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Performance Improvement of Pulverized Coal Fired Thermal Power Plant: A Retrofitting Option

[1]R.Paul, [2]L.Pattanayak
[1]*(Steag Energy Services India Pvt. Ltd.)*
[2]*(Steag Energy Services India Pvt. Ltd.)*

ABSTRACT - *The present study deals with the possibilities of renovation and modernization (R&M) options in an existing 210 MW pulverized coal fired thermal power plant. Three different options along with its cost implications have been discussed based on the performance and levelised cost of generation. The performance of the unit for all the three options is examined under the consideration of increasing the availability of the unit with continuous capabilities to generate power maintaining normal operating parameters over an extended life of at least 15 years. The results revels that with the R&M approach the unit availability can be increase to more than 85%, with a capacity enhancement of 215 MW and the heat rate of the unit will be approximately 2544 kcal/kWh.*
Keywords - *Coal fired power plant, Energy audit, Life extension, Moving electrostatic precipitator, Renovation and modernization, Techno-economic*

I. INTRODUCTION

For many decades, most countries have their electricity generation based on fossil fuel power plants. Fossil fuel-fired power plants, especially coal-fired ones, will keep playing a major role in global power generation. The majorities of these plants are still in operation and holds a major share in energy production. Consequently, taking into consideration for fulfillment of different government regulations, high cost involvement and other uncertainties in setting up a new unit, the option for need based improvement and upgrading the operation and efficiency of these old units is much more lucrative option to get the benefits from these old units within a short period.

The Government of India has embarked upon an ambitious plan to add 78,700 MW during the 11th plan and 94431 MW during the 12th plan. The central Electricity Authority (CEA) in consultation with state power utilities and other stake holders have prepared a national perspective plan for R&M and Life Extension (LE) of thermal power stations up to the year 2016-2017 [1]. However, in view of high investment requirement in the green field power station, resource constraints and environmental concern, there is an urgent need for optimal utilization of existing generating capacity as well. In this context R&M and LE [2-5] of existing old power plants is considered an economical option.

In India major part of the electricity generation is dependent on coal fired power plants. Coal is the main natural resource in the country. However, the quality and the heating value are low, mainly due to high levels of ash and moisture contained in the fuel. Most of the existing power plants of 210 MW are old units that have been in commercial operation for 2 to 3 decades. The low efficiency of these plants due to exhausted life causes important economic losses and environmental pollutions. Instead of replacing the old power plants before or at the end of their expected life, retrofitting of these units under LE & energy efficient R & M scheme seems to be the most economically viable solution [6, 7]. The retrofitting option is an alternative way, not only to increasing the life of the plant, but also for increasing the total energy output of the plant. The main benefits of R&M are:

- To increase unit availability and reliability.
- Restoration / up-rating of generation capacity.
- Achieving rated or better efficiency of the unit.
- To achieving an extended competitive plant-life of another 15 to 20 years.
- To meet current environmental norms.

