STUDY ON RELIABILITY IMPROVEMENTS OF LAKVIJAYA POWER STATION RELATED TO THE BALANCE OF PLANT SYSTEMS: A CASE STUDY

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Degree of Master of Science

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science

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The above candidate has carried out research for the Masters Dissertation under my supervision.

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Dr. Asanka Rodrigo. Date
Faculty of Engineering
University of Moratuwa

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ABSTRACT

Lakvijaya power station is the first coal fired power station in Sri Lanka having an installed capacity of 300MW. During 2012, it has supplied 18% of the Sri Lankan energy demand. The availability factor of this power station in 2012 was 68.8%. This is rather high compared with the average availability factor of coal powered power stations in countries in the region falls between 65% - 90%.According to the contract document, the availability factor of this plant has been expected as 85% [1].

However, there is a strong public opinion created by media that the plant is unreliable and prone to frequent failures. Therefore, any improvement in the availability of the power station will result in improving the public image as well as reducing overall costs spent on more expensive fuels. This research aims at critically analyzing the Auxiliary Systems of the power plant to identify their contribution to the reduction of plant availability and propose means of improving overall availability through increasing the reliability of auxiliary systems.

Data related to outages were collected from plant operational logs and defect reportsfrom 22.12.2010 to 09.06.2012. Existing systems and layouts were studied referring to plant operation and maintenance manuals and by field observations. Analyzing thedata, it was found that failures and unsatisfactory performance in the auxiliary systems havecontributed to the low availability of the power plant by delaying re-starts after failures and reducing the plant capacity while in operation.

Failures and problems in auxiliary systems such as The Sea Water Pre-Treatment System, De-salination System, De-mineralization System, Chlorination System and the Hydrogen Production and Storage System were critically analyzed during this research and improvements to the designs are proposed based on the results.

The present availability factor of 21% of the De-salination System can be improved to 91% by carrying out the proposals made by this research. The availability factor of other systems too can be improved above 90% using the results.

Estimated total cost of the proposals is Rs. 543 Million. However, by implementing themRs.2.7 Billion is expected to be saved annually, by reducing the operating and maintenance costs of auxiliary systems and improving the availability of the power plant.Expected payback period is only 2 ½ months. Therefore, the proposed modifications are extremely desirable and cost effective. They will make a good financial contribution due to the expected savings while improving the reliability and the public image of the power plant.

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LIST OF ABBREVITIONS

Abbreviation	Description
μ	Repair rate
μS	Micro Siemen
A	Availability
CEB	Ceylon Electricity Board
cm	Centimeter
CU	Copper
D	Pipe Diameter
DC	Direct Current
DI	Ductile Iron
DN	Nominal Diameter
FRP	Glass Reinforced Plastic Pipe
H	Head
h	Hour
H_2	Hydrogen Gas
IEE	The Institution of Electrical Engineers
kW	Kilo Watt
LVPS	LakVijaya Power Station
$\bar{m}$	Mean running time
Mn	Million
MPa	Mega Pascal
MSL	Mean sea level
MW	Mega Watt
NaOCl	Sodium Hypochlorite
NWS&DB	National Water Supply and Drainage Board
PVC	Polyvinyl chloride
PLC	Programmable Logic Circuit
Q	Flow rate

$\bar{r}$	Mean failure time
RO	Reverse osmosis system
Rs.	Sri Lanka rupees
RWP	Raw Water Pump
SWA	Steel Wire Armoured
SYS	System
UF	Ultra Filtration
v	flow velocity
V	Voltage
VSD	Variable Speed Drive
XLPE	Cross-linked Polyethylene
λ	Failure rate
USD	United States Dollar

LIST OF APPENDICES

Chapter 1

INTRODUCTION

1.1. Background.

Lakvijaya power station,witha target capacity of 900 MW, is the very first first ever coal fired power station constructed in Sri Lanka with 900 MW capacity[1]. ItThis is constructed situated in the village of Norochcholeiin bordering the sea shore ofatKalpitiya peninsula, approximately 12 km west of thecity ofPuttalam town. Construction was designed plannedintwo twophases. and fFirst phase was completed in 2011 and handed over to Ceylon Electricity Board (CEB) after commissioning. It has the acapacity of 300 MW. Second stage Other 600 MW will contribute an additional 600 MW. Stage two is being commissioned and expected to start commercial operations in (April 2014.)will be planned to commission in end of 2013 and 2014 [01].

Being the power plant having the largest capacity and the lowest cost out of all thermal plants, Ccontinuous power generation of this power station is verymore important to provide the uninterrupted power supply to the country at a reasonable cost. Therefore,maintainingwe have to maintaina high level of reliability of equipment's to ensurekeepuninterruptedsmooth operations is essential.The life time of power station is 30 years. Therefore improve of design failures also help to increase the efficiency for long time benefitAny improvements to the present systems to enhance reliability will definitely improve availability and long term benefits of the plant which has a life span of 30 years.

Bituminous coal with a calorific value more thanabove 6,300 kcal kg^{-1}, calorific value hais beingen purchased from Indonesia, South Africa and Australia, to supply the energy for steam production.

. IDaily feed water requirement of the plant needsis 350 m^3 tons of feed water for day.Required water is taken from Indian Oceanthe sea and purified to obtained the necessary feed water quality [1]. This wais done by using various severaltreatmentprocesses.and aAllof those processesem are considered evaluatedin this study with a view to improve the reliability of equipment's. B, asecause purified

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Formatted: Font: 12 pt, Complex Script Font: Times New Roman, 12 pt water supply to the boiler is a critical factor ~~critical~~contributing to smooth running of the power station.~~. It needs 350 tons of feed water for day.~~

The most important auxiliary systems in the power station are~~ listed below.~~:

1. Sea water intake & pre-treatment plant.
2. Desalination Plant.
3. Demineralization plant.
4. Hydrogen plant
5. Chlorination plant.
6. Compressed Air system(for Instrument & Service air)
7. Auxiliary boiler.
8. Condensate polishing plant
9. Waste water treatment plant

Most of suspended materials and particles, which ~~are possible to~~candamage water seals and obstruct~~effect~~filters of the~~in~~fine purification systems~~were~~ areremoved in the pretreatment plant~~. It is done by~~, using chemical treatments and physical methods such as filtration and precipitation.

Desalination plant plays a major role to reduce the high salinity of sea water. Reverse osmosis (RO) technology and ultra filtration (UF) technology are used to improve the quality of sea water up to ~~obtain~~ the required surface water quality~~ by sea water~~.

Demineralization water plant ~~performs to~~ produces feed water with a mineral content less than 0.2 µScm^{-1} [1]. An RO system and ion exchange resins are used in this process.

Hydrogen is used in generator cooling due to its excellent features to suit the application. It is the lightest~~a lighter~~ gas ~~with contain~~having a high~~er~~ heat capacity. However handling of hydrogen is dangerous due to its explosi~~on ability~~veness. Hydrogen can be generated easily by electrolysis of water in~~with~~the presence of catalytic conductive material.

Electro chlorination plant produces~~d~~ sodium hypochlorite (NaOCl) to control the marine growth in sea water~~ which is mainly~~ used for the condenser cooling. Common salt (sodium chloride) available in raw sea water is converted to NaOCl by ~~few~~

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chemical reactions associated with electrolysis [6]. P~~Th~~roper operation of this ~~is~~ plant is ~~very~~ critical ~~to~~ incontrolling the amount of debris~~s~~~~possible to~~ coming~~e~~ with cooling water to prevent clogging of~~otect~~ debris filters and condenser tubes. Lakvijaya power station had~~s~~ to reduce its power production several times due to the failure of these debris filters. Design of the ~~available~~ existingelectro chlorination plant had many ~~failures~~ deficiencies leading to failures,which~~are~~ severely affected ~~to~~ the continuous running of the power station.

Compressed air system produces instrument air and service air to fulfill the plant requirements. It ~~is containing~~includes condensers and dryers to obtain ~~proper quality~~ instrument airofproperpurity and humidity.

G~~The~~ eneration of steam ~~generation~~ required for the startup of main boiler~~, supply~~is carried out ~~by~~ using the auxiliary boiler. It can supply 20 to 25 tons of steam ~~for~~ perhour [1].

Accumulation of residue inside boiler drums ~~The residual materials accumulated with time in boiler drum will be~~is controlled by blow down procedure. This is done by draining some water at the bottom of boiler drum to remove residues. Though the plant continues to operate during a blow down, ~~But during the blow down~~this process decreases the pressure ~~of~~ insideboiler drum~~, should be decrease. I~~, which~~is a disadvantage for high pressure boilers~~requires addition of de-mineralized make up water.

The steam passing through the three stages of the turbine is condensed in the condenser and fed back to the boiler. However, this condensate has accumulated metal ions and other dissolved solids in it. A ~~C~~condensate polishing system ~~introduced~~ is usedto~~minimize the accumulation of residual~~remove such impurities using ion exchangerscontaining high temperature resistant ion exchange resins~~ metal ions and other dissolved solids~~. ~~Therefore b~~Blow down frequency ~~will be~~is decreased due to the action of this polishing system. ~~This system containing high temperature resistant ion exchange resins to remove the charge species.~~ Resins used for the purpose ~~can~~areregenerated~~by~~ using acidic and alkaline~~caustic.~~reagents.

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Treatment of Wwaste water treatment is very important to controlsuppressthe liquid pollutants including oil and greasetoensure the minimumminimizeeffectsto ontheenvironment. WThe aste water collecteding from various type of washing sections of the in power stationplant including blow down and sewerage iscollected in a pit and sent to two aeration basins where air is mixed using two aeration blowers. It is furthertreated in a waste water treatment plant by using chemicals. Solid particles are retained by sedimentation in clarifiers. Oils floating on the surface are removed in the oil separators. Treated water of this plant is used in fly ash unloading, bottom ash cooling, andcoal yard sprinklers and for gardening.

andphysical processes.

Boiler blow down water and discharge of sewerage treatment also collect to the waste water treatment plant. Treated water of this plant used in fly ash unloading, bottom ash cooling and coal yard sprinklers.

1.2. Motivation for the Project.

With the inherent large number of auxiliaries, the 1 x 300 MW unitisrunning in operationfor almost two and half years as a theleading thermal steam power plant while catering energy to the systemproviding approximately 18% of the annual energy demand of the power system. ItBeing the cheapest thermal power plant, it plays a major roleas a base load plant throughouttheyear,its contribution is especially important inďuringdroughtdraft seasons specially since the lack ofwhen the hydro power generation is minimaland as a base load plant in whole year.

There had been several failures of the plant during the past, attracting criticism from many parties. Most of these failures originated from the major components of the plant like the main boiler, turbine and coal handling system. However, the other equipment called Balance of Plant (BOP) too was subject to frequent failures. Due to Such failures rarely contributed to a plant outagedue to the availability of redundant equipment.Nonetheless, improving the reliability of such BOP would ensurea high reliability of the plant as well.

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~~But with the experienced issues in auxiliaries this project will scrutinize some key reliability indices in important auxiliary units to examine the possibility to improve the reliability.~~

~~So it~~ This study ~~will~~is aimed at ~~guide to any~~identifying weak points in the BOP and suggesting possible modifications of such systems to ensure their continuous operation to support the proper operation of ~~for~~ main units such as boiler, turbine and generator.

Chapter 2

PROBLEM STATEMENT

2.1. Identification of ~~the~~ Problems.

Several failures of BOP were noted ~~D~~during the data acquisition period from 22.12.2010 to 09.06.2012. ~~it was notice several failures of BOP section which belongs~~ Pretreatment plant, Desalination plant, Demineralization Plant, Chlorination plant and Hydrogen Plant can be identified as the components where major failures occurred~~that~~ leadings to ~~a~~ critical issues ~~to of~~ running the plant at full load. ~~Even those failures are not belongs to the main equipments such Turbine and boiler units it cannot neglect the availability and failures since those major units are totally depends on above supportive units.~~

Frequent failure of submersible pumps installed at the sea water intake and presence of fine sand particles in sea water were the major problemswhich occurred in the pretreatment plant.

Failure of the Reverse Osmosis (RO) membranes and the Variable Speed Drives (VSD) were the most frequent problemsin the desalination plant.

The de-mineralizing plant has a low reliability as only one blower is installed in the de-gasifier unit.

Frequent failure of booster pumps and the inability to achieve required chlorine dozing levels are the problems associated with the Chlorination Plant.

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Insufficient storage capacity was the problem associated with the Hydrogen Plant.

~~The major problem in pretreatment plant is, submersible pumps installed at the sea water intake fails frequently due to high conductivity in sea water and the fine sand particles which come with sea water. In addition to that, it was found that rubber seal at cable connection of the motor also damaged due to high conductivity~~

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2.2. Objectives of the Study.

Lakvijayapower station was a long awaited solution to the ever increasing demand for electricity in Sri Lanka. When the plant was constructed after a long delay, the general public had high expectations about reliable and low cost electricity. However, frequent failures of the plant have provided an arena for various pressure groups to agitate the public by pinpointing the failures while masking off the advantages brought out by the plant.

Due to the lack of potential for new large scale hydro power plants, the availability of this power station is of utmost importance to provide a reliable power supply to Sri Lankans at a reasonable cost.

The objective of this study is to identify deficiencies in the existing auxiliary systems (BOP) of the power plant and propose improvements to enhance the reliability of the whole plant in order to meet the aspirations of the general public for cheap and reliable electricity.

Another objective is to decrease the operational cost of the plant by reducing the cost of operating the BOP.

As the plant factor of the power station will be increased with the improved reliability, it is expected to improve the rate of return on investment of the plant too.

2.3. Methodology

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Past operational and failure data of the main auxiliary systems of BOP section during the period from22.12.2010 to 09.06.2012 were collected using operational and failure logs, defect notices and permits to work. Failure and repair durations of those equipment were summarised and tabulated in order to calculate the ~~Firstly it is expected to evaluate the c~~current availability and failure rates intheSea Water Pretreatment Plant, Desalination Plant, Chlorination Plant and ~~,~~Hydrogen Generation and Storage plant.

It was observed that the availability factors of these systems were low compared to the expected values. Major problems contributing to the low availability of these systems were studied and identified.

The possibility to improve the reliability by means of new modifications to relevant sections was investigated and modifications and new designs for the systems were proposed. Cost of proposed modifications was calculated using pricing details from former invoices and quotations obtained from equipment suppliers. The estimated cost for the erection and civil works was obtained from the invoices of the first phase of the Puttalam coal power project. Thereafter, the ~~new~~ expectedreliability figures after the improvements ~~also~~ werecalculated.

Finallythe overall reliability improvement of the power plant and the payback periods for the proposed improvementswere calculated and the overall project viability was evaluated.

Chapter 3

SEA WATER INTAKE & PRETREATMENT PLANT

3.1. Introduction

The total water ~~consumption~~ requirementofLakvijaya power station is achieved ~~from~~ by purification of sea water~~ purification~~. The required ~~with c~~capacity ~~of~~ is100 m^3 desalinated water per hour. Many impurities ~~consist~~ in sea water can affect~~ed~~ ~~on~~ thesensitiveU~~u~~ltra-F~~f~~iltration (UF) and R~~r~~everse ~~o~~Osmosis (RO) systems. Therefore,an effective pretreatment process is ~~more effective~~required to protect the above sensitive equipment. Pretreatment plant consists of raw water pumps, settling basin, gravity filters and clear water basin.

The most common outage ~~failure~~ of the pretreatment plant is the failure of submersibleraw water pump~~s outage.Submersible pumps~~ installed at the sea water intake~~.failed frequently by burn out of~~The motor windingsare frequently burnt due to water leaking into the motor housing~~ages~~(Figure: 3.1).One cause for ~~T~~this leakage was identified as the damage of water seal and packing due to the presence of sand particles and fine debris in sea water. ~~Also~~Another cause ~~it~~ was found to be the ~~that~~deterioration ofthe rubber seal at the cable ~~connection~~ entryto the motor,~~also damaged~~ due to high conductivity of sea water. The plant has been designed for sea water conductivity less than 50,000µS/cm [1]. However, the actual conductivity was found to vary between 60,000 and 90,000 µS/cm seasonally.

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Pretreatment plant consists of two channels each ~~one~~ havings~~the~~a handling capacity of 250 m^3 per hour. Combined, these two channels can ~~to~~ fulfill the total sea water requirement for desalination plant.

Sea water ~~was~~ ispumpedusing four submersible pumps,tothe pre-treatment plant consisting of a settling basin and sand filters~~by using four submersible pumps~~. Two pumps are in operation at any time while the other two are on standby.

Suspended solids and dissolved silicates in sea water are precipitated ~~by~~ using chemicals (poly aluminum chloride and poly amide) in the ~~pretreatment plant. This process occurred~~ in the ~~equipment call~~ settling basin. It contains plastic honey combs placed~~in~~ at 45^0angle to accelerate the precipitation process. Gravity filters which contains sand also help to remove the particles which were not precipitated in settling basin. Filtrate is collected in to clear water basin to be further filtered by~~feed for~~ UF filters.

The gravity filters are periodically cleaned using root blowers which send a stream of air through the filters in the reverse direction. Frequent overload tripping of these blowers has been observed in the past.

