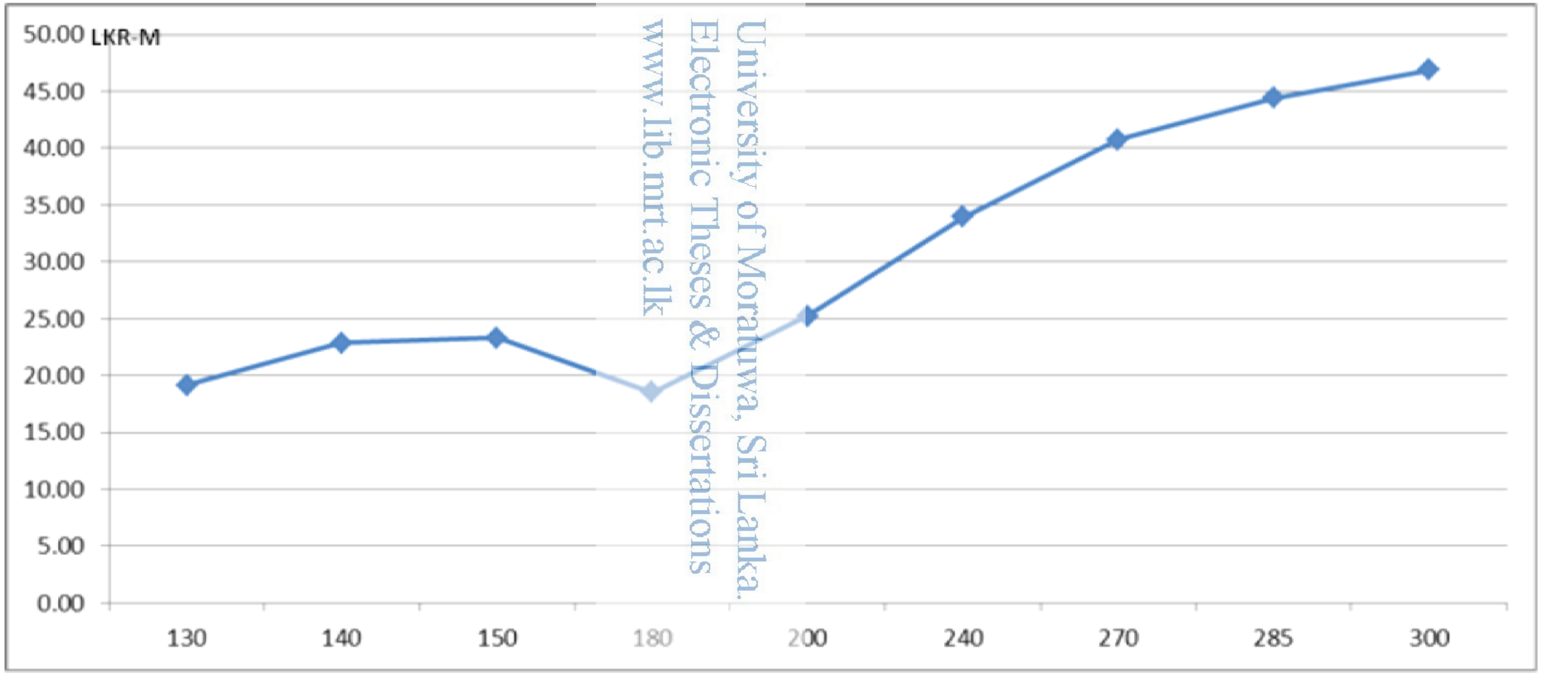


Figure 5.4 : Annual financial saving Vs Operated Power Conditions

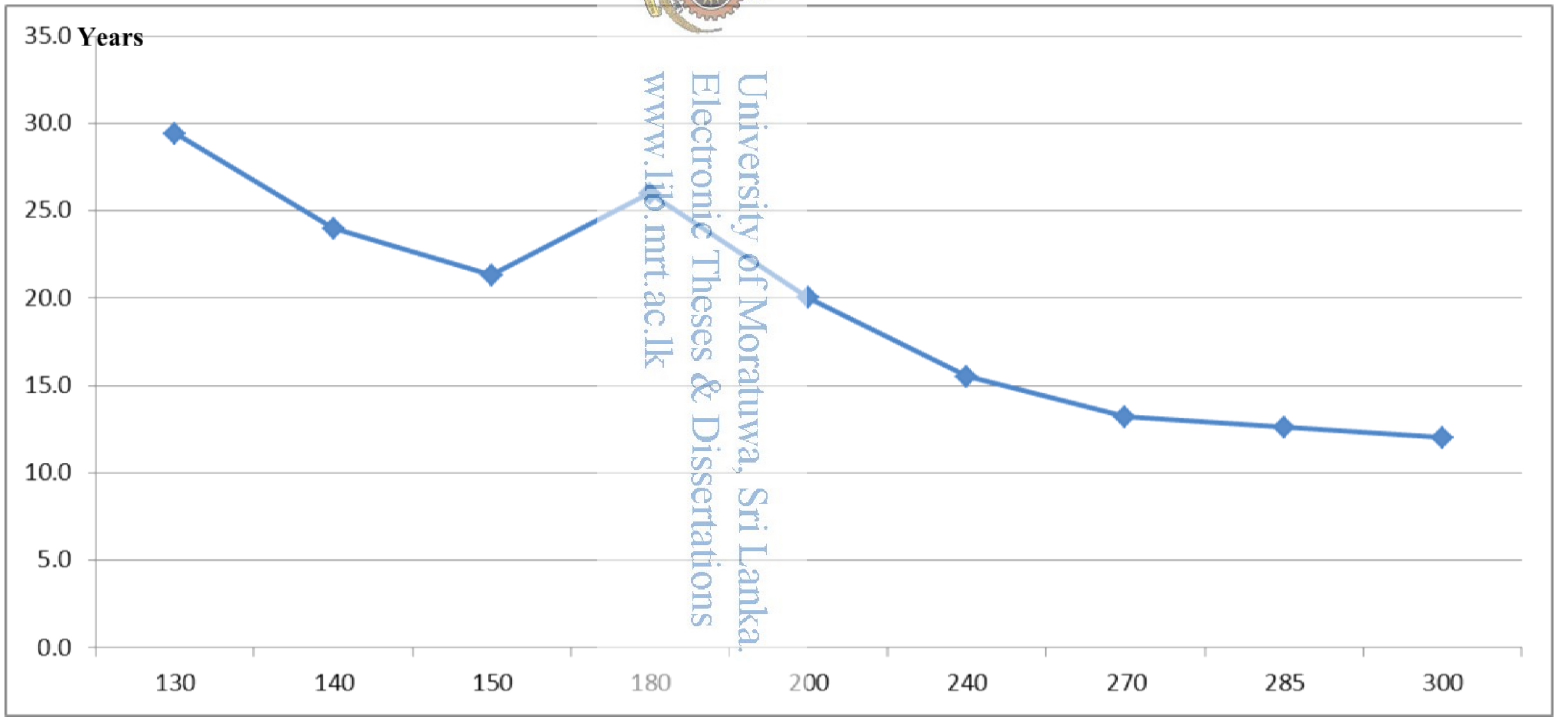


Figure 5.5 : Payback period Vs Operated Power Conditions

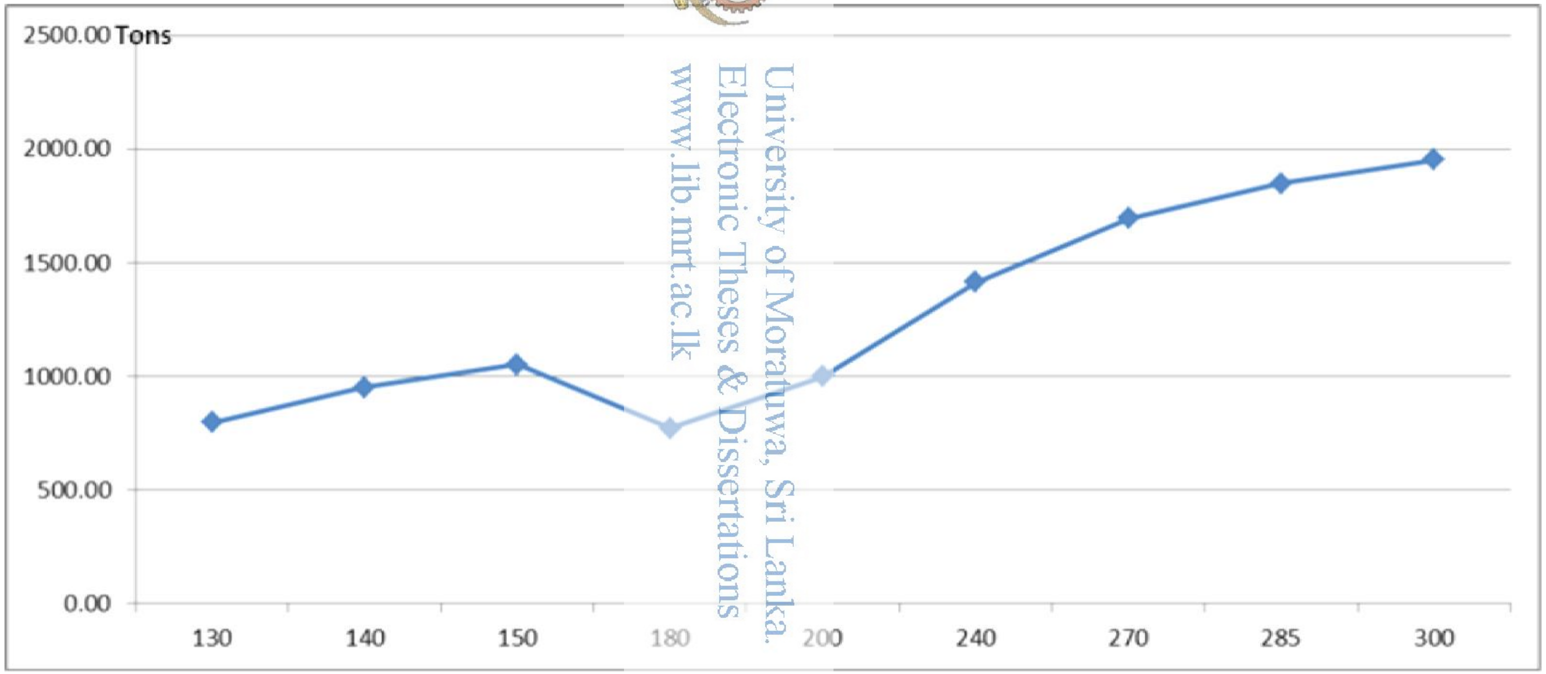


Figure 5.6 : Annual coal saving Vs Operated Power Conditions

CHAPTER 6 - DISCUSSION

6.1 Positive approach of the method

Alternative energy options and their nature in a particular coal power plant can be identified through this method. During this identification, the availability of alternative power sources and power potential of the sources are notified. This is very important for the organisation using coal power plant, because they can update their knowledge regarding the power capacities or alternatives around the power plant. Then they can try for similar additional implementations based on the available alternative power sources.

By using this method, the most suitable and feasible solution or solutions in relation to the coal power plants can be easily identified. The problem of minimising the home load and finding a feasible solution for coal power plant will not arise if this method is used. If this method is applied to a coal power plant and if its site available alternative energy options are feasible, the home load can be decreased. The grid supplied power can be increased. As a result, energy and money can be saved. Also saving a small power capacity in such a mega range power plant will lead to a massive saving for the power plant. After calculating the payback period with reference to the life time of the considered power plant, the feasibility of the solutions can be confirmed. From the payback period it is possible to evaluate the results off this method.

When the feasible alternative energy options selected through this method is implemented, a considerable annual saving of coal can be expected. Coal is one type of fossil fuel. It is a non-renewable resource. Although these non-renewable sources are used for the present power generation as our wish, they have been borrowed from future generation. As human beings, it is responsibility to save these no-renewable sources for future generation. After implementing this method, there will be a considerable saving of coal annually and a huge coal saving can be expected over the remaining life time of the power plant. This is the most important and valuable outcome of this method.

With reference to the Norochcholai coal power plant, the solution from the case study substitutes a steam turbine with extracted steam from extraction #1 or extraction #3 instead of the motor of boiler feed pumps. Among these extractions, operating a steam turbines with extracted steam from extraction #3 is the only suitable solution, because the payback time is nearly 12 years. The life time of the Norochcholai power plant is 30 years and it has been in operation for 4 years now. If this solution is implemented for the Norochcholai power plant today, nearly 14 years will remain to obtain benefits after the payback period. This means that nearly amount of 656.17M LKR will be saved or 82.02 GWhrs can be additionally generated. Further 27,340 Tons of coal will be saved for the future during these 14 years.