Li et al. [6] in his study did an investigation of over 100 large power plants in China to determine their potential for a retrofit with CO_2 capture, transport and storage. Korkmaz et al.[7] discussed retrofitting of existing coal fired power plants with a Carbon dioxide capture. The study deals with the integration of an amine-based flue gas scrubber within a coal-fired power plant including compression of CO_2 and the resulting effects of the integration on the power plant's operation. Xu G, et al.[8] in his work carried out process simulations, characteristic analysis, and system integration of CO_2 capture based on an existing typical coal-fired power plant in China with supercritical parameters. The main constraints encountered in decarburized retrofitting of the existing power plants using mono-ethanolamine solution are analyzed. Heyena and Kalitventzeff [9] in their study discussed three parallel proposals and compared on the basis of exergy efficiency for up gradation of existing power plants. Yan et al.,[10] did an analysis in a 600 MW tangentially coal fired boiler to develop an effective retrofit scheme to settle the problem of reheat steam under heating, excessive de-superheater water, and temperature deviation at the furnace outlet. Ayodhi [4] in his paper describes the salient details of R&M of a plant commissioned in the sixties. Srivastava and Sharna [5] in his study describes the RLA based R&M of a steam turbine. Gerbelová, et al. [11] assesses the retrofit potential of existing Portuguese fossil fuel power plants with post-combustion CO_2 capture and storage (CCS) technology. The Integrated Environmental Control Model (IECM) was used to provide a systematic techno-economic analysis of the cost of emission control equipment, the reduction in greenhouse gas emissions, and other key parameters. Escosa and Romeo [12] presented different repowering alternatives and a methodology for evaluating their integration within existing power plants with the aim of reducing its CO_2 emissions at minimum cost. As per the study the repowering as a suitable technology to reduce 10–30% of CO_2 emissions in existing power plants with cost well below 20 €/tCO_2. Dalia et al.[13] use an options-based analysis to determine the optimal capital investment for owners of an existing pulverized coal power plant to make today, given their beliefs about the future values of key variables that affect the investment outcomes.

In the present work we discuss the possibilities of renovation options in an existing 210 MW pulverized coal fired thermal power plant. The objective is to estimate the potential performance and cost implications of retrofitting in the existing fossil fuel power plant with improving the capacity of pulverizer and modification in ESP along with replacement of the some of the existing systems to improve the availability and plant life. Moving electrostatic precipitator (MEEP) technology have been introduced for the modification of ESP as this does not required any lay out changes and can reduce the emission level less than 50 mg/Nm^3. Three possible options have been discussed along with the cost of implementation of each option. Also thermodynamic simulation studies of the unit have been carried out to evaluate the current performance and best achievable performance by renovation options.

II. DESCRIPTION OF THE PLANT

Figure 1 shows the process flow diagram of the unit under study. The installed capacity of the unit is 210 MW. The unit is of single reheat type with regenerative feed heating cycle. Feed water heating is carried out in two stages. A first stage of heating is done with four low pressure heaters (LPH) and second stage with three high pressure heaters (HPH). The super heated steam at 535 ^oC and 130 kg/cm^2 pressure enters in high pressure turbine (HPT) and leaves the turbine at 330 ^oC and 28.04 kg/cm^2. At full load of 210 MW, main steam flow of 653 t/h enters the high pressure turbine and after expansion in HPT steam is reheated to 535 ^oC in reheater and enters the intermediate pressure turbine (IPT) at 24.1 kg/cm^2. The exhaust steam from IPT fed to the low pressure turbine (LPT) and finally it exhaust to a water cooled condenser operating at 0.103 at (abs).