~~The root blowers in gravity filters also fails several times due to unidentified reasons. In this study it is observed to take necessary actions to avoid it.~~

Figure 3.1: Failed~~ure~~ of a raw water pump showing water leakage.

3.2. Calculation of Availability

The availability of raw water pumps is more important to supply the water demand of power station. Therefore availability of the equipment was calculated according to the break down details recorded ~~by~~ using the Distributed Control System(DCS) history records,issued work permits and log books ~~in~~ duringtheperiodofone and half years under consideration.

Failures of roots blowers were also taken into consideration to derive combined reliability figure with raw water pumps since both equipment~~share~~areconnected in series manner.

3.2.1. Sample data collection for raw water pumps.

Nearly one and half years of data starting from 22/12/2010 are collected ~~for~~ on all four raw water pumps to find required parameters.

Table 3.1-: Outagedata for~~pump~~pump-01

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~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)~~Time of Recovered~~	Incident	Outage Periods (h)
10/11/11 9:22	10/12/11 12:50	Motor winding failure	27.47
11/19/11 11:45	11/20/11 21:45	Motor winding failure	34.00
12/02/11 14:00	12/30/11 8:30	Motor winding failure	666.5
1/16/12 10:09	1/16/12 20:53	Motor bearing failure	10.73
3/2/12 10:20	3/2/12 16:45	Motor winding failure	6.42
3/22/12 15:53	7/19/12 14:45	Motor winding failure	2854.87
Total Outage			3589.98

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Table 3.2 : Outage data for pump-02

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	~~Time of~~ Restoration (mm/dd/yyhh:mm)	Incident	Outage Periods (h)
3/2/12 10:20	3/2/12 16:45	Motor winding failure	6.42
5/24/12 8:07	7/9/12 18:10	Motor winding failure	1114.05
Total Outage			1120.47

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Table 3.3 : Outagedata for pump-03

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Incident	Outages (h)
10/11/11 8:40	10/13/11 17:30	Motor winding failure	56.83
3/2/12 10:10	3/2/12 16:45	Motor bearing failure	6.58
3/17/12 14:20	3/18/12 17:30	Motor winding failure	27.17
4/26/12 14:42	6/3/12 17:57	Motor winding failure	915.25
Total Outage			1,005.83

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Table 3.4 : Outagedata for pump-04

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Incident	Outages (h)
12/21/11 18:50	12/26/11 23:21	Motor winding failure	124.52
3/2/12 9:30	3/2/12 16:50	Motor Bearing failure	7.33
3/22/12 15:53	7/10/12 13:50	Motor winding failure	2637.95
Total Outage			2,769.80

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From the above data it is evident that the total outage time for all four pumps due to winding failure alone is 8,486.08 hrs and the total running time is 24,467.38 hrs. This is 34.68% of the total running time and a very high failure rate even at a glance.

~~3.2.2. Due to the motor winding failure problem arise in this pumps ,Total outage is 8486.08 hours and total running time is 24,467.38 According to above data total outages are very high with compare with total running time of pumps.It is approximately 34.68% out of the total running time.~~

3.2.2. Sample Reliability Calculation for Raw water pump -01

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Table 3.5 : Running and outage data for raw water pump 01

Running hours	Outage hours	No of Outages	No of Starts
4907.75	3589.98	6	7

~~By u~~Using the summarized data given in table 3.5, availability of the raw water pump-1 is calculated. A Run-Repair-Run cycle of a system having $m_1, m_2, m_3, m_4, \ldots, m_n$ run times and $r_1, r_2, r_3, \ldots, r_i$ repair times, is shown in figure 3.2

If system Working,

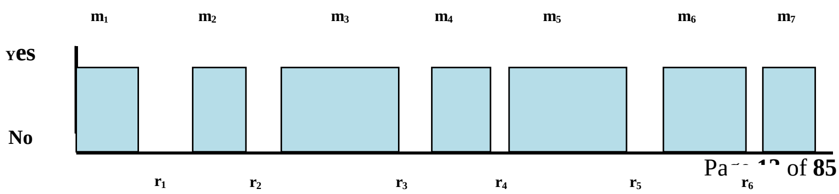

Figure 3.2: Raw water pump -01 Run-Repair-Run cycle

According to the reliability theory for the system shown in figure 3.2

Mean run time ($\bar{m}$) = $\frac{m1+m2+m3+\cdots mn}{n}$ (01)

Mean repair time ($\bar{r}$) = $\frac{r1+r2+r3+\cdots ri}{i}$ (02)

Availability = $\frac{Mean\ run\ time}{Mean\ run\ time + Mean\ repir\ time}$ (03)

By using the above equations (01),(02) and (03),raw water pump 1 reliability factors can be calculated as follow.

Mean running time ($\bar{m}$)= 4,907.75/7 = 701.11 h

Mean failure time ($\bar{r}$)= 3,589.98 = 598.33h

Availability **(A)**= $\frac{m}{m+r}$

=701.11/(701.11+598.33)= **0.5395**

Failure Rate (**λ**)= $\frac{1}{m}$ = **0.0014263 /h**

Repair Rate(**μ**)= $\frac{1}{r}$ =**0.001673 /h**

In the same way all above reliability factors of all raw water pumps are calculated and a summary is provided in table 3.6.

Table 3.6: Reliability factors for all raw water pumps

Pump	Running (h)	Outage (h)	No of running times	No of Outages	$\bar{m}$ (h)	$\bar{R}$ (h)	Availability	f	λ/h	μ/h

RW 1	4,907.75	3,589.98	7	6	701.11	598.33	0.53955	0.00077	0.0014	0.00167
RW 2	1,536.45	1,120.47	3	2	512.15	560.23	0.47758	0.000933	0.0020	0.00178
RW 3	5,949.17	1,005.83	5	4	1,189.83	251.46	0.82553	0.000694	0.0008	0.00398
RW 4	3,290.02	2,769.80	4	3	822.50	923.27	0.47114	0.000573	0.0012	0.00108

At full load operation two pumps are running and others two are in standby. The pump arrangement is as follows

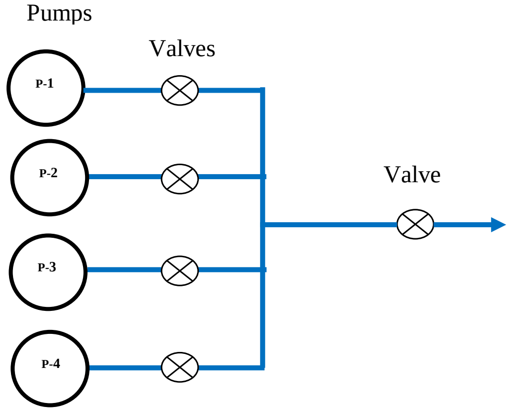

Figure:3.3–Raw water pumps arrangement.

Basic reliability factors calculation for the 2 out of 4 model equivalent, parallel & standby model is given by following equation [2].

$$Rsys(t) = \sum_{i=r}^{n} \begin{bmatrix} n \\ i \end{bmatrix} . [R(t)]^{i} . [1 - R(t)]^{n-i} \quad (4)$$

Source: Basic reliability “bottom-up” Model calculation [2].

Where:

$R_{sys}(t)$ = ~~the~~ System reliability

r = ~~the a~~Actual number of failures

n = ~~the t~~Total number of units in the system

$R(t)$ = ~~the r~~Reliability function of identical units

Assuming ~~the~~ identical raw water pumps, ~~which~~ having the average failure rate of 0.00135 per hour for each, the reliability function for the combined system is derived bel~~l~~ow.

Average failure rate λ = 0.00135/h

Total observation time period = 12,840h (22/12/2010-09/06/2012)

~~By u~~Using above equation, assuming exponential distribution

$R_{(RWP)} = e^{-\lambda t} = e^{-0.00135X12840} = 2.964 \times 10^{-8}$

$$Rsys(t) = \sum_{i=2}^{4} \begin{bmatrix} 4 \\ 2 \end{bmatrix} . [R(t)]^{i} . [1 - R(t)]^{3-i}$$

$$= \sum_{i=r}^{n} \frac{n!}{r!(n-r)!} e^{-\lambda t!} \left(1 - e^{-\lambda t}\right) n - 1$$

$$= {}^{4}_{2}C(2.964x10^{-8})^{2}(1 - 2.964x10^{-8})^{2} + {}^{4}_{3}C(2.964x10^{-8})^{3}(1 - 2.964x10^{-8})^{1} + {}^{4}_{4}C(2.964x10^{-8})^{4}(1\text{-}2.964x10^{-8})^{0}$$

R sys $=5.269 \times 10^{-15}$

Then, $5.296 \times 10^{-15} = e^{-\lambda x\, 12840}$

Failure rate λ_1 = **0.00256/h**

Average availability for raw water pumps A = **0.87517**

3.3. Availability of roots blowers in gravity filters

Availability calculations for gravity filters~~were~~ aregiven in table below.

Table 3.7: Repair time for root blower in gravity filter -01

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	period	Period in hrs
10/5/11 9:25 AM	10/5/11 4:40 PM	7:15:00	7.25
12/10/11 1:02 PM	12/10/11 4:16 PM	3:14:00	3.23
6/14/12 9:30 AM	6/14/12 9:40 PM	12:10:00	12.17
		Total	22.65

Table 3.8: Repair time for roots blower in gravity filter -02

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	period	Period in hrs
7/14/11 10:50 AM	7/16/11 8:05 AM	45:15:00	45.25
10/8/11 8:40 AM	10/8/11 2:25 PM	5:45:00	5.75
1/10/12 1:50 PM	2/1/12 4:02 PM	530:12:00	530.20
5/18/12 8:40 AM	5/19/12 2:15 PM	29:35:00	29.58
		Total	610.78

Table 3.9: Repair time for roots blower in gravity filter -03

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	period	Period in hrs
1/10/11 9:46 AM	2/1/11 2:49 PM	533:03:00	533.05
5/14/11 1:30 AM	5/15/11 8:15 PM	42:45:00	42.75
9/12/11 6:15 AM	9/12/11 8:50 PM	14:35:00	14.58
9/6/12 1:30 AM	9/6/12 6:45 PM	17:15:00	17.25
		Total	607.63

Summary of availability calculation~~'~~s for gravity filters is given in the following ~~table~~table ~~below~~.

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Table 3.10: Reliability F~~f~~actors for Root~~s~~B~~b~~lowers

Equipment	Running (h)	Outage (h)	No of running times	No of Outages	m (h)	r (h)	Availability	f	λ/h	μ/h
Roots blower -01	4,077.90	22.65	4	3	1,019.47	7.55	0.99265	0.000974	0.0010	0.13245
Root ~~s~~blower -02	4,077.90	610.78	5	4	815.58	152.70	0.84230	0.001033	0.0012	0.00655
Roots blower -03	4,077.90	607.63	5	4	815.58	151.91	0.84299	0.001034	0.0012	0.00658

Average failure rate (λ) = 0.0011/h

Total running time = 12840 h

U~~By u~~sing following equation for the 2 out of 3 model

$R_{(RB)} = e^{-\lambda t} = e^{-0.0011 X 12840} = 7.3x10^{-7}$

$$Rsys(t) = \sum_{i=2}^{3} \begin{bmatrix} 3 \\ 2 \end{bmatrix} . [R(t)]^{i} . [1 - R(t)]^{3-i}$$

$$= \sum_{i=r}^{n} \frac{n!}{r!(n-r)!} e^{-\lambda t!} (1 - e^{-\lambda t}) n - 1$$

$$= {}^{3}_{2}C(7.3x10^{-7})^{2}(1 - 7.3x10^{-7})^{1} + {}^{3}_{3}C(7.3x10^{-7})^{3}(1 - 7.3x10^{-7})^{0}$$

R sys $=1.6x10^{-12}$

Then, $1.6x10^{-12} = e^{(-\lambda x 12840)}$

Failure rate $\lambda_{(RB)}$ **= 0.0021/h**

Average availability for root blowers **= 0.99982**

Total reliability of pretreatment plant was calculated and factors are given below.

Then pretreatment plant failure rate $= \lambda_1 + \lambda_{(RB)}$

= **0.0047 / h**

System availability $= A_1 x A_2$

$= \mathbf{0.87501}$

According to the results of above calculations, it appears that the availability of the system can be improved.

Mathematically, the availability can be improved by :

1. Adding more pumps to the system
2. Completely doing away with pumps or
3. Improving the reliability of individual pumps.

In practical terms, the first solution can be achieved by installing more pumps with associated piping and valves etc. However, this does not appear to be desirable as the modifications and additional pumps are costly. As the pumps would operate outside designed conductivity values, this is not a prudent technical solution.

The second solution is possible by obtaining raw water from the cooling water lines after the cooling water pumps. However this requires modifications to the cooling water system which needs plant to be shut down. Further, the capacities of main cooling water pumps will have to be increased. Therefore, this solution is not prudent for the on-going plant but may be considered in the second stage work.

The third solution can be achieved by replacing the submersible pumps with vertical mixed flow pumps where the motor is kept above water. This is easier to implement and requires minimal interruptions. As pumps can be replaced one by one, no interruption is needed.

A proposal based on the ~~According to the reliabilitycalculations it seems the possibility of improve the system reliability to a higher value than this figure. Therefore some more equipment modifications and replacements could propose as follows.~~

third solution is discussed below.

3.4. Proposal for Improving Availability of Raw Water Pumps.

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~~a) Existing raw water pumps can change with suitable mixed flow pump.~~

It is proposed to ~~exchange~~ replace the existing pumps with vertical mix flow spindle pumps to eliminate the possibility of damage of water seal by debris and fine sand particles. Even the damages of water seal in new pump will have not effected on motor winding since it is located in an elevated position ~~from~~ above the water level. Even the suction part of new pump can be designed to tolerate the yearly variation of sea water ~~variation too~~level due to monsoons.

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The calculations of suitable pump capacity are given below.

Selection of pump capacity and motor power

Daily Water requirement = 7,680m^3

Number of working hours = 24hr/day

Then flow rate = 320m^3/hr~~min~~. (5m^3/min)

Required pump quantity = ~~Duty~~Running -2 and Standby -2

Pump capacity (Q)=2.5 m^3/min (0.04167m^3/sec)

Existing Pipe Diameter (D) = 146x$(Q/v)^{1/2}$ [13]

Selected velocity range (v) = 1.5 m/s – 3m/s [13]

Pipe diameter range = 267 mm – 188 mm

Selected pipe diameter (D) =200mm

Static Head:

Suction level **hs** = -9.4m (MSL)

Delivery level **hd** = 12m (MSL)

Static head = 21.4m

Friction loss (hf):

~~Selected~~ Existing pipe material is Fiber Reinforced plastic (FRP),which has C=150

Then using Hazen Williams equation,

$$hf = 10.666 \times C^{(-1.85)} \times D^{(-4.87)} \times q^{(1..85)} \times L$$ **[14]**

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(C =150, L=525m, D=200mm)

hf = 13.5m

Calculation of vVelocity head:

Cross section area	= $0.031416m^2$
Flow velocity	= 1.3m/s
Velocity head = $V^2/2g$	= 0.09m
Considering miner losses fittings around the pump	= 5m
Total pump head	= 45m
Hydraulic power	$= \frac{\sigma . g . Q . H}{1000 . \eta}\ kW$

Where,

σ Density in kg/m^3 (water)	= $1000kg/m^3$
g Gravitational constant	= $8.81m/s^2$
Q Flow rate in m^3/s	= 0.042 m^3/s
η Pump efficiency for mixed flow pump	= 63%

Hydraulic power of pump	= 18.39kW

By considering Motor efficiency(60%) and over capacity factor 115%

Motor power	**=35kW**

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According to the above calculation, most suitable pump was selected ~~by~~ using standard pump selection criteria [9].

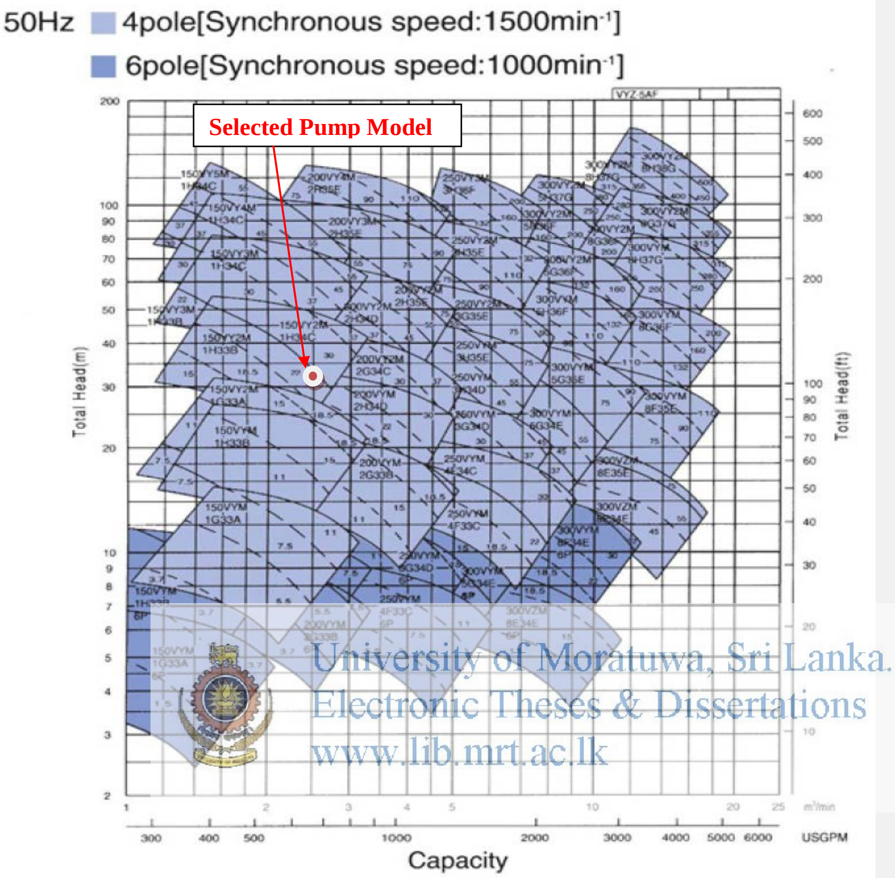

Figure 3.4 : Ebara brand pump selection chart

Source:MS series EBARA Pumps Selection Manual [9].