6.2 Generalisation of the method

Although this method is evaluated as a case study applicable to the Norochcholai coal power plant, this method can be commonly used for other existing coal power plants which have been constructed and are being operated with electric boiler feed pumps. By applying this method for a few selected coal power plants with different designs and in different geographical localisation, generalisation of the method can be proved. The concept of the method is common for all power plants.

6.3 Limitations

Using this method to a specific coal power plant as well as all power plants, some limitations can be observed. The most popular alternative energy options which were listed in previous research articles and also identified in the literature review only focused on the method. Although it is agreed that it is suitable for most of the coal power plants, there is a possibility to identify some coal power plants with different alternative energy options. For example, Tanjung Jati-B coal fired power plant is located in Central Java province, Indonesia (Location- 6°26′43″S 110°44′37″E) [89]. 180 MW Mount Salak geo thermal power station (Location 6°27′S 109°54′E) is being operated with closer to Tanjung Jati-B power plant[90]. It has been identified that additional geo thermal power potential of 210 MW is available in the valley of Mount Salak [90]. Therefore in the case of Tanjung Jati-B power plant, geo thermal sources can be more dominant than the most popular energy options which were listed in the literature review.

When selecting a renewable energy source as the most suitable solution among all alternative energy sources, feasibility of the solution can be changed a little with the way of data collected.

Maximum outcomes can be achieved only for the power plants which were constructed and had been operated for a short time over its plant life time. When considering a power plant with one or two years remaining life, technical and economic outcomes may not be worth.

In this study, it is tried to provide solutions only for motor of boiler feed pump as key contributor to the plant home load. Sometimes, there may be other pumps with considerable power consumption although they are not much influenced as boiler feed pumps. Due to concentrating only on the feed pumps, outcomes can be limited in this method.

CONCLUSIONS AND RECOMMENDATIONS

Under the present situation of energy crisis, energy saving and minimising losses are very popular topics. Among the ways which are used to minimise losses, optimisation of the existing systems and introducing alternative solutions are dominant. There are some considerable losses are being occurred in a coal power plant related to the home load. Many auxiliary equipment such as pumps, fans, cranes, and compressors are contributed to the plant home load. The boiler feed water system consumes a large portion of the home load. Therefore prime movers of feed pumps contribute automatically for a large percentage of the losses which occur in the power plant.

Motors of feed pumps are key players in the problem in such power plants. Therefore doing optimisations or introducing feasible alternative energy options related to the boiler feed system, more energy gain and financial benefits can be expected. Based on the above logic and the method which has been developed in chapter three and developed graphs related to the main outcomes in chapter five, energy and financial benefits can be generally obtained and estimated in coal power plants.

If the range of the most popular alternative energy options applicable to the coal power plants is expanded, the developed method will be more generalised. Energy gain and financial benefit can be increased by considering other major contributors of plant home load in addition to its key player. When selecting a renewable energy source as the most suitable solution among all the alternative energy sources, accurate data collection procedures and calculation method can be used to increase the reliability of the solution. To make it easy for the users, a dedicated computer programme can be developed based on the framework of the method with all possible inputs. Then results or outcomes can be extracted in a convenient manner.

REFERENCE LIST

[1]. US Energy Information Administration. (2014, Dec.) "Today Energy" [Online]. Available: http://www.eia.gov .[Jan. 3, 2015]

[2]. World coal organisation. (2014, May. 17). "Coal & Electricity" [Online]. Available: www.worldcoal.org/coal/.[Dec. 23, 2014]

[3]. Global Energy Observatory. (2014, Jun.). "Current List of Coal Power Plants" [Online]. Available http://globalenergyobservatory.org.[Jan. 5, 2015]

[4]. D. Carrington. (Nov.20, 2012) "More than 1,000 new coal plants." *The Guardian* [Online]. Available: www.theguardian.com/environment/2012/nov/20/coal-plants-world-resources-institute.[Dec.02,2014]

[5]. Ceylon Electricity Board. (Jan., 2014,). "Development Programs" [Online]. Available: www.ceb.lk/sub/dp/.[Jan. 2, 2015]

[6]. Ceylon Electricity Board. (Jan., 2014). "Major Projects" [Online]. Available: www.ceb.lk/sub/dp/majorprojects/.[Jan. 2, 2015]

[7]. *Equipment lay outing manual*, 4th Rev., Harbin Turbine Company, China, 2009, pp.168-192.

[8]. *Manual of General auxiliaries*, 12th Rev., Harbin Turbine Company, China, 2012, pp.17-32.

[9]. M. Finkenrath *et al.*, (Oct. 11, 2012). "Analysis of the Globally Installed Coal-Fired Power Plant Fleet" *Energy Agency* [Online]. Available: http://www.iea.org/publications .[Jan. 21, 2015]

[10]. *Procedures for Performance Testing of Coal power Plants*, Harbin Turbine Company, China, 2006, pp.54-82.

[11]. World coal Association. (Sep , 2013.). "Coal" [Online]. Available :http://www.worldcoal.org/coal.[Jan. 11, 2015]

[12]. *Unit operation and coal Handling of Coal power plants*, 6th Rev., Harbin Turbine Company, China, 2011, pp.118-142.

[13]. *Ledger of equipment & auxiliaries*, 3rd Rev., 300MW Norochcholai coal power plant, Sri Lanka, pp.036-062.

[14]. Ceylon Electricity Board. (Dec, 2014.). "Our Grid Network" [Online]. Available: www.ceb.lk/sub/other/networkg.html.[Jan. 14, 2015]

[15]. Ministry of Power & Energy-Sri Lanka. (Dec. 28, 2012.). "List of power stations in Sri Lanka" [Online]. Available: http://powermin.gov.lk/english.[Jan. 25, 2015]

[16]. *System Design Description of HIP/LP turbine and generator-300MW coal power plants*, 2nd Rev., Harbin Turbine Company, China, 2011, pp.27-49.

[17]. Power Engineering. (Jun, 2012.) "New Benchmarks for Steam Turbine Efficiency" Internet: http://www.power-eng.com/articles. [Dec. 11, 2014]

[18]. *Annual report of energy purchasing and distribution, 2013*, Ceylon Electricity Board, Sri Lanka, 2013, pp.16-21.

[19]. P.S. Weitzel. "Steam Generator for Advanced Ultra Supercritical Power Plants 700 to 760C". Internet: http://www.babcock.com/library, Jul.12, 2011 [Oct.25, 2014]

[20]. "Power Generation in the Chemical & Pharmaceutical Industry". Internet: http://www.energy.siemens.com/co/en/industries-utilities, [Oct.26, 2014]

[21]. R. K. Kapooria, S. Kumar and K. S. Kasana. "An analysis of a thermal power plant working on a Rankine cycle". Internet: http://www.energy.siemens.com/co/pool/hq/power-generation, Feb, 2008 [Oct.25,2014]

[22]. Alstom. "Coal and Oil Power". Internet:www.alstom.com/power/coal-oil, Nov,2012 [Dec.02,2014]

[23]. Alstom Power. "Steam Turbines-Full Range to fit your needs". Internet: http://www.alstom.com/Global/Power/Resources, 2011 [Sep21, 2014]

[24]. X. Xue and Y. Wang. "Particle Size Distribution as a Non-independent Variable Affecting Pulverized-Coal Burnout in Coal-Fired Power-Plant Boilers." *The International Journal of Coal Science & Technology*, vol.27(8), pp. 4930–4934, July 10, 2013

[25]. G. potter. (2013, Feb.) "What is Solar Power". *Solar Home*. [Online]. Available: http://www.solarhome.org/ , [Oct.26, 2014]

[26]. J. Franke and R. Kral. (2003, Oct.) "Supercritical boiler technology for future market conditions" *H30-K0018-X-X-7600.* [Online]. PP. 8-9. Available: http://www.energy.siemens.com/mx, [Oct.28,2014]

[27]. ABB. "Medium voltage drives for more efficient and reliable plant operation". Internet: http://www05.abb.com/global/scot/, 2011 [Sep21, 2014]

[28]. F. Cziesla *et al*,. (2009, Sep. 1). "Advanced 800+ MW Steam Power Plants and Future CCS Options". [Online]. Available: http://www.energy.siemens.com/co/pool/hq/power-generation, [Oct.25,2014]

[29]. K. Forsman and R. Hart. (2009, Jan.) "Motor Efficiency, Selection and Management". [Online]. Available: http://www.pge.com/includes/docs, [Dec.02, 2014]

[30]. US Department of Energy. (2012, Nov.). "Eliminate Excessive In-Plant Distribution System Voltage Drops". [Online]. Available: https://www1.eere.energy.gov/manufacturing/tech_assistance, [Dec.05, 2014]

[31]. S. Verma. (2012). "Invention Story of Electric Motor". [Online]. Available: http://www.engineersgarage.com/invention-stories, [Dec.01, 2014]

[32]. Flowserve. "Learn about the distinguished history of Flowserve pumps which spans more than two centuries". Internet: http://www.flowserve.com/Products/Pumps/Pumps-History, [Jn.25, 2015]

[33]. Dr. Mel. (2010, Feb 4.). "Fluid couplings". *Variable Speed Fluid Drives for Pumps*. [Online]. Available: http://turboresearch.wordpress.com, [Oct.16, 2014]

[34]. E. C. LEE. "Review of Variable Speed Drive Technology" Internet: http://powertecmotors.com/avsde4.pdf, [Oct.16, 2014]

[35]. Online Electrical Engineering. "Types of Transformer". Internet: http://www.electrical4u.com/electrical-power-transformer, [Oct.25, 2014]

[36]. K. Stępczyńska *et al*,. (2012, Apr. 27). "Diverse configurations of the boiler feed pump drive". *Ultra-supercritical 900-MWsteam plants*. [Online]. Available: http://www.journal-ijeee.com/content/pdf/2251-6832-3-3.pdf, [Dec. 22, 2014]

[37]. Ice Clean Coal Center. "The global resource on the clean use of coal". Internet: http://www.iea-coal.org.uk/site/2010/database-section/coal-power, [Dec. 19, 2014]

[38]. Sri Lanka Sustainable Energy Authority. "Renewable Energy". Internet: http://www.energy.gov.lk/sub_pgs/energy_renewable_wind_potential, [Dec. 31, 2014]

[39]. AENews. "Wave Power". Internet: http://www.alternative-energy-news.info/technology/hydro/wave-power, [Dec. 15, 2014]

[40]. M. Folley, B. Elsaesser and T. Whittaker. "Analysis of the wave energy resource". *European Marine Energy Centre*. [Online]. Available: http://www.aquamarinepower.com/sites/resources , [Aug. 28, 2014]

[41]. Nedstack. "World's largest PEM fuel cell power plant". Internet: http://www.nedstack.com/about-us/nedstack-in-the-news, [Dec. 19, 2014]

[42]. "The global resource on the clean use of coal". *Times*. Internet: http://time.com/3723592/inside-the-worlds-largest-solar-power-plant/, Nov. 2012, [Feb. 26, 2015]

[43]. D. Renné, R. George, B. Marion and D. Heimiller. (2003, Aug.). "Solar Resource Assessment for Sri Lanka and Maldives". [Online]. Available: http://www.nrel.gov/docs/fy03osti/34645.pdf, [Dec. 19, 2014]

[44]. Good Energy Solutions. "Solar Thermal Systems". Internet: http://www.goodenergysolutions.com/solarthermal.htm, [Nov. 29, 2014]

[45]. BDI. "Mechanical Power Transmission". Internet: http://www.bdi-usa.com/Products/Mechanical-Power-Transmission.aspx, Mar. 2012, [Dec. 02, 2014]

[46]. Alstom. "Highest reliability, flexibility and availability". Internet: http://www.alstom.com/Global/Power/Resources/Documents, [Jan. 11, 2015]

[47]. L. Rodrigues. (2009, Jul.). "Wave power conversion systems for electrical energy production". [Online]. Available: http://www.icrepq.com/icrepq-08/380-leao.pdf, [Oct.26,2014]

[48]. A. J. Counter. (2013, Oct.). "Solar Efficiency Limits". *Solar Energy System*. [Online]. Available: http://solarcellcentral.com/limits_page.html, [Oct.26, 2014]

[49]. Maplandia. "Online Map Finder". Internet: http://www.maplandia.com/sri-lanka/ , [Oct11, 2014]

[50]. *General Layout Drawing*, 2nd Rev., 3x300MW Norochcholai coal power plant, Sri Lanka, F5222S-Z0103-02.