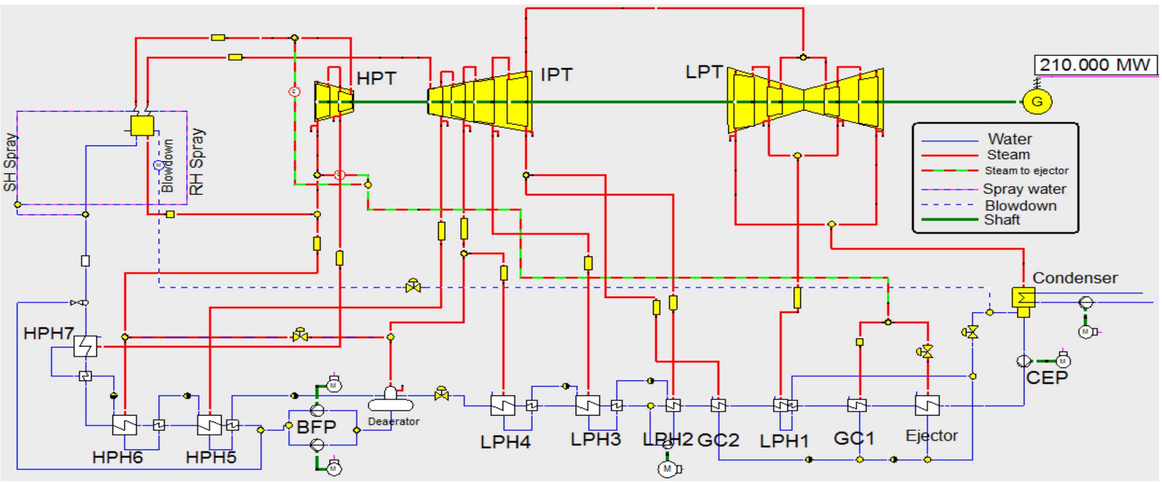

Figure 1. Process flow diagram of coal fired power plant

The boiler adopts pressurized direct firing system with 6 numbers of XRP 763 Bowl mills (5 working + 1 stand-by) with pulverizing capacity of 31.4 t/h each. Volumetric coal feeders are provided to feed raw coal to the pulverizes. 2 x 100 % capacity seal air (SA) fan, having suction from primary air (PA) fan discharge header, supplies the sealing air to the mills and coal feeders. The unit is having 4 oil fire elevations (1 for light diesel oil & 3 for heavy fuel oil), having a capacity of 7.85 t/h per elevation (4 guns), are located amidst of coal elevations for initial warm-up and support for low loading of the steam generator. Flame scanners are provided at every firing elevation. Burner tilting, primarily to control reheat steam temperature, is also provided in the system.

III. METHODOLOGY

The R&M measures suggested in this study are based on hot and cold walk down survey [14, 15] of the plant and energy audit measure taken during the course of the study. Need for the R&M of the unit was discussed and various options for improvement in energy efficiency and replacement of existing obsolete technology were indentified. The results of the analysis were verified using the Ebsilon(R) Professional [7, 16] simulation model. Figure 2 indicates the step wise methodology for taking R&M measure.

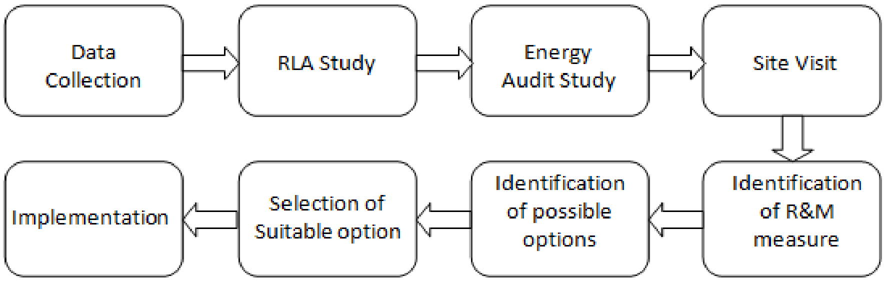

Figure 2. Methodology for R&M measure

IV. ENERGY ANALYSIS

The energy analysis is carried out based on thermodynamic model with mass and energy balance. Data required for modeling and analysis is collected from the plant distributed control system in a test run of the unit for a period of 1 hour. Efficiency of each of the main equipments and auxiliaries is determined by following the best practices as recommended by ASME PTC-6 for steam turbine & PTC-4.1 for boiler and also utilizing the most accurate and calibrated instruments meeting ASME standard accuracies. Figure 3 shows variation of plant load factor and unit cost over the last five years.

