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MECHANICAL ENGINEERING | RESEARCH ARTICLE

Combined effect of various operating loads, number of feed water heaters and makeup water quantities on the performance of coal fired thermal power plant: A case study

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Abstract: In this case study, combined effect of various operating parameters on the performance of thermal power plant is analyzed. For the analysis following operating parameters are selected: different operating loads, different number of feed water heaters and different mass flow rates of makeup water. To analyze the performance of the power plant: flow function, mass flow rates of steam at each stage, power output, heat rate, correction factors for power and heat rate are evaluated. And then performance characteristic curves are prepared. Finally those operating conditions are found at which power output is as high as possible but heat rate is as low as possible. This case study can be concluded as maximum power (121.21 MW) and minimum heat rate (2,393.05 kJ/MW s) both can be achieved at full operating load condition, with five feed water heaters and no makeup water addition in de-aerator. But minimum power (71.43 MW) and maximum heat rate (2,430.94 kJ/MW s) are found at low load, with large number of feed water heaters and more amount of makeup water addition.

Subjects: Mechanical Engineering; Power & Energy; Technology

Keywords: power output; heat rate; correction factor curves; thermal power plant

1. Introduction

In the previous years, many researchers have done lot of work on thermal power plant. Various case studies and research work have been done by Geete (2016), Geete and Khandwawala (2013, 2014,

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PUBLIC INTEREST STATEMENT

This research work is done on 120 MW coal fired thermal power plant. All power plants are designed on the basis of ideal conditions. But in actual, power plants are not working on ideal/designed conditions due to site situation, environmental conditions, leakages etc. It means, outputs from the plant will be different (less) then designed outputs. It will be matter of disputes between supplier/manufacturer and customer. To protect our design of the plant, correction curves are generated at various operating conditions. These curves are submitted as the time of installation of the plant to customer. With the help of these correction curves, plant design can be justified as if plant operating conditions are changed then plant outputs will be changed.

2015, 2016) with different operating parameters at different conditions like different inlet pressures, different inlet temperatures, different condenser pressures and different extraction line pressure drops. Vosough et al. (2011) have suggested that maximum efficiency and maximum power output can be achieved at minimum condenser pressure. Mateen and Roa (2011) have also observed some important considerations that are required for perfect design of a condenser. Rafiee, Siadatan, Afiei, and Abadi (2012) have concluded that about 3.3% of thermal energy can be increased by using of thermo-electric generator in the condensation cycle. Dutta, Das, and Chakrabarti (2013) have introduced a new term called Loss Factor. They have noted that the efficiency is maximum when the Loss Factor equals to one. Zhonghua, Jizhen, and Guangjian (2013) have developed a model which is used to analyze condenser, condenser back pressure and cooling tower of the thermal power plant. A coal fired thermal power plant is opted for this case study. Major components of thermal power plant are – high pressure feed water pump, boiler, high pressure steam turbine, intermediate pressure steam turbine, low pressure steam turbine, condenser, cooling tower, high pressure feed water heaters, low pressure feed water heaters, deaerator and low pressure feed water pump. Schematic diagram of the power plant is shown in Figure 1 (Geete, 2016; Geete & Khandwawala, 2013, 2014, 2015, 2016; Steam Turbine Engineering (STE) Department, 2010). In this case study, various operating parameters are selected and effects of these parameters on the performance of power plant are determined. Selected operating parameters are: (a) operating load conditions (like 100% load, 80% load and 60% load), (b) number of feed water heaters (like five heaters, six heaters and seven heaters) and (c) mass flow rates of water addition in deaerator (like 0, 1 and 2% of total mass flow rate of steam generated in boiler). In actual power plant, operating loads are varied according to requirement of power. Numbers of feed water heaters are varied according to the temperature of feed water required in the boiler. And mass flow raters of makeup water addition in deaerator are varied according to leakages from power plant. To evaluate performance of the power plant, power output and heat rate are calculated at different conditions. For calculations one new term is used which is flow function. This term shows relation between mass flow rate of steam, steam pressure, steam temperature and volume of steam generated in boiler. Some leakages are presumed during calculations; leakages are: (1) leakage L_1 some amount of steam is taken from main pipeline and entered at last stage of HP turbine. This steam is used to reduce pressure difference between first and last stage of HP turbine. (2) Before entering steam in HP turbine, some amount of steam is leaked from