[51]. Iberdrola. "Wind Farm Availability- TIME Vs ENERGY". Internet: http://www.ewea.org/events/workshops/ , Jul. 02, 2012. [Oct15, 2014]

[52]. *Annual Energy Minutes through Plant's SCADA system*, WindForce (Pvt.) Ltd., 2012-2013

[53]. A. A. A. Abdalazeez. "Wave run up estimates at gentle beaches in the northern Indian Ocean". Internet: http://www.oceandocs.org/bitstream/handle, Oct, 2012, [Dec. 02, 2014]

[54]. Department of Meteorology. "Climate in Sri Lanka". Internet: http://www.meteo.gov.lk/index.php, [Sep. 22, 2014]

[55]. Accuweather. "Forecast-Puttalam, Sri Lanka". Internet: http://www.accuweather.com/en/lk/puttalam/308849/month, [Sep. 17, 2014]

[56]. WindForce (Pvt.) Ltd. (2014, Jan.). "Towards to Green". *Project Report-2014*

[57]. *Report of Environmental Impact Analysis*, 0 Rev., 3x300MW Norochcholai coal power plant, Sri Lanka, 2005.

[58]. TLV. "Engineering Calculator". Internet: http://www.tlv.com/global/TI/calculator/, [Dec. 19, 2014]

[59]. US Department of Energy. “Appliance & Equipment Standards”. Internet:http://www1.eere.energy.gov/buildings/appliance_standards, Sep. 2012, [Dec. 24, 2014]

[60]. Solar System. “AC and DC electrical wire voltage drop and energy losses online calculator”. Internet: http://photovoltaic-software.com, [Dec. 19, 2014]

[61]. CSE Cables. “3 Core Medium Voltage SWA Power Cable”. Internet: http://www.csecables.com/power-cable/3-core-medium-voltagecable, 2010, [Dec. 22, 2014]

[62]. Global Wind System. “Climate Change”. Internet: http://earthguide.ucsd.edu, [Dec. 01, 2014]

[63]. Siemens. “Pre-designed Steam Turbines”. Internet: http://www.energy.siemens.com/hq/pool/steam-turbines-45kW-12MW_en.pdf, May, 2010, [Dec. 19, 2014]

[64]. *Price Schedule for Plant equipment, Material and Services*, 0 Rev., 3x300MW Norochcholai coal power plant, Sri Lanka, 2008.

[65]. Alibaba. “Condensing-5-MW-Steam Turbines”. Internet: http://www.alibaba.com/product-detail/SHUGUANG-Brand-Condensing-5-MW-Steam_60120801244.html, [Dec. 24, 2014]

[66]. *General Arrangement Drawing of Turbine House*, 4th Rev., 300MW Norochcholai coal power plant, Sri Lanka, F-5222S-J0201-06.

[67]. E. Baker *et al*,. (2013, Jun. 13.). “Site Costing”. *The Economics of Solar Electricity*. [Online]. Available: http://nature.berkeley.edu/~fowlie/PV_AR_2013.pdf, [Dec. 24, 2014]

[68]. “Structures, Platforms and Gallery Works” Chinese GB codes: DL/T 5072.(3B)-2009

[69]. ABB, (2009, Apr. 12.). “Power Generation-Energy Efficient Design of Auxiliary Systems in Fossil-Fuel Power Plants”, Rev 3.1, [Online]. Available: http://www.seeei.org.il/prdFiles/2702_desc3.pdf , [Mar. 24, 2015]

[70]. Y. M. Hamad *et al*,. (“2014, Jul. 15). “Study of energy recovery and power generation from alternative energy source”. , [Online]. Available: http://www.sciencedirect.com/science/article/pii/S2214157X14000227, [Mar. 28, 2015]

[71]. World Nuclear Association. (2015 Jan.). “Renewable Energy and Electricity” [Online]. Available: http://www.world-nuclear.org/info/Energy-and-Environment/Renewable-Energy-and-Electricity, [Mar. 8, 2015]

[72]. American History. “Thermal Generating Plants” [Online]. Available: http://americanhistory.si.edu/powering/generate/gnmain.htm, [Feb. 18, 2015]

[73]. Vallourec. (2014, Dec.). “Power Generation from Renewable Energy Sources”. [Online]. Available: http://www.vallourec.com/renewable/EN/Pages/default.aspx, [Mar. 21, 2015]

[74]. Conserve Energy Future. (2014). “Go for green energy “, [Online]. Available: http://www.conserve-energy-future.com/AlternativeEnergySources.php, [Mar. 21, 2015]

[75]. POWER-GEN Africa -2015. (2015, Jan. 21-23). “The Most Common Alternative Energy Sources” [Online]. Available: http://saveenergy.about.com/od/alternativeenergysources, [Mar. 11, 2015]

[76]. Listverse. (2009, May 1) “Top renewable Energy Sources”, [Online]. Available: http://listverse.com/2009/05/01/top-10-renewable-energy-sources, [Feb. 21, 2015]

[77]. Jawa Power, “The environment”, Internet: http://www.jawapower.co.id, 24 Dec, 2013. [Feb. 14, 2015]

[78]. Eskom, “Kendal Power Station Map”, Internet: http://www.eskom.co.za/Whatweredoing/ElectricityGeneration/PowerStations/Pages/Kendal_Power_Station.aspx, [Feb. 14, 2015]

[79]. SourceWatch. (2014, Mar. 18.) “External Resources”, [Online]. Available: http://www.sourcewatch.org/index.php/Kahalgaon_Super_Thermal_Power_Plant, [Dec. 23, 2014]

[80]. SKF Group. (2014, Jun.). “Mechanical power transmission strategy”, [Online]. Available: http://www.skf.com/group/investors/mechanical-power-transmission-market, [Dec. 28, 2014]

[81]. R. Adinberg, D. Zvegilsky, M. Epstein. (2009, Sep. 25). “Heat transfer efficient thermal energy storage for steam generation”, [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0196890409003112, [Jan. 7, 2015]

[82]. A. M. Eltamaly and H. M. Farh. (2013, Jan. 29). “Maximum power extraction from wind energy system based on fuzzy logic control”, [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0378779613000023, [Jan. 7, 2015]

[83]. R. Tirona *et al*,. (2015 Mar.). “The challenging life of wave energy devices at sea”, *Renewable and Sustainable Energy Reviews*, Vol.43, , pp 1263–1272 [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1364032114010521, [Apr. 2, 2015]

[84]. S. Armstrong and W.G. Hurley. (2009, Nov. 8). "A new methodology to optimise solar energy extraction under cloudy conditions", [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0960148109004443, [Dec. 21, 2014]

[85]. U.di Padova and S.S. Nicola. (2011, Sep. 1). "Mechanism and Machine Theory", [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0094114X11001418, [Dec. 21, 2014]

[86]. S. Ozlu, I. Dincer and G.F. Naterer. (2012, Dec.). "Comparative assessment of energy options in Ontario steel industries in Canada", [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0374477812004872, [Dec. 25, 2014]

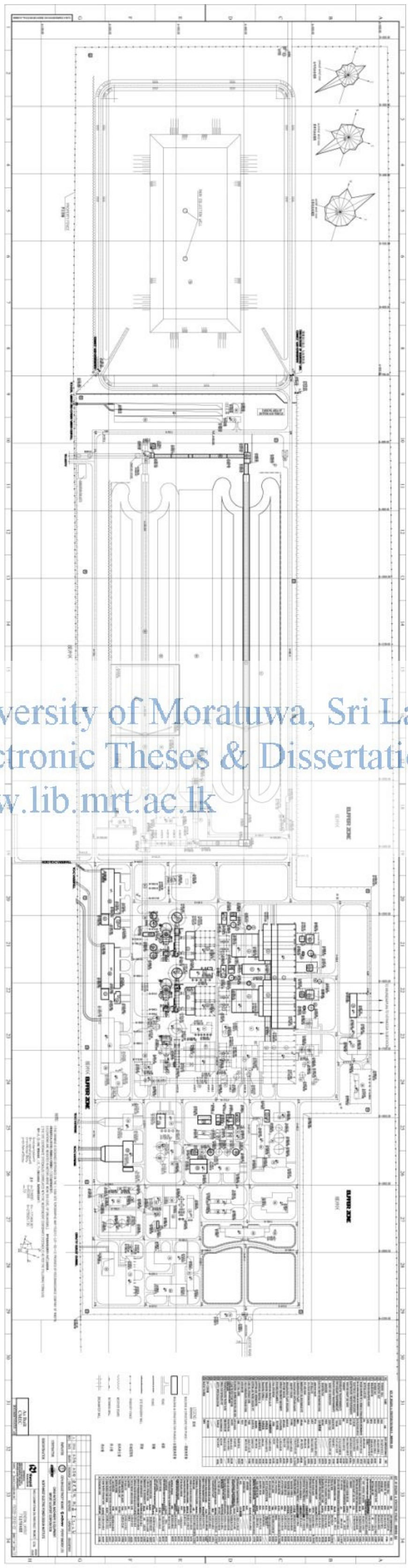
[87]. H. Doukas, C. Karakosta and J. Psarras. (2010, Feb. 14). "Computing to assess the sustainability of renewable energy options in dockyards", [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0954407413301004, [Dec. 5, 2014]

[88]. G.J. Dalton *et al*,. (2008, Aug. 15). "Case study and feasibility analysis of alternative energy supply options for small and medium scale cement processing factories", [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0960148108002619, [Dec. 5, 2014]

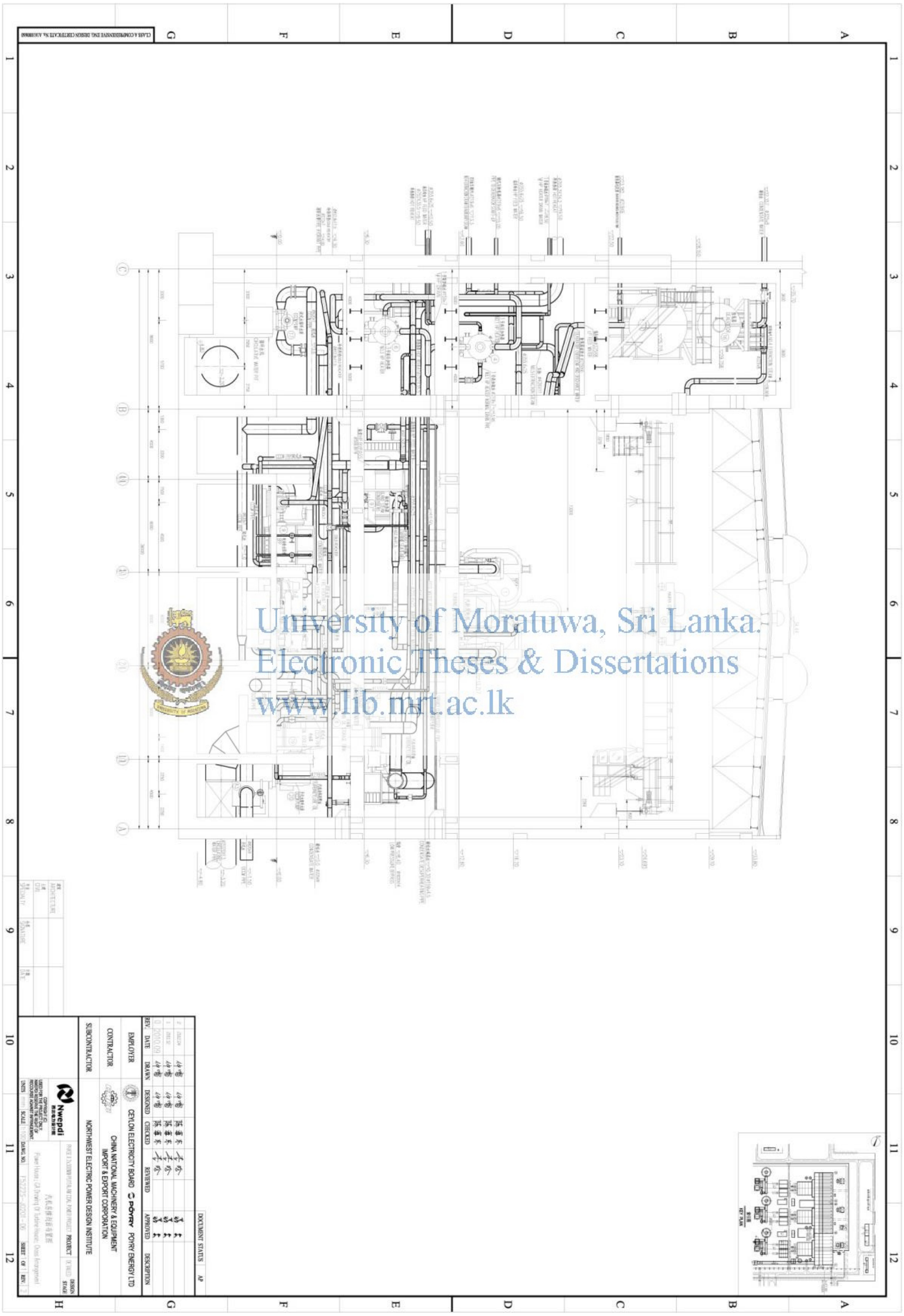
[89]. Sourcewatch, "Tanjung Jati B power station", Internet: http://www.sourcewatch.org/index.php, Dec, 2013. [Mar. 04, 2015]