Specifications of selected pump

Pump Head (H)	=	45m
Flow (Q)	=	2.5 m^3/min

Make :- Ebara

Type:- Vertical mixed flow pump

Model :- 150VY2M 1H33B

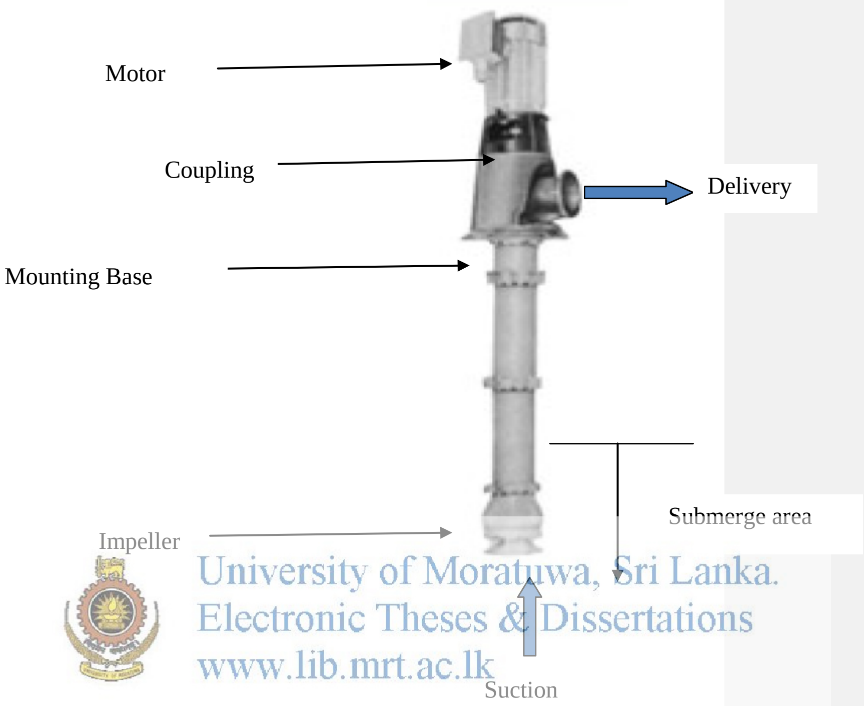

Figure 3.5:vertical mixed flow spindle pump

Source: MS series EBARA Pumps Selection Manual [9].

Total cost for the replacement of four raw water pumps is 9.6 million rupees according to the market price on May 2013. According to the past records, raw water pumps have been rewound seventh times and total maintenance cost per one motor was Rs.160,000.00.The maintenance saving by replacement of new pumps is nearly 1.1 million per year. Therefore payback period for the suggested modification is 8.7 year. The reliability improvement of modification also participate for the saving and improve the payback period. However, the financial benefit of that aspect is difficult to calculate.

3.5. Proposal for ~~Operation~~ changes in operation of~~of~~ air blowers in gravity filter

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Blocking of gravity filters is more effective when the particle size of flocks is too small. Therefore root blower has to supply air in high pressure. Due to this reason blowers are overload and failed. The variation of chemical dosing can achieved large amount of heavy particles. It is helps to reduce the strength of blockage. Therefore operation crew was advice to change the chemical dosing pattern.

Implementation of this suggestion does not effect to increase significant cost for the plant operation. Therefore from this study reliability of plant was increased without additional expenses.

After implementing the new design, there was no any motor winding failures due to water leakage.Therefore, those failures were avoided to recalculate the availabilities and failure rates as follows.

Table 3.11: New reliability factors for raw water pumps

Pump	Running (h)	Outage (h)	No of running times	No of Outages	$\overline{m}$ (h)	$\overline{r}$(h)	Availability	f	λ/h	μ/h
RW 1	4,907.75	10.73	2	1	6,845.87	10.73	0.99843	0.000146	0.0001	0.09317
RW 2	1,536.45	-	1	0	1,536.45	-	1.00000	0.000651	0.0007	-
RW 3	5,949.17	6.58	2	1	2,974.58	6.58	0.99779	0.000335	0.0003	0.15190
RW 4	3,290.02	-	1	0	3,290.02	-	1.00000	0.000304	0.0003	-

Improvement calculation can summarize as follows.

Table 3.12: Reliability and Failure comparison

Reliability factor	Present situation	After implementation of proposals
Availability (A)	0.87501	0.91954
Failure rate (λ)	0.0047/h	0.00225/h

It can distinguish the reduction of failure rate through a graph as follows with the time (Figure: 3.6).

Table 3.13: Failure rates variation with time

Time(h)	0	30	60	90	120	150	180	210	240	270	300	330	360	390	420	450	480
λ_1 = 0.0047/h	1	0.82	0.68	0.56	0.46	0.38	0.31	0.26	0.21	0.18	0.14	0.12	0.1	0.08	0.07	0.06	0.05
λ_2 = 0.0022/h	1	0.93	0.87	0.82	0.76	0.71	0.67	0.62	0.58	0.54	0.51	0.48	0.44	0.42	0.39	0.36	0.34

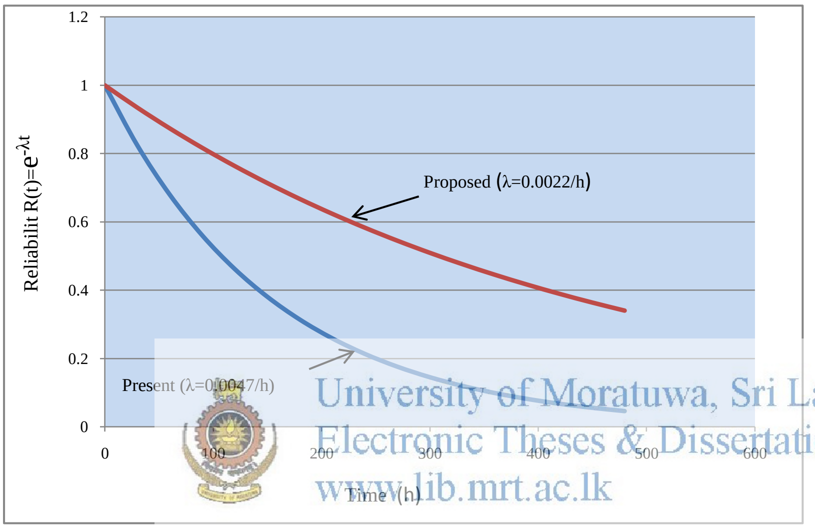

Figure: 3.6: Reduction of failure rates with the improvement in the system

According to the above figure, failure rate has been increased from 0.0047/h to 0.00225/h after the modification. Hence after this proposal implementation, system improvement can be expected.

4.1. Introduction to Desalination Plant

The main objective of desalination plant is reducing the salinity of sea water from its nominal value around 60,000µS/cm to 2,000 µS/cm which is almost equal to ground water salinity level. This unit plays a very critical and important role in the process of supplying water to fulfill all the requirements such as boiler makeup, service and firefighting, and drinking water.

This plant consists of two major parts namely Ultra Fine (UF)filtration(Figure 4.1) and Reverse Osmosis (RO) permeation which are connected in cascade.

UF filtration is taking place by vacuum filtration of sea water through 100 µm membranes. Three sets of UF systems having a capacity 125 m^3/hr. each are installed. At any time two units are in operation and the remaining unit is on standby. Therefore, the system is capable of producing 250 m^3 per hour. This system is acting as a supportive system to RO system by reducing the dissolved silica and alumina in sea water to ensure a long lifetime of RO membranes[10]. Growth of marine organisms on UF membranes were controlled by dosing sodium hypochlorite (NaOCl) to the inlet water floor. Correctlevel of dosing is critical as any excess NaOCl will severely damage RO membranes by corrosion.

According to the operation history records, it is seenthatthis unit has run with a satisfactory output and no critical breakdowns which lead to unit shut down or de-loadhas been recorded. However, auto cleaning of pre-filters of UF system was not successfully carried out due to the poor instrument and calibration (I & C) issues and erosion of filter material as well as the housing due to sea water. However it has not caused any plant shut downs. At present these pre-filters are bypassed. This can cause damage to the other equipment connected in cascade and shorten their life time.

Figure 4.1: UF system

RO system helps to reduce the salinity of sea water directly. The energy required for the RO process is supplied by a high pressure pump with the help of an energy recovery device. The pressure of RO concentrate water is between 4.0 and 4.5 M Pa. Energy recovery unit transfers this energy to RO feed water by reducing the pressure to 0.25 M Pa. A booster pumpisinstalled to match the energy of feed water after the energy recovery unit. The performance of booster pump and high pressure pump is balanced using a variable speed drive (VSD). Chemicals are dosed into RO feed water to enhance the permeation efficiency of membranes.

Frequent failures of membranes is the major issue of the RO system.The cause for these failures is the high conductivity of sea water in the Indian Ocean. The system was designedoperate at sea water conductivity below than 50, 000 µS /cm[1]. However, the conductivity of sea water varies between 60,000 and 90,000 µS/cm throughout the year.

VSDs of high pressure pumps and booster pumpswhich are installed very close to this system failed several times. Reason for these failures was identified as the presence of high salinity moisture in the vicinity. When the concentrated brine is released to the open trenches it creates sea water breeze,whichis drawn with the inlet draft of VSD main cooling fan mounted in the unit. This createsafavorable environment to form rust and make salty deposits on the circuit boards and several VSD cards had to be replaced due to short circuiting by salty deposits. The VSD enclosure is rated at IP 21 which doesn't provide sufficient protection against water and dust and not at all suitable for the prevailing conditions.

4.2. Unit Generation Cost of Water in Desalination Plant.

The cost for water production can be calculated based oncurrentconditions and the calculation is given below:

Table 4.1: Unit cost of water from Desalination plant

Cost component	Total Cost (Rs)
Annual Electricity	28,382,400.00
Annual membrane replacement	27,100,000.00
Raw water pump maintenance	1,100,000.00
VSD maintenance	6,700,000.00
Mechanical maintenance	36,192,000.00
Annual chemical usage	33,500,000.00
Operation Manpower	6,480,000.00
Total Cost	**139,454,400.00**

Annual water production = 864,000 m^3

Unit cost of water production (Rs) = $\frac{\text{Total annual water production cost}}{\text{No of units produced}}$

= $\frac{139{,}454{,}400.00}{864{,}000}$

= 161.04Rs. /m^3

With such a high cost it seems that it is much profitable to procure total water requirement for the power plant from National Water Supply and Drainage Board (NWS &DB)at the unit rate of Rs.16.00/m^3. But there is no such plan or capacity to provide the plant demand since there are no sufficient infrastructure facilities with NWS &DB.

4.3. Calculation of Availability in RO units.

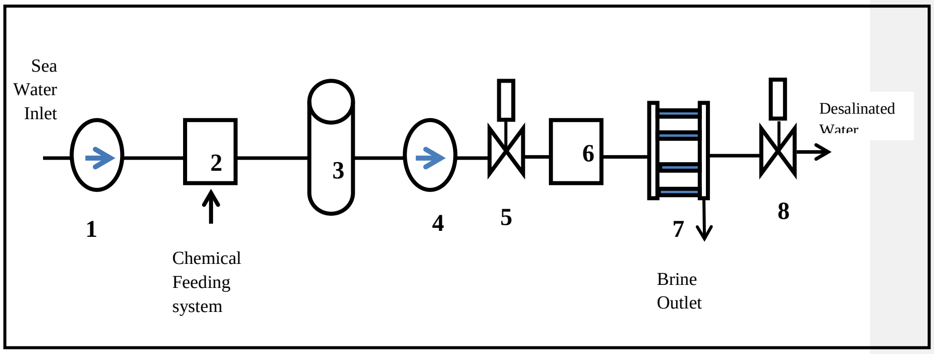

Figure 4.2: Desalination plant layout.

Description of Items.

1. RO feed water pump
2. Chemical dosing system
3. Pre-Filter
4. HP pump
5. Motorized valve -1
6. Energy recovery system
7. RO Membrane unit
8. Motorized valve -2

The reliability factor of each system is calculated separately using fault recordhistory in AppendixesA, B, andCfor the RO system.Summary of calculations is given in the following table.

Table 4.2: Summary of reliability factors in RO system

Name	Availability	f	λ/h	μ/h
RO Unit -1	0.3864	0.0022	0.0058	0.0037
RO Unit -2	0.3128	0.0017	0.0055	0.0025
RO Unit -3	0.2312	0.0014	0.0059	0.0018

Considering two out of three units have to be run at full load, system reliability can be calculated as follows.

Average failure rate λ= 0.0057/h

Total observation time period= 12,840 h (22/12/2010-09/06/2012)

Assuming exponential distribution

$R_{(RWP)} = e^{-\lambda t} = e^{-0.0057X12840} = 1.64x10^{-32}$

Using followingequation [02].

$$Rsys(t) = \sum_{i=2}^{3} \begin{bmatrix} 3 \\ 2 \end{bmatrix} . [R(t)]^i . [1 - R(t)]^{3-i}$$

$R_{Sys(t)}$= 8.0688X10^{-64}

Then, 8.0688x10^{-64}=e$^{-\lambda X12840}$

Failure rate (λ_{sys}) =0.011315/ h.

Availability (A_{sys}) :

A_{sys} =1-($A1*\overline{A2}*\overline{A3}+\overline{A1}*A2*\overline{A3}+\overline{A1}*\overline{A2}*A3+\overline{A1}*\overline{A2}*\overline{A3}$)

=1-(0.204143+0.147559+0.097489+0.324177)

= 1-0.773367

= 0.226633

Availability for RO_{sys} = 0.226633

Failure rateλ_{sys} = 0.011315 /h

4.4. Calculation of Availability in UF Units.

After analyzing the breakdown records inthepast(Appendix – D), the reliability factors of UF units can be summarized as follows.

Table 4.3: Summary of reliability factors in UF system

Item	Running time(h)	Outage time (h)	No of starts	No of Outages	m (h)	r (h)	A	f	λ/h	μ/h
UF-1	6,727.30	3,236.15	8	7	840.91	462.31	0.64526	0.000767	0.0012	0.00216
UF-2	5,228.93	3,740.38	6	5	871.49	748.08	0.53810	0.000617	0.0011	0.00134
UF-3	3,921.48	3,264.38	6	5	653.58	652.88	0.50027	0.000765	0.0015	0.00153

Using above method, availability and failure rate of UF systems are also calculated

A=0.919713 λ=.002381/h

Therefore,thetotal Desalination plant availability and failure rate is given below

A_d =0.208437 **λ_d =0.014095/h**

The reduction of failure rate can be demonstrated through the following (Figure: 4.3).

Reliability function, $R(t) = e^{(-0.0141t)}$

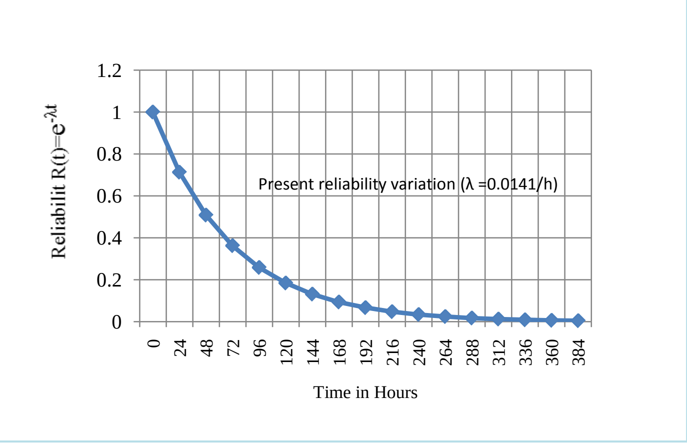

Figure: 4.3- reduction of failure rates with the improvement in the system

4.5. Suggestions and Calculation to Enhance the Reliability of Desalination Plant

Following two options can be proposed, as a target solution to improve the reliability.

