Scientific Journal of Impact Factor (SJIF): 4.72
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 4, Issue 4, April -2017

PERFORMANCE IMPROVEMENT THROUGH ENERGY AUDIT OF A 250MW COAL FIRED THERMAL POWER PLANT

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Abstract – *In this paper, performance of a 250MW coal fired thermal power plant has been investigated through the energy audit of all its important components at various loads. Energy efficiency of boiler, turbine-generator and condenser section as well as the overall plant is evaluated for 250MW, 200MW and 125MW loads. Similarly effectiveness of feed water heaters is evaluated for all the three loads.*

It is observed that the performance of all the sections except boiler is decreasing when the plant load decreases from its rated value. A similar trend is observed regarding overall plant as efficiency decreases from 38.5% to 34.63% when the load is reduced to half i.e. from 250MW to 125MW. From percentage loss point of view the area of major concerns are turbine-generator section and condenser section. Boiler efficiency seems to be satisfactory but it is still lower than the design value. This signifies that boiler have further scope of improvement.

***Keywords** - Energy audit, Thermal power plant, Plant performance, Efficiency, Energy loss.*

I. INTRODUCTION

Energy is among the top three expenses in any industry other two being labour and materials. If cost management is related then energy would be in top rank and a key step towards energy management is to conduct energy audit of the system, process or plant. Energy audit is the technique to know the fraction of total input energy being used for the intended purpose as well as the losses through various means. Thus energy audit is of utmost importance for cost reduction as it helps to understand the ways of energy use and in identifying the areas where waste can occur and scope for improvement exists [1].

Fast growing economy and increasing population are some of the major contributing factors behind enhanced energy demand in India. One of the basic source of energy for industrial and power sector in India is coal, as its consumption has raised at the compound annual growth rate of 6.69% from 433.27MT in 2005-06 to 827.57MT during 2014-15. Biggest consumer of coal is the electricity generation sector, followed by steel industries [2]. This increasing demand on one side and legislation in form of Energy Conservation Act 2001[3] on the other, has made it mandatory for the industries to consume energy at prescribed efficiency levels or even better. The act has prescribed the standards and directs the consumers on ways and means of efficient utilization of energy with a view to improve productivity, enhance operating efficiency, reduce operating costs and minimize pollution. Parameter of the power plants which comes under the ambit of the act are unit heat rate, auxiliary power, specific oil consumption and plant load factor.