[90]. Y. Sianipar, (2014, May). "Indonesia Fact Sheet", [Online]. Available: http://www.chevron.com/documents/pdf/indonesiafactsheet.pdf, [Mar. 04, 2015]

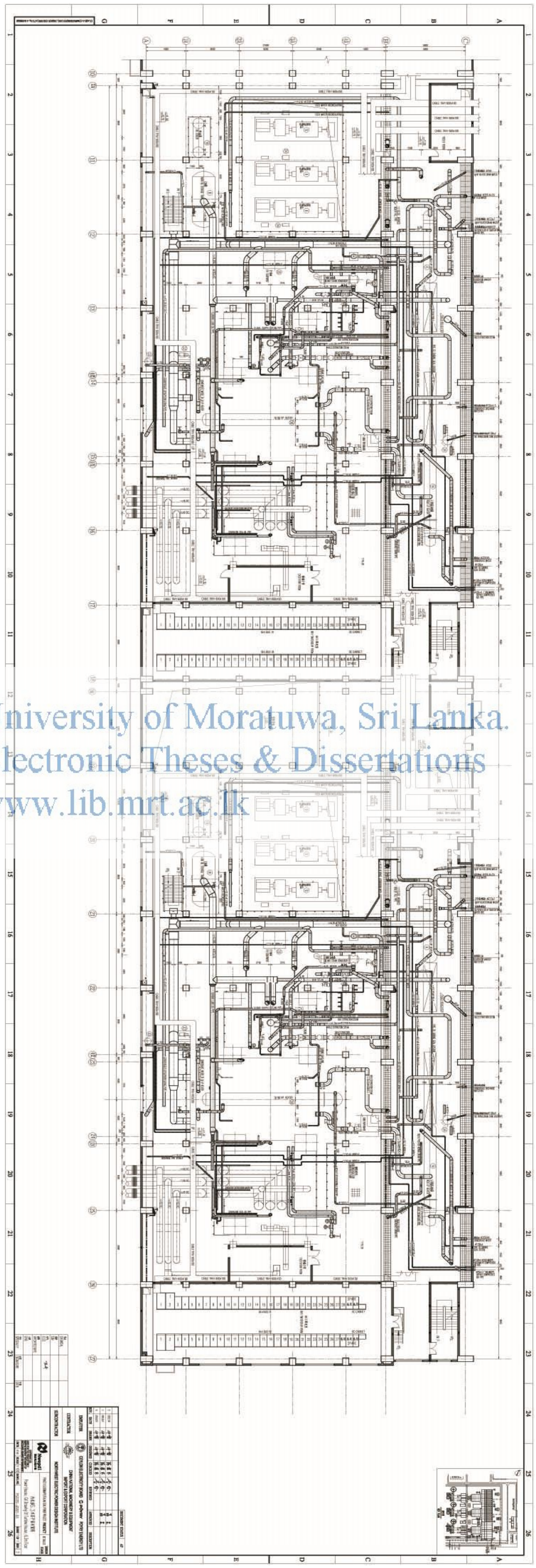
APPENDIX A: SITE LAYOUT OF NOROCHCHOLAI COAL POWER PLANT



APPENDIX B: EQUIPMENT LAYOUT DRAWING OF MPB IN NCPP



APPENDIX C: EQUIPMENT ARRANGEMENT DRAWING OF MPB IN NPP



APPENDIX D: EES CODE OF THE PROGRAMME TO CALCULATE OUTCOMES

EES program to find steam mass flow rate

```
H_1=Enthalpy(steam, P=P_1, T=T_1)
H_2=Enthalpy(steam, T=T_2,X=X_2)

S_1=Entropy(steam, P=P_1, T=T_1)
S_2=Entropy(steam, T=T_2,X=X_2)

P_2=Pressure(steam, T=T_2,X=X_2)


P_pump=5400[kW]
eta=0.75
m=P_pump/(H_1-H_2)/eta

"As a percentage of BMCR"

Per_BMCR=2*m*3600[s/h]/1000[kg/t]/1025[t/h]*100
```


EES program to analyze the current thermodynamic cycle of the power plant without an extraction for the BFPT (i.e. with a motor driven BFP)

```
    "-----------------------------------------
    P : Pressure in MPa
    T: Temperature in C
    G: Steam mass flow in kg/h
    H: Enthalpy in kJ/kg
    -----------------------------------------"

P_1=16700[kPa]
T_1=538[C]
G_1=964000[kg/h]
H_1=Enthalpy(steam, P=P_1, T=T_1)     {3396.9[kJ/kg]}
S_1=Entropy(steam, P=P_1, T=T_1)

P_2=3913[kPa]
```

T_2=331.2[C]

G_2=799380[kg/h]

H_2=Enthalpy(steam, P=P_2, T=T_2) {3049.4[kJ/kg]}

S_2=Entropy(steam, P=P_2, T=T_2)

P_3=3521[kPa]

T_3=538[C]

G_3=799380[kg/h]

H_3=Enthalpy(steam, P=P_3, T=T_3) {3536.0[kJ/kg]}

S_3=Entropy(steam, P=P_3, T=T_3)

P_4=951[kPa]

T_4=355.5[C]

G_4=726850[kg/h]

H_4=Enthalpy(steam, P=P_4, T=T_4) {3170.1[kJ/kg]}

S_4=Entropy(steam, P=P_4, T=T_4)

P_5=9.7[kPa]

T_5=45.2[C]

G_5=610560[kg/h]

H_5=2404.2[kJ/kg]

X_5=Quality(steam, H=H_5,T=T_5)

S_5=Entropy(steam, P=P_5, X=X_5)

P_6=Pressure(steam, T=T_6,H=H_6)

T_6=45.2[C]

G_6=G_7

H_6=189.3[kJ/kg]

S_6=Entropy(steam, H=H_6, T=T_6)

P_7=Pressure(steam, T=T_7,H=H_7)

T_7=45.6[C]

G_7=757730[kg/h]

H_7=191.1[kJ/kg]

S_7=Entropy(steam, H=H_7, T=T_7)

P_8=Pressure(steam, H=H_8, T=T_8)

```
T_8=46[C]
G_8=G_7
H_8=192.8[kJ/kg]
S_8=Entropy(steam, H=H_8, T=T_8)

P_9=Pressure(steam, H=H_9, T=T_9)
T_9=61.4[C]
G_9=G_7
H_9=258.5[kJ/kg]
S_9=Entropy(steam, H=H_9, T=T_9)

P_10=Pressure(steam, H=H_10, T=T_10)
T_10=85.4[C]
G_10=G_7
H_10=358.8[kJ/kg]
S_10=Entropy(steam, H=H_10, T=T_10)

P_11=Pressure(steam, H=H_11, T=T_11)
T_11=106.3[C]
G_11=G_7
H_11=446.6[kJ/kg]
S_11=Entropy(steam, H=H_11, T=T_11)

P_12=Pressure(steam, H=H_12, T=T_12)
T_12=139.2[C]
G_12=G_7
H_12=586.6[kJ/kg]
S_12=Entropy(steam, H=H_12, T=T_12)

P_13=Pressure(steam, H=H_13, T=T_13)
T_13=179.8[C]
G_13=G_16
H_13=773.5[kJ/kg]
S_13=Entropy(steam, H=H_13, T=T_13)

P_14=Pressure(steam, H=H_14, T=T_14)
T_14=205.4[C]
```

```
G_14=G_16
H_14=884.6[kJ/kg]
S_14=Entropy(steam, H=H_14, T=T_14)

P_15=Pressure(steam, H=H_15, T=T_15)
T_15=246.0[C]
G_15=G_16
H_15=1068.2[kJ/kg]
S_15=Entropy(steam, H=H_15, T=T_15)

P_16=20320[kPa]
T_16=277.9[C]
G_16=992920[kg/h]
H_16=Enthalpy(steam, P=P_16, T=T_16)          {1220.9[kJ/kg]}
S_16=Entropy(steam, P=P_16, T=T_16)

"---------------------------- Extraction Steam -HTR_in-------------------------------------------------"

P_htr8_in=25.4[kPa]
T_htr8_in=65.3[C]
G_htr8_in=18910[kg/h]
H_htr8_in=2514.7[kJ/kg]

P_htr7_in=69[kPa]
T_htr7_in=89.5[C]
G_htr7_in=29140[kg/h]
H_htr7_in=2651.4[kJ/kg]

P_htr6_in=146[kPa]
T_htr6_in=154.5[C]
G_htr6_in=26180[kg/h]
H_htr6_in=Enthalpy(steam, P=P_htr6_in, T=T_htr6_in)     {2781.8[kJ/kg]}

P_htr5_in=402[kPa]
T_htr5_in=251.5[C]
G_htr5_in=42430[kg/h]
H_htr5_in=Enthalpy(steam, P=P_htr5_in,T=T_htr5_in)     {2967.6[kJ/kg]}
```

P_htr4_in=970[kPa]

T_htr4_in=355.2[C]

G_htr4_in=42580[kg/h]

H_htr4_in=Enthalpy(steam, P=P_htr4_in, T=T_htr4_in)   {3170.1[kJ/kg]}

P_htr3_in=1830[kPa]

T_htr3_in=442.1[C]

G_htr3_in=32000[kg/h]

H_htr3_in=Enthalpy(steam, P=P_htr3_in, T=T_htr3_in)   {3342.8[kJ/kg]}

P_htr2_in=3913[kPa]

T_htr2_in=331.2[C]

G_htr2_in=78400[kg/h]

H_htr2_in=Enthalpy(steam, P=P_htr2_in, T=T_htr2_in)   {3049.4[kJ/kg]}

P_htr1_in=6380[kPa]

T_htr1_in=395.4[C]

G_htr1_in=73320[kg/h]

H_htr1_in=Enthalpy(steam, P=P_htr1_in, T=T_htr1_in)   {3160.9[kJ/kg]}

"------------------------------HTR_out--"

T_htr8_out=51.6[C]

G_htr8_out=G_htr7_out+G_htr8_in

H_htr8_out=216.0[kJ/kg]

T_htr7_out=67.0[C]

G_htr7_out=G_htr6_out+G_htr7_in

H_htr7_out=280.3[kJ/kg]

P_htr6_out=Pressure(steam, H=H_htr6_out, T=T_htr6_out)

T_htr6_out=90.9[C]

G_htr6_out=G_htr5_out+G_htr6_in

H_htr6_out=380.8[kJ/kg]

P_htr4_out=Pressure(steam, H=H_htr5_out, T=T_htr5_out)
T_htr4_out=175.9[C]
G_htr4_out=992920[kg/h]
H_htr4_out=747.4[kJ/kg]

P_htr5_out=Pressure(steam, H=H_htr5_out, T=T_htr5_out)
T_htr5_out=111.8[C]
G_htr5_out=G_htr5_in
H_htr5_out=469.0[kJ/kg]

T_htr3_out=185.4[C]
G_htr3_out=G_htr2_out+G_htr3_in
H_htr3_out=786.8[kJ/kg]

P_htr2_out=Pressure(steam, H=H_htr2_out, T=T_htr2_out)
T_htr2_out=211.0[C]
G_htr2_out=G_htr1_out+G_htr2_in
H_htr2_out=902.3[kJ/kg]

P_htr1_out=Pressure(steam, H=H_htr1_out, T=T_htr1_out)
T_htr1_out=251.6[C]
G_htr1_out=G_htr1_in
H_htr1_out=1093.5[kJ/kg]