Figure 1. Layout of 120 MW thermal power plant.
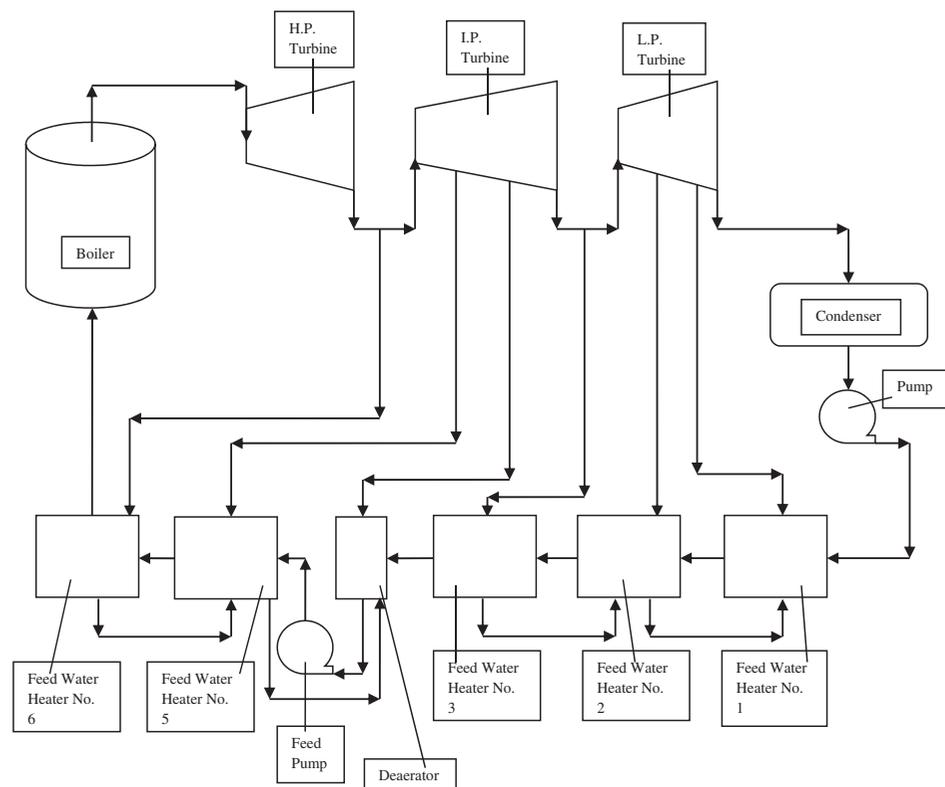
pipeline, leakages are L_2, L_3 and L_4. (3) After expanding steam in HP turbine, L_5 and L_6 amount of steam are leaked. (4) L_7 and L_8 are leakages before entering steam in IP turbine. And (5) L_9 is a leakage before entering steam in LP turbine. All extraction quantities (Ex_i) are also taken into account during calculations, extraction quantities are: (1) Ex_1 is first extraction quantity of steam after expansion in high pressure turbine, (2) Ex_2 and Ex_3 are extraction quantities of steam from intermediate pressure turbine at different stages respectively, (3) Ex_4, Ex_5 and Ex_6 are extraction quantities of steam from low pressure turbine at different stages respectively. Mechanical losses and generator efficiency are also considered to calculate net output to improve accuracy of the results. Here heat rate is calculated and it can be defined as the ratio of total heat addition in the boiler and net amount of power output from the plant. Designed/ideal conditions of power plant are—mass flow rate of steam is 363,313.0 kg/h, steam pressure is 125.1 bar, steam temperature is 537.78°C, specific volume is 0.0186 m³/kg and flow function is 4,430.051 kg²/bar m³h. In this work, case studies are performed on coal fired thermal power plant. For case studies, power output and heat rate are evaluated for selected operating parameters at various conditions. After that performance characteristic curves are made. From these characteristic curves those operating conditions are found at which power output is maximum but heat rate is minimum.

2. Methodology

Here designed value of the flow function is calculated with the designed values of mass flow rate of steam, steam pressure and steam volume. Then with the help of calculated flow function, mass flow rates of steam are calculated at various operating conditions by relationship between flow function, mass flow rate, pressure and specific volume. Mathematic relation is given below (Cotton, 1993; Geete, 2016; Geete & Khandwawala, 2013, 2014, 2015, 2016; Steam Turbine Engineering (STE) Department, 2010):