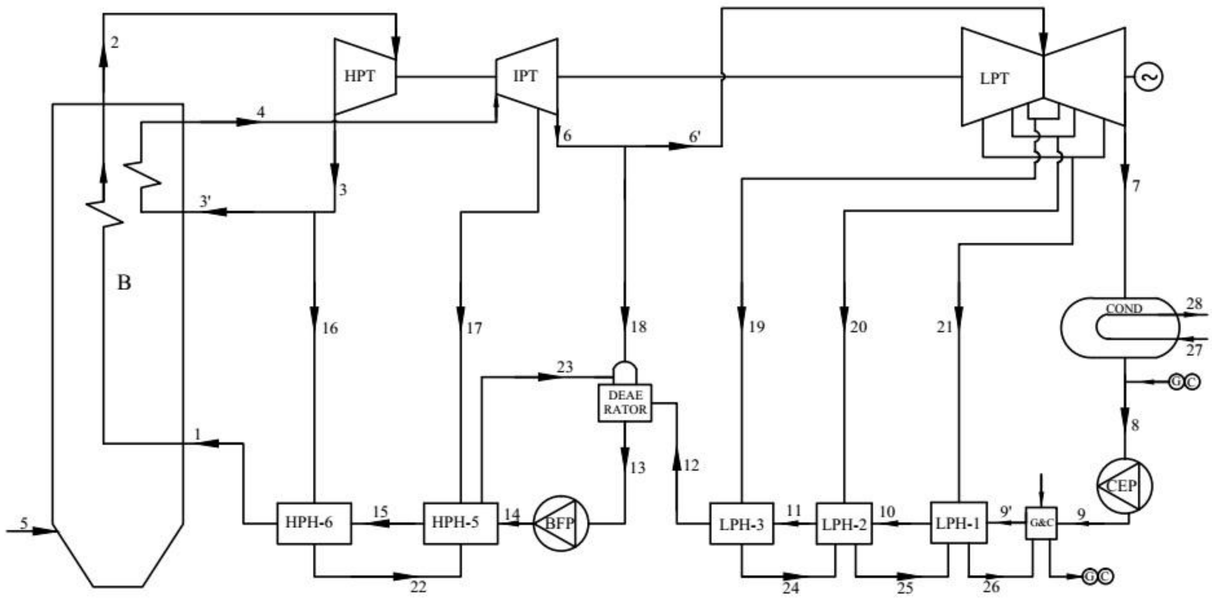
Many authors have used the energy audit technique for performance analysis of the respective plants considered under their study. Talwar P. et al. [4] conducted energy audit for boiler of a coal based thermal power plant and found the boiler efficiency as 81.07%. They concluded that except the heat loss due to fly ash and bottom ash all other losses were within the design values. M. Bajwa and P. Gulati [5], Bhardwaj V. et al. [6] and N. Kaur and N. K. Brar [7] uses energy audit technique to compare the performance of thermal power plant components at various loads and recommends few measures for improvement. A. K. Namdev et al. [8] in an energy audit of a boiler and waste heat recovery system in thermal power plant determines losses in the boiler and effectiveness of air preheater and concluded that the total unburnt carbon loss was 6.14% and dry gas loss was 4.59%. To reduce above losses they suggested to maintain coal particle size in the range of 70 to 74 micron and controlling excess air supply.

P. Sindhu and S. Arya [9] carry out the energy audit of a thermal power plant at the operating load of 232 MW and found the overall efficiency of the plant as 35.89% and suggested the plant operation at higher loads. V. Duhan and J. Singh [10] in the energy audit of Rajiv Gandhi thermal power plant at Hisar studied the dynamic responses of power plants through mathematical modeling and simulation by developing a model using genetic algorithms for parameter identification and model response optimization. Study also conducted the energy audit of the 600MW unit at various loads by taking data from the control room. Several authors [11–15] analyses the performances of different thermal power plants through energy audit and suggested some potential saving measures.

U. Ahmed and J. A. Chattha [16] in a case study evaluated the performance of combined cycle power plant and identified the areas requiring improvement. G. T. Dhanre et al. [17] in a review paper on energy audit of the boiler of thermal power plants summarizes the various studies carried out by different authors and concluded that energy audit evolves many ways to reduce energy consumption and energy cost.

II. FLOW LAYOUT AND OPERATIONAL DATA OF THE POWER PLANT

For present analysis 250MW thermal power plant located in Chhattisgarh, India is considered and its flow layout is shown in the Figure 1. Recorded operating parameters of the plant at different points are given in Table 1 to 3.



B – Boiler

HPT – High Pressure Turbine

IPT – Intermediate Pressure Turbine

LPT – Low Pressure Turbine

G and C – Gland Steam Condenser and Drain Cooler

LPH – Low Pressure Heater

HPH – High Pressure Heater

CEP – Condensate Extraction Pump

BFP – Boiler Feed Pump

COND – Condenser

Figure 1. Flow layout of the power plant

Table 1. Data of power plant for250MW load

Point	Physical State	t (°C)	p (bar)	m (kg/s)	h (kJ/kg)	E (kW)
1	Water	255.00	167.78	204.79	1077.20	220604.10
2	Steam	537.00	143.75	204.79	3426.24	701673.39
3	Steam	347.20	40.05	204.79	3088.43	632491.93
3'	Steam	347.20	40.05	183.24	3088.43	565923.91
4	Steam	537.00	36.04	183.24	3534.66	647690.73
5	Coal	85.00	1.03	47.05	13800	649290.00
6	Steam	302.80	6.81	172.47	3065.40	528680.34
6'	Steam	302.80	6.81	161.74	3065.40	495810.06
7	Steam	46.30	0.106	141.33	2410.72	340701.81
8	Water	46.30	0.106	162.78	193.81	31548.00
9	Water	46.50	19.66	162.78	196.74	32025.27