- Relocation of existing VSD's to a better environment
- Reduction of salinity of feed water by adding ground water.

4.5.1. Relocation of Existing VSDs

According to the history data, failure rate of high pressure pump variable speed drivers were significant. These failures affect the water purification system. Therefore,relocation of the VSDs to a proper environment is suggested. As an interim solution to avoid failures of VSDs,a temporary air conditioned cubicle was constructed enclosing the VSDs according to the space availability as shown in Figure 4.4 below.

Figure 4.4: Temporary isolation of VSD unit in Desalination plant.

Although the effectiveness of isolation from the existing environment was proven, it has created some difficulties in the maintenance work on membranes.

Therefore the suggestion was made to relocate the VSD's into separate partition in the next building comingunder phase II of the project, which is close to this placeand has air conditioning as well.

The detailed selection of equipment for the particular modifications and cost is given below.

Selection of required size of cable

For selecting a suitable cable for this requirement, cable selecting guideline [8] was used.

- Motor capacity= 160 kW
- Full Load Motor Current = 288 A
- Required cable length =73m
- Ambient air temperature =30^0C
- Ground temperature =25^0C
- Depth of laying =0.6 m
- Soil thermal resistivity = 2 K.m/W

Considering the full load current,a suitable cable can be selected as follows:

Choice 01 : 3x120mm^2 Cu/XLPE/SWA/PVC

Applicable de-rating factors are as follows;

- For ambient air temperature(30˚C) =1
- Ground temperature (25 ˚C) =0.93
- Depth of laying (0.6m) =0.98
- For soil thermal resistivity (1.5Km/W) =0.83

Actual current rating =363 x 1 x 0.93 x 0.98 x 0.83 s=274.6A

Therefore, selected cable is not sufficient for our application.

Choice 02 : 3x 150mm^2 Cu/XLPE/SWA/PVC

Actual current rating for the cable with de-rating factors =406 x 1 x 0.93 x 0.98 x 0.83

=307.1A

Calculating the voltage drop = 0.3 x 289 x 73

=6.33V<16V

(Maximum allowable voltage drop is 4% as per IEE wiring regulations)

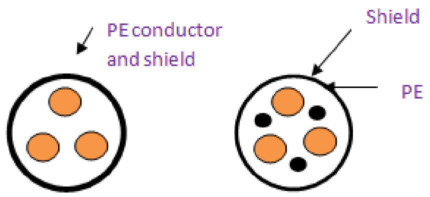

Figure 4.5: Cross section of recommended symmetrical cable.

Using a symmetrical shielded cable is recommended to effectively suppress radiated and conducted radio-frequency emissions.

Therefore 3 x 150 Cu /XLPE/SWA/PVC is the suitable cable for above modification.

The costing for the particular modification is as follows.

Table 4.4: Cost for the modification listed as relocation of VSD's

	Description	Unit Cost (Rs)	Quantity	Total Cost(Rs)
1	3X150 Cu/XLPE/SWA/PVC	5,750	219.00	1,259,250.00
2	Cable lugs	500	18	9,000.00
3	Panels mounting material	3,500	3	10,500.00
4	Cost for control cable	2,500	250	625,000.00
5	sundry items	2,500	1	2,500.00
6	Total material cost			1,906,250.00
7	Labour charges	287	400	114,800.00
8	Transportation charges	20,000	1	20,000.00
Total cost (Rs)				**2,041,050.00**

4.5.2. Dilution of Feed Water by Ground Water Source.

The major reason for the failure of RO membranes was identified as the high conductivity of sea water. Therefore, reduction of conductivity of RO feed water is the best solution to avoid membrane failures. Conductivity of feed water to RO units can be reduced to acceptable limits by mixing sea water with low salinity fresh water.

Water from a surface water source can used to dilute sea water. However, as Kalpitiya peninsula is located in the dry zone, neither a fresh water stream nor a reservoir is available at a reasonable distance.

A geological survey was done to identify a suitable water source within the puttalam district boundary.A rich surface water stream was identified at Eluwankulamareawhich is located 10 km away from puttlam. The water source is fed from the famous river "Kala Oya".

It is necessary to mix sea water with fresh water in equal amounts to bring the conductivity to the recommended level of less than 50,000 µS/cm.

Since the total water requirement for RO plant is 260 m^3/h; it is necessary to feedfresh water at the rate of 130m^3/h (around 2m^3/min) to mix with a similar quantity of sea water.

A detailed historical data analysis was performed to find out the availability of water from this river to fulfill the requirement of RO plant to ensure satisfactory continuous operation. Actual flow discharge data collected by National Water Supply & Drainage Board for a period of one year from February 2010 to January 2011 was based for calculations.[12].

Table 4.5: Daily average flow discharge of Eluvankulamstream in m^3/sec

Date / Month	2010											2011
	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	20.20	7.64	1.53	29.26	4.36	5.09	2.64	0.31	49.22	56.15	41.39	90.73
2	16.90	8.29	1.30	29.78	2.69	2.35	1.80	0.23	26.97	38.28	68.35	79.18
3	13.35	8.25	0.53	28.66	1.67	1.42	0.53	0.25	48.97	11.97	105.6	78.29
4	10.82	7.9	0.84	25.16	1.50	0.97	0.32	0.39	43.74	3.05	104.8	62.15
5	10.32	7.32	0.93	18.25	1.26	0.64	0.24	0.17	31.66	9.85	107.2	44.32
6	10.62	7.08	4.27	13.65	0.86	0.40	0.88	0.17	29.97	45.27	111	19.66
7	11.00	7.49	2.83	10.29	1.63	1.19	4.01	0.13	16.48	91.20	113	42.85
8	9.71	7.55	2.79	8.59	5.85	8.33	7.17	0.13	6.77	74.19	112.5	59.56
9	8.59	7.03	2.35	9.11	9.25	24.76	6.81	0.16	4.91	25.60	106.6	65.22
10	9.17	7.05	1.38	8.15	7.74	18.36	4.52	0.18	2.98	16.01	64.55	105.27
11	11.05	6.84	2.88	5.12	3.85	15.7	1.45	0.11	2.17	38.35	35.42	112.22
12	11.91	6.87	5.17	3.25	2.18	14.18	0.40	0.14	2.18	35.00	34.36	122.01
13	10.72	7.11	5.03	4.96	1.14	9.23	0.23	0.20	1.82	50.50	48.16	130.17
14	10.68	5.99	6.06	8.24	1.06	4.96	0.20	0.23	1.49	60.50	35.47	122.72
15	10.72	6.61	7.84	13.93	0.85	3.03	0.18	0.23	1.29	57.31	31.14	88.01
16	10.07	5.93	9.66	26.3	0.73	2.88	0.13	0.20	1.28	19.74	58.27	86.78
17	12.54	5.1	12.04	33.97	1.00	3.07	0.08	0.19	1.29	16.63	52.58	76.72
18	18.36	5.17	17.44	33.31	5.56	7.63	0.02	0.16	1.04	25.87	48.19	74.9
19	28.17	5.59	17.35	31.3	8.97	10.32	0.03	0.16	0.82	56.86	31.43	46.6
20	12.58	5.41	8.30	30.62	10.46	10.87	0.03	0.42	0.86	56.79	23.75	21.52
21	11.00	5.33	5.17	13.76	6.31	5.11	2.37	0.17	1.06	55.19	21.98	19.6
22	10.39	5.71	3.48	6.94	3.27	2.30	16.77	0.05	1.51	58.37	53.53	19.04
23	9.77	5.7	5.99	6.4	1.36	1.05	18.79	0.04	2.09	56.11	52.34	18.44
24	8.64	4.22	21.66	4.95	0.61	0.42	32.58	0.02	2.66	40.75	66.62	17.47
25	7.97	3	16.08	3.4	0.58	0.40	14.89	0.04	3.18	48.81	106.6	19.49
26	8.16	2.45	11.42	2.91	0.84	0.58	3.81	0.04	4.06	53.75	108.4	44.25
27	7.75	1.97	44.04	2.44	2.05	1.96	2.06	0.04	4.86	60.51	95.8	58.46
28	7.28	1.86	17.41	7.96	4.87	7.13	1.39	0.13	6.74	66.11	80.32	61.74
29		2.3	17.33	16.44	8.22	9.26	1.18	37.33	12.73	58.20	59.48	38.96
30		1.76	28.11	11.89	9.13	9.59	0.66	81.42	53.17	40.72	24.37	29.08
31		1.76		9.03		6.05	0.38		74.69		64.74	48.72
Maximum	28.17	8.29	44.04	33.97	10.46	24.76	32.58	81.42	74.69	91.20	112.99	130.17
Minimum	7.28	1.76	0.53	2.44	0.58	0.40	0.02	0.02	0.82	3.05	21.98	17.47

Average	11.73	5.56	9.37	14.77	3.66	6.10	4.08	4.11	14.28	44.25	66.71	61.42
Standard Deviation	4.42	2.11	9.73	10.58	3.17	5.97	7.25	16.10	20.08	20.75	31.59	34.25
Runoff (MCM)	28.38	14.89	24.3	39.83	9.49	16.35	10.93	10.66	38.25	114.7	178.7	164.52

A flow duration curve was drawn to find out the availability of required water quantity during a period of one year.

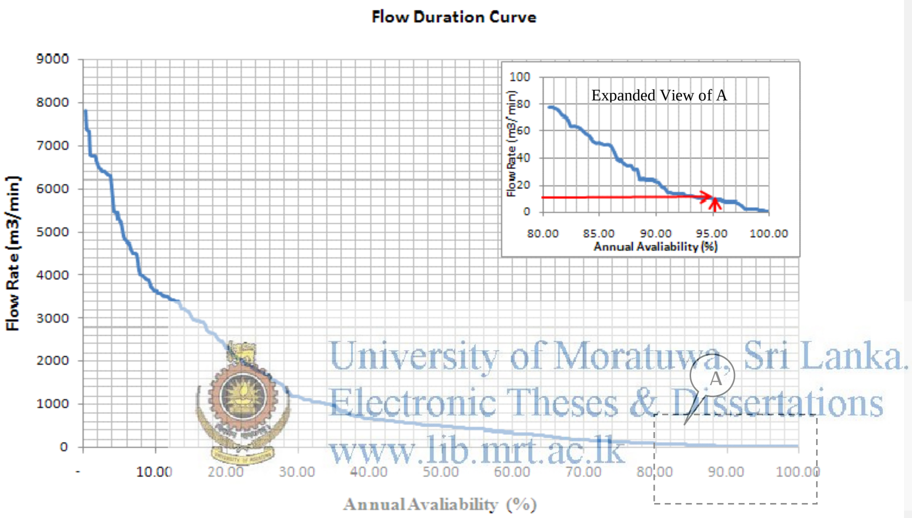

Figure 4.6: Flow duration curve at “Eluwankulam” gauging station.

It is clearlyevident from above curve thatthe fresh water requirement can be met with an availability factor of 95% (ie. 345 days in an year) even with the flow rate of $10m^3$/min.As the requirement of the plant is only 2 m^3/min, the remaining water flow is sufficient to maintain the eco – system stability.

The proposed 39 km piping layout connecting the fresh water source and the power plant is given in figure 4.7 below.

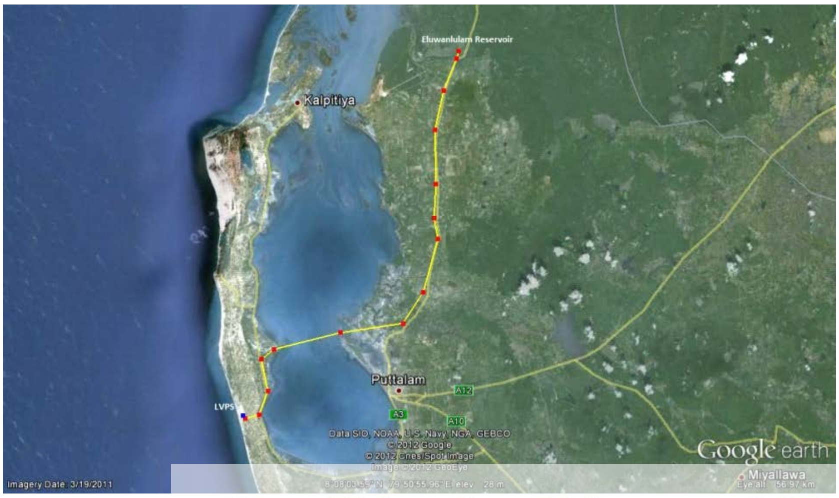

Figure 4.7: Proposed piping layout between the source and plant.

Cost is calculatedby considering different pipe sizes as the independent parameter and corresponding cost components such as material cost, transport cost, laying cost and operational cost etc as dependent parameters. Then the suitable pump is selected considering the pump head and the costs of motor, installation, electrical control panel , spare parts and electricity.

Table 4.6: Cost calculation for proposed piping layout

NO.	DESCRIPTION	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5
1	**General Data**					
	Nominal Diameter (mm)	**180**	**225**	**250**	**300**	**350**
	Pipe Material	**HDPE**	**HDPE**	**HDPE**	**HDPE**	**HDPE**
	Pipe line length (m)	**38,000**	**38,000**	**38,000**	**38,000**	**38,000**
2	**Transmission Pipe Cost Analysis**					
2.1	**Basic Supplying costRs./mtr**					
	CIF value of pipes	2,200.00	3,010.00	4,900.00	7,406.00	10,100.00
	CIF value of special accessories	770.00	1,054.00	1,715.00	2,593.00	3,535.00
	Transport and clearing	297.00	407.00	662.00	1,000.00	1,564.00
	Custom duty	1,049.00	1,436.00	2,337.00	3,532.00	4,816.00
	Total cost for 1m material at site	4,316.00	5,907.00	9,614.00	14,531.00	20,015.00

	Price escalation factor	1.22	1.22	1.22	1.22	1.22
	Total cost for pipe line material supply	**200,089,760.00**	**273,848,520.00**	**445,705,040.00**	**673,657,160.00**	**927,895,400.00**
2.2	**Pipe laying CostRs. /mtr**					
	Basic laying cost	246.00	276.00	276.00	325.00	360.00
	Excavation cost	355.00	408.00	438.00	520.00	574.00
	Cost for specials	242.00	281.00	281.00	321.00	364.00
	Earth Work Supports cost	201.00	313.00	317.00	438.00	493.00
	Cost for hydro test	32.00	37.00	39.00	47.00	52.00
	Total laying cost for one meter	1,076.00	1,315.00	1,351.00	1,651.00	1,843.00
	Price escalation factor	1.22	1.22	1.22	1.22	1.22
	Estimated cost for pipe laying for transmission line	**49,883,360.00**	**60,963,400.00**	**62,632,360.00**	**76,540,360.00**	**85,441,480.00**
2.3	**Total cost for Supplying material and laying the pipe line**	**249,973,120.00**	**334,811,920.00**	**508,337,400.00**	**750,197,520.00**	**1,013,336,880.00**

A detailed calculation was made to identify the suitable motor power and pump head as shown bellow for further analysis of respective cost components. The sample pump data calculation for pipe size Φ 300mm is as follows.

4.5.3 Pump Calculation for Eluwankulama intake

Total Capacity 2,880 m^3/Day

No. of operating hours 24 hrs/day

Flow rate 120 m^3/hr = 2 m^3/min

Quantity of pumps

Duty 1

Standby 1

Pump Capacity

Q 2 m^3/min

q 0.0333 m^3/Sec

Pipe Diameter = $146X(Q/v)^{(1/2)}$ [13]

Velocity range = 1.5 to 2.5 m/s [13]

Diameter Range = 169 to 131 Mm

Selected Diameter	=	300	mm	

Static Head

Suction headh_s	=	-6.4	m	(MSL)
Delivery headh_d	=	8	m	(MSL)
Static Head	=	14.4	m	

Friction losses

Assuming all transmission pipes to be DI having a C = 130

Applying of Hazen William's Equation

$$hf = 10.666 x C^{(-1.85)} x D^{(-4.87)} x q^{(1.85)} x L$$ [14]

C	=	130	
L	=	38	km
	=	38000	m
hf	=	32.4	m

Velocity Head

Cross sectional Area	=	0.070686	m^2
Flow velocity	=	0.5	m/s
$V^2/2g$	=	0.01	m
Allow for minor losses fittings at the pump	=	4	m
Static head at pump Discharge	=	5	m
Pump Total Head	=	43	m

Now Hydraulic power $= \frac{\sigma.g.Q.H}{1000.\eta} \; kW$

Where,

σ Density in kg/m^3 (water)	= 1000kg/m^3
g Gravitational constant	= 8.81m/s^2
Q Flow rate in m^3/s	= 0.0333 m^3/s
η Pump efficiency for mixed flow pump	= 63%
Hydraulic power of pump	= 14.06 kW

Considering Motor efficiency(75%) and over capacity factor 115%

Motor Power = **22 kW**

Same calculation is repeated for other pipe sizes to find the relevant motor power and the other cost components associated with motors of different ratings.

Table 4.7

Cost calculation for different motor capacities.