$$FF = W/\sqrt{(P/V)} \tag{1}$$

Here FF is flow function, W is mass flow rate of working fluid in kg/s, P is steam pressure in bar and V is specific volume in m³/kg. By considering extraction quantities and leakages, different mass flow rates are calculated for high pressure turbine, intermediate pressure turbine and low pressure turbine (Cotton, 1993; Geete, 2016; Geete & Khandwawala, 2013, 2014, 2015, 2016; Steam Turbine Engineering (STE) Department, 2010). Calculations of mass flow rates of steam at various stages are done as follows. Mass flow rate of steam for high pressure steam turbine (W_1) is calculated by subtracting leakages L_1, L_2, L_3 and L_4 from steam which is generated in boiler. Mass flow rate of steam for intermediate pressure turbine after 1st extraction of steam for high pressure feed water heater (W_2) is calculated by adding L_1 and then subtracting leakages L_5, L_6 and extraction quantity Ex_1 from mass flow rate of steam for high pressure steam turbine. Mass flow rate of steam (W_3) after 2nd extraction of steam for high pressure feed water heater is calculated by subtracting extraction quantity Ex_2, leakages L_7 and L_8 from flow rate of steam for intermediate pressure turbine after 1st extraction. Mass flow rate of steam (W_4) after 3rd extraction of steam for deaerator is calculate by subtracting extraction quantity Ex_3 from flow rate of steam after 2nd extraction. Mass flow rate of steam (W_5) for low pressure turbine after 4th extraction of steam for low pressure feed water heater is calculated by subtracting extraction quantity Ex_4 from flow rate of steam after 3rd extraction. Mass flow rate of steam (W_6) after 5th extraction of steam for low pressure feed water heater is calculated by subtracting extraction quantity Ex_5 and leakage L_9 from flow rate of steam for low pressure turbine after 4th extraction. And finally mass flow rate of steam (W_7) after 6th extraction of steam for low pressure feed water heater is calculated by subtracting extraction quantity Ex_6 from flow rate of steam after 5th extraction of steam. Where Ex_1, Ex_2, Ex_3, Ex_4, Ex_5 and Ex_6 are different extraction quantities which are extracted from high pressure, intermediate pressure and low pressure steam turbines. After finding mass flow rates at various stages of steam turbines, power and heat rate are calculated. Power is calculated with the relationship between mass flow rate and enthalpy drop in the turbine and net power is calculated by considering mechanical losses and generator efficiency. Heat rate is calculated with relationship between total heat addition and net power

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output. Power, net power and heat rate are calculated by Equations (3–5) (Geete, 2016; Geete & Khandwawala, 2013, 2014, 2015, 2016; Steam Turbine Engineering (STE) Department, 2010):

$$P = \{W_1(h_1 - h_2)\} + \{[W_2(h_3 - h_4)] + [W_3(h_4 - h_5)] + [W_4(h_5 - h_6)]\}$$
$$+ \{[W_5(h_6 - h_7)] + [W_6(h_7 - h_8)] + [W_7(h_8 - h_9)]\} \tag{2}$$

$$P_n = (P - L_{mech})\,\eta_g \tag{3}$$

here P is power in MW, P_n is net power output from the plant in MW, L_{mech} is mechanical losses in generator in MW and η_g is generator efficiency.

$$HR = Q/P_n = (Q_1 + Q_2)/P_n \tag{4}$$

Here Q is summation of heat addition in boiler and superheater (Q_1 is amount of heat transfer in boiler and Q_2 is amount of heat transfer in superheater) in kJ/s and HR is heat rate in kJ/MW sec. After calculations of net power outlet and heat rate, correction factors are calculated. These correction factors are required to prepare performance characteristic curves for coal fired thermal power plant.

$$CF_p = (P_d)/(P_n) \tag{5}$$

$$CF_h = (HR_d)/(HR) \tag{6}$$

Here CF_p is correction factor for power output and CF_h is correction factor for heat rate. P_d is designed power output from the power plant at ideal operating conditions in MW and HR_d is designed heat rate from the plant in kJ/MW sec. In this case study, some quantities like leakages and extractions for designed conditions are collected from BHEL plant. Different leakages are—L_1: 1.263 kg/s; L_2: 0.042 kg/s; L_3: 0.311 kg/s; L_4: 0.108 kg/s; L_5: 0.233 kg/s; L_6: 0.083 kg/s; L_7: 0.366 kg/s; L_8: 0.101 kg/s and L_9: 0.041 kg/s. And different extraction quantities are—Ex_1: 6.397 kg/s; Ex_2: 4.116 kg/s; Ex_3: 5.522 kg/s; Ex_4: 2.092 kg/s; Ex_5: 3.811 kg/s and Ex_6: 3.383 kg/s (Steam Turbine Engineering (STE) Department, 2010).