"---------------Calculations------------------"

{BFP Power}
P_bfp=G_htr4_out/3600[s/h]*(H_13-H_htr4_out)/1000[kW/MW] {Power added by BFPs}

eta_motor_electric=0.98
eta_pump_mech=0.75

P_bfp_motor=P_bfp/eta_motor_electric/eta_pump_mech

"----------Turbine Power Out put----------"

{HP Turbine}

P_hpt=(G_1*(H_1-H_htr1_in)+(G_1-G_htr1_in)*(H_htr1_in-H_2))/3600[s/h]/1000[kW/MW]

{IP Turbine}

P_ipt=(G_3*(H_3-H_htr3_in)+(G_3-G_htr3_in)*(H_htr3_in-H_4))/3600[s/h]/1000[kW/MW]

{LP Turbine}

P_lpt=(G_4*(H_4-H_htr5_in)+(G_4-G_htr5_in)*(H_htr5_in-H_htr6_in)+(G_4-G_htr5_in-G_htr6_in)*(H_htr6_in-H_htr7_in)+(G_4-G_htr5_in-G_htr6_in-G_htr7_in)*(H_htr7_in-H_htr8_in)+(G_4-G_htr5_in-G_htr6_in-G_htr7_in-G_htr8_in)*(H_htr8_in-H_5))/3600[s/h]/1000[kW/MW]

eta_mech_turb=0.98
eta_elec_gen=0.975

P_net=P_total-P_bfp_motor

P_Gen=(P_hpt+P_ipt+P_lpt)*eta_mech_turb*eta_elec_gen

HR_gross_motor=(G_1*(h_1-h_16)+G_3*(h_3-h_2))/3600[s/h]`/1000[kW/MW]/P_Gen

HR_net_motor=(G_1*(h_1-h_16)+G_3*(h_3-h_2))/3600[s/h]`/1000[kW/MW]/(P_Gen-P_bfpm)

EES program to find steam extraction point for BFPT

Four different EES programs were created for each extraction point and only the program for extraction point A is shown here.

"--
P : Pressure in MPa
T: Temperature in C
G: Steam mass flow in kg/h

```
H: Enthalpy in kJ/kg
-----------------------------------------"

P_1=16700[kPa]
T_1=538[C]
G_1=G_1_0-G_1_1
H_1=Enthalpy(steam, P=P_1, T=T_1)     {3396.9[kJ/kg]}
S_1=Entropy(steam, P=P_1, T=T_1)

{SH outlet of boiler }
P_1_0=16700[kPa]
T_1_0=538[C]
G_1_0=964000[kg/h]
H_1_0=Enthalpy(steam, P=P_1, T=T_1) {3396.9[kJ/kg]}
S_1_0=Entropy(steam, P=P_1, T=T_1)

{BFPT inlet}
P_1_1=16700[kPa]
T_1_1=538[C]
```



```
H_1_1=Enthalpy(steam, P=P_1, T=T_1) {3396.9[kJ/kg]}
S_1_1=Entropy(steam, P=P_1, T=T_1)

P_2=3913[kPa]
T_2=331.2[C]
G_2=799380[kg/h]-G_1_1
H_2=Enthalpy(steam, P=P_2, T=T_2)     {3049.4[kJ/kg]}
S_2=Entropy(steam, P=P_2, T=T_2)

P_3=3521[kPa]
T_3=538[C]
G_3=G_2
H_3=Enthalpy(steam, P=P_3, T=T_3)     {3536.0[kJ/kg]}
S_3=Entropy(steam, P=P_3, T=T_3)

P_4=951[kPa]
```

```
T_4=355.5[C]
G_4=726850[kg/h]-G_1_1
H_4=Enthalpy(steam, P=P_4, T=T_4)     {3170.1[kJ/kg]}
S_4=Entropy(steam, P=P_4, T=T_4)

P_5=9.7[kPa]
T_5=45.2[C]
G_5=610560[kg/h]-G_1_1
H_5=2404.2[kJ/kg]
X_5=Quality(steam, H=H_5,T=T_5)
S_5=Entropy(steam, P=P_5, X=X_5)

P_6=Pressure(steam, T=T_6,H=H_6)
T_6=45.2[C]
G_6=G_7
H_6=189.3[kJ/kg]
S_6=Entropy(steam, H=H_6, T=T_6)

P_7=Pressure(steam, T=T_7,H=H_7)
T_7=45.6[C]
G_7=757730[kg/h]
H_7=191.1[kJ/kg]
S_7=Entropy(steam, H=H_7, T=T_7)

P_8=Pressure(steam, H=H_8, T=T_8)
T_8=46[C]
G_8=G_7
H_8=192.8[kJ/kg]
S_8=Entropy(steam, H=H_8, T=T_8)

P_9=Pressure(steam, H=H_9, T=T_9)
T_9=61.4[C]
G_9=G_7
H_9=258.5[kJ/kg]
S_9=Entropy(steam, H=H_9, T=T_9)

P_10=Pressure(steam, H=H_10, T=T_10)
```

T_10=85.4[C]

G_10=G_7

H_10=358.8[kJ/kg]

S_10=Entropy(steam, H=H_10, T=T_10)

P_11=Pressure(steam, H=H_11, T=T_11)

T_11=106.3[C]

G_11=G_7

H_11=446.6[kJ/kg]

S_11=Entropy(steam, H=H_11, T=T_11)

P_12=Pressure(steam, H=H_12, T=T_12)

T_12=139.2[C]

G_12=G_7

H_12=586.6[kJ/kg]

S_12=Entropy(steam, H=H_12, T=T_12)

P_13=Pressure(steam, H=H_13, T=T_13)

T_13=179.8[C]

G_13=G_16

H_13=773.5[kJ/kg]

S_13=Entropy(steam, H=H_13, T=T_13)

P_14=Pressure(steam, H=H_14, T=T_14)

T_14=205.4[C]

G_14=G_16

H_14=884.6[kJ/kg]

S_14=Entropy(steam, H=H_14, T=T_14)

P_15=Pressure(steam, H=H_15, T=T_15)

T_15=246.0[C]

G_15=G_16

H_15=1068.2[kJ/kg]

S_15=Entropy(steam, H=H_15, T=T_15)

P_16=20320[kPa]

T_16=277.9[C]

G_16=992920[kg/h]

H_16=Enthalpy(steam, P=P_16, T=T_16) {1220.9[kJ/kg]}

S_16=Entropy(steam, P=P_16, T=T_16)

"---------------------------- Extraction Steam -HTR_in---"

P_htr8_in=25.4[kPa]

T_htr8_in=65.3[C]

G_htr8_in=18910[kg/h]

H_htr8_in=2514.7[kJ/kg]

P_htr7_in=69[kPa]

T_htr7_in=89.5[C]

G_htr7_in=29140[kg/h]

H_htr7_in=2651.4[kJ/kg]

P_htr6_in=146[kPa]

T_htr6_in=154.5[C]

G_htr6_in=26180[kg/h]

H_htr6_in=Enthalpy(steam, P=P_htr6_in, T=T_htr6_in) {2781.8[kJ/kg]}

P_htr5_in=402[kPa]

T_htr5_in=251.5[C]

G_htr5_in=42430[kg/h]

H_htr5_in=Enthalpy(steam, P=P_htr5_in,T=T_htr5_in) {2967.6[kJ/kg]}

P_htr4_in=970[kPa]

T_htr4_in=355.2[C]

G_htr4_in=42580[kg/h]

H_htr4_in=Enthalpy(steam, P=P_htr4_in, T=T_htr4_in) {3170.1[kJ/kg]}

P_htr3_in=1830[kPa]

T_htr3_in=442.1[C]

G_htr3_in=32000[kg/h]

H_htr3_in=Enthalpy(steam, P=P_htr3_in, T=T_htr3_in) {3342.8[kJ/kg]}

P_htr2_in=3913[kPa]

T_htr2_in=331.2[C]

G_htr2_in=78400[kg/h]

H_htr2_in=Enthalpy(steam, P=P_htr2_in, T=T_htr2_in) {3049.4[kJ/kg]}

P_htr1_in=6380[kPa]

T_htr1_in=395.4[C]

G_htr1_in=73320[kg/h]

H_htr1_in=Enthalpy(steam, P=P_htr1_in, T=T_htr1_in) {3160.9[kJ/kg]}

"-----------------------------HTR_out--"

T_htr8_out=51.6[C]

G_htr8_out=G_htr7_out+G_htr8_in

H_htr8_out=216.0[kJ/kg]

T_htr7_out=67.0[C]

G_htr7_out=G_htr6_out+G_htr7_in

H_htr7_out=280.3[kJ/kg]

P_htr6_out=Pressure(steam, H=H_htr6_out, T=T_htr6_out)

T_htr6_out=90.9[C]

G_htr6_out=G_htr5_out+G_htr6_in

H_htr6_out=380.8[kJ/kg]

P_htr4_out=Pressure(steam, H=H_htr5_out, T=T_htr5_out)

T_htr4_out=175.9[C]

G_htr4_out=992920[kg/h]

H_htr4_out=747.4[kJ/kg]

P_htr5_out=Pressure(steam, H=H_htr5_out, T=T_htr5_out)

T_htr5_out=111.8[C]

G_htr5_out=G_htr5_in

H_htr5_out=469.0[kJ/kg]

```
T_htr3_out=185.4[C]
G_htr3_out=G_htr2_out+G_htr3_in
H_htr3_out=786.8[kJ/kg]

P_htr2_out=Pressure(steam, H=H_htr2_out, T=T_htr2_out)
T_htr2_out=211.0[C]
G_htr2_out=G_htr1_out+G_htr2_in
H_htr2_out=902.3[kJ/kg]

P_htr1_out=Pressure(steam, H=H_htr1_out, T=T_htr1_out)
T_htr1_out=251.6[C]
G_htr1_out=G_htr1_in
H_htr1_out=1093.5[kJ/kg]

"---------------Calculations------------------"

{BFP Power}
P_bfp=G_htr4_out/3600[s/h]*(H_13-H_htr4_out)/1000[kW/MW]     {Power added by BFPs}

eta_bfpt=0.98
eta_pump_mech=0.75

P_bfpt=P_bfp/eta_bfpt/eta_pump_mech
P_bfpt=G_1_1/3600[s/h]*(H_1_1-H_5)/1000[kW/MW]

"----------Turbine Power Out put----------"

{HP Turbine}

P_hpt=(G_1*(H_1-H_htr1_in)+(G_1-G_htr1_in)*(H_htr1_in-H_2))/3600[s/h]/1000[kW/MW]

{IP Turbine}

P_ipt=(G_3*(H_3-H_htr3_in)+(G_3-G_htr3_in)*(H_htr3_in-H_4))/3600[s/h]/1000[kW/MW]

{LP Turbine}
```

P_lpt=(G_4*(H_4-H_htr5_in)+(G_4-G_htr5_in)*(H_htr5_in-H_htr6_in)+(G_4-G_htr5_in-G_htr6_in)*(H_htr6_in-H_htr7_in)+(G_4-G_htr5_in-G_htr6_in-G_htr7_in)*(H_htr7_in-H_htr8_in)+(G_4-G_htr5_in-G_htr6_in-G_htr7_in-G_htr8_in)*(H_htr8_in-H_5))/3600[s/h]/1000[kW/MW]

eta_mech_turb=0.98
eta_elec_gen=0.975

P_Gen=(P_hpt+P_ipt+P_lpt)*eta_mech_turb*eta_elec_gen

HR_gross_turb=(G_1*(h_1-h_16)+G_3*(h_3-h_2))/3600[s/h]`/1000[kW/MW]/(P_Gen+P_bfpt)

HR_net_turb=(G_1*(h_1-h_16)+G_3*(h_3-h_2))/3600[s/h]`/1000[kW/MW]/P_Gen

Solutions to EES programs for each outcomes.

