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Technical and Economic Impacts of the First Coal-fired Power Station in Sri Lanka

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Abstract

The first coal-fired power plant in Sri Lanka was successfully connected to the national grid in year 2011. The proposal of implementing coal-fired power plants in Sri Lanka has been appearing in power sector master plans since year 1985. It was delayed for many years, mainly due to public protests and indecision of the political leadership of the country. This research analyzes the social and economic barriers faced during the implementation stage. Operation of the plant in terms of system inertia, reliability and stability is discussed. This is the single largest power sector investment in Sri Lanka and returns on the investment were analyzed in this study. As this is the first coal-fired power plant in Sri Lanka, success of this project will create the platform for the public acceptance of future coal-fired power plants. There were some technical failures during the initial years of operation of the plant, and now it records a higher reliability.

Furthermore, it is important to summarize the lessons learnt after implementing this project. Future plans of the utility, energy policy of the country and the political agenda of a country should reflect the experience with this project. This is a good example that teaches the lesson; projects which require to be implemented in the national interest should not be postponed or cancelled due to the protest by small groups of people perceived to be affected by the project.

It is highlighted that system stability is improved in many cases due to the increase of power system inertia, to which this power plant makes the largest contribution. System inertia is improved in six out of nine scenarios, which were analyzed in this study. Economic benefits gained by the power plant were examined and the study proves that this power plant will have a significant positive effect on the national economy. Loss incurred delaying the project was calculated and it proves the importance of this project.

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1 INTRODUCTION

Ceylon Electricity Board (CEB) is the main electricity utility in Sri Lanka and it has been facing a financial crisis for more than 10 years due to the high electricity production cost and the inability to pass such high costs to customers. It was essential to reduce the electricity production cost using an economical method of power generation. The proposal for constructing a coal-fired power station was prepared more than 20 years ago. Implementation of this project was delayed due to social and economic constraints. Finally, construction commenced in year 2006 and completed in year 2011. Now it is successfully dispatched to the national grid. The second phase of the project too is connected to the national grid.

This study was focused on the social, technical and economic constraints which were faced during the implementation of this large-scale project. Operation of the plant in terms of technical and economic aspects is the main section that will be covered. Being the first coal-fired power station, experiences gained from this project will decide the future public acceptance of coal power in Sri Lanka. The current generation plan published by CEB claims that power generation in Sri Lanka will be coal dominant after year 2015. It is important to analyze the electricity production costs, capital cost and economic aspects of this coal-fired power station.

I am interested in studying and analyzing the impacts of the large scale power projects on Sri Lankan power system, which had been implemented after facing lot of challenges. That interest was the main motivation for me to undertake this study.

1.1 Objectives

Assess the technical and economical impacts on the Sri Lankan power system by the first coal-fired power station in Sri Lanka and analyzing the important lessons which would be helpful for the future coal-fired power plant development.

1.2 Expected Outcomes

Following are the expected outcomes of this project.

1. Social and environmental constraints faced when implementing the project.
2. Technical impacts on the Sri Lankan power system in terms of inertia, stability and reliability.
3. Economic benefits gained by operating the plant and loss incurred delaying the project.

1.3 History of the Coal-fired Power Plant

The concept of coal-fired power generation in Sri Lanka was first initiated in mid 1980s with the recurring power crises and the completion of developing the country's hydro power generation sources. The first coal-fired power plant of 300 MW was proposed to build in Trincomalee by 1992. When selecting the site, CEB mainly considered the harbor facility, because that is the easiest and most economical way to import coal to the plant. However, the project did not succeed due to public protest on the perceived impacts on environment and the lifestyles of people in the area. Although a feasibility study was conducted for this project, it did not proceed to the construction stage.

Thereafter, a site in the south of the country at Mawella was proposed for the plant, because this site has a natural bay, at which a harbor can be built to deliver coal. A pre-feasibility study was conducted for this site also, but that too was abandoned due to public objections. There were some other problems such as the dense population of the area and land availability.

Again in 1993, CEB investigated siting options in the west coast, selected a site in the Kalpitiya peninsula, and a feasibility study commenced in 1994. This time the study was completed in 1997 inclusive of approvals under the environmental protection regulations, to build the plant in Norochcholai, in Puttlam district. However, this project too delayed for many years due to the same issue as for other sites, namely public protests and political indecision.

Finally in 2005, countering all the objections, the government decided to start the construction work and the first phase of the plant with 300 MW capacity, was commissioned in March 2011. The second phase with another 300 MW was completed by end of 2013 and the third phase with another 300 MW was completed by May 2014.

1.4 Site Selection Study

The final site selection study was carried out covering eight sites located in four districts; Puttlam, Hambantota, Ampara and Matara. This study was conducted by CEB and report was published in March 2001. The following are the factors considered when selecting the site.

- Availability of sufficient area of land for plant, coal storage, ash disposal and future expansion
- Harbor facilities for safe and easy unloading and handling of coal
- Suitable geological conditions
- Availability of sufficient condenser cooling water
- Length of the transmission line
- Environmental aspects including impacts on the population
- Capability to unload and transport of heavy equipment
- Availability of electric power for construction work

On the aspects of land utilization and availability, resettlement, shorter transmission line length and ash disposal, the site at Norochcholai in Puttlam district was selected. There was a drawback in Norochcholai site that the sea depth required for handling the coal carriers was far away from the coast compared with other sites in southern coast. It is clearly mentioned in the site selection study report that, commencing at the time of the study (2001), the Norochcholai coal-fired power plant can be implemented at least three years prior to the implementation of a coal-fired power plant in any other location in the country. The environmental clearance was obtained for the Norochcholai coal-fired power plant in year 1999. Considering all the facts, Norochcholai site was the best to develop the first coal- fired power plant of the country.

1.5 Methodology

Following steps will be followed to obtain the expected outcomes.

CEB environmental newsletter and publications related to the coal-fired power plant will be analyzed to study the environmental impacts. Also the relevant legislations will be referred. It is expected to interview the key people involved in the project to study the problems faced during the implementation stage.

Inertia constants of all the power stations, which are connected to the national grid will collected from either the system control centre of CEB or contacting the relevant power stations. System inertia will be calculated under three different scenarios considering the fact that the availability and non availability of the coal-fired power plant. Actual operation data will be analyzed to study the plant factor. Operation data will be taken from the system control centre monthly reports.

Operation costs and relevant data will be analyzed to study the economic benefits gained by operating the plant. Loss incurred to the CEB by delaying the project will be calculated. Long term generation expansion plans published by CEB will be taken into consideration for this analysis. Expected and the actual generation of year 2008, 2009 and 2010 will analyzed to calculate the loss incurred delaying the project. Unit of cost of different plants of those years will be taken from the statistical digest published by the CEB.

2 IMPLEMENTATION PROBLEMS AND LESSONS LEARNED

Evaluation of social and environmental impacts caused by the coal-fired power station is important since it was one of the major constraints to build the plant.

2.1 Relevant Environmental Regulations

As stated in the National Environment Acts No 56 of 1988 and No 53 of 2000, conducting an Environmental Impact Assessment (EIA) and obtaining the Environmental Protection License (EPL) from the Central Environmental Authority (CEA) became mandatory for the power generation sector. It should be noted that EPL should be renewed once a year. Apart from the EPL of CEA, it is required to obtain the Certificate of Environmental Clearance (CEC) from the North Western Provincial Environmental Authority for the coal-fired power plant since it is located in North Western Provincial Council area. It is clearly mentioned that certain emission standards have to be maintained in the plant.
It should be highlighted that the EPL and CEC, had been taken prior to starting the construction work. Also the EPL is renewed once a year and it is an indication that the plant is in line with the prevailing environmental regulations of Sri Lanka.