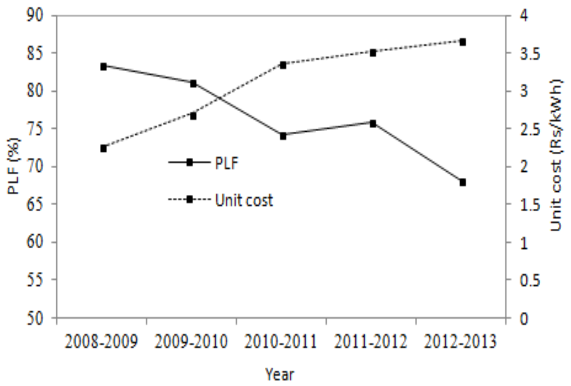

Figure 3. Variation of plant load factor and unit cost

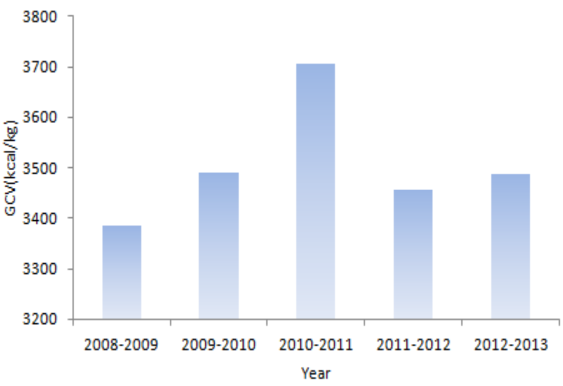

Figure 4. Variation of GCV of coal

Based on condition and age, it is necessary to study the renovation possibilities if the unit is to be continued in service. Variation of gross calorific value (GCV) of coal feed in the boiler for a period of 2009 to 2013 is shown in Figure 4. The coal GCV varies from 3300 to 3700 kcal/kg against the design GCV of 5000 kcal/kg. Based on the data collected and model simulation variation of boiler efficiency performance at a test run of 1 hour period is shown in Figure 5. The average boiler efficiency was found to be 84.88 %.

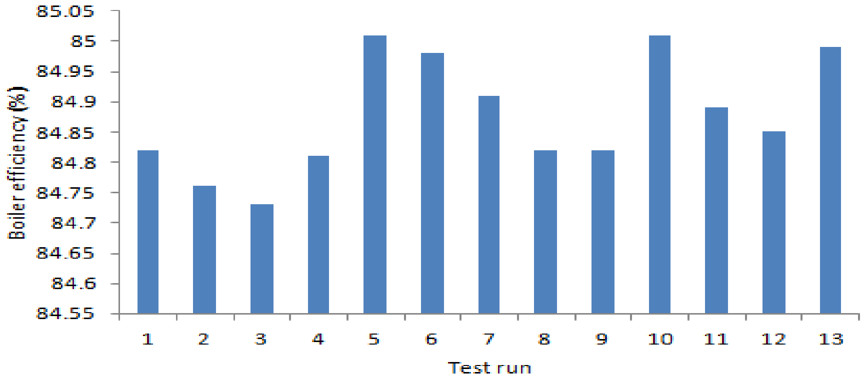

Figure 5. Boiler efficiency on a test run

Figure 6 indicates the variation of turbine efficiency during the test run period. The average efficiency of high pressure turbine (HPT), intermediate pressure turbine (LPT) and low pressure turbine (LPT) is found to be 81.59%, 87.31% and 78.36 % respectively.