Iterated inputs	Outcome_1	Outcome_2	Outcome_3	Outcome_4	Outcome_5
eta_bfpt=0.98	eta_bfpt=0.98	eta_bfpt=0.98	eta_elec_gen=0.975	eta_elec_gen=0.975	eta_bfpt=0.98
eta_elec_gen=0.975	eta_elec_gen=0.975	eta_elec_gen=0.975	eta_mech_turb=0.98	eta_mech_turb=0.98	eta_elec_gen=0.975
eta_mech_turb=0.98	eta_mech_turb=0.98	eta_mech_turb=0.98	eta_pump_mech=0.75	eta_motor_electric=0.98	eta_mech_turb=0.98
eta_pump_mech=0.75	eta_pump_mech=0.75	eta_pump_mech=0.75	eta_turbine=0.98	eta_pump_mech=0.75	eta_pump_mech=0.75
G_1=928476 [kg/h]	G_1=964000 [kg/h]	G_1=964000 [kg/h]	G_1=964000 [kg/h]	G_1=964000 [kg/h]	G_1=964000 [kg/h]
G_10=757730 [kg/h]	G_10=757730 [kg/h]	G_10=757730 [kg/h]	G_10=757730 [kg/h]	G_10=757730 [kg/h]	G_10=757730 [kg/h]
G_11=757730 [kg/h]	G_11=757730 [kg/h]	G_11=757730 [kg/h]	G_11=757730 [kg/h]	G_11=757730 [kg/h]	G_11=757730 [kg/h]
G_12=757730 [kg/h]	G_12=757730 [kg/h]	G_12=757730 [kg/h]	G_12=757730 [kg/h]	G_12=757730 [kg/h]	G_12=757730 [kg/h]
G_13=992920 [kg/h]	G_13=992920 [kg/h]	G_13=992920 [kg/h]	G_13=992920 [kg/h]	G_13=992920 [kg/h]	G_13=992920 [kg/h]
G_14=992920 [kg/h]	G_14=992920 [kg/h]	G_14=992920 [kg/h]	G_14=992920 [kg/h]	G_14=992920 [kg/h]	G_14=992920 [kg/h]
G_15=992920 [kg/h]	G_15=992920 [kg/h]	G_15=992920 [kg/h]	G_15=992920 [kg/h]	G_15=992920 [kg/h]	G_15=992920 [kg/h]
G_16=992920 [kg/h]	G_16=992920 [kg/h]	G_16=992920 [kg/h]	G_16=992920 [kg/h]	G_16=992920 [kg/h]	G_16=992920 [kg/h]
G_1_0=964000 [kg/h]	G_2=744463 [kg/h]	G_2=799380 [kg/h]	G_2=799380 [kg/h]	G_2=799380 [kg/h]	G_1_0=999524 [kg/h]
G_1_1=35524 [kg/h]	G_2_0=799380 [kg/h]	G_3=768255 [kg/h]	G_3=799380 [kg/h]	G_3=799380 [kg/h]	G_1_1=35524 [kg/h]
G_2=763856 [kg/h]	G_2_1=54917	G_3_0=799380 [kg/h]	G_4=680809 [kg/h]	G_4=726850 [kg/h]	G_2=763856 [kg/h]
G_3=763856 [kg/h]	G_3=744463 [kg/h]	G_3_1=31125	G_4_0=726850 [kg/h]	G_5=610560 [kg/h]	G_3=763856 [kg/h]
G_4=691326 [kg/h]	G_4=671933 [kg/h]	G_4=695725 [kg/h]	G_4_1=46041	G_6=757730 [kg/h]	G_4=691326 [kg/h]
G_5=575036 [kg/h]	G_5=555643 [kg/h]	G_5=579435 [kg/h]	G_5=564519 [kg/h]	G_7=757730 [kg/h]	G_5=575036 [kg/h]
G_6=757730 [kg/h]	G_6=757730 [kg/h]	G_6=757730 [kg/h]	G_6=757730 [kg/h]	G_8=757730 [kg/h]	G_6=757730 [kg/h]
G_7=757730 [kg/h]	G_7=757730 [kg/h]	G_7=757730 [kg/h]	G_7=757730 [kg/h]	G_9=757730 [kg/h]	G_7=757730 [kg/h]
G_8=757730 [kg/h]	G_8=757730 [kg/h]	G_8=757730 [kg/h]	G_8=757730 [kg/h]	G_htr1_in=73320 [kg/h]	G_8=757730 [kg/h]

G_9=757730 [kg/h]	G_9=757730 [kg/h]	G_9=757730 [kg/h]	G_9=757730 [kg/h]	G_htr1_out=73320 [kg/h]	G_9=757730 [kg/h]
G_htr1_in=73320 [kg/h]	G_htr1_in=73320 [kg/h]	G_htr1_in=73320 [kg/h]	G_htr1_in=73320 [kg/h]	G_htr2_in=78400 [kg/h]	G_htr1_in=73320 [kg/h]
G_htr1_out=73320 [kg/h]	G_htr1_out=73320 [kg/h]	G_htr1_out=73320 [kg/h]	G_htr1_out=73320 [kg/h]	G_htr2_out=151720 [kg/h]	G_htr1_out=73320 [kg/h]
G_htr2_in=78400 [kg/h]	G_htr2_in=78400 [kg/h]	G_htr2_in=78400 [kg/h]	G_htr2_in=78400 [kg/h]	G_htr3_in=32000 [kg/h]	G_htr2_in=78400 [kg/h]
G_htr2_out=151720 [kg/h]	G_htr2_out=151720 [kg/h]	G_htr2_out=151720 [kg/h]	G_htr2_out=151720 [kg/h]	G_htr3_out=183720 [kg/h]	G_htr2_out=151720 [kg/h]
G_htr3_in=32000 [kg/h]	G_htr3_in=32000 [kg/h]	G_htr3_in=32000 [kg/h]	G_htr3_in=32000 [kg/h]	G_htr4_in=42580 [kg/h]	G_htr3_in=32000 [kg/h]
G_htr3_out=183720 [kg/h]	G_htr3_out=183720 [kg/h]	G_htr3_out=183720 [kg/h]	G_htr3_out=183720 [kg/h]	G_htr4_out=992920 [kg/h]	G_htr3_out=183720 [kg/h]
G_htr4_in=42580 [kg/h]	G_htr4_in=42580 [kg/h]	G_htr4_in=42580 [kg/h]	G_htr4_in=42580 [kg/h]	G_htr5_in=42430 [kg/h]	G_htr4_in=42580 [kg/h]
G_htr4_out=992920 [kg/h]	G_htr4_out=992920 [kg/h]	G_htr4_out=992920 [kg/h]	G_htr4_out=992920 [kg/h]	G_htr5_out=42430 [kg/h]	G_htr4_out=992920 [kg/h]
G_htr5_in=42430 [kg/h]	G_htr5_in=42430 [kg/h]	G_htr5_in=42430 [kg/h]	G_htr5_in=42430 [kg/h]	G_htr6_in=26180 [kg/h]	G_htr5_in=42430 [kg/h]
G_htr5_out=42430 [kg/h]	G_htr5_out=42430 [kg/h]	G_htr5_out=42430 [kg/h]	G_htr5_out=42430 [kg/h]	G_htr6_out=68610 [kg/h]	G_htr5_out=42430 [kg/h]
G_htr6_in=26180 [kg/h]	G_htr6_in=26180 [kg/h]	G_htr6_in=26180 [kg/h]	G_htr6_in=26180 [kg/h]	G_htr7_in=29140 [kg/h]	G_htr6_in=26180 [kg/h]
G_htr6_out=68610 [kg/h]	G_htr6_out=68610 [kg/h]	G_htr6_out=68610 [kg/h]	G_htr6_out=68610 [kg/h]	G_htr7_out=97750 [kg/h]	G_htr6_out=68610 [kg/h]
G_htr7_in=29140 [kg/h]	G_htr7_in=29140 [kg/h]	G_htr7_in=29140 [kg/h]	G_htr7_in=29140 [kg/h]	G_htr8_in=18910 [kg/h]	G_htr7_in=29140 [kg/h]
G_htr7_out=97750 [kg/h]	G_htr7_out=97750 [kg/h]	G_htr7_out=97750 [kg/h]	G_htr7_out=97750 [kg/h]	G_htr8_out=116660 [kg/h]	G_htr7_out=97750 [kg/h]
G_htr8_in=18910 [kg/h]	G_htr8_in=18910 [kg/h]	G_htr8_in=18910 [kg/h]	G_htr8_in=18910 [kg/h]	HR_gross_motor=2.304	G_htr8_in=18910 [kg/h]
G_htr8_out=116660 [kg/h]	G_htr8_out=116660 [kg/h]	G_htr8_out=116660 [kg/h]	G_htr8_out=116660 [kg/h]	HR_net_motor=2.382	G_htr8_out=116660 [kg/h]
HR_gross_turb=2.248	HR_gross_turb=2.331	HR_gross_turb=2.287	HR_gross_turb=2.301	H_1=3397 [kJ/kg]	HR_gross_turb=2.295
HR_net_turb=2.325	HR_net_turb=2.412	HR_net_turb=2.364	HR_net_turb=2.378	H_10=358.8 [kJ/kg]	HR_net_turb=2.373
H_1=3397 [kJ/kg]	H_1=3397 [kJ/kg]	H_1=3397 [kJ/kg]	H_1=3397 [kJ/kg]	H_11=446.6 [kJ/kg]	H_1=3397 [kJ/kg]
H_10=358.8 [kJ/kg]	H_10=358.8 [kJ/kg]	H_10=358.8 [kJ/kg]	H_10=358.8 [kJ/kg]	H_12=586.6 [kJ/kg]	H_10=358.8 [kJ/kg]
H_11=446.6 [kJ/kg]	H_11=446.6 [kJ/kg]	H_11=446.6 [kJ/kg]	H_11=446.6 [kJ/kg]	H_13=773.5 [kJ/kg]	H_11=446.6 [kJ/kg]
H_12=586.6 [kJ/kg]	H_12=586.6 [kJ/kg]	H_12=586.6 [kJ/kg]	H_12=586.6 [kJ/kg]	H_14=884.6 [kJ/kg]	H_12=586.6 [kJ/kg]
H_13=773.5 [kJ/kg]	H_13=773.5 [kJ/kg]	H_13=773.5 [kJ/kg]	H_13=773.5 [kJ/kg]	H_15=1068 [kJ/kg]	H_13=773.5 [kJ/kg]
H_14=884.6 [kJ/kg]	H_14=884.6 [kJ/kg]	H_14=884.6 [kJ/kg]	H_14=884.6 [kJ/kg]	H_16=1220 [kJ/kg]	H_14=884.6 [kJ/kg]
H_15=1068 [kJ/kg]	H_15=1068 [kJ/kg]	H_15=1068 [kJ/kg]	H_15=1068 [kJ/kg]	H_2=3046 [kJ/kg]	H_15=1068 [kJ/kg]
H_16=1220 [kJ/kg]	H_16=1220 [kJ/kg]	H_16=1220 [kJ/kg]	H_16=1220 [kJ/kg]	H_3=3537 [kJ/kg]	H_16=1220 [kJ/kg]
H_1_0=3397 [kJ/kg]	H_2=3046 [kJ/kg]	H_2=3046 [kJ/kg]	H_2=3046 [kJ/kg]	H_4=3170 [kJ/kg]	H_1_0=3397 [kJ/kg]
H_1_1=3397 [kJ/kg]	H_2_0=3046 [kJ/kg]	H_3=3537 [kJ/kg]	H_3=3537 [kJ/kg]	H_5=2404 [kJ/kg]	H_1_1=3397 [kJ/kg]
H_2=3046 [kJ/kg]	H_2_1=3046 [kJ/kg]	H_3_0=3537 [kJ/kg]	H_4=3170 [kJ/kg]	H_6=189.3 [kJ/kg]	H_2=3046 [kJ/kg]
H_3=3537 [kJ/kg]	H_3=3537 [kJ/kg]	H_3_1=3537 [kJ/kg]	H_4_0=3170 [kJ/kg]	H_7=191.1 [kJ/kg]	H_3=3537 [kJ/kg]
H_4=3170 [kJ/kg]	H_4=3170 [kJ/kg]	H_4=3170 [kJ/kg]	H_4_1=3170 [kJ/kg]	H_8=192.8 [kJ/kg]	H_4=3170 [kJ/kg]
H_5=2404 [kJ/kg]	H_5=2404 [kJ/kg]	H_5=2404 [kJ/kg]	H_5=2404 [kJ/kg]	H_9=258.5 [kJ/kg]	H_5=2404 [kJ/kg]
H_6=189.3 [kJ/kg]	H_6=189.3 [kJ/kg]	H_6=189.3 [kJ/kg]	H_6=189.3 [kJ/kg]	H_htr1_in=3158 [kJ/kg]	H_6=189.3 [kJ/kg]
H_7=191.1 [kJ/kg]	H_7=191.1 [kJ/kg]	H_7=191.1 [kJ/kg]	H_7=191.1 [kJ/kg]	H_htr1_out=1094 [kJ/kg]	H_7=191.1 [kJ/kg]
H_8=192.8 [kJ/kg]	H_8=192.8 [kJ/kg]	H_8=192.8 [kJ/kg]	H_8=192.8 [kJ/kg]	H_htr2_in=3046 [kJ/kg]	H_8=192.8 [kJ/kg]
H_9=258.5 [kJ/kg]	H_9=258.5 [kJ/kg]	H_9=258.5 [kJ/kg]	H_9=258.5 [kJ/kg]	H_htr2_out=902.3	H_9=258.5 [kJ/kg]