2.2 Environmental Pollutions Related to Coal-fired Power Plants

Generally coal-fired power stations can contribute to all three sorts of pollutions like air, water and land. Air polluters such as CO_2, CO, NOx and SOx which are produced by the combustion of coal can increase the threat on global warming, acid rains, health related problems etc. In addition to that, particulate matter like fly ash, bottom ash and coal dust can cause further air pollution. Contaminations from leachate through ash landfills or coal stock piles can have impacts on ground water and soil which will lead to deterioration of native animals and vegetation. Marine water can be polluted from warm water discharges, coal falling from unloading, coal dust and the fuel and greases releasing from ships. Apart from those, there are other impacts such as coastal erosion, impacts on buildings due to the jetty etc.

2.3 Measures Applied to Minimize the Environmental Impacts

All the environmental impacts that may be created by the coal-fired plant had been considered when designing. Also the CEA expects the plant to be operated meeting ambient air quality standards as given in table 6. The stack height had been decided considering the ambient air quality standards given by the CEA and in accordance to the CEC of the Provincial Council.

A very high stack (about 150 m high) has been built to release the flue gases, so the effect of the released pollutant gases will be minimized.

Table 1 Ambient Air Quality Standards

Ambient Air Quality Standards			
Pollutant	Averaging Time	Maximum Permissible Limit (mg/m^3)	ppm
NO_2	1 hour	0.25	0.08
SO_2	1 hour	0.20	0.08

EIA report prepared by the CEB for this coal-fired power station discusses the environmental issues relating to the plant and their potential impacts. Mitigation measures were implemented according to the local environmental regulations and standards to control the possible impacts on the environment.

According to that, only low sulphur containing coal has been imported and every load is checked for the certification of low sulphur content before importing. It is expected to reduce the emission of SOx by burning only the low sulphur coal. A Flue Gas Desulphurization (FGD) unit has been installed to absorb SO_2 from the flue gas. In this unit, flue gas is passed through a limestone bed in which SOx reacts with limestone producing gypsum which can be used in the Cement Industry.

A low NOx producing boiler is used to reduce the emission of NOx. To control the emission of particulate matter, an electrostatic precipitator is used to collect fly ash and water is spilled frequently on coal piles to control coal dust. Base of ash landfill and coal stock yard has been sealed to avoid leachate to ground water and soil.

In order to minimize the contamination with marine water, a draping canvas is used between the unloading ship and the jetty to catch falling coal. There was a concern on whether the warm water discharge from condenser, having a temperature of 70 ^{0}C which is above the intake water temperature can affect marine water and animals. A study has revealed that there will be no such impacts as the warm water temperature will fall down to an acceptable value within an area of 500 m after discharged, due to the rapid mixing with sea water [1].

2.4 Resettlements

The other major constraint to build this plant is the social impacts and public objections. Therefore resettlement of the project affected people and effect on their lifestyle has been considered thoroughly before implementing the project.

80 families were resettled at Daluwa approximately 10 km south from power plant site [2]. It is close to sea and a very good agricultural area, environment of which is similar to that of plant site, where the main livelihoods are fishery and agriculture.

80 houses were constructed with 20 perches land per each. Every house is consisted with two bed rooms, a kitchen, a living room and a toilet. Apart from that, each family has been given an agricultural land close to the site. All the other infrastructure facilities were also provided.

2.5 Implementation Problems Observed by the Project Staff

There were many persons behind the development of this large scale coal-fired power plant. I was able to identify two key personalities who were involved in this project from the beginning. They are as follows and both of them are engineers.

1. Mr. Shavindranath Fernando, Deputy General Manager of the Generation Planning Branch of Ceylon Electricity Board (during the feasibility study: 1994-1997), presently, General Manager, Ceylon Electricity Board
2. Mr. Jayantha Saram, Project Manager (during the feasibility study: 1994 to 1997), presently, Deputy General Manager, Ceylon Electricity Board

Mr. Fernando stated that wrong perceptions about the coal-fired technology among policy makers, decision makers and some intelligent people of the country caused wrong information being fed to the general public. That was the main reason for public protests. People first thought coal power is only used in coal locomotives. The general public had observed the coal-fired locomotives run with thick black smoke, and they initially thought this would be same for power plants too, and that will create environmental pollution. Also he mentioned that the following people actively initiated or backed the protests against the Norochcholai power plant

- Religious leader of the area, the Bishop of Chilaw.
- Some local politicians with vested interests
- Environmental lobbies with vested interests
- Some businessmen in Kalpitiya area, out of fear of losing their opportunity to obtain cheap labour
- Drug peddlers, since the proposed power plant siting area was an easy route for drug peddlers for their business
- Fisherman out of fear of losing their livelihood owing to possible restrictions of fishing in water around the power plant

He further said that CEB conducted several public awareness programs, and the general public was able to understand that this power plant will not adversely affect their lifestyle. He said that most of them were illiterate, and they were misled again and again by parties external to the power plant siting area, providing wrong information after those programs.

He reminded that Hon. Opposition Leader of Sri Lanka at that time said that they will cancel the project if they win the elections in 1999. After that statement, the then President of Sri Lanka suspended the project to get political benefits in the face of elections.

He mentioned that the government of the period 2001 to 2003 did not show any interest in proceeding with the project. There was a loan offered from Japan International Cooperation Agency (JICA) for this project, the offer remained open from about 1997to 2003, and it was finally withdrawn because the then governments did not want to proceed with the project.

Subsequently, in year 2005, this project was recommenced with a loan offered by the Chinese government. He also stated that most of the media institutions had written articles against the developing of coal-fired plants.

Mr. Saram said that there were public protests and they were backed by a number of environmental groups. He reminded that whenever they identified a new site, there were protests against developing of coal-fired plants. Also he mentioned that a coal-fired plant was included for the first time in the long term generation plan published by CEB in year 1985. He could remember one tragedy which occurred during public protests in year 1997. Police tried to control an aggressive protest, and one protester died. That was the only death reported during those public protests.

He mentioned that there were 80 families in the land at Norochcholai where the power plant was proposed to be built. He said that they were not the owners of the land, but they were only the occupants. He said that all the families agreed, and they were relocated once the project was started. He also confirmed the fact that most of the media institutions backed the protestors and published articles against developing coal-fired power plants in Sri Lanka. He said that the Institution of Engineers, Sri Lanka had supported the construction of coal-fired plants, but it was rejected by then governments.

2.6 Lessons Learned from this Project

As explained above, only eighty families were relocated due to the implementation of the first phase of the project. It is obvious that massive public protests occurred mainly in relation to relocation of these families. Also public protests took place due to environmental concerns. These massive protests weakened the interest of politicians to take necessary actions to implement the project. This project was delayed and postponed several times, causing a big loss to the CEB, leading to affect twenty million people in Sri Lanka.

Following table is extracted from Sri Lanka energy policy which was published in 2008 [3].

Table 2 Electricity Sector Fuel Diversity

Year	Electrical Energy Supplied to the Grid as a Share of the Total			
	Conventional Hydro Electric	Maximum from Oil	Coal	Minimum from Non-conventional Renewable Energy
1995	94%	6%	0	0
2000	45%	54%	0	1%
2005	36%	61%	0	3%
2010	42%	31%	20%	7%
2015	28%	8%	54%	10%

Above table gives a clear idea to the Sri Lankan electricity sector to manage their plans and to select the most appropriate fuel options in planning for new generation. **This kind of policy would have been implemented in late 80's and it should have been the directive for politicians to take correct decisions.** Even though CEB prepared and planned to implement coal-fired plants in late 90's, the government repeatedly neglected them since the energy policy wasn't properly implemented. It is clearly stated in the Sri Lankan energy policy that "The Government shall not initiate or entertain any proposal either by the electric utilities or private developers to build power plants that will use oil, oil based products or fuels of which the price is indexed to the oil price, unless they are required to be included in the generation expansion plan due to technical limitations in other plant types" [3]. This kind of strong points should be included in policies that directly affect national level projects.