1	**Pumping Cost Analysis**					
1.1	**Pump General Data**					
	Plant Capacity (m^3/day)	2880	2880	2880	2880	2880
	No. of working Hours	20	20	20	20	20
	No. of Pumps					
	Duty	1	1	1	1	2
	Stand By	1	1	1	1	1
	Pump Duty Point					
	Flow Rate - Q (m3/min)	2	2	2	2	2
	Head (m)	401	142	90	43	26
	Motor Power (kW)	201	71	45	22	13
1.2	**Cost for pumping system**					
	Pump Supply Cost	3,843,000.00	1,952,000.00	1,464,000.00	915,000.00	585,600.00
	Installation cost	384,300.00	195,200.00	146,400.00	91,500.00	58,560.00
	Spare Part supply cost	768,600.00	390,400.00	292,800.00	183,000.00	117,120.00
	Electrical Panel boards					
	Motor controller	3,904,000.00	1,830,000.00	1,220,000.00	256,200.00	170,800.00
	Installation cost	390,400.00	183,000.00	122,000.00	25,620.00	17,080.00
	Total cost for supply & installation of one pump with motor controller	9,290,300.00	4,550,600.00	3,245,200.00	1,471,320.00	949,160.00
	Total for two pumps	18,580,600.00	9,101,200.00	6,490,400.00	2,942,640.00	2,847,480.00
	Main power incoming section (Capacity for 1 duty pump)	1,220,000.00	451,400.00	390,400.00	292,800.00	231,800.00
	Total Cost for Supply and installation of pumps and electrical panel boards	**19,800,600.00**	**9,552,600.00**	**6,880,800.00**	**3,235,440.00**	**3,079,280.00**
1.3	**Energy Cost for pump operation for one year**					
	Power consumption	201	71	45	22	13
Assume plant to be operated 20 hrs/ Day X 365 days/ year X 20 years and cost for 1 kWh (Rs.) is 17.50.						
	Total energy consumption (kWh)	29,346,000	10,366,000	6,570,000	3,212,000	1,898,000
	Total Energy cost (Rs)	**513,555,000.00**	**181,405,000.00**	**114,975,000.00**	**56,210,000.00**	**33,215,000.00**
Note:-All rates from Rate Book 2012 published by National Water Supply & Drainage Board (NWS&DB)						

The total installation cost and energy cost were combined to take the optimum pump and pipe specifications.

Table 4.8: Combination of pipe, pump cost and energy cost

Pipe Diameter (mm)	Pump Head (m)	Pipe line + Pump cost (MnRs)	Energy cost (MnRs)	Total (MnRs)
180	401	270	514	783
225	142	344	181	526
250	90	515	115	630
300	43	753	56	810
350	26	1,016	33	1,050

According to the above table, capital cost increases with the increase of pipe diameter, but at the same time energy cost decreases. Therefore, the pipe system has to be selected in such a way to minimize the total cost. These three variables are drawn in the graph (Figure 4.8). It can be clearly identifiedthat the best economical pipe system is the one with a diameter of 225mm.

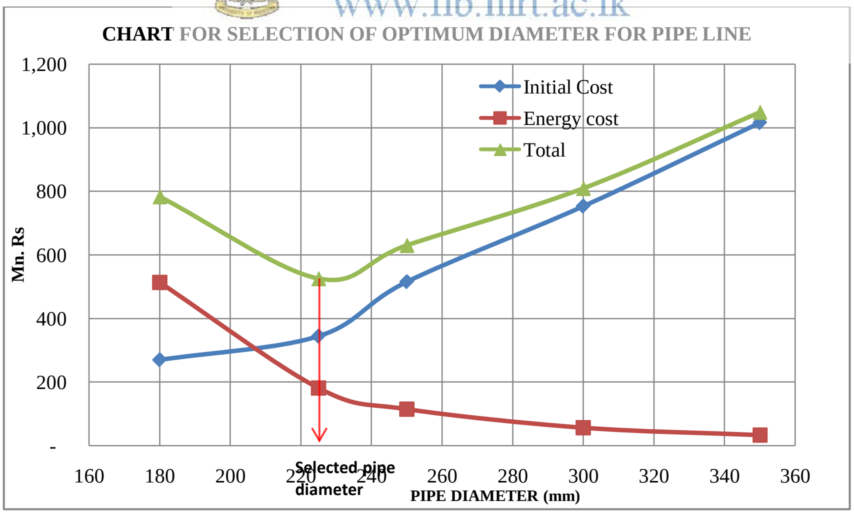

Figure 4.8: Combined cost of initial cost and energy cost.

The minimum cost point is identified with respect to the pipe diameter 225mm and its cost is noted as Rs.525 Mn. The payback period is calculated below.

4.6. Payback Period Calculation for the Proposal.

The cost to generate one unit of water is calculated by considering the in-house plant energy consumption, additional energy to pump water from the river and all maintenance cost components as follows.

Table 4.9: Calculation of unit cost for feed water as per the proposal

.	Description	Unit.	Amount	Remark
1	Annual water production requirement	m^3	864,000	(2,400 x 30 x 12)
2	Energy consumption per day	kWh	7,776	
2.1	Annual energy consumption	kWh	2,799,360	
2.3	Annual energy cost for existing units	Rs.	27,993,600.00	Assume, electricity unit cost is Rs 10/kWh
3	Additional energy for supply surface water	kWh	190,080	(22 x 24 x 30 x 12)
3.1	Energy cost for additional pump	Rs	2,586,960.00	Assume unit cost is Rs 12/kWh and Maxi Demand charge is Rs 850/kVA
3	Annual membrane replacement cost	Rs.	9,464,000.00	According to membrane manufacture's manual(DOW FILMTEC) It has three year warranty period for recommended operation limits)
3.1	Annual VSD maintenance cost	Rs.	1,340,000.00	(6,700,000.00/5)
4	Annual Chemical usage cost	Rs.	26,800,000.00	(33,500,000 x 80%)
5	Annual manpower cost	RS.	6,480,000.00	(80,000 x 3 x 12+50,000 x 6 x 12)
6	Total maintenance and Operation cost	Rs.	74,664,560.00	
7	Unit production cost of water with the proposed system	Rs./m^3	85.41	(74,664,560/864,000)

As calculated in Table 4.1 (page 25), the unit cost of feed water at present is Rs. 161.04, taking into consideration the operation and maintenance costs.

Therefore, the annual cost savings (Rs) = (161.04-85.41) x 2,880 x 365

= Rs. 79,502,256.00

Total project cost (Rs) = 528,041,050.00

Payback period (Years) = $\frac{528,041,050.00}{79,502,256.00}$

= **6.6**

As the expected life time of the plant is 30 years, this payback period is desirable.

5.1. Introduction to Demineralization Plant (RO-2 plant).

De-mineralized water production plant mainlyconsistsof domestic water RO system which is commonly named as RO-2 and ion exchange process. Conductivity of water produced from desalination plant should be less than 2,000 µS cm^{-1} to be treated in this RO-2 plant[1]. RO-2 system will reduce the conductivity of water below 50 µS $cm^{-1.}$ It isfurther reduced to 0.2 µS cm^{-1}after passing through the ion exchange columns. Treated water from Ro-2 system is used to fulfill the potable water requirement of the plant as well.

Treated water from RO-1 unit is pumped through RO membranes using high pressure pumps. Then the water is stored in an intermediate storage tank called RO-2 water tank. Part of this water is sent through limestone filters to make potable water. Rest of the water is sent through a cat-ion bed, de-gassifier, An-ion bed and a mix bed connected in cascade. The final product is collected in a storage tank as Demineralized water which suitable to be fed into the boiler.

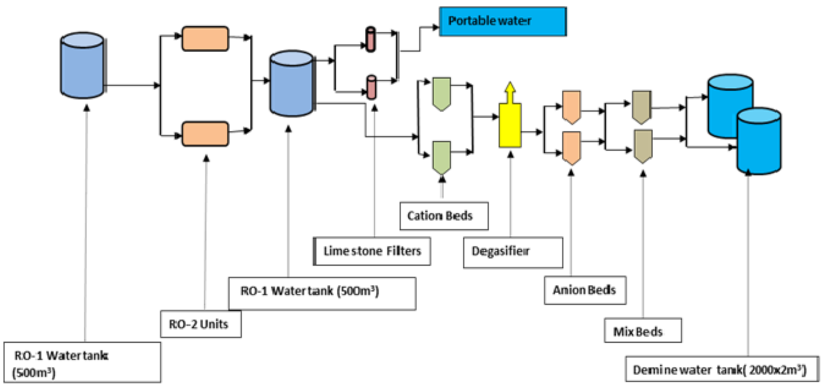

Figure 5.1: Flow diagram of Demineralization system.

The system operating data was collected to identify the causes and durations of failures to identify and explore the areas which need modifications or improvements. The collected data issummarized below.

Table 5.1System outage data in demineralization unit.

~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Incident	Outage (h)
11/16/11 9:38	11/16/11 16:11	Ro-2 System (HP pump #1)	6.55
10/19/11 9:20	10/19/11 17:40	Ro-2 System (HP pump #2)	8.33
9/30/11 9:35	10/1/11 18:10	Degasified blower	32.58
9/30/11 10:45	10/1/11 18:20	Anion Bed #1	31.58
12/8/11 8:35	1/5/12 9:33	Broken pipe line which connect with portable water tank	672.97
5/21/12 8:13	5/22/12 8:45	Anion Bed #2	24.53
4/19/12 15:05	4/21/12 17:05	Degasified blower	50.00
4/19/12 3:18	4/21/12 5:10	Anion Bed #1	49.87
Total Outage			876.42

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The longest outage during this evaluation period was caused by a failure of pipe line which is not directly related to the demineralization process. However, the second longest outage was due to the failure of blower attached to the de-gasifier unit. There is only a single blower installed according to the design and no redundancy is available in case of a failure of the blower. Further, a failure of degasifier blower will cause an overload on the anion bed located next causing it to cease the iron exchange operationsand shut its inlet and outlet valves.

Using the above data equipment wise reliability indices can be calculated to facilitate making recommendations to improve availability.

Table 5.2: Equipment wise reliability factors.

Equipment	Running (h)	Outage (h)	No of running times	No of Outages	m (h)	r (h)	Availability	f	λ/h	μ/h
Ro-2 System (HP pump #1)	10,845	6.55	3	2	3,615.00	3.275	0.999	0.000276	0.000277	0.305
Ro-2 System (HP pump #2)	10,845	8.33	2	1	5,422.50	8.333	0.998	0.000184	0.000184	0.120
Degasified blower	10,845	82.58	4	3	2,711.25	27.527	0.990	0.000365	0.000369	0.036
Anion Bed #1	10,845	31.58	5	4	2,169.00	7.896	0.996	0.000459	0.000461	0.127
Pipe Line	10,845	672.97	5	4	2,169.00	168.242	0.928	0.000428	0.000461	0.006
Anion Bed #2	10,845	24.53	2	1	5,422.50	24.533	0.995	0.000184	0.000184	0.041
Anion Bed #1	10,845	49.87	3	2	3,615.00	24.933	0.993	0.000275	0.000277	0.040
		876.42			**417.12**	**45.21**	**0.902214**	0.002356	0.002397	0.751

Therefore, demineralization plant has an availability of 0.902214 and a failure rate of 0.002397/h.

5.2. Suggestions to Improve System Reliability.

The easiestpoint of improvement is thedegasifierby installing an additional blower (Figure 5.2) to operate on standby basis to avoid the tripping of entire plant. It can be demonstrated as follows in the graphic window which is in the control system.

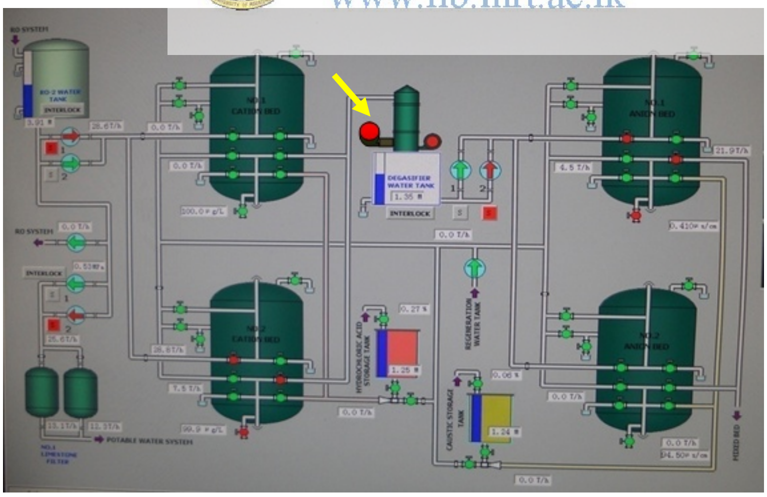

Figure 5.2: Proposed standby blower to degasifier.

In order to connect the additional blower to degasifier it is needed to modify the logic ladder diagram in PLC program as follows.

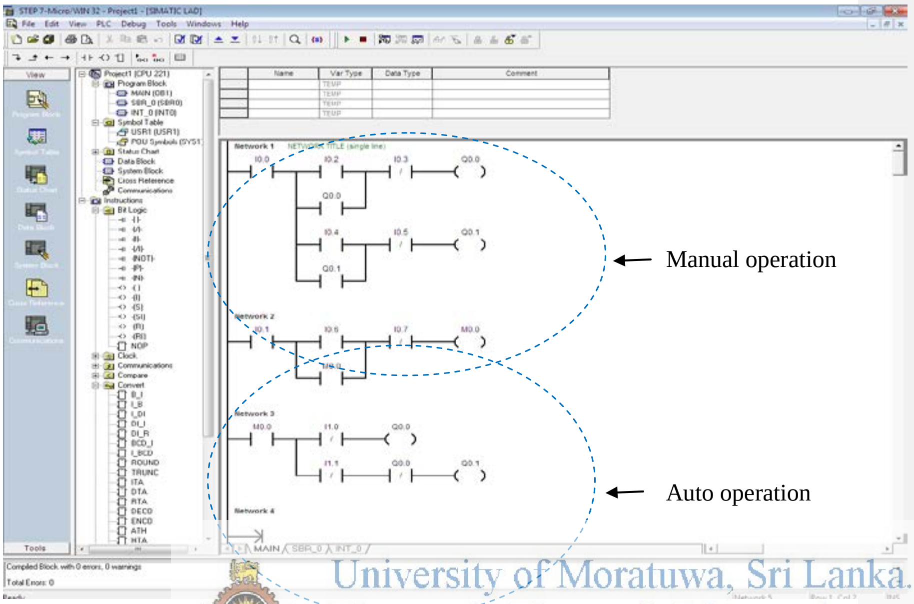

Figure 5.3: Proposed logic modification in PLC ladder program.

Legends of the gates are as follows.

Inputs

Manual mode selection I0.0

Auto mode selection I0.1

P1 manual start I0.2

P1 manual stop I0.3

P2 manual start I0.4

P2 manual stop I05

Auto sequence start I0.6

Auto sequences stop I0.7

P1 thermal overload I1.0

P2 thermal overload I1.1

OUT PUTS

P1 start Q0.0

P2 start Q0.1

After doing this implementation,failures in thedegasifies and anionbed systems can be reduced.

According to the new design, two identical degasifies are in parallel. Therefore, the availability of this particular section can be calculated as follows:

A_p = $A_1 \times A_2$

= $(1-A_1) \times (1-A_2)$

= $A_1=A_2$

= (1- 0.990) x (1-0.990)

= 0.01 x 0.01

= 0.0001

A_p = $(1-A_p)$

= 0.9999

Mean running value of parallel blowers are denoted by m_p

m_p = $(1+\lambda_1 r_1+\lambda_2 r_2)/((\lambda_1\lambda_2)(r_1+r_2))$

Where,

λ_1= Failure rate of blower 1

λ_2 = Failure rate of blower 2

r_1= Mean repair time of blower 1

r_2= Mean repair time of blower 2

Assuming the identical blowers having same failure rates,$\lambda_1=\lambda_2$

Therefore, the mean value of above parallel system can be calculated as follows:

$$=\frac{1+0.000369\ x\ 27.527+0.000369\,x\ 27.527}{(0.000369\ x\ 0.000369)(27.527+27.527)}$$

= 13000

Failure rate $\lambda_p = 1/\overline{m}_p$

$= 0.00000075/h$

Considering these values and other existing reliability factors, the expected factors can be obtained.

Expected reliability factors are as follows:

Table 5.3: Expected equipment wise reliability factors.

Equipment	Running (h)	Outage (h)	No of running times	No of Outages	m (h)	r (h)	Availability	f	λ/h	μ/h
HP pump #1	10845.00	6.55	3	2	3,615	3.28	0.999	0.000276	0.000277	0.305
HP pump #2	10845.00	8.33	2	1	5,422	8.333	0.998	0.000184	0.000184	0.120
Pipe Line	10845.00	672.97	5	4	2,169	168.24	0.928	0.000428	0.000461	0.006
Anion Bed	10845.00	49.87	3	2	3,615	24.93	0.993	0.000275	0.000277	0.040
Blower 1&2							0.9999		0.00000075	
		737.72			**834.23**	**73.12**	**0.919413**	0.001163	0.001199	0.471

Now availability is increased to 0.919413 and failure rate is reduced to 0.001199.This is a good achievement for boiler water production system.