				[kJ/kg]	
H_htr1_in=3158 [kJ/kg]	H_htr1_in=3158 [kJ/kg]	H_htr1_in=3158 [kJ/kg]	H_htr1_in=3158 [kJ/kg]	H_htr3_in=3343 [kJ/kg]	H_htr1_in=3158 [kJ/kg]
H_htr1_out=1094 [kJ/kg]	H_htr1_out=1094 [kJ/kg]	H_htr1_out=1094 [kJ/kg]	H_htr1_out=1094 [kJ/kg]	H_htr3_out=786.8 [kJ/kg]	H_htr1_out=1094 [kJ/kg]
H_htr2_in=3046 [kJ/kg]	H_htr2_in=3046 [kJ/kg]	H_htr2_in=3046 [kJ/kg]	H_htr2_in=3046 [kJ/kg]	H_htr4_in=3169 [kJ/kg]	H_htr2_in=3046 [kJ/kg]
H_htr2_out=902.3 [kJ/kg]	H_htr2_out=902.3 [kJ/kg]	H_htr2_out=902.3 [kJ/kg]	H_htr2_out=902.3 [kJ/kg]	H_htr4_out=747.4 [kJ/kg]	H_htr2_out=902.3 [kJ/kg]
H_htr3_in=3343 [kJ/kg]	H_htr3_in=3343 [kJ/kg]	H_htr3_in=3343 [kJ/kg]	H_htr3_in=3343 [kJ/kg]	H_htr5_in=2967 [kJ/kg]	H_htr3_in=3343 [kJ/kg]
H_htr3_out=786.8 [kJ/kg]	H_htr3_out=786.8 [kJ/kg]	H_htr3_out=786.8 [kJ/kg]	H_htr3_out=786.8 [kJ/kg]	H_htr5_out=469 [kJ/kg]	H_htr3_out=786.8 [kJ/kg]
H_htr4_in=3169 [kJ/kg]	H_htr4_in=3169 [kJ/kg]	H_htr4_in=3169 [kJ/kg]	H_htr4_in=3169 [kJ/kg]	H_htr6_in=2782 [kJ/kg]	H_htr4_in=3169 [kJ/kg]
H_htr4_out=747.4 [kJ/kg]	H_htr4_out=747.4 [kJ/kg]	H_htr4_out=747.4 [kJ/kg]	H_htr4_out=747.4 [kJ/kg]	H_htr6_out=380.8 [kJ/kg]	H_htr4_out=747.4 [kJ/kg]
H_htr5_in=2967 [kJ/kg]	H_htr5_in=2967 [kJ/kg]	H_htr5_in=2967 [kJ/kg]	H_htr5_in=2967 [kJ/kg]	H_htr7_in=2651 [kJ/kg]	H_htr5_in=2967 [kJ/kg]
H_htr5_out=469 [kJ/kg]	H_htr5_out=469 [kJ/kg]	H_htr5_out=469 [kJ/kg]	H_htr5_out=469 [kJ/kg]	H_htr7_out=280.3 [kJ/kg]	H_htr5_out=469 [kJ/kg]
H_htr6_in=2782 [kJ/kg]	H_htr6_in=2782 [kJ/kg]	H_htr6_in=2782 [kJ/kg]	H_htr6_in=2782 [kJ/kg]	H_htr8_in=2515 [kJ/kg]	H_htr6_in=2782 [kJ/kg]
H_htr6_out=380.8 [kJ/kg]	H_htr6_out=380.8 [kJ/kg]	H_htr6_out=380.8 [kJ/kg]	H_htr6_out=380.8 [kJ/kg]	H_htr8_out=216 [kJ/kg]	H_htr6_out=380.8 [kJ/kg]
H_htr7_in=2651 [kJ/kg]	H_htr7_in=2651 [kJ/kg]	H_htr7_in=2651 [kJ/kg]	H_htr7_in=2651 [kJ/kg]	P_1=16700 [kPa]	H_htr7_in=2651 [kJ/kg]
H_htr7_out=280.3 [kJ/kg]	H_htr7_out=280.3 [kJ/kg]	H_htr7_out=280.3 [kJ/kg]	H_htr7_out=280.3 [kJ/kg]	P_10=58.73 [kPa]	H_htr7_out=280.3 [kJ/kg]
H_htr8_in=2515 [kJ/kg]	H_htr8_in=2515 [kJ/kg]	H_htr8_in=2515 [kJ/kg]	H_htr8_in=2515 [kJ/kg]	P_11=126.3 [kPa]	H_htr8_in=2515 [kJ/kg]
H_htr8_out=216 [kJ/kg]	H_htr8_out=216 [kJ/kg]	H_htr8_out=216 [kJ/kg]	H_htr8_out=216 [kJ/kg]	P_12=353.1 [kPa]	H_htr8_out=216 [kJ/kg]
P_1=16700 [kPa]	P_1=16700 [kPa]	P_1=16700 [kPa]	P_1=16700 [kPa]	P_13=997.3 [kPa]	P_1=16700 [kPa]
P_10=58.73 [kPa]	P_10=58.73 [kPa]	P_10=58.73 [kPa]	P_10=58.73 [kPa]	P_14=1737 [kPa]	P_10=58.73 [kPa]
P_11=126.3 [kPa]	P_11=126.3 [kPa]	P_11=126.3 [kPa]	P_11=126.3 [kPa]	P_15=3712 [kPa]	P_11=126.3 [kPa]
P_12=353.1 [kPa]	P_12=353.1 [kPa]	P_12=353.1 [kPa]	P_12=353.1 [kPa]	P_16=20320 [kPa]	P_12=353.1 [kPa]
P_13=997.3 [kPa]	P_13=997.3 [kPa]	P_13=997.3 [kPa]	P_13=997.3 [kPa]	P_2=3913 [kPa]	P_13=997.3 [kPa]
P_14=1737 [kPa]	P_14=1737 [kPa]	P_14=1737 [kPa]	P_14=1737 [kPa]	P_3=3521 [kPa]	P_14=1737 [kPa]
P_15=3712 [kPa]	P_15=3712 [kPa]	P_15=3712 [kPa]	P_15=3712 [kPa]	P_4=951 [kPa]	P_15=3712 [kPa]
P_16=20320 [kPa]	P_16=20320 [kPa]	P_16=20320 [kPa]	P_16=20320 [kPa]	P_5=9.7 [kPa]	P_16=20320 [kPa]
P_1_0=16700 [kPa]	P_2=3913 [kPa]	P_2=3913 [kPa]	P_2=3913 [kPa]	P_6=9.689 [kPa]	P_1_0=16700 [kPa]
P_1_1=16700 [kPa]	P_2_0=3913 [kPa]	P_3=3521 [kPa]	P_3=3521 [kPa]	P_7=9.89 [kPa]	P_1_1=16700 [kPa]
P_2=3913 [kPa]	P_2_1=3913 [kPa]	P_3_0=3521 [kPa]	P_4=951 [kPa]	P_8=10.09 [kPa]	P_2=3913 [kPa]
P_3=3521 [kPa]	P_3=3521 [kPa]	P_3_1=3521 [kPa]	P_4_0=951 [kPa]	P_9=21.26 [kPa]	P_3=3521 [kPa]
P_4=951 [kPa]	P_4=951 [kPa]	P_4=951 [kPa]	P_4_1=951 [kPa]	P_bfp=7.199 [kW]	P_4=951 [kPa]
P_5=9.7 [kPa]	P_5=9.7 [kPa]	P_5=9.7 [kPa]	P_5=9.7 [kPa]	P_bfpm=9.794	P_5=9.7 [kPa]
P_6=9.689 [kPa]	P_6=9.689 [kPa]	P_6=9.689 [kPa]	P_6=9.689 [kPa]	P_Gen=300.2	P_6=9.689 [kPa]
P_7=9.89 [kPa]	P_7=9.89 [kPa]	P_7=9.89 [kPa]	P_7=9.89 [kPa]	P_hpt=91.58 [MW]	P_7=9.89 [kPa]
P_8=10.09 [kPa]	P_8=10.09 [kPa]	P_8=10.09 [kPa]	P_8=10.09 [kPa]	P_htr1_in=6380 [kPa]	P_8=10.09 [kPa]
P_9=21.26 [kPa]	P_9=21.26 [kPa]	P_9=21.26 [kPa]	P_9=21.26 [kPa]	P_htr1_out=4082 [kPa]	P_9=21.26 [kPa]
P_bfp=7.199 [MW]	P_bfp=7.199 [MW]	P_bfp=7.199 [MW]	P_bfp=7.199 [MW]	P_htr2_in=3913 [kPa]	P_bfp=7.199 [MW]
P_bfpt=9.794	P_bfpt=9.794	P_bfpt=9.794	P_bfpt=9.794	P_htr2_out=1945 [kPa]	P_bfpt=9.794