Policy of His Excellency the President Mahinda Rajapakse "Mahinda Chinthanaya" which was published in year 2005 clearly states that "The thermal power plants including coal-fired ones and the hydro power plants will be constructed expeditiously according to generation plans of Ceylon Electricity Board, while taking into consideration the social problems and environmental implications" [4]. The firm decision of making the coal-fired plant was taken in year 2005 and now we all are getting benefits of it.

Following important points can be listed as lessons learned from this project.

1. National energy policy, policy developed by the electricity utility or the plans of the utility and the political agenda of the country should reflect the same.

2. Important projects which are planned for the benefit of public must not be postponed due to protests of small groups of people who are perceived to be affected by the project.

3. Carry out awareness programs targeting affected people and try to minimize public protests by providing necessary information to them.

4. It should be the responsibility of the ministry or the regulatory authority for the energy sector to revise/introduce the national energy policy of the country at regular intervals.

3 TECHNICAL IMPACTS ON THE SRI LANKA POWER SYSTEM

It is important to get a clear idea about the meaning of power system inertia in order to analyze the technical impacts caused to the Sri Lankan power system by coal-fired power station. The coal-fired power plant inertia constant is high compared to the inertia constants of diesel engines. The power system inertia value affects to the system stability and higher the inertia higher the stability.

3.1 Power System Inertia Constant

The equation which governs the motion of a rotor of a synchronous machine is based on the elementary principle of dynamics. The accelerating toque which acts on the rotor is equal to the product of moment of inertia of the rotor and the angular acceleration. Synchronous machines will experience two unbalanced torques in opposite directions which are mechanical torque from prime mover and the electrical torque from the load.

Motion of a rotor which consists of the prime mover and generator can be characterized as follows ([5], [6], [7], [8]),

$T_a = T_m - T_e$

$J\,(d^2\theta_m/dt^2) = T_m - T_e$

Where,

J : Moment of inertia

θ_m : Angular position of rotor with respect to a stationary axis

T_m : Mechanical torque acting on the rotor

T_e : Electrical torque acting on the torque

T_a : Accelerating torque

Multiplying both sides by ω_m (Rated Speed of the rotor),

$J\,\omega_m\,(d^2\theta_m/dt^2) = \omega_m T_m - \omega_e T_e$

P_m (Mechanical Power) $= \omega_m T_m$

P_e (Electrical Power) $= \omega_e T_e$

M (Angular Momentum) $= J\,\omega_m$

By substituting above,

$M\,(d^2\theta_m/dt^2) = P_m - P_e$

Also θ_m can be written as follows,

$\theta_m = \omega_m t + \delta_m$

ω_m = Average angular speed of the rotor

δ_m = Rotor angle with respect to a synchronously rotating reference frame ω_m

$M (d^2\theta_m/dt^2) = P_m - P_e$

$M (d^2 (\omega_m t + \delta_m) /dt^2) = P_m - P_e$

$M (d^2 \delta_m/ dt^2) = P_m - P_e$

Express in base units are more convenient and let S_B be the base MVA value.

$(M/ S_B) (d^2 \delta_m/ dt^2) = P_{m(PU)} - P_{e(PU)}$

Where,

$P_{m\ (PU)}$: Mechanical power in terms of per unit.

$P_{e\ (PU)}$: Electrical power in terms of per unit.

$(M/ S_B) (d^2 \delta_m/ dt^2) = P_{m(PU)} - P_{e(PU)}$

$(J\ \omega_m / S_B) (\omega_B/\omega_B) (2/ P) (d^2\delta/dt^2) = P_{m(PU)} - P_{e(PU)}$

$(J\ \omega^2_m/ S_B\ \omega_B) (d^2\delta/dt^2) = P_{m(PU)} - P_{e(PU)}$

Where,

$\delta = \delta_m (P/2)$, δ is the load angle

P = Number of poles

$\omega_B = \omega_m (P/2)$, ω_B is the electrical angular frequency

H = Inertia Constant

Substituting H into the formula will result,

$(J\ \omega^2_m/ S_B\ \omega_B) (d^2\delta/dt^2) = P_{m(PU)} - P_{e(PU)}$

$(2\ H/ \omega_B) (d^2\delta/dt^2) = P_{m(PU)} - P_{e(PU)}$

H is defined as follows,

$H = (1/2) (J\ \omega^2_m/ S_B)$

H = Kinetic Energy Stored in Megajoules/ Rating in MVA

Units of H are either MJ/MVA or MW-s/MVA.

This is generally defined as the swing equation.

$$(2 H/ \omega_B) (d^2\delta/dt^2) = P_{m(PU)} - P_{e(PU)}$$

This equation is widely used in the rotational dynamics in stability studies. That equation consists of H constant and it shows the importance of H constant for stability related studies.
System H constant should be calculated to observe the effect caused to the power system.
Power system H constant can be defined as follows [9],

$$H = \frac{H1 \times MVA1 + H2 \times MVA2 + \ldots\ldots + Hn \times MVAn}{MVA1 + MVA2 + \ldots\ldots + MVAn}$$

Where,
Hi = Inertia Constant of each machine connected to the grid.
MVAi = Rated MVA of each machine.

As mentioned above unit of H constant is either MW-s/ MVA or kW-s/ kVA.

3.2 Importance of H Constant

Importance of H constant can be identified by the following formula [10].

$$df/dt = - (\Delta P) / 2 \times H \qquad \text{Equation 1}$$

Where,
df/dt = Rate of change of frequency after a system disturbance (Hz/s)
ΔP = Rejected Load (MW)
H = Power System Inertia Constant (MW-s/ MVA)

It can be easily visualized that when system inertia is high, rate of change of frequency is low for a certain rejected load.
H constant of Puttlam coal-fired power station is 4.376 MW-s/MVA and it is a very high value compared to the H constants of diesel engines that dominated Sri Lanka's thermal generating system in the period up to the commissioning for coal-fired power plants.

3.3 System H Constant under Different Scenarios

It is better to calculate the system H constant for different scenarios. Sri Lanka is a country which experiences different weather conditions throughout the year. During rainy seasons, water availability is maximum since reservoirs are full. It is more economical to dispatch all the available hydropower plants during the rainy season. During a drought, almost all the reservoirs are empty and the maximum thermal dispatch is required. There are some intermediate periods with average conditions where a mix of hydropower and thermal plants can be dispatched. The power system H constant for three different scenarios were calculated.

1. Dispatch when hydro availability is maximum
2. Dispatch when hydro availability is minimum
3. Dispatch in average conditions with mixed hydro and thermal

It is useful to observe the behavior of Sri Lankan power system during three different time intervals. The information below is for a typical weekday in year 2012. The day peak is about 1550 MW and it occurs around 11.30 am. The peak is about 2000 MW, occurring around 7.30 pm. The minimum demand is about 750 MW, recorded around 3 am. The system H constant was calculated for the following scenarios, with and without the coal-fired power plant. The calculations represent the conditions in year 2012.

1. Day Peak (demand: 1550 MW)
2. Night Peak (demand: 2000 MW)
3. Off Peak (demand: 750 MW)

Table1 shows the format developed to calculate the H constant for these cases and it shows a sample calculation for night peak with the availability of coal-fired plant.