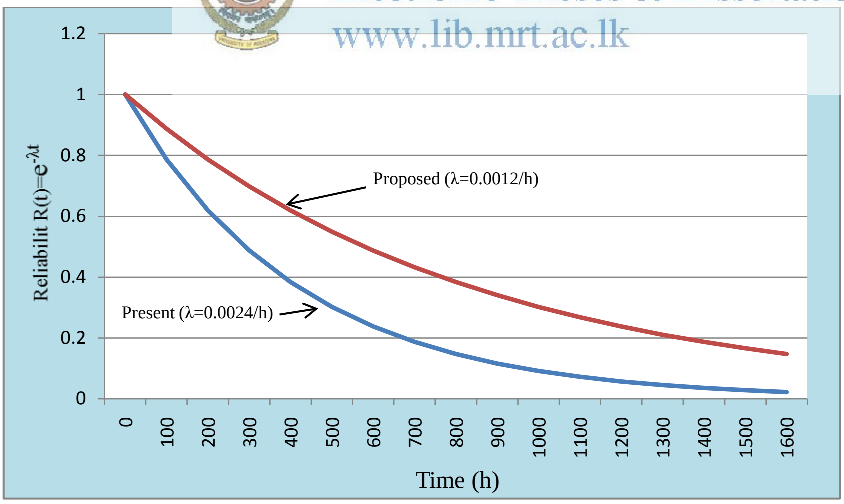

Figure 5.4: Graphical representation of the improvement of reliability.

We can clearly see that from the above graph (Figure 5.4), that failure rate will be reduced after the improvement.

CHLORINATION PLANT

6.1 Operation of Chlorination Plant.

The electro chlorination system operates on 44V DC power derived from the 6kV AC systemusinga transformer and rectifier, The DC voltage is applied between the cathode and anode of the electrolytic cell to electrolyze the seawater and produce sodium hypochlorite. The hypochlorite is then injected into cooling seawater using two dosing methods. A continuous dosage of mg/l is carried out using one pump and an impulsive dosage of 3mg/l is performed three times a day using three pumps.[6].

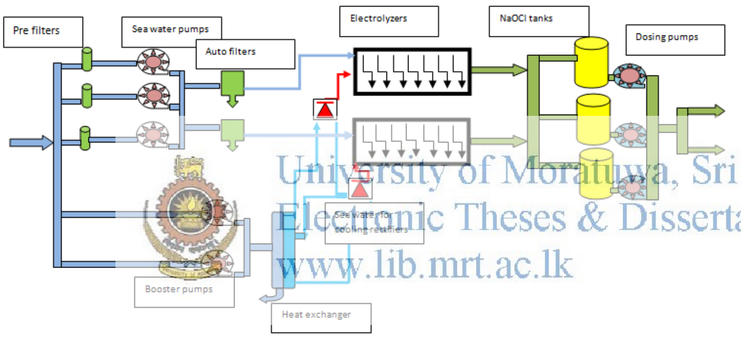

Figure 6.1: Layout of the chlorination plant.

Sodium hypochlorite produced by the electro chlorination system is used to destroy the organisms in seawater. Otherwise, massive marine organism breeds, grows and attaches to the surfaces of the cooling water pipelines, debris filers and condenser coil pipes can degrade the conveying capability of pipelines, reduce the cooling efficiency of the condenser, and force the generator to run at lower loads.

6.2Calculation of Availability

The identified defects and frequencyofoccurrence for the entire chlorination plant are tabulated as follows.

Table 6.1: Equipment outages and running hours record.

Equipment	Running Hrs	Outage (h)	No of Operations	No of Outages
sea water pre filter#1	12,663.50	46.97	3	2
sea water pre filter#2	12,663.50	14.75	3	2
sea water pre filter#3	12,663.50	43.12	3	2
sea water pump #1	12,663.50	1,272.50	3	2
sea water pump #2	12,663.50	29.40	2	1
sea water pump #3	12,663.50	344.18	3	2
Auto back wash filter #1	12,663.50	15.67	3	2
Auto back wash filter #2	12,663.50	20.40	4	3
Sea water cooling booster pump-1	6,485.40	3,311.33	5	4
Sea water cooling booster pump-2	6,178.10	3,591.00	4	3
Rectifier #1	6,485.40	851.73	3	2
Rectifier #2	6,178.10	1,651.35	4	3
NaOCl Dosing pipe line	12,663.50	71.78	8	7

Using above data, the following reliability indices can be calculated.

Table 6.2: Calculated equipment wise reliability indices.

Equipment	m	r	Availability	f	λ/h	μ/h
Sea water pre filter#1	4,221.17	23.48	0.99447	0.000236	0.0002	0.04258
Sea water pre filter#2	4,221.17	7.38	0.99826	0.000236	0.0002	0.13559
Sea water pre filter#3	4,221.17	21.56	0.99492	0.000236	0.0002	0.04639
Sea water pump#1	4,221.17	636.25	0.86901	0.000206	0.0002	0.00157
Sea water pump#2	6,331.75	29.40	0.99538	0.000157	0.0002	0.03401
Sea water pump#3	4,221.17	172.09	0.96083	0.000228	0.0002	0.00581
Auto back wash filter #1	4,221.17	7.83	0.99815	0.000236	0.0003	0.12766
Auto back wash filter #2	3,165.88	6.80	0.99786	0.000315	0.0008	0.14706
Sea water cooling booster pump#1	1,297.08	827.83	0.61042	0.000471	0.0008	0.00121
Sea water cooling booster pump#2	1,544.53	1,197.00	0.56338	0.000365	0.0006	0.00084
Rectifier #1	2,161.80	425.87	0.83542	0.000386	0.0005	0.00235
Rectifier#2	1,544.53	550.45	0.73725	0.000477	0.0006	0.00182
NaOCl dosing pipe line	1,582.94	10.25	0.99356	0.000628	0.0006	0.09752

The individual reliability indices are combined according to the process path design to calculate the total failure rate and total system availability.

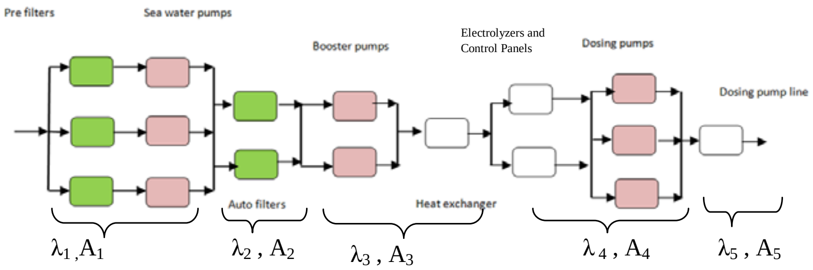

Figure 6.2: Process layout of the chlorination plant.

Considering the series combination of equipment of chlorination plant present failure rate and availability can be calculate as follows.

Total failure rate (λ) $= \lambda1+\lambda2+\lambda3+\lambda4+\lambda5$

$=0.000674+0.0001998+0.00033855+0.000352+0.000628$

= 0.00219/h

Total system availability (A) $=A_1 x A_2 x A_3 x A_4 x A_5$

$= 0.992952 x 0.999996 x 0.829901 x 0.956757 x 0.993560$

=0.78334

This value indicates a low availability rate of 78.3%.

Two major defects which directly contributed to the failure of chlorination plant were observed. Major design changes were identified to improve the reliability of the chlorination system.

First defect is the regular damage of mechanical water seal in the sea water cooling pumps which feed water to heat-exchangers. High content of sand in the sea water causes damages the carbon water seals of pumps. Leaking water seals is a very common sight at the chlorination plant (Figure 6.3).

Figure 6.3: water leak through mechanical seal.

In order to prevent the damage caused by sand to the booster pump mechanical seals it is suggest to installasand filter before the booster pump with a bypass line as follows.(Figure 6.4)

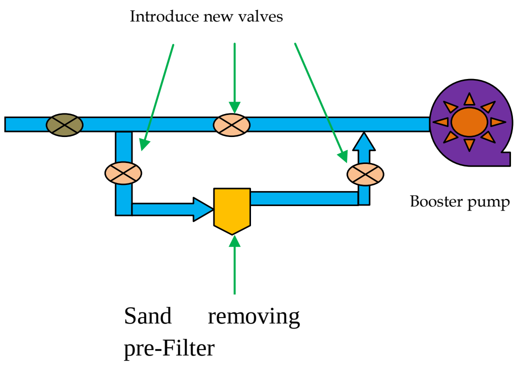

Figure 6.4: Installation of sand filter to protect booster pump.

The second defect is inadequate dosing of NaOCl to the pump intake due to wrong piping layout from the chlorination plant to cooling water intake. This insufficient dosing fails to arrest the growthof barnacles and causes blockage of the sea water intake(Figure 6.5).

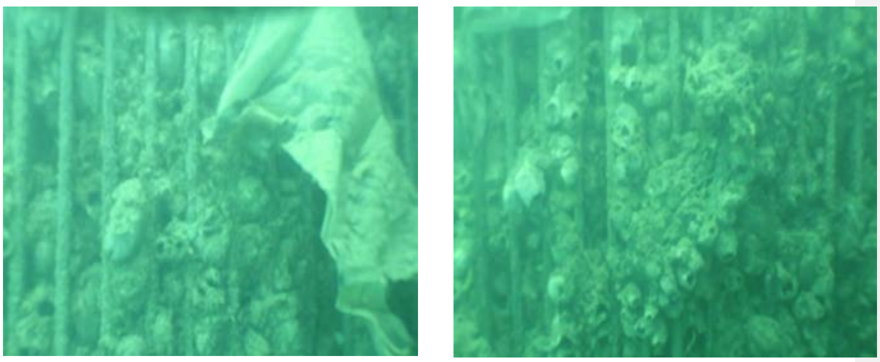

Figure 6.5: Barnacles growth in bar screen due to lack of dosing of NaOCl .

According to the design there must be two distinct dosing modes of NaOCl to the cooling intake head and pump bay (continuous and shock dozing). Continuous dosing is done at the sea water intake where as shock dosing is done at the pump bay.

In the initial section, the same pipe line (DN125) is used for both purposes as shown in figure 6.6.

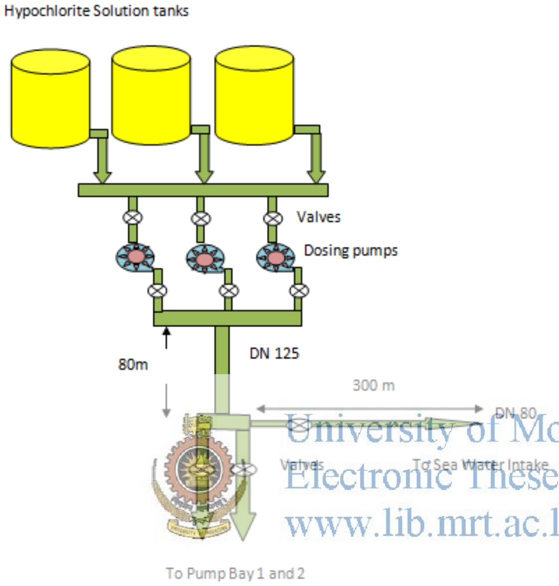

Figure 6.6: present pipe line arrangement.

The disadvantage of this arrangement is that the common section of pipe line frequently gets damaged due to the high pressure of shock dosing pumps. Then the continuous dosing too is affected due to leakages and pressure drops.

Presently continuous dosing is attempted using gravity flow as the operation of pumps aggravates leakages. However, this arrangement violates the designs and provides virtually no chlorination.

For proper operation of dosing systems the velocity of NaOCl along a pipe should be between 1.5 m/s and 3 m/s. Slower speeds would cause coagulation while higher speeds need higher pressures which may cause damages to pipe line. In the present system the speed of continuous dosing at the common section of pipeline is too slow because it has a larger diameter to accommodate the flow required for the shock dosing. Therefore, this section tends to be blocked due to coagulation.

The correct design is to use two separate pipe lines for the two types of dosing as shown in figure 6.7.

The following situation is considered:

- Design Point: continuous dosing (34 m^3/h) in DN125 => v = 0.77 m/s
- Current operation: gravity dosing (ca. 25 m^3/h) in DN125 =>v = 0.56 m/s
- Current operation: dosing pump (ca. 80 m^3/h) in DN125 =>v = 1.8 m/s

This means that the chlorination plant, which is presently operated by gravity in the continuous dosing mode alone, is sendinganNaOClsolutionalong the DN125 distribution pipe at a velocity of 1.8m/s, which is far too low. The risk of forming deposit scales is considered very high. It is suggested to inspect the dosing pipe to find out if scaling deposits have already occurred and suitable actions should be taken to clean the same.

As an improvement, it is proposed to install a separate dosing pipe (DN80) from the continuous dosing pumps header into the Intake. Each line shall be equipped with flow control valves and respective control loops (see proposal in Figure6.6). In this way during continuous dosing to the Intake a pipe velocity of 1.9 m/s will be achieved, which is deemed appropriate. For shock dosing (102 m^3/h) the current DN125 pipe to Pump bay will have a velocity of 2.3 m/s, which is also deemed appropriate.

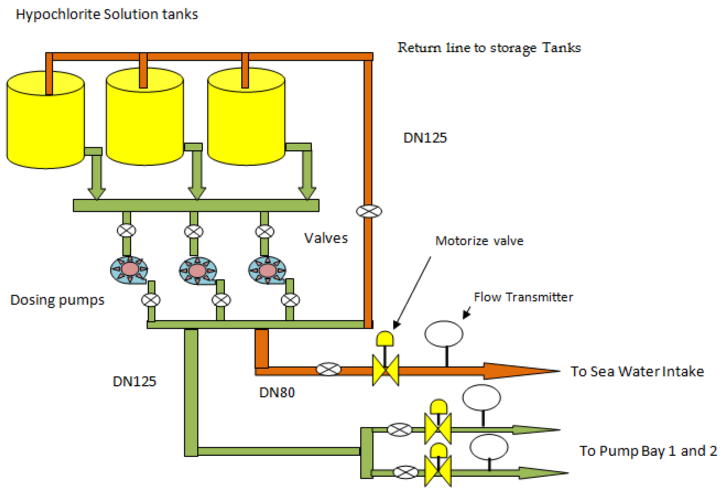

Figure 6.7: Proposal for installation of separate dosing line (DN80) and necessary flow control equipment

By implementing the above modifications the expected results are as follows.

Let's assumethefailure time is reduced by 50% after introducing sand pre-filter for booster pump line and the dosing lines are in separate parallel circuit.

Failure rate for cooling water booster pumps λ_3 =0.000201

Availability of booster pumpsA_3 = 0.9339

Failure rate of new dosing line λ_5 = 0.00000074

Availability A_5 = 0.999995

Total failure rate (λ) $=\lambda_1+\lambda_2+\lambda_{3\ new}+\lambda_4+\lambda_{5\ new}$

= 0.000674+0.0001998+0.000201+0.000352 +0.00000074

= 0.001427/h

Total system availability (A) = A_1 x A_2 x A_{3new}x A_4xA_{5new}

= 0.992952 x 0.999996 x 0.9339 x 0.956757 x0.999995

=0.88721

The comparison of reliability improvement before and after the modification is as follows.

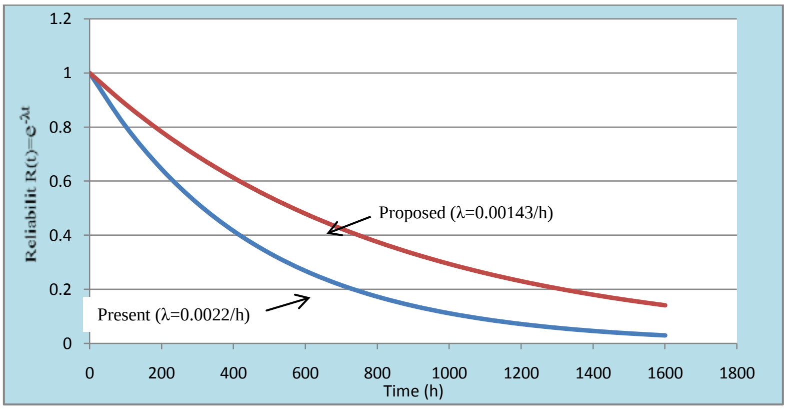

Figure 6.8 :Reliability curve of chlorination system before and after the modifications.

According to the graph shown in figure 6.8, show a clear improvement of the reliability by the proposed design.

Chapter7

HYDROGEN PLANT

7.1. Introduction to Hydrogen Plant.

To fill the air gap between the stator and rotor is filledwith highly purified hydrogen gas, considering its excellent qualities comparing with conventional air. The pressure of hydrogen in the generator needs tobemaintained at 0.3 M Pa with 98% purity to obtain an efficient cooling at the rated load of300MW[1].Due to the explosive nature of hydrogen, CEB operation and maintenance crew pays extra attention to the whole area covering the generator, hydrogen feeding and piping system, hydrogen generation plant as well as storage premises.