3. Results

It has been observed that (a) when power plant is running at full load condition then it gives maximum performance, (b) when number of feed water heater increases then power output decreases because extraction quantity increases but heat rate improves whereas when number of feed water heater decreases then power output increases but heat rate decreases and (c) when makeup water quantity increases it means leakages from the plant increase and finally performance of the plant decreases because power output decreases. For the work, 120 MW coal fired thermal power plant is opted. And different operating loads, various number of feed water heaters and different mass flow rates of makeup water are selected as operating parameters for this case study. All the results are tabulated in Tables 1 and 2. Then by using correction factors, power plant's characteristic curves are prepared as shown in Figures 2 and 3. These characteristic curves are important to improve the performance of the power plant. By these curves optimum operating conditions are also identified at which power output from the plant is highest but heat rate is lowest.

With the help of these results following characteristic curves are formed one is based on power outputs and other one is based on heat rates. In these figures, *x*-axis shows various case studies (which are combine effects of various operating loads, different number of feed water heaters and different mass flow rates addition in deaerator) and *y*-axis shows correction factors.

From these case studies, it is also found that when operating load decreases, number of feed water heater increases and percentage of makeup water addition in deaerator increases then power output from the plant decreases but correction factor increases whereas for the same conditions heat rate increases but correction factor decreases.

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Table 1. Power outputs with correction factors due to combined effect of various operating parameters

Case study	Operating parameters			Power outputs (in MW)	Correction factors
	Operating loads (in %)	Numbers of feed water heaters	Mass flow rates of makeup water add in deaerator (in %)		
1	100	5	0	121.21	0.99
2	80	6	1	97.56	1.23
3	60	7	2	71.43	1.68
4	100	7	1	116.50	1.03
5	80	5	2	97.56	1.23
6	60	6	0	73.62	1.63
7	100	6	2	119.40	1.005
8	80	7	0	94.49	1.27
9	60	5	1	74.53	1.61

Table 2. Heat rates with correction factors due to combined effect of various operating parameters

Case study	Operating parameters			Heat rates (in kJ/MW s)	Correction factors
	Operating loads (in %)	Numbers of feed water heaters	Mass flow rates of makeup water add in deaerator (in kg/s)		
1	100	5	0	2,393.05	1.008
2	80	6	1	2,428.49	0.994
3	60	7	2	2,430.94	0.993
4	100	7	1	2,418.76	0.998
5	80	5	2	2,413.92	1.00
6	60	6	0	2,421.18	0.997
7	100	6	2	2,426.05	0.995
8	80	7	0	2,416.34	0.999
9	60	5	1	2,413.92	1.00

Figure 2. Characteristic curve for power at combined effect of various operating conditions.
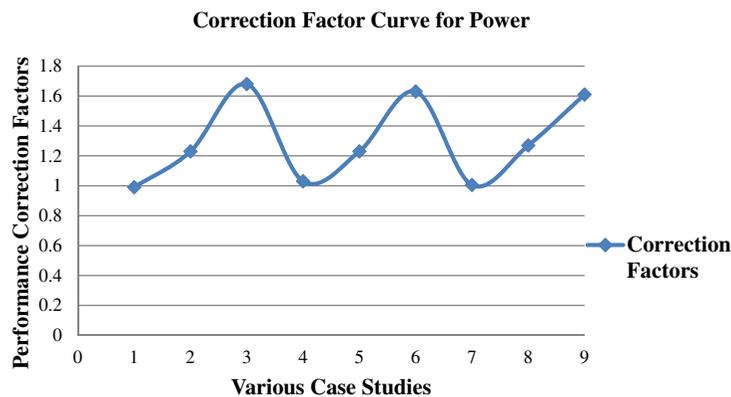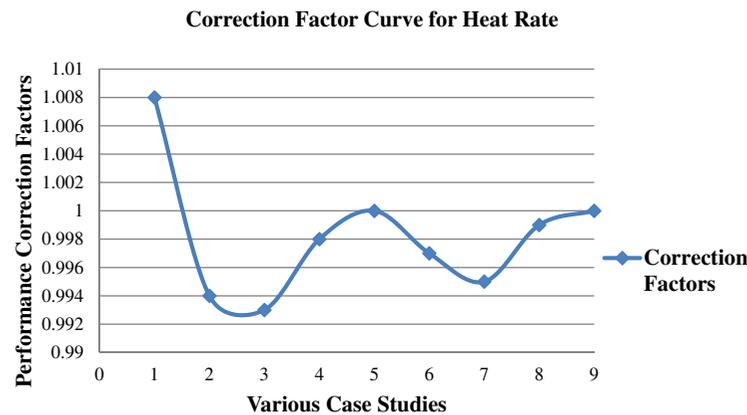

Correction Factor Curve for Power

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Figure 3. Characteristic curve for heat rate at combined effect of various operating conditions.