Table 3 : H constant calculation table for different scenarios (Sample calculation for night peak)

Power Plant	No of units	No of Units Connected	Rated Capacity of Each Unit (MVA)	Rated Capacity of Each Unit(MW)	Total Gene-ration (MW)	H (MW-s/MVA)	Total capacity (MVA)	H x MVA (MW-s)
Laxapana Complex								
Old Laxapana 1	3	1	9.8	8.33	8.33	3	9.8	29.4
Old Laxapana 2	2	1	18.375	12.5	12.5	3	18.375	55.125
New Laxapana 1	1	1	62.5	50	50	3.32	62.5	207.5
New Laxapana 2	1	1	62.5	50	50	3.32	62.5	207.5
Wimalasurendra 1	1	0	31.25	25	0	3	0	0
Wimalasurendra 2	1	0	31.25	25	0	3	0	0
Polpitiya 1	1	0	46.9	37.5	0	2.83	0	0
Polpitiya 2	1	0	46.9	37.5	0	2.83	0	0
Cannyon 1	1	1	37.5	30	30	3.8	37.5	142.5

Cannyon 2	1	0	37.5	30	0	3.8	0	0
Mahaweli Complex								
Ukuwela 1	1	0	22.7	20	0	2.72	0	0
Ukuwela 2	1	0	22.7	20	0	2.72	0	0
Kotmale 1	1	1	90	67	67	3.02	90	271.8
Kotmale 2	1	1	90	67	67	3.02	90	271.8
Kotmale 3	1	1	90	67	67	3.02	90	271.8
Victoria 1	1	1	82.5	70	70	3.44	82.5	283.8
Victoria 2	1	0	82.5	70	0	3.44	0	0
Victoria 3	1	0	82.5	70	0	3.44	0	0
Upper Kotmale	1	0	88	75	0	3.2	0	0
Upper Kotmale	1	0	88	75	0	3.2	0	0
Randenigala 1	1	0	81	61	0	3.65	0	0
Randenigala 2	1	0	81	61	0	3.65	0	0
Rantambe 1	1	0	32	25	0	2.62	0	0
Rantambe 2	1	0	32	25	0	2.62	0	0
Bowathenna	1	0	47	40	0	4	0	0
Other Hydro								
Samanalawewa 1	1	1	70.6	60	60	3.18	70.6	224.508
Samanalawewa 2	1	0	70.6	60	0	3.18	0	0
Kukule 1	1	1	42	37	37	2.84	42	119.28
Kukule 2	1	0	42	37	0	2.84	0	0
Mini Hydro (Listed according to the connecting points in the power system)								
Wimalasurendra	1	0	26.6	21	0	5.084	0	0
Ukuwela	1	0	8.8	7	0	5.084	0	0
Rantambe	1	0	16.5	13	0	5.084	0	0
Seethawaka	1	0	25.8	20	0	5.084	0	0
Nuwara Eliya	1	0	15.4	12	0	5.084	0	0
Badulla	1	0	10.9	8	0	5.084	0	0
Balangoda	1	0	41.6	32	0	5.084	0	0
Ratnapura	1	0	35.7	28	0	5.084	0	0
Kiribathkumubura	1	0	18.8	15	0	5.084	0	0
CEB Thermal								
Puttlam Coal	1	1	353	300	300	4.376	353	1544.73
Sapugaskanda 1	2	2	26.5	20	40	1.54	53	169.6
Sapugaskanda 2	2	2	26.5	20	40	1.54	53	169.6
Sapugaskanda 3	8	8	12.9	10	80	1.54	103.2	330.24
KCCP GT	1	1	146.1	110	110	4	146.1	584.4
KCCP ST	1	1	72.177	55	55	4	72.177	288.708
GT 7	1	0	135.3	115	0	8	0	0
GT 1	1	0	27	20	0	4.5	0	0

GT 2 and GT 3	2	0	27	20	0	4.5	0	0
GT 4 and GT 5	2	0	31	20	0	4.5	0	0
IPP								
Kerawalapitiya GT 1	1	1	142.2	100	100	7.253	142.2	1031.38
Kerawalapitiya GT 2	1	1	142.2	100	100	7.253	142.2	1031.38
Kerawalapitiya STs	1	1	142.2	100	100	8	142.2	1137.6
AES Kelanitissa GT	1	1	132	110	110	8	132	1056
AES Kelanitissa ST	1	1	95.955	53	53	4	95.955	383.82
Ace Power - Embilipitiya	1	1	117.6	100	100	1.1	117.6	129.36
Ace Power - Horana	1	1	23.8	20	20	0.83	23.8	19.754
Ace Power- Matara	1	0	23.8	20	0	0.83	0	0
Asia Power	1	1	60	49	49	1	60	60
Colombo Power	1	1	70.6	60	60	1.62	70.6	114.372
Heladhanavi	1	1	117.6	100	100	1.29	117.6	151.704
Lakdhanavi	1	0	26.5	20	0	0.53	0	0
Total					**1935.8**		**2480.41**	**10287.7**

Tables 2 and 3 show the typical dispatch schedule of during day peak, with and without the coal-fired power plant, respectively.

Table 4 : Dispatch Plan without the Coal-Fired Power Plant (In 2012 day peak of 1550 MW when hydro availability is maximum)

Power Plant	**No of Units**	**Capacity of Each Unit (MW)**	**Total Capacity (MW)**
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	1	25	25
Cannyon	1	25	25
Upper Kotmale	2	75	150
Samanalawewa	2	60	120
Sapugaskanda	1	100	100
Heladhanavi	1	100	100
Colombo Power	1	60	60
Ace Power Embilipitiya	1	100	100
Mini Hydro	1	84	84
Total			**1550**

Table 5 : Dispatch Plan with the Coal-Fired Plant (In 2012, day peak of 1550 MW, when hydro availability is maximum)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	1	25	25
Cannyon	1	25	25
Upper Kotmale	2	75	150
Samanalawewa	2	60	120
Sapugaskanda	1	100	100
Puttlam Coal	1	300	300
Mini Hydro	1	44	44
Total			**1550**

The above tables show a typical dispatch during day peak when hydro availability is maximum. Depending on the available hydro and thermal plants, this generation mix may be different.

The summary of H constants calculated using the above format for different scenarios is given in the table below. All the dispatch schedules are provided in the annexes.

Table 6 : Summary of System H Constants for Different Scenarios in 2012

Dispatch Scenario	Availability or Non Availability of the Coal-fired Power Plant	System H Constant During Different Times of a Day in MW-s/ MVA		
		Day Peak	Night Peak	Off Peak
Maximum Hydro	**With Coal**	3.4756	3.2035	3.6804
	Without Coal	3.0086	3.7539	3.3851
Maximum Thermal	**With Coal**	4.6357	4.4136	4.1601
	Without Coal	4.5144	4.2464	3.3173
Average	**With Coal**	3.3503	3.943	3.3949
	Without Coal	3.3631	4.0051	3.1891

According to the above results, it is clear that there is an improvement to system H constant when the coal-fired plant is connected to the grid.

It is also observed that in some cases, system inertia is good without the coal-fired plant. When hydro availability is maximum and during the night peak, the system has a high inertia value without the coal-fired plant. It is mainly due to the replacement of coal-fired plant with the Kerawalapitiya combined cycle plant during the night peak, and the Kerawalapitiya combined cycle plant has a very high inertia being a combined cycle power plant.

In the average scenario, during night-peak and day-peak, the inertia value is high without the coal-fired plant. It can be expected since the coal-fired plant is replaced with gas turbines at Kelanittisa power station, and gas turbine inertia values are high.

It is clear that six cases out of the nine have a high inertia value when the coal-fired plant is connected to the national grid.

If system H constant is high, the system may be recovered without a total failure during system disturbances. It is proven that in using two contingencies occurred in Sri Lankan power system [11]. Also according to the equation 1, it is clear that higher the system inertia lower the rate of change of frequency during a system disturbance.

3.4 Operation of the Plant

Puttlam coal-fired plant was successfully connected to the grid and dispatched 2,591 GWh from its commissioning date May 2011 to Jan 2013. Table 5 shows the breakdowns and maintenance works carried out in the plant from Jun 2011 to Jan 2013.