9'	Water	50.10	19.66	162.78	210.56	34273.72
10	Water	73.50	19.66	162.78	308.93	50286.36
11	Water	92.70	19.66	162.78	388.00	63157.86
12	Water	119.80	19.66	162.78	502.85	81852.92
13	Water	158.30	6.108	204.79	668.09	136819.80
14	Water	161.40	185.56	204.79	693.45	142013.78
15	Water	197.70	185.56	204.79	848.92	173853.72
16	Steam	347.20	40.05	20.10	3088.43	62086.71
17	Steam	417.10	15.99	11.20	3291.87	36868.94
18	Steam	302.50	6.80	10.72	3065.40	32864.15
19	Steam	188.10	2.35	7.66	2854.00	21855.93
20	Steam	104.70	0.94	5.31	2686.15	14263.46
21	Steam	78.40	0.44	6.97	2583.60	17999.94
22	Water	202.50	39.81	20.10	864.40	17377.03
23	Water	166.30	15.78	31.31	703.25	22018.69
24	Water	97.70	2.12	7.66	409.39	3135.11
25	Water	78.40	0.73	12.97	328.60	4261.94
26	Water	76.4	0.71	19.93	319.4	6363.64
27	Water	34.00	2.02	8750	142.32	1245300
28	Water	42.20	1.49	8750	176.65	1545687.5

Table 2. Data of power plant for200MW load

Point	Physical State	t (°C)	p (bar)	m (kg/s)	h (kJ/kg)	E (kW)
1	Water	236.00	161.50	164.89	1042.00	171815.38
2	Steam	537.00	144.84	164.89	3432.00	565902.48
3	Steam	340.50	32.57	164.89	3089.27	509389.73
3'	Steam	340.50	32.57	148.87	3089.27	459899.62
4	Steam	537.00	29.32	148.87	3549.73	528448.31
5	Coal	85.00	1.03	38.61	13800	532818.00
6	Steam	303.90	5.57	140.24	3070.85	430640.65
6'	Steam	303.90	5.57	132.05	3070.85	405505.74
7	Steam	46.30	0.106	117.05	2434.16	284918.43
8	Water	46.30	0.106	132.90	193.81	25757.35
9	Water	46.60	21.73	132.90	196.74	26147.01
9'	Water	49.20	21.73	132.90	208.88	27760.15
10	Water	70.20	21.73	132.90	294.27	39108.48
11	Water	86.20	21.73	132.90	369.62	49122.50
12	Water	114.40	21.73	132.90	480.13	63809.28
13	Water	150.80	5.02	164.89	635.43	104776.05
14	Water	153.80	174.98	164.89	658.45	108571.82
15	Water	189.70	174.98	164.89	813.34	134111.63
16	Steam	340.50	32.58	15.01	3089.27	46369.94
17	Steam	417.90	13.05	8.80	3298.15	29023.72
18	Steam	303.80	5.57	8.19	3070.85	25134.91
19	Steam	189.30	1.93	5.97	2849.41	16999.58
20	Steam	105.40	0.77	4.03	2689.50	10849.44

21	Steam	74.20	0.37	4.93	2587.36	12742.75
22	Water	193.40	32.3	15.01	831.76	12484.72
23	Water	157.60	12.82	23.81	666.41	15867.22
24	Water	92.30	1.75	5.97	344.92	2057.79
25	Water	74.20	0.656	10.00	310.60	3106.00
26	Water	72.1	0.625	14.92	301.81	4503
27	Water	32.75	2.01	7500	137.10	1028250
28	Water	40.87	1.489	7500	171.08	1283100