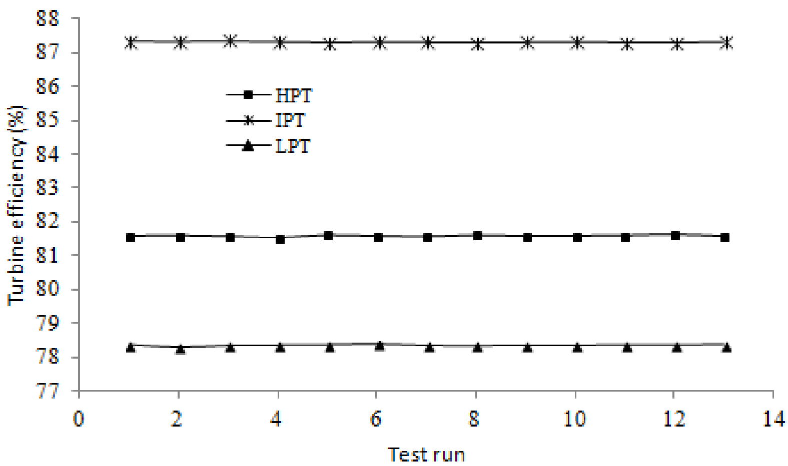

Figure 6. Turbine efficiency

In Figure 7 variations of TG heat rate and unit heat rate is shown and the average TG heat rate is found to be 2468.56 kcal/kWh and the average unit heat rate found to be 2905.28 kcal/kWh. Figure 8 shows that stack emissions were above the prescribed norm of 150 mg/Nm^3. The highest suspended particle matter (SPM) level in the stack emission was recorded as 387 mg/Nm^3 in 2012 and the second highest was recorded as 320 mg/Nm^3 during 2011.

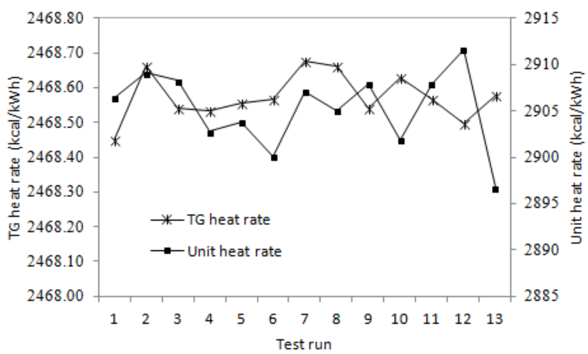

Figure 7. TG heat rate and gross unit heat rate

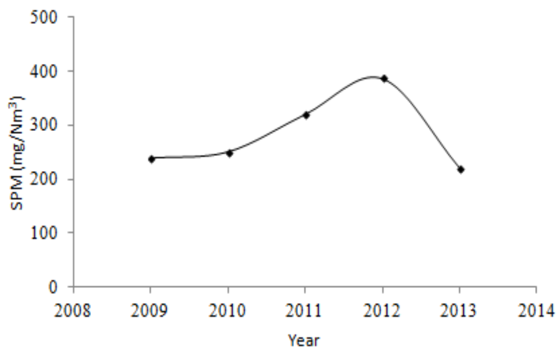

Figure 8. Variation of SPM level

V. IDENTIFICATION OF RENOVATION & MODERNIZATION MEASURE

The power station is a 210 MW unit commissioned in the year 1981 and have been operated for more than 30 years. As a standard practice, a plant is designed for 25 yrs of operation and has already exceeded this criterion. The boiler was originally designed for fired coal with GCV of 5000 kcal/kg, and presently operates with GCV in a range of 3000 to 3800 kcal/kg. Due to firing of low GCV and high ash coal the percentage of un-burnt increases significantly in bottom ash and fly ash. In order to maintain the rated steam parameters higher quantity of coal to be fired compared to the actual design, leading to increased power consumption for milling system and auxiliaries and also increase the wear rate for the milling system. The increased gas volume flow rate results in deviation of heat pick up in different zone of the furnace and high heat pick up in the convective zone of the super heater and reheater thus making difficult to control the temperature and attemperation within the design limit. As per the data collected, in order to maintain the furnace draft under the mentioned condition, heavy erosion of induced draught fan impeller and overloading takes place leaving very little margin which also can result in restriction of unit loading. The performance of ESP under the above condition deteriorate significantly resulting in high dust concentration at outlet thus deviating from the standard emission norms as stipulated by pollution control board. It is clear from the study that, in the present condition of the plant, it is not possible to run the unit reliably within safety limits without major modification / renovation / modernization measures. R&M is required to extend its useful life by another at least 15-20 years even if it is to be restored only to its original condition.