Hydrogen plant contains two electrolyzers. Each unit has a generating capacity of 5 m^3/h of Hydrogen. Daily use of hydrogen in generator is in between 30-50 m^3. Therefore generating capacity is clearly sufficient to fulfill the requirement of hydrogen in the power station. During maintenance periods the generator hydrogen will be replaced with carbon dioxide as a safety measure. Therefore,during the startup procedure, extra amount of hydrogen is needed to re-fill the generator enclosure. For this purpose more than 800 m^3 of hydrogen is required. Total hydrogen storage capacity of the plant is 1,000 m^3.Provided by four storage tankswith a capacity of 250 m^3 each. Therefore, hydrogen storage capacity is insufficient for two consecutive fillings if a need arises.(Figure 7.1). During the time of data collection there was one incident on 16/02/2012 where the generator failed to start after a repair and a second filling of hydrogen was needed.However, as the remaining capacity of the tanks (200m^3) was not sufficient and the total Hydrogen production capacity is 240 m^3/day, the start of power plant was delayed by 4 days. No new Hydrogen tanks are included in the second stage of the power plant as well. With the operation of the second stage the possibility of needing two consecutive fills would be further increased.

Figure 7.1: Hydrogen storage tanks with the total capacity of 4 x 250 m^3

7.2. Unit Wise Availability and Failure Rate Calculations

The system operating data was collected to identify the causes of failures and durations to have an idea to explore the areas which need modifications or improvements. The entire hydrogen plant is sub divided in to three units as generation plant No: 01, generation plant No: 02 and storage tank. The collected data can be summarized as follows:

Table 7.1:Plant No - 01 Outage data

	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Outage time(hrs)
1	Power failure of Electrolyzer #1	1/18/2012 12:10	2/11/12 10:45 AM	574.58
2	Plant #1 PLC fault	2/2/2012 14:00	2/11/12 4:43 PM	218.72
3	Solenoid valve #1	5/3/2012 8:07	5/3/12 4:16 PM	8.15
4	Rectifier fault #1	4/10/2012 10:18	4/11/12 11:10 AM	24.87
5	Solenoid valve #1	4/9/2012 14:07	4/9/12 3:05 PM	0.97
Total Outage				**827.28**

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Table 7.2: Plant No - 02 Outage data

	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Outage time(hrs)
1	Humidity Analyzer #2	1/18/2012 14:03	2/13/12 3:52 PM	625.82
2	Rectifier cooler #2	5/17/2012 10:45	5/17/12 12:10 PM	1.42
3	Feed water pump #2	4/30/2012 14:49	5/4/12 11:00 AM	92.18
4	Solenoid valve #2	4/9/2012 14:07	4/9/12 3:05 PM	0.97
Total Outage				**720.38**

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Table 7.3: Outage data for storage tank.

	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Outage time (h)
1	Storage tank capacity problem	2/16/2012 8:30	2/19/12 9:45 PM	**85.25**

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Above facts can be combined to calculate reliability factors as follow:

Table 7.4: Calculated summary of reliability factors for entire Hydrogen system.

Equipment	Running (h)	Outage (h)	No of running time	No of Outages	m (h)	r (h)	A	F	λ/h
Unit #1	6,350	827.28	6	5	1,058.33	165.46	0.86480	0.000817	0.0009
Unit#2	5,440	720.38	5	4	1,088.00	180.10	0.85798	0.000789	0.0009
Storage tank	8,674	85.25	2	1	4,337.38	85.25	0.98072	0.000226	0.0002

Hydrogen system canberepresented by the following block diagram and the reliability factors can be combined as follows.

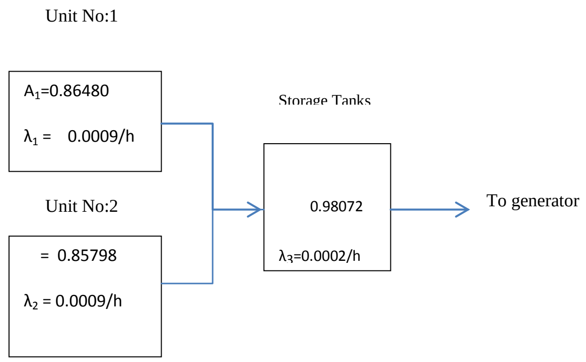

Figure 7.2: Simplified block diagram of hydrogen plant.

Hydrogen generators number one and two are in parallel.Therefore, the availability of this particular section can be calculated as follows:

$\bar{A}_p = \bar{A}_1 \text{ x } \bar{A}_2$

$= (1\text{-}A_1) \text{ x } (1\text{-}A_2)$

$= (1\text{- }0.86480) \text{ x } (1\text{-}0.85798)$

$= 0.1352 \text{ x } 0.14202$

$= 0.01920$

$A_p = (1\text{-}\bar{A}_p)$

= **0.9808**

Mean running value of parallel system is denoted by$\bar{m}_p$

$$\bar{m}_p = \frac{1+\lambda 1 r1+\lambda 2 r2}{(\lambda 1\lambda 2)(r1+r2)}$$

Where,

λ_1= Failure rate of system 1

λ_2 = Failure rate of system 2

r_1= Mean repair time of system 1

r_2= Mean repair time of system 2

Therefore, the mean value of above parallel system can be calculated as follows:

$$=\frac{1+0.0009\ x\ 165.46+0.0009\ x\ 180.10}{(0.0009\ x\ 0.0009)(165.46+180.10)}$$

= 4683.79

Failure rate $\lambda_p = 1/\overline{m}_p$

= 0.000214/h

Since the Electrolyzers and storage tanks are in series, their total system availability and failure rates are calculated as follows:

Total system Availability(A_T)= $A_p x A_3$

= 0.9808 x 0.98072

= **0.9619**

System failure rate $\lambda_s = \lambda_p + \lambda_3$

= 0.000214 +0.0002

= **0.000414/h**

After eliminating the storage issue by installing additional identical H_2 storage tanks to the system and assuming these H_2 tank also have same failure rate and availability, the present system the failure rate and availability can be calculated as follows.

Because propose H_2 tanks are installed in parallel to the existing tanks,

A_{ht} = A_3x A_3

= $(1-A_3)^2$

= $(1- 0.98072)^2$

= 0.0003717

A_{ht} = $(1-A_{ht})$

= 0.99962

Mean running value of parallel system is denoted by m_{ht}

$$m_{ht} = (1+\lambda_1 r_1+\lambda_2 r_2)/[(\lambda_1\lambda_2)(r_1+r_2)]$$

Where,

$\lambda_1 = \lambda_2$

Therefore, the mean value of above parallel system,

$m_{ht} = 146,670.19$

Failure rate $\lambda p = 1/m_{ht}$

$= 0.0000068/h$

Total system Availability,

$A_T = ApxA_{ht}$

$= 0.9808 \times 0.99962$

$= 0.9804$

System failure rate

$\lambda s = \lambda p + \lambda_{ht}$

$= 0.000214 + 0.0000068$

$=$ **0.00022/h**

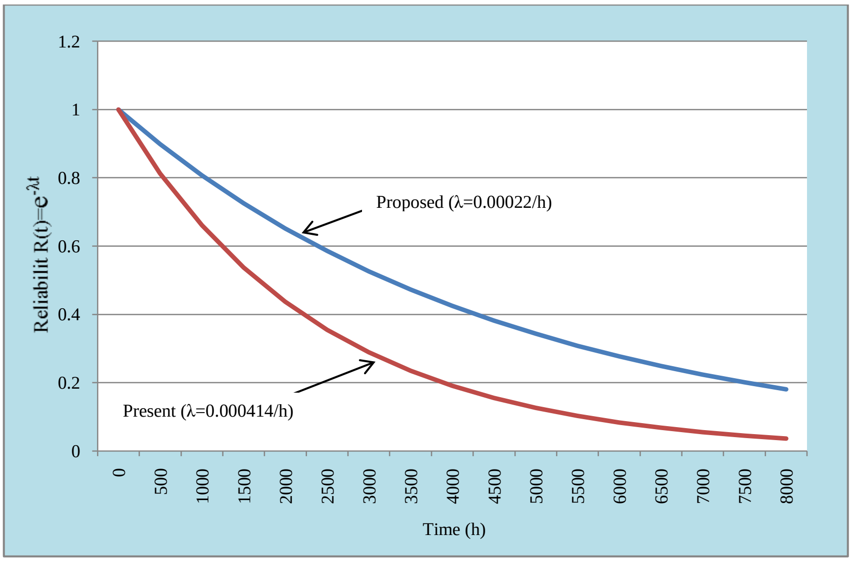

Figure 7.3: Improvement of reliability with the modification to H_2 generation plant.

Additional expenditure for installing additional storage tanks with a total capacity of 1,000 m^3 is around Rs.3 million and it is not a considerable cost when the opportunity cost for improving the availability of power plant.

Chapter 8

COST ANALYSIS

The invoices in puttalam coal power project and some quotations called from various organizations were used for the cost analysis. Here the financial loss due to loss of a unit from LVPS is approximated as nine rupees.

8.1. Cost estimation for installing new dosing pipe arrangement for Chlorination plant.

Because of solution are given for some of dosing system failures in chlorination plant, the related outages in chlorination system and maintenance cost ignored and considered only the energy loss due to blocking the debris filters in main machine.

Table 8.1:Cost estimation for constructing new dosing pipe arrangement for Chlorination plant.

NO.	DESCRIPTION		
1	**General Data**		
	Nominal Diameter (mm)	125	80
	Pipe Material	FRP	FRP
	Pipe line length (m)	25	40
2	**Pipe Cost**		
2.1	**Basic Supplying cost**		
	CIF value Rs/m	13,124.80	7,675.20
	CIF value for specials	5,249.92	3,070.08
	Transport & clearing	125.00	115.00
	Total cost for 1m material at site	**18,499.72**	**10,860.28**
2.2	**Pipe laying Cost**		
	Basic laying cost	474.00	276.00
	Excavation cost	216.00	206.00
	Cost for specials	280.00	240.00
	Cost for hydro test	32.00	37.00
	Total laying cost for one meter	1,002.00	759.00
	Price escalation factor	1	1
	Estimated cost for pipe laying for transmission line	**25,050.00**	**30,360.00**
	Cost for motorized butterfly valve	187,200.00	139,776.00
	No of valves	2	1
	Total cost for motorized butterfly valve	374,400.00	139,776.00
2.3	**Total cost for Supplying and laying cost of FRP Pipe line**	**1,463,143.00**	**1,788,587.20**
	Total cost for proposed modification (Rs.)		**3,251,730.20**

Energy could be recovered from loss = 9,000,000 kWh

Saving from a unit generation of LVPS = Rs 9.00

Total expected annual saving by the new design =Rs 81,000,000.00

Total cost for new improvement = Rs3200000.00

Simple payback period $= \frac{3,200,000}{81,000,000}$years

= 0 .5 Month

The simple payback period for proposed improvement is very low. Therefore this proposal can be considered as an economical viable.

8.2. Cost estimation for installing new sand filter for booster pump at Chlorination plant.

Total cost for install a sand filter before the booster pump with a bypass line as follows.

Table 8.2:Cost estimation for installing new sand filter for booster pump at Chlorination plant.

	Item	Quantity	Unit Cost (Rs)	Total Cost(Rs)
1	"Y" type strainer	2 Nos.	16,400.00	32,800.00
2	2" PVC pipe L-bow	4 Nos.	250.00	1,000.00
3	2" PVC pipe T-Socket	3 Nos.	320.00	960.00
4	2" PVC 4m pipe	2 Nos.	2,520.00	5,040.00
5	sundry items	1 Item	500.00	500.00
	Total material cost			**40,300.00**
	Labour charges	8*2	287.00	4,592.00
	Transportation charges	1	1,000.00	1,000.00
	Total cost			**45,892.00**

Total maintenance cost saving per year = Rs 300,000.00

Total cost for new improvement = Rs 45,892.00

Simple payback period = $\frac{45,892}{300,000}$ years

= 2 month

The simple payback period for proposed improvement in booster pumps is very low. Therefore this proposal can be considered as an economical viable project.

8.3. Cost estimation for installing new vertical mixed flow spindle pumps for Sea water intake.

The cost for supplyingandinstallingnew vertical mixed flow spindle pumps for sea water intake are calculated by using year 2013 market price in table 8.3.

Table 8.3:Cost estimation for installingnew vertical mixed flow spindle pumps for sea water intake.

	Item	Quantity	Unit Cost (Rs)	Total Cost(Rs)
1	35 kW mixed flow pump	4 Nos.	2,100,000.00	8,400,000.00
2	supporting material cost	4 Nos.	100,000.00	400,000.00
	Total material cost			**8,800,000.00**
	Installation charges	8*12*10	300.00	288,000.00
	Total cost			**9,088,000.00**

Considering only cost saving for motor rewinding cost per year =Rs 1,100,000.00

Total cost for new improvement = Rs 9,088,000.00

Simple payback period $= \frac{9,088,000}{1,100,000}$ years

= 8.3years

Plant has a 30 year life time period. Therefore this project can be considered as an economical viable project.

8.4. Cost estimation for relocating the Existing VSDs.

Considering the local market prices estimated total cost for relocate the existing VSDs in table 8.4

Table 8.4:Cost estimation for relocating the existing VSDs.

	Item	Quantity	Unit Cost (Rs)	Total Cost(Rs)
1	3x150 Cu/XLPE/SWA/PVC	219 m	5,750.00	1,259,250.00
2	Cable lugs	18 nos.	500.00	9,000.00
3	Panels mounting material	3 Nos.	3,500.00	10,500.00
4	Control cable	250 m	2,500.00	625,000.00
5	sundry items	1 No.	2,500.00	2,500.00
	Total material cost			**1,906,250.00**
	Labour charges	8*5*10	287.00	114,800.00
	Transportation charges	1 item	20,000.00	20,000.00
	Total cost			**2,041,050.00**

Considering the failures for one year period maintenance cost for repairing VSDs salty deposits on the circuit board.

Maintenance cost saving per year = Rs 6,700,000.00

Total cost for new improvement = Rs 2,041,050.00

Simple payback period $= \frac{2,041,050}{6,700,000}$ years

= 3.5 Month

The simple payback period for relocating the Existing VSDs improvement is very low. Therefore this proposal can be considered as an economical viable project.

8.5. Cost estimation for installing of standby blower to degasified system.

Total cost calculation for installing standby blower to present degasified system are given in table 8.5

Table 8.5: Cost estimation for installing of standby blower to degasified system.

	Item	Quantity	Unit Cost (Rs)	Total Cost(Rs)
1	2.2kW blower fan	1 No.	250,000.00	250,000.00
2	supporting material cost	1 No.	10,000.00	10,000.00
3	Cable cost	1 No.	20,500.00	20,500.00
4	Contactor and relay	1 Nos	12,500.00	12,500.00
5	sundry items	1 Item	500.00	500.00
	Total material cost			**293,500.00**
	Labour charges	8*2*3	287.00	13,776.00
	Transportation charges	1	5,000.00	5,000.00
	Total cost			**312,276.00**

Considering total maintenance cost for last year = Rs 240,000.00

Assumed this maintenance cost will be reduced by 50% after introducing new standby blower.

Now expecting Maintenance cost saving =Rs 120,000.00

Total cost for new improvement = Rs 312,276.00

Simple payback period $= \frac{312,276}{120,000}$ years

= 2.6 year

The simple payback period for installing of standby blower to degasified system is very low. Therefore this proposal can be considered as an economical viable project.

8.6. Cost estimation for installation of new hydrogen tanks system.

According to year 2013 market price total H_2 storage tanks installing cost was calculated in table 8.6

Table 8.6: Cost estimation for installation of new hydrogen tanks system.

	Item	Quantity	Unit Cost (Rs)	Total Cost (Rs)
1	200m^3 H_2 tank	4 Nos.	600,000.00	2,400,000.00
2	20mm 304 SS pipe	100 m	250.00	25,000.00
3	20mm Valve	4 Nos.	15,000.00	60,000.00
4	20 mm Pneumatic valve	4Nos.	35,000.00	140,000.00
5	sundry items	10 Nos.	500.00	5,000.00
	Total material cost			**2,630,000.00**
	Labour charges	8*3*10	287.00	68,880.00
	Transportation charges	1 item	50,000.00	50,000.00
Total cost				**2,748,880.00**

Energy could be recovered from loss = 25,575MWh

Saving from a unit generation of LVPS =Rs 9.00

Total expected annual saving by the new design =Rs230,175,000.00

Total cost for new improvement =Rs2,748,880.00

Simple payback period = $\frac{2,748,880}{230,175,000}$years

= **5 Days**

The simple payback period for proposed improvement is very low. Therefore this proposal can be considered as an economical viable.

Chapter 9

CONCLUSION AND RECOMMENDATIONS

9.1 Conclusion.

The objective of this study is to evaluate the reliability in Balance of Plant section including sea water pre treatment plant, desalination plant, demineralization system, chlorination plant and hydrogen generation plant against the noted history starting from the date of commissioning of the power plant. Then the study is extended to identify the possible improvements to increase the reliability of the power plant and calculate improved reliability figure with the above design proposals. Results of the study show that it is possible to improve the systems using simple and cost effective modifications at areasonablecost, to increase theoverall availability of the power plant in a measurable way.