Table 3. Data of power plant for 125MW load

Point	Physical State	t (°C)	p (bar)	m (kg/s)	h (kJ/kg)	E (kW)
1	Water	219.70	154.60	108.39	945.00	102428.55
2	Steam	537.00	147.92	108.39	3417.45	370417.41
3	Steam	323.20	18.78	108.39	3076.71	333484.60
3'	Steam	323.20	18.78	94.30	3076.71	290133.75
4	Steam	537.00	17.80	94.30	3551.00	334859.30
5	Coal	85.00	1.02	26.16	13800	361008.00
6	Steam	313.50	3.82	94.30	3095.12	291869.82
6'	Steam	313.50	3.82	89.53	3095.12	277106.09
7	Steam	46.30	0.11	81.27	2527.08	205375.79
8	Water	46.30	0.11	90.10	193.81	17462.28
9	Water	46.70	23.88	90.10	197.58	17801.96
9'	Water	49.10	23.88	90.10	205.95	18556.10
10	Water	62.60	23.88	90.10	262.46	23647.65
11	Water	79.40	23.88	90.10	332.36	29945.64
12	Water	104.40	23.88	90.10	429.50	38697.95
13	Water	138.20	3.65	108.39	581.43	63021.20
14	Water	141.70	169.70	108.39	606.97	65789.48
15	Water	173.10	169.7	108.39	741.34	80353.84
16	Steam	323.20	20.77	8.27	3076.71	25429.01
17	Steam	420.90	8.47	4.97	3311.12	16439.71
18	Steam	313.50	3.81	5.04	3095.13	15599.46
19	Steam	198.00	1.33	3.75	2869.50	10769.23
20	Steam	111.60	0.52	2.49	2704.57	6734.38
21	Steam	65.50	0.24	2.15	2598.66	5594.91
22	Water	175.90	20.42	8.27	749.68	6196.85
23	Water	144.00	8.29	13.23	606.13	8019.71
24	Water	82.30	1.17	3.75	344.56	1292.10
25	Water	65.50	0.384	6.24	274.18	1711.98
26	Water	63.3	0.182	8.40	264.97	2225.75
27	Water	29.90	2.01	5500	125.16	688380
28	Water	38.00	1.49	5500	159.07	874885

III. METHODOLOGY OF DATA ANALYSIS

Following methodology of data analysis and determination of efficiencies and effectiveness of different units and overall plant is used in this present paper.

(i) Boiler section

Input energy to the boiler = Fuel energy = Mass flow rate of the fuel × gross calorific value of the fuel

$$= m_f \times G.C.V. = m_5 h_5 = E_5 \quad (1)$$

Net energy output from the boiler = (Energy of superheated steam – Energy of feed water)

+ (Energy of hot reheat steam – Energy of cold reheat steam)

= (Energy at 2 – Energy at 1) + (Energy at 4 – Energy at 3')

$$= (m_2h_2 - m_1h_1) + (m_4h_4 - m_{3'}h_{3'}) = (E_2 - E_1) + (E_4 - E_{3'}) \quad (2)$$

Where m, h and E are mass flow rate, specific enthalpy and total energy at corresponding points.

$$\text{Efficiency of the boiler, } \eta_b = \frac{\text{Net energy output from the boiler}}{\text{Input energy to the boiler}} \times 100\% \quad (3)$$

(ii) Turbine and generator section

HPT: Energy inlet to HPT = E_2

Energy outlet from HPT = E_3

Net energy at HPT = $(E_2 - E_3)$ (4)

IPT: Energy inlet to IPT = E_4

Energy outlet from IPT = $E_6 + E_{17}$

Net energy at IPT = $E_4 - (E_6 + E_{17})$ (5)

LPT: Energy inlet to LPT = $E_{6'}$

Energy outlet from LPT = $E_{19} + E_{20} + E_{21}$

Net energy at LPT = $E_{6'} - (E_{19} + E_{20} + E_{21})$ (6)