The following important developments are included as part of R&M measures in the unit:

- Improvement in fuel preparation/handling and firing system towards, uniformity of the flue gas temperature distribution.
- Uprating/modifying the milling system to grind low quality fuel (low calorific value and more % of ash) available for the next 20 years. Proper grinding of coal to desired size together with the appropriate air-fuel mixing should contribute to achieving complete combustion and the reduction of the unburnt in the bottom and fly ash
- Modification of combustion system to fire more amount of low grade coal and generate the rated capacity steam at desired operating parameters to ensure the rated output
- Implementation of techniques for low NOx burners & staged combustion for reduction of thermal NOx emissions
- Improvement of the air distribution system through modified Secondary Air Damper Control (SADC) & wind box arrangement to maintain the desired air fuel ratio for each burner group in operation
- Introduction of FSSS (Furnace safeguard and supervisory system) and BMS (Burner management system)
- Replacement, rearrangement or modification of heat exchange surfaces to match the distribution of heat in different zones of the furnace.
- Optimization of soot blower operation
- Supplementary heat exchange surfaces within the existing furnace volume for further uniform heat distribution of flue gas thermal energy
- Improvement of the air preheating system with replacement for new basket and improved sealing system.
- Improved metallurgy for boiler pressure parts and heat exchanger components, which permit trouble free operations and longer life (as also recommended by latest code for Indian Boiler Regulation)
- Steam turbine retrofitting(blades with new design and improvement of the labyrinths operation and turbine control system)
- Distributed Control System (DCS).
- Energy efficient auxiliaries such as improved control of BFP within the operating range, advanced microprocessor based ESP controls, Vapor absorption system for HVAC system etc.
- Enhanced safety features and environmental improvements using, effluent treatment plant, modified fire fighting system, online pollution monitoring, dry ash utilization etc.

Since the unit is firing with poor grade coal of GCV around 3500 kcal/kg, the flue gas volume is on higher side compared to the design and the ESP is incapable to handle this higher volume. Thus the ESP performance deteriorated drastically with heavy SPM level at outlet exceeding 200 mg/Nm^3 which seems to be high compared to the current norms of 50 mg/Nm^3 as per MOEF guidelines. To address the above situation, it is proposed to retrofit the ESP with MEEP [17] technology. This technology can be applied to the last field of the ESP without any requirement of extra space, so that the issue of the layout which is a common problem for the older units can be addressed without any major layout modification. Moreover, this technology shall bring down the emission level less than 50 mg/Nm^3 resulting reduction in pollution. Also the unit was originally designed with four mills in service and two standbys. In current condition due to deterioration in coal quality and the aging factor, the unit is not able to generate 210 MW on a sustainable basis with all 6 mills in service without no standby. The consequences will be on generation in case of breakdown of a single mill. Thus keeping in view of the station requirements to achieve 210 MW, it is being proposed that the existing mills are up rated from XRP 763 to six numbers of new XRP 803 mills of 39.8 t/h each to increase the throughput. With the above modifications, with the current coal quality the unit shall be able to achieve full load condition with four mills in service and other two in standby for emergency operation.

The energy audit and RLA studies have indicated the measures to be undertaken to restore the unit at a minimum to its original design conditions and extend its life by 15-20 years. This has been considered as the base case of the study. Each of these naturally requires additional investments. However, there are returns in terms of improved efficiency, output, availability and plant load factor, which can pay back the investments. The combination of measures in each option is the result of recommendations arising out of the energy audit and the practical possibilities based on proven technology currently available. Based on the above, three options have been considered for techno-economic study as shown in Table 1.