Table 7 Outages of Puttlam Coal-fired Plant

No	Outage Date	Resumed Operation	Type	Reasons	Outage Duration
1	7 Jun 2011	10 Jul 2011	Forced outage	Tripped indicating lube oil pressure low/ Veyangoda 220 kV line tripped	35 days
2	29 Sep 2011	3 Oct 2011	Forced outage	Shutdown for flue gas desulphurizer unit commissioning	5 days
3	4 Nov 2011	6 Nov 2011	Forced outage	Shutdown for desuperheater leak repair	3 days
4	21 Nov 2011	22 Nov 2011	Forced outage	Tripped due to unit auxiliary transformer, current transformer failure	2 days
5	29 Nov 2011	30 Nov 2011	Forced outage	Shutdown due to a fire in coal mill	2 days
6	5 Jan 2012	10 Jan 2012	Forced outage	Shutdown due to a fire in coal mill	6 days
7	18 Jan 2012	16 Feb 2012	Forced outage	Tripped indicating lube oil pressure low	30 days
8	17 Feb 2012	20 Feb 2012	Forced outage	Shutdown due to bearing oil leak and vibration in steam turbine	4 days
9	26 Apr 2012	28 Apr 2012	Forced outage	Tripped due to a cooling water pump fault	3 days

10	28 Apr 2012	28 Apr 2012	Forced outage	Tripped due to loss of fuel	1 day
11	21 Jul 2012	26 Jul 2012	Forced outage	Shutdown due to a water leak in boiler	6 days
12	29 Jul 2012	29 Jul 2012	Forced outage	Tripped due to air preheating motor fault	1 day
13	8 Aug 2012	7 Sep 2012	Forced outage	Tripped due to tripping of Veyangoda line 1, while line 2 has been released for maintenance	31 days
14	7 Nov 2012	9 Nov 2012	Forced outage	Tripped due to failure in cooling water system	3 days
15	23 Nov 2012	2 Jan 2013	Planned outage	Tripped while deloading for annual overhaul	40 days
16	29 Jan 2013	30 Jan 2013	Forced outage	Tripped due to the high pressure in boiler	2 days

Forced Outage: Forced outage is an unplanned shutdown of the power plant as a consequence of an unexpected failure of a component or a system.

Planned Outage: Planned outage is the scheduled inspection/ overhaul works.

It can be clearly observed that the plant outages are less in year 2012 compared with year 2011. The plant was not operated for 56 days due to forced outages within six months (Jun 2011 to Dec 2011 since it was commissioned in May 2011) of year 2011 and for 85 days in year 2012. It is a known fact that forced outages are high during power plant commissioning and immediately after commissioning. This fact is reflected here, with the plant gradually becoming more reliable in year 2012 compared with 2011. The plant factor of Puttlam coal-fired plant in year 2011 was 56%, which increased to 67% in year 2012. It claims that plant is becoming more reliable and with less number of breakdowns.

4 ECONOMIC IMPACTS TO THE SRI LANKAN POWER SECTOR

It is essential to analyze the economic impacts caused to the Sri Lankan power system by operating this coal-fired power plant. Basic operating data can be summarized as follows ([12]-[23]),

Table 8 Basic Operating Data

Type of fuel	Low sulphur coal
Type of operation	Base load
Capacity	300 MW (First phase)
Capital Cost (Only for phase 1)	USD Million 455
Auxiliary consumption	30 MW
Startup and shutdown	Use Lanka auto diesel
Theoretical maximum energy per day	7.2 GWh (First phase)
Practical maximum energy per day	6.2 GWh (First phase)
Units generated (2011)	1,038 GWh
Plant factor (2011)	56%
Units generated (2012)	1,404 GWh
Plant factor (2012)	67%
Unit cost (2011)	6.49 Rs/kWh
Unit cost (2012)	7.92 Rs/kWh
Generation share 2011	9%
Generation share 2012	12%

It is better to look at the coal price variations in years 2011 and 2012 to get an idea about the cost of the fuel. Fuel efficiency of the coal-fired plant in year 2011 was 0.38 kg/kWh and in 2012 was 0.45 kg/kWh.

Table 9 Coal Price Variations 2011/2012

	Price (Rs/kg)	
Month	**2011**	**2012**
Jan	13.80	16.94
Feb	13.80	17.11
Mar	13.80	17.11
Apr	13.80	17.11
May	15.70	18.78
Jun	13.80	18.10
Jul	16.61	18.23
Aug	16.61	18.54
Sep	16.94	18.49
Oct	16.94	18.34
Nov	16.94	17.94
Dec	16.94	17.94

4.1 Total Generation Cost Calculation of Thermal Plants

There are two methods to calculate the generation cost of thermal plants. It can be summarized as below.

Total generation Cost

→ **CEB thermal power plants**
= Total fuel cost + Total Operations and Maintenance (O &M) cost

→ **IPPs**
= Total fuel cost + Total O & M cost +IPP capacity charge

4.1.1 IPP Capacity Charge and Energy Charge

Following arrangement explains the capacity charge and energy charge calculation of IPPs.

Capacity charge (Escalable and Non-Escalable) — Does not vary with the dispatch. Depends only on the plant capacity and plant type

Energy Charge

- Fuel → Related to fuel prices and dispatch
- Non-Fuel, Escalable } Can be defined as an O & M cost. Vary with the dispatch.

With these explanations, it is clear that IPP unit cost calculation involves a lot of formulas and all the relevant terms are defined in the power purchase agreements. In CEB thermal plants, the fuel cost governs generation cost of that particular plant.

It is better to go through these terms before comparing the unit cost of generation of coal-fired plant. If the coal-fired plant was implemented based on IPP approach, the unit cost would have been higher.

Capacity charge calculation is mainly related to the repayment of the loan as capital for the implementation of the plant. All those terms include an escalable and non-escalable component.

4.2 Unit Cost Comparison of Thermal Plants

Following table provides a basic idea about the unit costs of IPPs and CEB owned power stations.

Table 10 Thermal Plants Unit Costs

Plant Name, Capacity and Type of Fuel			Average Unit Cost (Rs/kWh)		Energy Dispatch (GWh)	
Power Plant	Capacity (MW)	Fuel	2011	2012	2011	2012
Asia Power	49	HFO	16.72	22.70	317	333
Lakdhanavi	22.5	Furnace oil	15.28	20.81	114	99
Colombo Power	60	Furnace oil	12.53	18.22	467	481
ACE Power - Horana	20	Furnace oil	13.94	19.45	160	178
Heladhanavi	100	Furnace oil	11.83	17.32	710	699
ACE Power - Embilipitiya	100	Furnace oil	15.11	18.63	442	621
Kerawalapitiya	270	Furnace oil	21.61	24.32	1,151	1,536
AES Kelanitissa	163	Diesel	26.69	30.17	580	721
Puttlam Coal-fired Plant	**300**	**Coal/Diesel**	**6.49**	**7.92**	**1,038**	**1,404**
Sapugaskanda - Plant A	80	HFO/Diesel	9.56	14.62	411	391
Sapugaskanda - Plant B	80	HFO/Diesel	8.69	13.26	496	529
Kelanitissa Combined Cycle	165	Naphtha/Diesel	28.51	24.15	254	879

It is clear that coal-fired plant has the lowest unit cost among all the thermal plants in Sri Lanka.

4.3 Economic Benefits of the Coal-Fired Plant

Table 11 Comparison of Different Thermal Plants

	Type of Plant	2011			2012		
		Energy (GWh)	Price Rs/kWh	Cost (MRs.)	Energy (GWh)	Price Rs/kWh	Cost (MRs.)
IPP	Diesel Engines	1038	16.72	17,355	1404	22.7	31,870
	Combined Cycle	1038	26.69	27,704	1404	30.17	42,358
CEB	Diesel Engines	1038	9.56	9,923	1404	14.62	20,526
	Combined Cycle	1038	28.51	29,593	1404	24.15	33,906
	Coal	**1038**	**6.49**	**6,736**	**1404**	**7.92**	**11,119**

The above table alludes to the significance of the coal-fired plant to the Sri Lankan power system. If the coal-fired plant is replaced by a combined cycle or diesel engines, CEB could end-up with a big financial loss.

According to the Central Bank annual report 2012 ([24], [25]), CEB incurred a financial loss of Rs. 61.2 billion in the year 2012 and Rs. 19.3 billion in 2011.