Total net energy at turbines = (4) + (5) +(6) **(7)**

Energy outlet from turbine-generator = Operating load of the plant

$$\text{Efficiency of the turbine-generator, } \eta_{tg} = \frac{\text{Operating load of the plant}}{\text{Total net energy at turbines}} \times 100\% \quad (8)$$

(iii) Condenser section

$$\text{Condenser efficiency, } \eta_c = \frac{\text{Actual rise in cooling water temperature}}{\text{Maximum possible rise in cooling water termperature}} \times 100\%$$

$$= \frac{T_{28} - T_{27}}{T_7 - T_{27}} \times 100\% \quad (9)$$

Where T represent the temperature at corresponding point.

(iv) Feed Water Heaters

$$\text{Effectiveness of heaters} = \frac{\text{Actual increase in temperature of feedwater}}{\text{Maximum possible increase in temperature of feedwater}} = \frac{T_{wo} - T_{wi}}{T_s - T_{wi}} \quad (10)$$

Where T_{wi} and T_{wo} are the temperature of feed water entering to and leaving from the feed water heater respectively and T_s is the temperature of the steam entering to the feed water heater.

(v) Overall plant efficiency

$$\text{Overall plant efficiency, } \eta_{plant} = \frac{\text{Output of the plant}}{\text{Mass flow rate of the fuel} \times \text{gross calorific value of the fuel}} \times 100\%$$

$$= \frac{\text{Load}}{m_f \times G.C.V.} \times 100\% \quad (11)$$

IV. RESULTS AND DISCUSSION

Using recorded data and following the method of analysis as stated above, performance at section wise as well as for whole plant at 250MW, 200MW and 125MW load is determined. The results obtained are presented both in tabular (Table 4) and graphical forms (Figure 2 to 4) for ease of comparison and better understanding.

All the components are performing better at higher load (except boiler). As shown in Figure 2, when load decreases to 50% of rated value, turbine-generator efficiency reduced considerably over 2.5% and condenser efficiency reduces more than 10%. Effectiveness of feed water heaters are shown separately in Figure 3. Effectiveness in general is also reducing with decrease in load. Overall plant efficiency as shown in Figure 4 also reduces by almost 4% with the load being half of the rated value.

Table 4. Results of the analyzed data

Section/Components	Description	Load		
		250MW	200MW	125MW
Boiler	Energy input to boiler, kW	649290.00	532818.00	361008.00
	Net energy output from boiler, kW	562836.12	462635.78	312714.40
	Energy loss in boiler, kW	86453.88	70182.22	48293.60
	Efficiency of boiler, %	**86.68**	**86.83**	**86.62**
Turbine-generator	Net Energy at HPT	69181.46	56512.75	36932.81
	Net Energy at IPT	82141.45	68783.94	26549.77
	Net Energy at LPT	441690.73	364913.97	254007.57
	Net Input at Turbines	593013.64	490210.66	317490.15
	Efficiency of Turbine-generator, %	**42.16**	**40.80**	**39.37**
Condenser	Condenser efficiency,%	**62.94**	**59.93**	**49.39**
Feed Water Heaters	Effectiveness of LPH1	0.82	0.84	0.82
	Effectiveness of LPH2	0.61	0.45	0.34
	Effectiveness of LPH3	0.28	0.27	0.21
	Effectiveness of HPH5	0.14	0.13	0.11
	Effectiveness of HPH6	0.38	0.31	0.31
Overall Plant Efficiency,%		**38.50**	**37.54**	**34.63**