Table 1. Options for renovation and modernization

Option	Scope	Status After R&M			Levelised heat rate (kcal/kWh)	Cost (Rs Million)	Shutdown (months)
		Capacity (MW)	Life Extension (Years)	Gross Heat rate (kcal/kWh)			
A	Restore capacity of unit to its design value of 210 MW after doing modification to fire higher GCV coal	210	20	2400	2597	6864.05	6
B	Increase capacity to 215 MW LP retrofit, without generator replacement.	215	20	2370	2565	7120.25	6
C	Increase capacity to 215 MW by retrofit of energy efficient turbine, ESP and Mill modification without generator replacement.	215	20	2350	2544	7446.48	6

Levelised heat rate = (X+50)*1.06, where X is the Heat rate measured as per PGT procedure and 50 kcal/kWh is the variation of operation correction from design parameters and 6% allowance as per CERC norms [18]. The estimated costs of different options have been calculated taking into account the measures recommended for the particular option.

VI. TECHNO-ECONOMIC ANALYSIS

The Government of India policies and priorities enunciated under the National electricity policy and the tariff policy notified under the electricity act, 2003, technical and cost details, financial analysis and cost-benefit analysis have been considered to ascertain the economic aspects of the proposed investment [19]. The technical and financial inputs and assumptions adopted are based on the norms specified by the Government of India/Central Electricity Regulatory Commission (CERC) [20] and, where no norms have been specified, the prevailing industry practice has been considered. CERC (Terms and Conditions of Tariff) Regulations, 2009 [21] provide that any expenditure admitted by the Commission for determination of tariff on renovation and modernization and life extension shall be serviced on normative debt-equity ratio specified in regulation 20 after writing off the original amount of the replaced assets from the original project cost. Based on the technical examination and assessment, three options have been considered. These are A, B and C as shown in Table 1. The cost estimates made under each option include equipment cost, erection and commissioning, taxes and duties and interest during construction. The proposed items of equipment and works take into account the effects of investment cost, increased outage period, reduced capacity, change in heat rate, other variable costs, fixed costs, works power consumption, unit capacity and availability. Economic assumptions for financial analysis are,

- Rate of interest: 12.5 %
- Discount factor for levelising: 13.4%
- Service tax: 12.36%
- Oil cost: Rs 40,000.00 INR per kl
- Short term cost of power purchase: Rs 5.30 INR per kWh
- Return on equity:15.5%
- Debt- equity ratio:70:30

Table 2. Financial analysis of each option

Particulars	Unit	Without R&M	Options		
			A	B	C
Capacity	MW	190	210	215	215
Capital cost	Rs Million	-	6909.45	7183.65	7509.88
Capital cost/MW	Rs Million	-	32.90	33.41	34.93
Residual Plant life	Year	5	20	20	20
Project duration	Month	-	24	24	24
Shut down duration	Month	-	6	6	6
PLF (0th Year)	%	84.51	41.50	42.50	42.50
PLF (1st Year)	%	81.51	83	85	85
PLF (annual reduction of PLF)		3	0.15	0.15	0.1
Heat Rate	kcal/kWh	2889.37	2597	2565	2544

The levelised cost of generation (COG) is calculated for all the three options. The quantum of generation loss during the shutdown of the plant is taken as a cost and taken into account as the short term price of power to be procured at Rs. 5.30/kWh, being the costliest power available for purchase by the Utility for the short term. Summary of results of financial analysis is presented in Table 2.

VII. DISCUSSION AND CONCLUSION

The R&M measures suggested are based on hot and cold walk down survey of the plant, the tests and energy audit measurements taken during the course of the study, the available documentation from the plant site and discussions with the plant engineers. Need for the R&M of the unit was discussed and various options including cost implication for improvement in energy efficiency and replacement of existing obsolete technology were formulated. Improved operability, enhancement of efficiency and environmental aspects are the main objectives of R&M strategy. The measures for R&M were first considered for a base case in which the recommendations were restricted to the bare minimum to extend the plant life by at least 15-20 years without restoring design capacity. Further measures not only to extend plant life but also substantially improve efficiency, and to reduce auxiliary consumption and enhance output. Benefits to the utility include the following:

- Low capital investment per MW of equivalent additional capacity as compared to that for a new project.
- Shorter shutdown period
- Beneficial environment impact with no additional requirement of plant or water.
- Lower cost of generation
- No requirement of rehabilitation and resettlement of people.