As mentioned above, if coal-fired plant was not implemented, CEB would have incurred an additional financial loss of around Rs. 20 billion in year 2011, since it would have been replaced by a high cost combined cycle plant like AES Kelanitissa. Then the total loss would have been around Rs. 40 billion. Applying the same principle to year 2012 case, CEB total loss would have been around Rs. 90 billion in year 2012, if the coal-fired plant was not implemented.

In year 2012, the total budget deficit of Sri Lanka was Rs. 489 billion and it would have been around Rs. 510 billion, had the coal-fired plant was not implemented. That is a 6% increase in the budget deficit.

4.4 Loss Incurred Delaying the Project

The coal-fired plant was commissioned in year 2011. If it could have been commissioned in year 2008, according to the generation expansion plan published in year 2003, CEB could have made profits.

Here, it is expected to calculate the loss incurred by the CEB due to the delay of the project. Specially, the losses incurred by the CEB in years 2008, 2009 and 2010. Table 11 shows the dispatch in 2008 as mentioned in the generation expansion plan published in year 2003. It should be noted that the IPPs unit cost reflects the addition of capacity charge and energy charge.

Table 12 Expected dispatch in 2008 according to the generation expansion plan published in 2003

Power Plant	Annual Energy (GWh) in 2008					
	Hydrological Condition					
	Very Wet	Wet	Medium	Dry	Very Dry	Average
Sapugaskanda A	190	272	322	380	380	316
Sapugaskanda B	471	471	471	471	471	471
Gas Turbine 7	0	0	0	1	2	0
Lakdhanavi	49	74	108	150	156	109
Asia Power	329	330	329	329	329	329
Kelanitissa Combined Cycle	293	236	542	902	1,085	582
AES Kelanitissa	115	69	113	176	633	169
Colombo Power	385	419	419	419	419	416
Ace Power Horana	104	159	160	167	167	156
Ace Power Matara	104	167	167	167	167	161
Heladhanavi	659	697	697	697	697	693
Ace Power Embilipitiya	524	697	697	697	697	680
Kerawalapitiya	8	11	14	25	69	21
Puttlam Coal	**2,272**	**2,272**	**2,272**	**2,272**	**2,272**	**2,272**
Total Hydro	5,063	4,692	4,255	3,713	3,022	4,191
Total Generation	**10,566**	**10,566**	**10,566**	**10,566**	**10,566**	**10,566**

It is clear that this was planned assuming that the coal-fired plant would be in the system by year 2008. Also it was expected that the coal-fired plant would dispatch 2,272 GWh, irrespective of the hydrological condition.

Actual generation in year 2008 was 9,901 GWh and pro-rata basis is applied to match the expected dispatch with the actual dispatch. It should be noted that the medium hydrological condition has been selected considering the actual hydro dispatch of the year.

Following table 12 shows the actual dispatch of the year 2008.

Table 13 Actual Dispatch in 2008

Plant Type	Units (GWh)
Hydro	3,700
CEB Thermal	2,083
Wind	3
Hired	0
IPP Thermal	3,680
Mini hydro	435
Total	**9,901**

Table 13 shows the total generation cost for the year 2008 had the coal-fired plant been available in the system according to the planned dispatch schedule in year 2003. It is assumed that the unit cost of the coal-fired plant in years 2008, 2009 and 2010 is same as the actual unit cost of the coal-fired plant in year 2011 (6.49 Rs/kWh).

Table 14 Total Generation Cost in 2008 as Planned in 2003 with the Coal-fired Plant

Power Plant	Planned Units (GWh)	Matching to actual dispatch (GWh according to the pro-rata basis)	Unit Cost (Rs/ kWh)	Total Cost (Million Rupees)
Sapugaskanda A	322	302	13.39	4,040
Sapugaskanda B	471	441	12.49	5,513
Gas Turbine 7	0	0	27.86	-
Lakdhanavi	108	101	19.29	1,952
Asia Power	329	308	19.75	6,089
Kelanitissa Combined Cycle	542	508	18.24	9,264
AES Kelanitissa	113	106	23.33	2,470
Colombo Power	419	393	19.79	7,771
Ace Power Horana	160	150	19.32	2,897
Ace Power Matara	167	156	19.74	3,089
Heladhanavi	697	653	16.80	10,973
Ace Power Embilipitiya	697	653	18.70	12,214
Kerawalapitiya	14	13	33.94	445
Puttlam Coal	2,272	2,129	6.49	13,818
Total Hydro	4,255	3,987	-	-
Total	**10,566**	**9,901**		**80,537**

Table 14 shows the actual generation cost incurred by the CEB in year 2008 with the unavailability of the coal-fired plant.

Table 15 Actual Generation Cost in 2008

Power Plant	Units (GWh)	Unit Cost (Rs/kWh)	Cost of Generation (Million Rupees)
Hydro	3700	-	-
Mini Hydro	435	9.12	3,967
Aggreko -Chunnakam	96	34.07	3,286
Lakdanavi	129	19.29	2,482
Asia Power	371	19.75	7,319
Colombo Power	480	19.79	9,507
Ace Power Matara	170	19.74	3,349
Ace Power Horana	165	19.32	3,179
AES- Kelanitissa	797	23.33	18,593
Heladhanavi	692	16.80	11,619
ACE Power Embilipitiya	667	18.70	12,482
Kerawalapitiya	114	33.94	3,869
Sapugaskanda A	383	13.39	5,128
Sapugaskanda B	527	12.49	6,582
Frame V GTs	25	29.29	732
Gas Turbine 7	94	27.86	2,619
Kelanitissa Combined Cycle	1,044	18.24	19,043
Chunnakkam	10	34.68	347
Wind	3	-	-
Total	**9,901**		**114,103**

Following table compares actual and planned total generation cost in year 2008. Also it highlights the total revenue in year 2008.

Table 16 Total Generation Costs (Actual and Planned) and Total Revenue

Generation Costs and Revenue in 2008	Million Rs
Actual cost without the coal-fired plant	114,103
Planned cost with the coal-fired plant	80,537
Total revenue	110,896
Loss due to the delay	33,566

It can be clearly observed that, CEB could have made a profit if the coal-fired plant was available in the system in year 2008 as planned. As it was not available, the total cost incurred by the CEB was Rs 33 billion.

Following table shows the losses incurred by the CEB in year 2009 and 2010 due to the unavailability of the coal-fired plant. Calculations are similar to the calculation done for year 2008 and the steps are provided in the annexes.

Table 17 Total Generation Costs (Actual and Planned) and Total Revenues

Generation Costs and Revenues	**Million Rs**	
Year	**2009**	**2010**
Actual cost without the coal-fired plant	87,693	82,024
Planned cost with the coal-fired plant	61,081	59,641
Total revenue of the year	110,551	120,780
Loss due to the delay	26,612	22,384

It should be noted that dry hydrological condition has been selected for year 2009 and very wet hydrological condition has been selected for year 2010 considering the actual hydro dispatch of the year. Also the generation costs of the large hydro and wind were neglected considering the negligible impacts to the total generation cost.

It is clear that the total loss incurred to CEB for these three years (2008, 2009 and 2010) due to the unavailability of the coal-fired plant was around Rs 80 billion.

5 CONCLUSION

Above analyzes proves that the coal-fired plant has caused a significant impacts to the Sri Lankan power system in terms of economic and technical. Also it is a known fact that implementation of this project had been planned twenty years back and was delayed due to a mix of reasons including public protests, lack of finance, poor investor interest and weak approach to procurement and political considerations[26]. It is clear that the social and environmental impacts relating to coal-fired power plants can be controlled and we must ensure to maintain the standards continuously. Also, it is important to highlight the fact that the resettlement and compensations should be handled very carefully considering the life standards of the affected people.

It was highlighted that the six cases out of the nine proves that the power system inertia constant is high, when the coal-fired power plant is connected to the national grid. As described above, higher the inertia constant higher the system reliability and stability. It is proven that the system stability has improved because of the coal-fired plant.