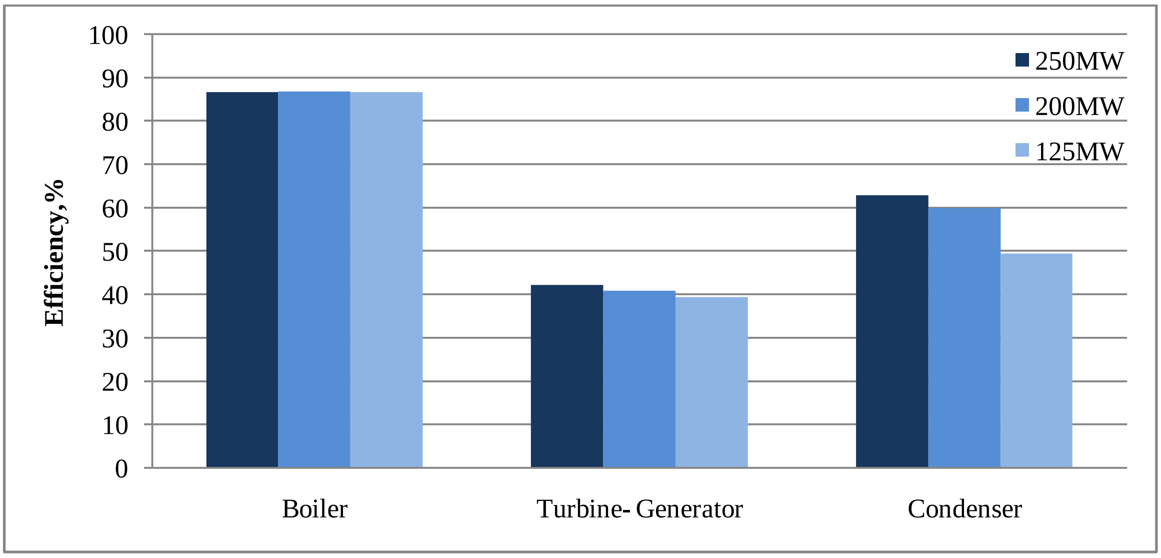


Figure 2. Efficiency of various sections at different loads

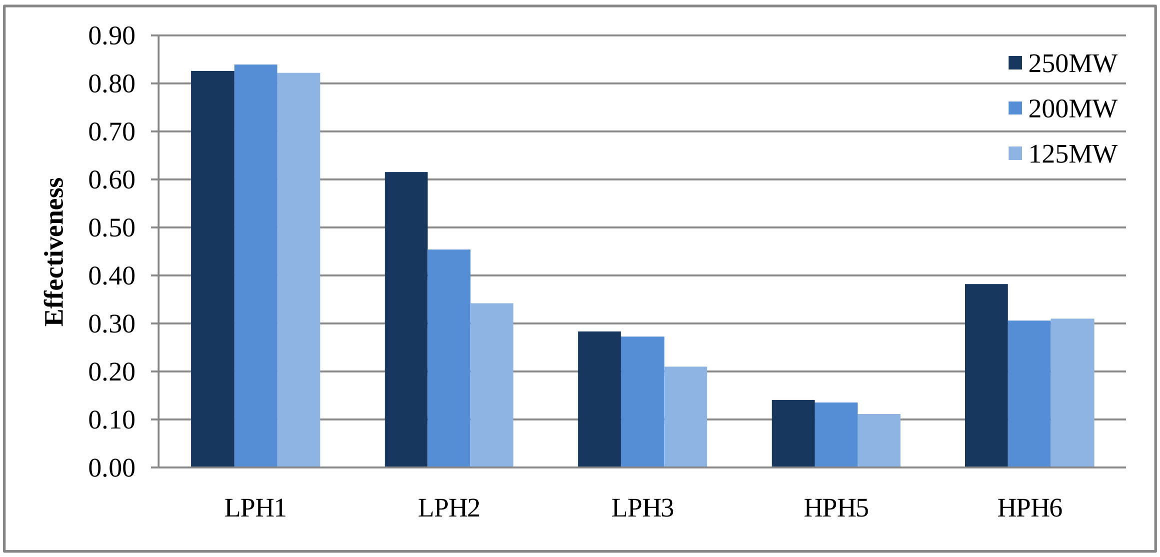


Figure 3. Effectiveness of heaters at different loads

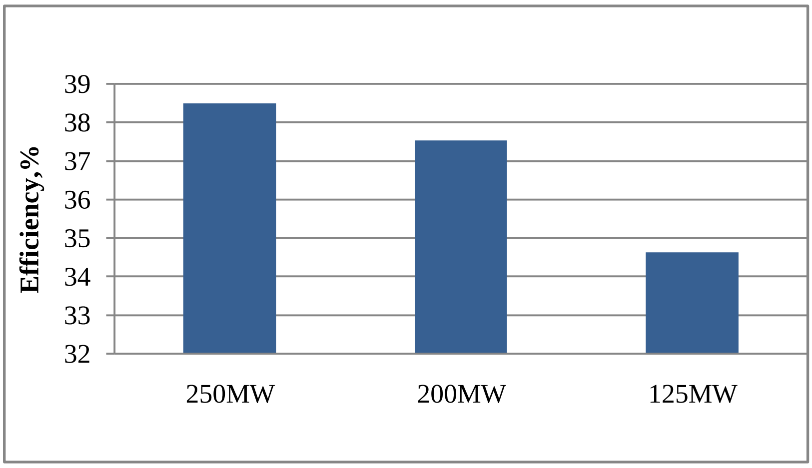


Figure 4. Overall plant efficiency at different loads

V. RECOMMENDED MEASUSRES

Based on the observations and results of analyzed data, few measures have been recommended to improve the performance of each section. These measures include both categories of recommendations viz. short term, requiring little time and cost to be implemented, and long term, covering bigger activities therefore requires larger investment and longer time to be implemented. Section wise improvement objectives and recommended measures are summarized in Table 5.

Table 5. Recommendations for improvement of plant efficiency

Section	Possible Improvement	Recommended Measures
Boiler	Improving efficiency, reducing losses and curbing environmental pollution	*Reducing flue gas exhaust temperature to the minimum possible limit. * Maintaining optimum quantity of excess air. * Controlling dampers for proper combustion. * Better control of furnace temperature to reduce spray. * Improving coal quality to control moisture in the fuel. * Avoid part load operation and shut down by regular periodic maintenance * Improving air preheater performance by controlling air ingress across seals. Check air preheater baskets and replace if necessary.
Turbine-generator	Better utilization of energy of steam for higher efficiency and output both	* Reduce gland losses by proper sealing. * Optimize the quantity of extracted steam by metering it properly. * Improve design and material of the turbine blade to permit efficient operation and longer life.