Correction Factor Curve for Heat Rate

4. Conclusion

In this paper, different case studies are performed by selecting various operating parameters like operating loads, number of feed water heaters and makeup water addition in deaerator. Then performance operating correction curves are formed. These curves are used to identify those operating conditions at which optimum outputs can be achieved from power plant. Case studies are done on plant to find out maximum power output/minimum heat rate from the power plant. And work can be concluded as maximum power output can be achieved at 100% operating load, five feed water heaters and zero percent of makeup water addition in deaerator but minimum power output is found at 60% operating load, seven feed water heaters and two percent makeup water addition in deaerator. Similar case studies are done to evaluate minimum heat rate from the plant. And work can also be concluded as – maximum heat rate can be achieved with seven feed water heaters, two percent makeup water addition in deaerator and at 60% operating load but minimum heat rate is found with five feed water heaters, zero percent makeup water addition in deaerator and at 100% operating load. From these case studies, optimum conditions (100% operating load, 5 feed water heaters and no makeup water addition) are identified at which power output is maximum (121.21 MW) and heat rate is minimum (2,393.05 kJ/MW s).

List of symbols, abbreviation and nomenclature

Ex_i extraction quantity from HP, IP and LP Turbines at different stages (kg/s)

h_i enthalpy of steam at different stages (kJ/kg)

L_i leakage from pipeline (kg/s)

W_i mass flow rate of steam at different stages (kg/s)

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References
Cotton, K. C. (1993). *Evaluating & improving steam turbine performance* (1st ed., Vol. 1, pp. 254–262). Rexford, NY: Cotton Fact.

Dutta, A., Das, A. K., & Chakrabarti, S. (2013). Study on the effect of cooling water temperature rise on loss factor and efficiency of a condenser for a 210 MW thermal power unit. *International Journal of Emerging Technology and Advanced Engineering, 3*, 485–489.

Geete, A. (2016). Performance analysis of thermal power plant under various operating conditions: A case study. *MAYFEB Journal of Mechanical Engineering, 1*(1), 1–9.

Geete, A., & Khandwawala, A. I. (2013). Thermodynamic analysis of 120MW thermal power plant with combined effect of constant inlet pressure (124.61bar) and different inlet temperatures. *Case Studies in Thermal Engineering, 1*, 17–25.
http://dx.doi.org/10.1016/j.csite.2013.08.001

Geete, A., & Khandwawala, A. I. (2014). Thermodynamic analysis of 120 MW thermal power plant with combined

effect of constant inlet pressure (127.06 Bar) and different condenser back pressures. *IUP Journal of Mechanical Engineering, 7,* 25–46.

Geete, A., & Khandwawala, A. I. (2015). Thermodynamic analysis of thermal power plant with combined effect of constant inlet temperature (507.78°C) and different inlet pressures. *IUP Journal of Mechanical Engineering, 8,* 38–49.

Geete, A., & Khandwawala, A. I. (2016). To analyse the combined effect of different extraction line pressure drops on the performance of coal-fired thermal power plant. *International Journal of Ambient Energy,* 1–6. doi:10.1080/01430750.2015.1121919

Mateen, A. S., & Roa, N. A. N. (2011). Structural and thermal analysis of condenser by using finite element analysis. *International Journal of Mathematical Sciences, Technology and Humanities, 4,* 37–52.

Rafiee, M., Siadatan, A., Afiei, E., & Abadi, E. Z. A. (2012). Improving the efficiency of thermal power plant using thermoelectric material. In *International Conference on Intelligent and Advanced Systems* (Vol. 1, pp. 450–454), Kuala Lumpur.

Steam Turbine Engineering (STE) Department. (2010). (Documents). Bhopal: BHEL.

Vosough, A., Falahat, A., Vosough, S., Esfehani, H. N., Behjat, A., & Rad, R. N. (2011). Improvement of power plant efficiency with condenser pressure. *International Journal of Multidisciplinary Sciences and Engineering, 2,* 38–43.

Zhonghua, N., Jizhen, L., & Guangjian, L. (2013). Influence of cooling circulating water flow on back pressure variation of thermal power plant. *International Conference on Measuring Technology and Mechatronics Automation, Hong Kong, 5,* 619–622.

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