P_Gen=286.2	P_Gen=283.7	P_Gen=290.9	P_Gen=290.9	P_htr3_in=1830 [kPa]	P_Gen=289.5
P_hpt=88.13 [MW]	P_hpt=91.58 [MW]	P_hpt=91.58 [MW]	P_hpt=91.58 [MW]	P_htr4_in=970 [kPa]	P_hpt=91.58 [MW]
P_htr1_in=6380 [kPa]	P_htr1_in=6380 [kPa]	P_htr1_in=6380 [kPa]	P_htr1_in=6380 [kPa]	P_htr4_out=152.1 [kPa]	P_htr1_in=6380 [kPa]
P_htr1_out=4082 [kPa]	P_htr1_out=4082 [kPa]	P_htr1_out=4082 [kPa]	P_htr1_out=4082 [kPa]	P_htr5_in=402 [kPa]	P_htr1_out=4082 [kPa]
P_htr2_in=3913 [kPa]	P_htr2_in=3913 [kPa]	P_htr2_in=3913 [kPa]	P_htr2_in=3913 [kPa]	P_htr5_out=152.1 [kPa]	P_htr2_in=3913 [kPa]
P_htr2_out=1945 [kPa]	P_htr2_out=1945 [kPa]	P_htr2_out=1945 [kPa]	P_htr2_out=1945 [kPa]	P_htr6_in=146 [kPa]	P_htr2_out=1945 [kPa]
P_htr3_in=1830 [kPa]	P_htr3_in=1830 [kPa]	P_htr3_in=1830 [kPa]	P_htr3_in=1830 [kPa]	P_htr6_out=72.55 [kPa]	P_htr3_in=1830 [kPa]
P_htr4_in=970 [kPa]	P_htr4_in=970 [kPa]	P_htr4_in=970 [kPa]	P_htr4_in=970 [kPa]	P_htr7_in=69 [kPa]	P_htr4_in=970 [kPa]
P_htr4_out=152.1 [kPa]	P_htr4_out=152.1 [kPa]	P_htr4_out=152.1 [kPa]	P_htr4_out=152.1 [kPa]	P_htr8_in=25.4 [kPa]	P_htr4_out=152.1 [kPa]
P_htr5_in=402 [kPa]	P_htr5_in=402 [kPa]	P_htr5_in=402 [kPa]	P_htr5_in=402 [kPa]	P_ipt=79.96 [MW]	P_htr5_in=402 [kPa]
P_htr5_out=152.1 [kPa]	P_htr5_out=152.1 [kPa]	P_htr5_out=152.1 [kPa]	P_htr5_out=152.1 [kPa]	P_lpt=142.7 [MW]	P_htr5_out=152.1 [kPa]
P_htr6_in=146 [kPa]	P_htr6_in=146 [kPa]	P_htr6_in=146 [kPa]	P_htr6_in=146 [kPa]	S_1=6.412 [kJ/kg-K]	P_htr6_in=146 [kPa]
P_htr6_out=72.55 [kPa]	P_htr6_out=72.55 [kPa]	P_htr6_out=72.55 [kPa]	P_htr6_out=72.55 [kPa]	S_10=1.142 [kJ/kg-K]	P_htr6_out=72.55 [kPa]
P_htr7_in=69 [kPa]	P_htr7_in=69 [kPa]	P_htr7_in=69 [kPa]	P_htr7_in=69 [kPa]	S_11=1.38 [kJ/kg-K]	P_htr7_in=69 [kPa]
P_htr8_in=25.4 [kPa]	P_htr8_in=25.4 [kPa]	P_htr8_in=25.4 [kPa]	P_htr8_in=25.4 [kPa]	S_12=1.733 [kJ/kg-K]	P_htr8_in=25.4 [kPa]
P_ipt=76.34 [MW]	P_ipt=74.36 [MW]	P_ipt=76.78 [MW]	P_ipt=79.96 [MW]	S_13=2.162 [kJ/kg-K]	P_ipt=76.34 [MW]
P_lpt=135.1 [MW]	P_lpt=131 [MW]	P_lpt=136 [MW]	P_lpt=132.9 [MW]	S_14=2.398 [kJ/kg-K]	P_lpt=135.1 [MW]
S_1=6.412 [kJ/kg-K]	S_1=6.412 [kJ/kg-K]	S_1=6.412 [kJ/kg-K]	S_1=6.412 [kJ/kg-K]	S_15=2.76 [kJ/kg-K]	S_1=6.412 [kJ/kg-K]
S_10=1.142 [kJ/kg-K]	S_10=1.142 [kJ/kg-K]	S_10=1.142 [kJ/kg-K]	S_10=1.142 [kJ/kg-K]	S_16=3.005 [kJ/kg-K]	S_10=1.142 [kJ/kg-K]
S_11=1.38 [kJ/kg-K]	S_11=1.38 [kJ/kg-K]	S_11=1.38 [kJ/kg-K]	S_11=1.38 [kJ/kg-K]	S_2=6.516 [kJ/kg-K]	S_11=1.38 [kJ/kg-K]
S_12=1.733 [kJ/kg-K]	S_12=1.733 [kJ/kg-K]	S_12=1.733 [kJ/kg-K]	S_12=1.733 [kJ/kg-K]	S_3=7.263 [kJ/kg-K]	S_12=1.733 [kJ/kg-K]
S_13=2.162 [kJ/kg-K]	S_13=2.162 [kJ/kg-K]	S_13=2.162 [kJ/kg-K]	S_13=2.162 [kJ/kg-K]	S_4=7.344 [kJ/kg-K]	S_13=2.162 [kJ/kg-K]
S_14=2.398 [kJ/kg-K]	S_14=2.398 [kJ/kg-K]	S_14=2.398 [kJ/kg-K]	S_14=2.398 [kJ/kg-K]	S_5=7.599 [kJ/kg-K]	S_14=2.398 [kJ/kg-K]
S_15=2.76 [kJ/kg-K]	S_15=2.76 [kJ/kg-K]	S_15=2.76 [kJ/kg-K]	S_15=2.76 [kJ/kg-K]	S_6=0.6413 [kJ/kg-K]	S_15=2.76 [kJ/kg-K]
S_16=3.005 [kJ/kg-K]	S_16=3.005 [kJ/kg-K]	S_16=3.005 [kJ/kg-K]	S_16=3.005 [kJ/kg-K]	S_7=0.647 [kJ/kg-K]	S_16=3.005 [kJ/kg-K]
S_1_0=6.412 [kJ/kg-K]	S_2=6.516 [kJ/kg-K]	S_2=6.516 [kJ/kg-K]	S_2=6.516 [kJ/kg-K]	S_8=0.6523 [kJ/kg-K]	S_1_0=6.412 [kJ/kg-K]
S_1_1=6.412 [kJ/kg-K]	S_2_0=6.516 [kJ/kg-K]	S_3=7.263 [kJ/kg-K]	S_3=7.263 [kJ/kg-K]	S_9=0.8532 [kJ/kg-K]	S_1_1=6.412 [kJ/kg-K]
S_2=6.516 [kJ/kg-K]	S_2_1=6.516 [kJ/kg-K]	S_3_0=7.263 [kJ/kg-K]	S_4=7.344 [kJ/kg-K]	T_1=538 [C]	S_2=6.516 [kJ/kg-K]
S_3=7.263 [kJ/kg-K]	S_3=7.263 [kJ/kg-K]	S_3_1=7.263 [kJ/kg-K]	S_4_0=7.344 [kJ/kg-K]	T_10=85.4 [C]	S_3=7.263 [kJ/kg-K]
S_4=7.344 [kJ/kg-K]	S_4=7.344 [kJ/kg-K]	S_4=7.344 [kJ/kg-K]	S_4_1=7.344 [kJ/kg-K]	T_11=106.3 [C]	S_4=7.344 [kJ/kg-K]
S_5=7.599 [kJ/kg-K]	S_5=7.599 [kJ/kg-K]	S_5=7.599 [kJ/kg-K]	S_5=7.599 [kJ/kg-K]	T_12=139.2 [C]	S_5=7.599 [kJ/kg-K]
S_6=0.6413 [kJ/kg-K]	S_6=0.6413 [kJ/kg-K]	S_6=0.6413 [kJ/kg-K]	S_6=0.6413 [kJ/kg-K]	T_13=179.8 [C]	S_6=0.6413 [kJ/kg-K]
S_7=0.647 [kJ/kg-K]	S_7=0.647 [kJ/kg-K]	S_7=0.647 [kJ/kg-K]	S_7=0.647 [kJ/kg-K]	T_14=205.4 [C]	S_7=0.647 [kJ/kg-K]
S_8=0.6523 [kJ/kg-K]	S_8=0.6523 [kJ/kg-K]	S_8=0.6523 [kJ/kg-K]	S_8=0.6523 [kJ/kg-K]	T_15=246 [C]	S_8=0.6523 [kJ/kg-K]
S_9=0.8532 [kJ/kg-K]	S_9=0.8532 [kJ/kg-K]	S_9=0.8532 [kJ/kg-K]	S_9=0.8532 [kJ/kg-K]	T_16=277.9 [C]	S_9=0.8532 [kJ/kg-K]
T_1=538 [C]	T_1=538 [C]	T_1=538 [C]	T_1=538 [C]	T_2=331.2 [C]	T_1=538 [C]
T_10=85.4 [C]	T_10=85.4 [C]	T_10=85.4 [C]	T_10=85.4 [C]	T_3=538 [C]	T_10=85.4 [C]
T_11=106.3 [C]	T_11=106.3 [C]	T_11=106.3 [C]	T_11=106.3 [C]	T_4=355.5 [C]	T_11=106.3 [C]
T_12=139.2 [C]	T_12=139.2 [C]	T_12=139.2 [C]	T_12=139.2 [C]	T_5=45.2 [C]	T_12=139.2 [C]
T_13=179.8 [C]	T_13=179.8 [C]	T_13=179.8 [C]	T_13=179.8 [C]	T_6=45.2 [C]	T_13=179.8 [C]

T_14=205.4 [C]	T_14=205.4 [C]	T_14=205.4 [C]	T_14=205.4 [C]	T_7=45.6 [C]	T_14=205.4 [C]
T_15=246 [C]	T_15=246 [C]	T_15=246 [C]	T_15=246 [C]	T_8=46 [C]	T_15=246 [C]
T_16=277.9 [C]	T_16=277.9 [C]	T_16=277.9 [C]	T_16=277.9 [C]	T_9=61.4 [C]	T_16=277.9 [C]
T_1_0=538 [C]	T_2=331.2 [C]	T_2=331.2 [C]	T_2=331.2 [C]	T_htr1_in=395.4 [C]	T_1_0=538 [C]
T_1_1=538 [C]	T_2_0=331.2 [C]	T_3=538 [C]	T_3=538 [C]	T_htr1_out=251.6 [C]	T_1_1=538 [C]
T_2=331.2 [C]	T_2_1=331.2 [C]	T_3_0=538 [C]	T_4=355.5 [C]	T_htr2_in=331.2 [C]	T_2=331.2 [C]
T_3=538 [C]	T_3=538 [C]	T_3_1=538 [C]	T_4_0=355.5 [C]	T_htr2_out=211 [C]	T_3=538 [C]
T_4=355.5 [C]	T_4=355.5 [C]	T_4=355.5 [C]	T_4_1=355.5 [C]	T_htr3_in=442.1 [C]	T_4=355.5 [C]
T_5=45.2 [C]	T_5=45.2 [C]	T_5=45.2 [C]	T_5=45.2 [C]	T_htr3_out=185.4 [C]	T_5=45.2 [C]
T_6=45.2 [C]	T_6=45.2 [C]	T_6=45.2 [C]	T_6=45.2 [C]	T_htr4_in=355.2 [C]	T_6=45.2 [C]
T_7=45.6 [C]	T_7=45.6 [C]	T_7=45.6 [C]	T_7=45.6 [C]	T_htr4_out=175.9 [C]	T_7=45.6 [C]
T_8=46 [C]	T_8=46 [C]	T_8=46 [C]	T_8=46 [C]	T_htr5_in=251.5 [C]	T_8=46 [C]
T_9=61.4 [C]	T_9=61.4 [C]	T_9=61.4 [C]	T_9=61.4 [C]	T_htr5_out=111.8 [C]	T_9=61.4 [C]
T_htr1_in=395.4 [C]	T_htr1_in=395.4 [C]	T_htr1_in=395.4 [C]	T_htr1_in=395.4 [C]	T_htr6_in=154.5 [C]	T_htr1_in=395.4 [C]
T_htr1_out=251.6 [C]	T_htr1_out=251.6 [C]	T_htr1_out=251.6 [C]	T_htr1_out=251.6 [C]	T_htr6_out=90.9 [C]	T_htr1_out=251.6 [C]
T_htr2_in=331.2 [C]	T_htr2_in=331.2 [C]	T_htr2_in=331.2 [C]	T_htr2_in=331.2 [C]	T_htr7_in=89.5 [C]	T_htr2_in=331.2 [C]
T_htr2_out=211 [C]	T_htr2_out=211 [C]	T_htr2_out=211 [C]	T_htr2_out=211 [C]	T_htr7_out=67 [C]	T_htr2_out=211 [C]
T_htr3_in=442.1 [C]	T_htr3_in=442.1 [C]	T_htr3_in=442.1 [C]	T_htr3_in=442.1 [C]	T_htr8_in=65.3 [C]	T_htr3_in=442.1 [C]
T_htr3_out=185.4 [C]	T_htr3_out=185.4 [C]	T_htr3_out=185.4 [C]	T_htr3_out=185.4 [C]	T_htr8_out=51.6 [C]	T_htr3_out=185.4 [C]
T_htr4_in=355.2 [C]	T_htr4_in=355.2 [C]	T_htr4_in=355.2 [C]	T_htr4_in=355.2 [C]	X_5=0.9254	T_htr4_in=355.2 [C]
T_htr4_out=175.9 [C]	T_htr4_out=175.9 [C]	T_htr4_out=175.9 [C]	T_htr4_out=175.9 [C]		T_htr4_out=175.9 [C]
T_htr5_in=251.5 [C]	T_htr5_in=251.5 [C]	T_htr5_in=251.5 [C]	T_htr5_in=251.5 [C]		T_htr5_in=251.5 [C]
T_htr5_out=111.8 [C]	T_htr5_out=111.8 [C]	T_htr5_out=111.8 [C]	T_htr5_out=111.8 [C]		T_htr5_out=111.8 [C]
T_htr6_in=154.5 [C]	T_htr6_in=154.5 [C]	T_htr6_in=154.5 [C]	T_htr6_in=154.5 [C]		T_htr6_in=154.5 [C]
T_htr6_out=90.9 [C]	T_htr6_out=90.9 [C]	T_htr6_out=90.9 [C]	T_htr6_out=90.9 [C]		T_htr6_out=90.9 [C]
T_htr7_in=89.5 [C]	T_htr7_in=89.5 [C]	T_htr7_in=89.5 [C]	T_htr7_in=89.5 [C]		T_htr7_in=89.5 [C]
T_htr7_out=67 [C]	T_htr7_out=67 [C]	T_htr7_out=67 [C]	T_htr7_out=67 [C]		T_htr7_out=67 [C]
T_htr8_in=65.3 [C]	T_htr8_in=65.3 [C]	T_htr8_in=65.3 [C]	T_htr8_in=65.3 [C]		T_htr8_in=65.3 [C]
T_htr8_out=51.6 [C]	T_htr8_out=51.6 [C]	T_htr8_out=51.6 [C]	T_htr8_out=51.6 [C]		T_htr8_out=51.6 [C]
X_5=0.9254	X_5=0.9254	X_5=0.9254	X_5=0.9254		X=687