The benefits anticipated as a result of implementation of the preferred option for this project, as noted in the report, could briefly be the following:

- Life of the unit will be extended for 15-20 years.
- Rated capacity/ designed capacity of 210 MW will be restored and will be improved further with additional measures.
- Forced outages will be reduced.
- Environmental improvement measures taken will enable plant to meet Pollution Control Board norms.
- Higher safety will be ensured for operational personnel and equipment.
- Savings in maintenance expenditure, fuel oil consumption and auxiliary power consumption.

On the basis of the financial analysis, the operational benefits include percentage reduction in auxiliary consumption, increase PLF, reduction in station heat rate with resultant savings in coal and oil consumption and availability of incremental saleable energy. The economic benefits accruing (1st year) after implementation of R&M program under each option as a result of improved operational performance of the plant over the position as existed prior thereto (Business As Usual) are summarized in Table 3.

Table 3. Economic benefits (1st Year) after R&M (in INR Million)

Description	Without R&M	After R&M		
		Option A	Option B	Option C
Revenue	5745	6600.3	6981.4	6996.7
Coal cost	4619	4626.2	4790.7	4751.4
Savings in coal cost		-7.6	-172.1	-132.9
Oil cost	83	91.6	64	64
Savings in oil cost		-8.8	18.8	18.8
O&M cost	613	504.9	516.9	601.0
O&M cost savings		107.8	95.8	95.8
Annual overall additional revenue		946.4	1178.6	1233.1

BCR is higher under option C followed by options B and then A. R&M capital cost compared to the capital cost for new capacity addition under different options is shown Table 4. The R&M capital cost compared to capital cost of new capacity addition is considered to be more economical resulting in savings to the utility both in terms of capital cost and the cost per MW. Benefit-Cost-Ratio (BCR) as worked out in the financial analysis in the report for option A, B and C are 1.13, 1.34 and 1.37 respectively as shown in Table 5.

Table 4. R&M capital cost comparison

Particulars	Option A	Option B	Option C
Capacity (MW)	210	215	215
Cost (Rs Million) under R&M	6909.45	7183.65	7509.88
Cost under new capacity of 250 MW (Rs Million)	15962.56	15962.56	15962.56
Savings under R&M (Rs Million)	9053.11	8778.91	8452.68
Savings in cost per MW under R&M(Rs Million)	43.11	40.83	39.31
Percentage of R&M Cost to New Capacity Cost (%)	43.29	45.0	47.05

Table 5. Summary of measures of performance

Particulars	Units	Without R&M	AFTER R&M		
			option A	option B	option C
FIRR (at indicative tariff)			17.88 %	20.41%	20.61%
Payback Period	Years		4.6	3.7	3.7
Benefit-Cost Ratio			1.13	1.34	1.37
First year of full operation after completion of R&M					
PLF	%	81.51	83	85	85
Increase in Gross Generation	MkWh	1356.7	1526.9	1600.9	1600.9
Reduction in coal consumption	kg/kWh	0.926	0.865	0.855	0.848

R&M of the units will result in additional generation and use of beneficiated coal will result in savings in coal and fuel oil consumption. The incremental saleable energy becoming available after implementation of R&M program will minimize dependence on power purchase from outside the State. In monetary terms, this is also expected to result in appreciable savings in power purchase cost. Sensitivity analysis considering the impact of variation due to adverse implementation scenarios such impact of change in capital cost, change in power tariff & increase in shutdown duration, it is observed that the project would be able to sustain the variation and will remain financially viable with different marginal considerations. Given the considerations to the economic and financial benefits as well as the risk factors under the various options as have been brought, option C is considered as the best option based on the comfort ability margin, and the BCR. It is also the best suited technical solution as regards sustainability to risk factors.

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