It is proposed to replace the existing submerged raw water pumps by suitable mix flow vertical spindle pumps to eliminate frequent winding failure in sea water intake and pretreatment system to improve the system reliability.

There are two modifications proposed to improve the reliability of desalination plant which has the lowest availability figure in BOP section. First is to relocate the VSDs to a separate,air conditioned compartment in order toimprove the operation to eliminate the failures of VSDs.Secondmodification is the introduction of river water from “Kala Oya” to mix with the sea water to bring the conductivity of inlet water to RO unit within design value range. However, a considerable time is needed to construct the pipe line to bring river water from the source nearly 48 km away from the power plant.

It is proposed to introduce a standby blower parallel with the existing one to de-gasifier tank with suitable logic modifications to act as a backup.

Also it is proposed to modify the piping layout from the chlorination plant to cooling water intake to meet the appropriatedosingspeeds for both shock dosing at the pump bay and continuous dosing at the intake head.This modification can eliminate many issues caused by sea born organisms such as barnacles and herbs. It will also increase the life time of pipe lines, heat exchangers and auto clean filters and debris filters located before the condenser main cooling water line.

Also it is proposed to introduce a sand filter before the rectifier cooling water pump to eliminate the ingress of sand to the pump unit to reduce water leaks through mechanical seal damage.

Installation of additional storage tanks having a total capacity of 1,000$m^3$to store $H_2$for use in emergency situations when consecutive fillings of generator enclosures are needed, is recommended to eliminate unnecessary delays.

The summarized availability figures of each section before and after the proposed modifications are compared below:.

Table 9.1: Plant wise availability comparison in BOP section.

Plant	Availability	
	Existing	Expected
Chlorination Plant	0.783337	0.88721
Pretreatment Plant	0.875010	0.919544
Desalination Plant	0.208372	0.919506
Demineralization Plant	0.902214	0.919413
Hydrogen generation plant	0.96189	0.9804

Simple payback period also was calculated for each modification to prove the credibility of each proposal as follows:

Table 9.2: Simple payback period for each modification.

No.	Proposals	Total Cost(Rs)	Saving/year	Pay back period	Remak
1	Design new dosing pipe line arrangement	3.2 M	81M	0.5 Month	Feasible
2	Design suitable pre-filter for cooling booster pumps	0.05M	0.3 M	2 Month	Feasible
3	Replace existing raw water submersible pumps with vertical mixed flow pumps	9.1 M	1.1 M	8.3 year	Feasible
4	Dilute of RO feed water by using river water	528 M	79 M	6.6 year	Feasible
5	Change the VSD location from the sea water mist environment	2 M	6.7 M	3.5 Month	Feasible
6	Introducing IP 54 VSD	15 M	6.7 M	2.2 year	Feasible but No 5 is more desirable
7	Design new standby blower fan for degasified system	0.3 M	0.12 M	2.6 Year	Feasible
8	Enhance hydrogen Storage capacity	2.8 M	230.2 M	5 Days	Feasible

9.2 Recommendations.

It is obvious that the reliability of BOP section of the Lakvijaya Power Plant can be improved byaconsiderable extent to increase the plant availability. Also it is recommended to make those modifications simultaneously to sub divisions to achieve total improvement for the division as per the table 8.2.

CEB as well as all consumers and citizens of Sri Lanka will reap the befitsas the Lakvijaya Power Plant is the cheapest thermal power provider among the CEB generation division.

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[Appendix- A]

Fault Record for RO-1 Unit				
	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Period in hrs
1	Energy recovery Unit	12/21/11 6:50 PM	12/21/11 11:21 PM	4.52
2	Energy recovery Unit	2/9/12 2:40 PM	2/13/12 4:34 PM	97.90
3	Chemical feeding unit	2/10/12 9:12 AM	2/10/12 9:50 AM	0.63
4	Energy recovery Unit	1/16/12 10:09 AM	1/16/12 10:53 AM	0.73
5	HP pump VSD	12/2/11 2:00 PM	12/30/11 8:30 AM	666.50
6	Chemical feeding unit	12/20/11 2:02 PM	12/20/11 3:45 PM	1.72
7	RO membrane unit	12/8/11 9:00 PM	12/10/11 8:57 AM	35.95
8	RO membrane unit	12/4/11 10:10 AM	12/10/11 8:58 AM	142.80
9	RO membrane unit	12/1/11 10:13 AM	12/1/11 5:04 PM	6.85
10	RO membrane unit	11/30/11 3:25 PM	12/1/11 9:14 AM	17.82
11	RO membrane unit	11/29/11 4:40 PM	11/30/11 3:25 PM	22.75
12	RO feed water pump	11/19/11 4:02 PM	11/30/11 3:25 PM	263.38
13	Chemical feeding unit	11/3/11 11:20 AM	11/3/11 3:40 PM	4.33
14	HP pump VSD	11/2/11 3:11 AM	11/2/11 5:12 PM	14.02
15	HP pump VSD	10/27/11 2:05 PM	10/27/11 5:42 PM	3.62
16	RO feed water pump	11/19/11 3:40 PM	11/19/11 5:50 PM	2.17
17	Chemical feeding unit	11/12/11 3:27 PM	11/16/11 5:49 PM	98.37
18	Pre filter	10/4/11 2:36 PM	10/4/11 6:22 PM	3.77
19	Chemical feeding unit	10/2/11 2:23 PM	10/2/11 7:06 PM	4.72
20	HP pump VSD	10/1/11 3:22 PM	10/1/2011 17:20	1.97
21	RO membrane unit	9/20/11 11:35 AM	10/27/11 5:30 PM	893.92
22	Pre filter	9/13/11 6:18 PM	9/13/11 11:00 PM	4.70
23	Chemical feeding unit	9/13/11 2:45 PM	9/15/11 7:55 PM	53.17
24	Energy recovery Unit	6/30/12 10:10 AM	6/30/12 2:27 PM	4.28
25	HP pump VSD	12/7/11 10:10 AM	2/14/12 8:05 AM	1653.92
26	RO membrane unit	1/15/12 9:10 AM	2/29/12 1:42 PM	1084.53
27	RO membrane unit	2/28/12 2:47 PM	2/29/12 1:42 PM	22.92
28	Pre filter	2/3/12 3:15 PM	3/2/12 6:51 PM	675.60
29	Pre filter	3/6/12 5:59 PM	3/6/12 7:07 PM	1.13
30	Chemical feeding unit	3/12/12 7:38 PM	3/13/12 10:03 PM	26.42
31	Chemical feeding unit	3/15/12 10:40 AM	3/18/12 3:05 PM	76.42
32	Chemical feeding unit	3/29/12 2:31 PM	3/31/12 8:34 AM	42.05
33	Chemical feeding unit	3/29/12 9:29 AM	4/3/12 2:49 PM	125.33
34	HP pump VSD	4/6/12 10:42 AM	4/6/12 1:02 PM	2.33
35	Pre filter	4/18/12 10:20 AM	4/18/12 11:36 AM	1.27
36	RO membrane unit	4/9/12 10:32 AM	4/13/12 8:49 AM	94.28
37	HP pump VSD	4/9/12 9:08 AM	4/9/12 12:10 PM	3.03
38	HP pump VSD	4/30/12 4:17 PM	4/30/12 7:26 PM	3.15
39	RO membrane unit	5/17/12 8:52 AM	5/17/12 8:58 AM	0.10

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40	HP pump VSD	5/5/12 12:00 AM	5/22/12 9:00 PM	429.00
41	RO membrane unit	5/23/12 12:20 PM	5/24/12 4:10 PM	27.83
42	RO membrane unit	6/7/12 8:53 AM	6/7/12 6:50 PM	9.95
43	Pre filter	6/18/12 3:25 PM	6/18/12 4:06 PM	0.68
44	Chemical feeding unit	6/19/12 10:08 AM	6/19/12 6:13 PM	8.08
45	RO feed water pump	6/23/12 9:57 AM	6/23/12 5:17 PM	7.33
46	HP pump VSD	6/25/12 3:00 PM	6/25/12 5:46 PM	2.77
Total Outage (h)				6,648.70

[Appendix- B]

Fault Record for RO-2 Unit				
	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Period in hrs
1	HP pump VSD	7/12/11 10:10 AM	2/14/12 8:05 AM	5205.92
2	HP pump VSD	8/29/11 5:22 PM	8/30/11 3:00 PM	21.63
3	HP pump VSD	8/30/11 4:00 PM	9/2/11 8:46 AM	64.77
4	Pre filter	9/13/11 2:45 PM	9/13/11 11:00 PM	8.25
5	RO membrane unit	11/29/11 4:40 PM	11/30/11 3:25 PM	22.75
6	RO membrane unit	11/30/11 3:25 PM	12/1/11 9:14 AM	17.82
7	RO membrane unit	12/1/11 10:13 AM	12/1/11 5:04 PM	6.85
8	RO membrane unit	12/4/11 10:10 AM	12/10/11 8:58 AM	142.80
9	Energy recovery Unit	12/10/11 9:58 AM	12/10/11 5:26 PM	7.47
10	HP pump VSD	12/20/11 1:46 PM	12/20/11 3:40 PM	1.90
11	Chemical feeding unit	12/20/11 2:32 PM	12/20/11 3:45 PM	1.22
12	RO membrane unit	12/25/11 10:38 AM	12/26/11 3:34 PM	28.93
13	Pre filter	1/3/12 5:52 PM	1/3/12 9:13 PM	3.35
14	Pre filter	2/2/12 1:49 PM	2/2/12 5:50 PM	4.02
15	Pre filter	2/3/12 3:15 PM	2/3/12 6:51 PM	3.60
16	RO feed water pump	2/8/12 8:40 AM	2/8/12 2:25 PM	5.75
17	Energy recovery Unit	2/9/12 1:40 PM	2/9/12 4:02 PM	2.37
18	Pre filter	2/19/12 5:30 PM	2/19/2012 21:15	3.75
19	Chemical feeding unit	3/3/12 9:22 AM	3/3/12 5:45 PM	8.38
20	Pre filter	3/5/12 3:30 PM	3/5/12 5:45 PM	2.25
21	Energy recovery Unit	3/12/12 4:27 PM	3/12/12 7:33 PM	3.10

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22	HP pump VSD	4/19/12 3:07 PM	6/8/12 8:21 PM	1205.23
23	RO feed water pump	4/23/12 9:19 AM	4/23/12 10:48 AM	1.48
24	RO feed water pump	4/23/12 12:20 PM	4/24/12 5:09 PM	28.82
25	RO membrane unit	5/20/12 1:39 PM	5/20/12 3:12 PM	1.55
26	HP pump VSD	5/27/12 3:55 PM	8/27/12 7:16 PM	2211.35
27	RO membrane unit	5/28/12 12:00 AM	5/29/12 11:33 AM	35.55
28	RO membrane unit	5/28/12 2:47 PM	5/28/12 4:09 PM	1.37
29	RO membrane unit	6/1/12 9:35 AM	6/1/12 10:37 AM	1.03
30	RO membrane unit	6/9/12 12:02 AM	6/9/12 1:10 AM	1.13
31	RO membrane unit	6/21/12 7:15 AM	6/29/12 9:30 PM	206.25
32	Energy recovery Unit	7/7/12 10:02 AM	7/9/12 11:43 AM	49.68
33	Energy recovery Unit	7/12/12 2:45 PM	7/13/12 3:54 PM	25.15
		Total Outage (h)		9,335.47

[Appendix - C]

Fault Record for RO-3 Unit				
	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Period(hrs)
1	RO membrane unit	2/10/12 9:12 AM	2/10/12 1:15 PM	4.05
2	Pre filter	2/3/12 1:44 PM	2/3/12 3:21 PM	1.62
3	HP pump VSD	12/29/11 2:00 PM	12/30/11 8:30 AM	18.50
4	HP pump VSD	12/20/11 2:32 PM	12/30/11 12:00 AM	225.47
5	Chemical feeding unit	12/20/11 2:32 PM	12/20/11 3:45 PM	1.22
6	RO membrane unit	12/20/11 9:10 AM	12/28/11 1:54 PM	196.73
7	RO membrane unit	12/4/11 10:10 AM	12/10/11 8:58 AM	142.80
8	RO membrane unit	12/4/11 10:10 AM	12/10/11 8:58 AM	142.80
9	RO membrane unit	12/1/11 10:13 AM	12/1/11 5:04 PM	6.85
10	RO membrane unit	11/30/11 3:25 PM	12/1/11 9:14 AM	17.82
11	Chemical feeding unit	11/3/11 11:20 AM	11/3/11 3:25 PM	4.08
12	Energy recovery Unit	10/27/11 2:05 PM	10/27/11 3:42 PM	1.62
13	Pre filter	10/4/11 2:36 PM	10/4/11 6:22 PM	3.77
14	RO membrane unit	10/2/11 2:23 PM	10/2/11 7:05 PM	4.70
15	RO membrane unit	10/2/11 2:04 PM	10/2/11 7:05 PM	5.02
16	RO membrane unit	9/20/11 11:35 AM	10/27/11 5:30 PM	893.92
17	Energy recovery Unit	9/2/11 5:59 PM	9/3/11 2:40 PM	20.68
18	HP pump VSD	9/5/11 10:20 AM	9/6/11 1:45 PM	27.42
19	Chemical feeding unit	6/14/12 2:30 PM	6/14/2012 14:50	0.33
20	Pre filter	6/12/12 1:48 PM	6/12/12 3:16 PM	1.47
21	RO membrane unit	1/15/12 9:10 AM	2/29/12 1:42 PM	1084.53
22	RO membrane unit	2/28/12 2:47 PM	2/29/12 1:42 PM	22.92
23	Pre filter	2/3/12 3:15 PM	3/2/12 6:51 PM	675.60
24	Pre filter	3/6/12 5:59 PM	3/6/12 7:07 PM	1.13
25	RO membrane unit	3/1/12 3:07 PM	3/6/12 11:16 AM	116.15
26	Chemical feeding unit	3/12/12 9:48 AM	3/12/12 3:45 PM	5.95
27	HP pump VSD	2/13/12 4:58 AM	3/27/12 6:50 PM	1045.87
28	HP pump VSD	2/13/12 5:02 PM	3/27/12 6:28 PM	1033.43
29	Pre filter	4/7/12 4:10 PM	4/7/12 4:55 PM	0.75
30	HP pump VSD	4/12/12 8:49 AM	4/13/12 5:50 PM	33.02
31	RO membrane unit	5/10/12 4:48 PM	5/25/12 1:26 PM	356.63
32	RO membrane unit	6/3/12 12:00 AM	7/12/12 12:00 PM	948.00
Total Outage (h)				7,044.83

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[Appendix – D]

Fault record for UF filter 01

	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Period in hrs
1	UF Filter vacuum pump#1	3/10/11 10:14 AM	3/26/11 5:40 PM	391.43
2	UF auto cleaning filter #1	11/10/11 10:00 PM	12/1/11 8:57 AM	490.95
3	UF Chemical dosing pump	12/20/11 2:02 PM	12/20/11 3:45 PM	1.72
4	UF auto cleaning filter #1	12/28/11 6:50 PM	12/29/11 11:21 PM	28.52
5	UF Filter vacuum pump#1	2/9/12 2:40 PM	2/13/12 4:34 PM	97.90
6	UF Feed water pump#1	2/10/12 9:12 AM	2/10/12 9:50 AM	0.63
7	UF Chemical dosing pump	3/8/12 12:00 AM	6/8/12 5:00 PM	2,225.00
	Total outage(h)			3,236.15

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Fault record for UF filter 02

	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Period in hrs
1	UF auto cleaning filter #2	9/13/11 10:45 AM	1/6/12 8:05 AM	2757.33
2	UF Filter vacuum pump#2	2/8/12 8:40 AM	2/8/12 2:25 PM	5.75
3	UF Feed water pump#1	2/10/12 1:50 PM	2/11/12 4:02 PM	26.20
4	UF Chemical dosing pump	6/19/12 3:31 PM	6/19/12 4:22 PM	0.85
5	UF Feed water pump#1	8/21/12 8:15 AM	9/29/12 10:30 PM	950.25
	Total outage (h)			3,740.38

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Fault record for UF filter 3

	Item	~~Time of start~~Time of Failure (mm/dd/yyhh:mm)	Time of Restoration (mm/dd/yyhh:mm)	Period in hrs
1	UF auto cleaning filter #3	1/10/11 9:46 AM	2/10/11 2:49 PM	749.05
2	UF Chemical dosing pump	5/10/11 10:12 AM	6/10/11 11:15 PM	757.05
3	UF Filter vacuum pump#3	7/20/11 10:14 AM	7/26/11 5:40 PM	151.43
4	UF auto cleaning filter #3	1/4/12 1:14 PM	1/9/12 7:05 PM	125.85
5	UF Filter vacuum pump#3	3/8/12 12:00 AM	5/8/12 5:00 PM	1481.00
	Total outage (h)			3,264.38

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