Economic benefits gained by operating this plant are vital for the development of Sri Lankan power sector. As discussed above, CEB could have been able to save around Rs 80 billion, if this plant was connected to the national grid three years back. As far as operation of the plant is considered, CEB saved around Rs 50 billion only in the years 2011 and 2012 as this was successfully dispatched to the national grid.

ANNEX 1 – Dispatch plan during day peak when hydro availability is minimum considering the availability and non availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Sapugaskanda	1	160	160
Kerawalapitiya	1	300	300
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
AES	1	163	163
Lakdhanavi	1	20	20
ACE Power Embilipitita	1	100	100
ACE Power Horana	1	20	20
ACE Power Matara	1	20	20
Asia Power	1	49	49
Small GTs	3	20	60
GT – 7	1	115	115
New Laxapana	1	100	100
Victoria	1	70	70
Cannyon	1	25	25
Total			**1527**

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Sapugaskanda	1	160	160
Kerawalapitiya	1	300	300
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
AES Kelanitissa	1	163	163
Lakdhanavi	1	20	20
ACE Power Embilipitita	1	100	100
ACE Power Horana	1	20	20
ACE Power Matara	1	20	20
Asia Power	1	49	49
Puttlam Coal	1	300	300
GT – 7	1	100	100
Total			**1557**

ANNEX 2 - Dispatch plan during night peak and off peak when hydro availability is minimum considering the non availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Sapugaskanda	1	160	160
Kerawalapitiya	1	300	300
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
AES Kelanitissa	1	163	163
Lakdhanavi	1	20	20
ACE Power Embilipitita	1	100	100
ACE Power Horana	1	20	20
ACE Power Matara	1	20	20
Asia Power	1	49	49
Small GTs	5	20	100
GT - 7	1	115	115
New Laxapana	1	100	100
Victoria	2	70	140
Cannyon	1	25	25
Kotmale	2	67	134
Samanalawewa	1	60	60
Kukule	1	37.5	37.5
Randenigala	1	60	60
Rantambe	2	25	50
Total			**1978.5**

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Sapugaskanda	1	160	160
Colombo Power	1	60	60
KCCP	1	165	165
ACE Power Embilipitita	1	100	100
Heladhanavi	1	100	100
GT - 7	1	115	115
Asia Power	1	49	49
Total			**749**

ANNEX 3 - Dispatch plan during night peak and off peak when hydro availability is minimum considering the availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Sapugaskanda	1	160	160
Kerawalapitiya	1	300	300
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
AES Kelanitissa	1	163	163
Lakdhanavi	1	20	20
ACE Power Embilipitita	1	100	100
ACE Power Horana	1	20	20
ACE Power Matara	1	20	20
Asia Power	1	49	49
Puttlam Coal	1	300	300
GT - 7	1	115	115
Small GTs	5	20	100
New Laxapana	1	100	100
Victoria	2	70	140
Samanalawewa	1	60	60
Polpitiya	1	37.5	37.5
Total			**2009.5**

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Sapugaskanda	1	160	160
KCCP	1	165	165
GT - 7	1	115	115
Puttlam Coal	1	200	200
ACE Power Embilipitita	1	100	100
Total			**740**

ANNEX 4 - Dispatch plan during night peak and off peak when hydro availability is maximum considering the non availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	2	25	50
Cannyon	2	25	50
Samanalawewa	2	60	120
Ukuwela	2	20	40
Upper Kotmale	2	75	150
Sapugaskanda	1	100	100
Heladhanavi	1	100	100
Colombo Power	1	60	60
Ace Power Embilipitiya	1	100	100
KCCP	1	163	163
Kerawalapitiya	1	270	270
Mini Hydro	1	11	11
Total			**2000**

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Kotmale	2	67	134
Victoria	2	70	140
New Laxapana	1	100	100
Cannyon	1	25	25
Samanalawewa	2	60	120
Ukuwela	1	20	20
Randenigala	1	60	60
Wimalasurendra	2	25	50
Old Laxapana	1	50	50
Rantambe	1	25	25
Mini Hydro	1	26	26
Total			**750**

ANNEX 5 - Dispatch plan during night peak and off peak when hydro availability is maximum considering the availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	1	25	25
Cannyon	2	25	50
Samanalawewa	2	60	120
Ukuwela	2	20	40
Upper Kotmale	2	75	150
Heladhanavi	1	100	100
Colombo Power	1	60	60
Sapugaskanda	1	100	100
Ace Power Embilipitiya	1	100	100
Puttlam Coal	1	300	300
KCCP	1	163	163
Mini Hydro	1	11	11
Total			**2005**
Power Plant	**No of Units**	**Capacity of Each Unit (MW)**	**Total Capacity (MW)**
Kotmale	1	67	67
Victoria	2	70	140
New Laxapana	1	100	100
Cannyon	1	25	25
Samanalawewa	2	60	120
Ukuwela	1	20	20
Randenigala	1	60	60
Puttlam Coal	1	200	200
Mini Hydro	1	18	18
Total			**750**

ANNEX 6 - Dispatch plan during day peak considering an average scenario considering the availability and non availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	1	25	25
Sapugaskanda	1	160	160
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
AES Kelanitissa	1	163	163
ACE Power Embilipitita	1	100	100
Total			**1559**

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capac ity (MW)
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	1	37.5	37.5
Wimalasurendra	1	25	25
Sapugaskanda	1	160	160
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
Puttlam Coal	1	300	300
Total			**1558.5**

ANNEX 7 - Dispatch plan during night peak and off peak considering an average scenario considering the non availability of the coal-fired power plant (in 2012)

Power Plant	No of Units	Capacity of Each Unit (MW)	Total Capacity (MW)
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	2	60	120
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	2	25	50
Sapugaskanda	1	160	160
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
AES Kelanitissa	1	163	163
ACE Power Embilipitita	1	100	100
Kerawalapitiya	1	300	300
Asia Power	1	49	49
Total			**1993**
Power Plant	**No of Units**	**Capacity of Each Unit (MW)**	**Total Capacity (MW)**
Kotmale	1	67	67
Victoria	1	70	70
New Laxapana	1	100	100
Cannyon	1	25	25
Samanalawewa	1	60	60
Sapugaskanda	1	160	160
Heladhanavi	1	100	100
KCCP	1	165	165
Total			**747**

ANNEX 8 - Dispatch plan during night peak and off peak considering an average scenario considering the availability of the coal-fired power plant (in 2012)

Power Plant	**No of Units**	**Capacity of Each Unit (MW)**	**Total Capacity (MW)**
Kotmale	3	67	201
Victoria	3	70	210
Randenigala	1	60	60
Rantambe	2	25	50
Bowatenna	1	40	40
New Laxapana	1	100	100
Old Laxapana	1	50	50
Polpitiya	2	37.5	75
Wimalasurendra	1	25	25
Sapugaskanda	1	160	160
Colombo Power	1	60	60
Heladhanavi	1	100	100
KCCP	1	165	165
Puttlam Coal	1	300	300
Ace Power Embilipitiya	1	100	100
Kerawalapitiya	1	300	300
Total			**1996**
Power Plant	**No of Units**	**Capacity of Each Unit (MW)**	**Total Capacity (MW)**
Kotmale	2	67	134
Victoria	1	70	70
New Laxapana	1	100	100
Cannyon	1	25	25
Sapugaskanda	1	160	160
Heladhanavi	1	100	100
Puttlam Coal	1	200	200
			789

ANNEX 9 - Expected generation in 2009 as mentioned in the long term generation expansion plan published in 2003