Condenser	Maintaining low vacuum and effective heat transfer through tubes	* Avoiding air ingress to maintain low vacuum. * Cleaning tubes by high pressure jets and remove scale. * Regular cleaning by online tube cleaning system. * Attend tube leakages immediately as and when required. * Ensure performance of each cooling tower. * Ensure adequate flow of cooling water.
Heaters	Maintaining desired terminal temperatures	*Properly measure the temperatures using calibrated instruments. *Maintain recommended condensate levels in feed water heaters. With this no heat transfer areas are immersed in the drain condensate.
Overall plant	Higher thermal efficiency	*Overall plant efficiency is a function of efficiencies of boiler and steam turbine both. In this case, improving boiler efficiency can make a major contribution.

VI. CONCLUSION

From results of the analyzed data it may be concluded that for higher energy efficiency, plant should run at full load. As the loss at boiler is the loss of energy of high quality, therefore boiler efficiency should be improved by adopting the suggested measures and following the good maintenance practices. Efficiency of turbine-generator section and condenser are also lower than their design values. Also the effectiveness of feed water heaters particularly 3 and 5 requires to be improved.

VII. FUTURE SCOPE OF WORK

Total loss in the boiler is more than 13% in all the cases of loading which requires further detailed analysis to identify the major sources of losses in the boiler and to investigate the parameters affecting these losses.

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