Power Plant	Annual Energy (GWh) in 2009					
	Hydrological Condition					
	Very Wet	**Wet**	**Medium**	**Dry**	**Very Dry**	**Average**
Sapugaskanda A	207	320	371	380	380	347
Sapugaskanda B	471	471	471	471	471	471
Gas Turbine 7	-	-	-	1	1	-
Lakdhanavi	67	109	128	157	157	127
Asia Power	329	329	329	329	329	329
Kelanitissa Combined Cycle	311	347	648	1,023	1,167	681
AES Kelanitissa	87	100	190	305	906	256
Colombo Power	419	419	419	419	419	419
Ace Power Horana	105	167	167	167	167	161
Ace Power Matara	105	167	167	167	167	161
Heladhanavi	697	697	697	697	697	697
Ace Power Embilipitiya	615	697	697	697	697	689
Kerawalapitiya	10	12	15	27	153	30
Puttlam Coal	2,272	2,272	2,272	2,272	2,272	2,272
Total Hydro	5,666	5,254	4,790	4,249	3,378	4,721
Total Genration	**11,361**	**11,361**	**11,361**	**11,361**	**11,361**	**11,361**

ANNEX 10 – Actual dispatch of the year 2009

Actual generation in 2009 by different sources	
Plant Type	**Units (GWh)**
Hydro	3,356
CEB Thermal	2,091
Wind	3
Hired	-
IPP Thermal	3,884
Mini hydro	548
Total	**9,882**

ANNEX 11 – Total Generation Cost in 2009 as Planned in 2003 with the Coal-fired Plant (Dry hydrological condition has been selected considering the actual hydro dispatch of the year).

Power Plant	Planned Units (GWh)	Matching to actual dispatch (GWh according to pro-rata basis)	Unit Cost (Rs/ kWh)	Total Cost (Million Rupees)
Sapugaskanda A	380	331	6.10	2,016
Sapugaskanda B	471	410	5.50	2,253
Gas Turbine 7	1	1	22.95	20
Lakdhanavi	157	137	11.16	1,524
Asia Power	329	286	13.15	3,763
Kelanitissa Combined Cycle	1,023	890	14.81	13,179
AES Kelanitissa	305	265	21.72	5,762
Colombo Power	419	364	10.94	3,987
Ace Power Horana	167	145	11.05	1,605
Ace Power Matara	167	145	10.77	1,564
Heladhanavi	697	606	9.57	5,802
Ace Power Embilipitiya	697	606	10.11	6,129
Kerawalapitiya	27	23	27.62	649
Puttlam Coal	2,272	1,976	6.49	12,826
Total Hydro	4,249	3,696	-	-
Total	**11,361**	**9,882**		**61,081**

ANNEX 12 – Actual generation cost in 2009

Power Plant	Units (GWh)	Unit Cost (Rs/kWh)	Cost of Generation (Million Rupees)
Hydro	3,356	-	-
Mini Hydro	548	10.72	5,875
Aggreko -Chunnakam	83	27.57	2,283
Nothern Power	34	25.09	853
Lakdanavi	149	11.16	1,663
Asia Power	362	13.15	4,756
Colombo Power	502	10.94	5,491
Ace Power Matara	184	10.77	1,982
Ace Power Horana	189	11.05	2,088
AES- Kelanitissa	587	21.72	12,750
Heladhanavi	688	9.57	6,584
ACE Power Embilipitiya	704	10.11	7,117
Kerawalapitiya	403	27.62	11,128
Sapugaskanda A	393	6.10	2,397
Sapugaskanda B	535	5.50	2,943
Frame V GTs	98	28.78	2,820
Gas Turbine 7	138	22.95	3,167
Kelanitissa Combined Cycle	920	14.81	13,625
Chunnakkam	7	24.34	170
Wind	3	-	-
Total	**9,882**		**87,693**

ANNEX 13 – Expected generation in 2010 as mentioned in the long term generation expansion plan published in 2003

Power Plant	**Annual Energy (GWh) in 2010**					
	Hydrological Condition					
	Very Wet	**Wet**	**Medium**	**Dry**	**Very Dry**	**Average**
Sapugaskanda A	331	380	380	380	380	375
Sapugaskanda B	471	471	471	471	471	471
Gas Turbine 7	3	4	4	8	8	5
Lakdhanavi	105	156	157	157	157	151
Asia Power	329	329	329	329	329	329
Kelanitissa Combined Cycle	607	919	1,086	1,244	1,250	1,053
AES Kelanitissa	232	217	475	816	1,118	531
Colombo Power	419	419	419	419	419	419
Ace Power Horana	167	167	167	167	167	167
Ace Power Matara	167	167	167	167	167	167
Heladhanavi	697	697	697	697	697	697
Ace Power Embilipitiya	697	697	697	697	697	697
Kerawalapitiya	50	63	101	137	700	156
Puttlam Coal	2,272	2,272	2,272	2,272	2,272	2,272
Total Hydro	5,666	5,254	4,790	4,249	3,378	4,721
Total Generation	**12,213**	**12,212**	**12,212**	**12,210**	**12,210**	**12,211**

ANNEX 14 – Actual generation in year 2010

Generation in 2010 by different sources	
Plant Type	**Units (GWh)**
Hydro	4,988
CEB Thermal	1,394
Wind	3
Hired	-
IPP Thermal	3,600
Mini hydro	729
Total	**10,714**

ANNEX 15 – Total Generation Cost in 2010 as Planned in 2003 with the Coal-fired Plant (Very wet hydrological condition has been selected considering the actual hydro dispatch of the year).

Power Plant	Planned Units (GWh)	Matching to actual dispatch (GWh according to pro-rata basis)	Unit Cost (Rs/ kWh)	Total Cost (Million Rupees)
Sapugaskanda A	331	290	7.37	2,140
Sapugaskanda B	471	413	6.36	2,628
Gas Turbine 7	3	3	27.53	72
Lakdhanavi	105	92	12.37	1,139
Asia Power	329	289	14.21	4,101
Kelanitissa Combined Cycle	607	533	17.87	9,516
AES Kelanitissa	232	204	25.44	5,178
Colombo Power	419	368	11.28	4,146
Ace Power Horana	167	147	11.61	1,701
Ace Power Matara	167	147	12.01	1,760
Heladhanavi	697	611	10.24	6,261
Ace Power Embilipitiya	697	611	11.40	6,971
Kerawalapitiya	50	44	24.87	1,091
Puttlam Coal	2,272	1,993	6.49	12,936
Total Hydro	5,666	4,971	-	-
Total	**12,213**	**10,714**		**59,641**

ANNEX 16 – Actual generation cost in 2010

Power Plant	Units (GWh)	Unit Cost (Rs/kWh)	Cost of Generation (Million Rupees)
Hydro	4,988	-	-
Mini Hydro	729	12.11	8,828
Aggreko -Chunnakam	88	28.42	2,501
Nothern Power	56	16.58	928
Lakdanavi	123	12.37	1,522
Asia Power	316	14.21	4,490
Colombo Power	461	11.28	5,200
Ace Power Matara	149	12.01	1,789
Ace Power Horana	160	11.61	1,858
AES- Kelanitissa	452	25.44	11,499
Heladhanavi	637	10.24	6,523
ACE Power Embilipitiya	612	11.40	6,977
Kerawalapitiya	546	24.87	13,579
Sapugaskanda A	361	7.37	2,661
Sapugaskanda B	480	6.36	3,053
Frame V GTs	26	34.62	900
Gas Turbine 7	27	27.53	743
Kelanitissa Combined Cycle	494	17.87	8,828
Chunnakkam	6	24.22	145
Wind	3	-	-
Total	**10,714**		**82,024**

LIST OF ABBREVIATIONS

KTH	Royal Institute of Technology
OUSL	Open University of Sri Lanka
CEB	Ceylon Electricity Board
SCC	System Control Centre
EIA	Environmental Impact Assessment
IPP	Independent Power Producers
EPL	Environmental Protection License
CEC	Certificate of Environmental Clearance
KCCP	Kelanitissa Combined Cycle Plant
GT	Gas Turbine
FGD	Flue Gas Desulphurization
O & M	Operations and Maintenance

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