Review Article — Open Access

Performance of Coal Based Thermal Power Plant at Full Load and Part Loads

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Abstract

Power is the critical for the economy development of a country. As the economy grows, the need for more and more power is self-justified. New power installations are capital intensive, and hence, there is urgent need for optimal utilization of existing capacities by efficiently running of thermal power stations and saving energy used as fuel or auxiliary power for running the installations.

The present study aims at determining the actual performance of a coal based 210 MW power plant at full and part loads (210 MW and 195.86 MW). Design and actual performance values of boiler efficiency, specific fuel consumption, heat rate and overall efficiency are compared. During actual performance, although small deviations are observed from design values, they may result in substantial loss of revenue and excess operating expenditure. The possible reasons for deterioration are analysed and some possible remedies are suggested.

Keywords: SFC; TPS; LPH; Part load; Full load; HPH

Introduction

Thermal power plants have played a vital role in improving the power and economic position in India. In every economy, power is a critical input for its development. The quality of life is governed by the per capita power consumption of an economy. For developed countries the per capita power consumption is far too greater than that of the developing countries and hence it is said that the quality of life is very good in developed countries than that in developing countries.

India as a developing economy has added substantially to its installed power capacity in the period right after independence, from 1362 MW in 1947 to 310005 MW on 31 December 2016 [1] (Tables 1 and 2).

India, coal found to be the most important and abundant fossil fuel and about 80% of the coal produced consume by India's electricity sector. Also, this is of particular relevance as coal-fired power stations form the backbone of the Indian power generation sector. Mostly, coal-fired power plants in India operate on subcritical steam parameters with the exception of a few plants that use supercritical steam parameters. Most of the coal-fired power plants have efficiencies less than 35% by using indigenous high ash coal. Now a day, efforts are taking place to bring in highly efficient super critical technology in the country for thermal power plants. Energy analysis of coal-fired power plant is done using mass and energy balance equation [2].

Coal fired power plants have made a significant contribution in the past in meeting our energy needs and they would continue to play a dominant role in the coming two to three decades. The power industry has witnessed an unprecedented increase in fuel prices and cost of energy production making it imperative to use performance monitoring techniques to effectively control the power plant system for its optimum operating performance [3].

Performance Evaluation Criteria

The power plant performance is measured by assessing the performance of main plant i.e., boiler and turbine-generator as well as auxiliary plants through measurement of prime performance functions like turbine efficiency, boiler efficiency, specific fuel consumption(SFC)

Symbol/Abbreviations	Meaning
C_{ps}	Specific Heat of Water Vapour
C_{pw}	Specific Heat of Water
C_{pdf}	Specific Heat of Dry Flue Gas
CV_c	Calorific Value of Carbon
m_{df}	Mass of Dry Flue Gas
m_m	% Moisture in Coal
m_{uc}	Unburnt Carbon mass
W_{it}	Total isentropic work done of turbine
CV_c	Calorific Value of Carbon
m_{df}	Mass of Dry Flue Gas
m_m	% Moisture in Coal
SFC	Specific Fuel Consumption
t_{ai}	Air Temperature at Inlet
t_{fgo}	Flue Gas Temperature at Outlet
W_{at}	Total actual work done of turbine

Table 2: Nomenclature.

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Power Plant	Installed Capacity (MW)
Coal based power plant	188967.88
Gas power plant	25282.13
Diesel based	918.89
Nuclear power plant	5780.00
Renewable power plant	45916.95
Hydro power plant	43139.43

Table 1: Comparison of different power sectors in India.

and plant heat rate. To keep high standard of overall performance it is necessary to monitor these performance functions at regular interval. The frequency at which these measurements can be taken, will govern the closeness of optimization control in much the same way as a control system functions to keep a given parameter at its pre-determined value [4,5].

Case Studies

Case study-1: Full load

Figure 1 shows the cycle diagram of TPS at operating condition at full load.

Case study-2: Part load

Figure 2 shows the cycle diagram of actual power plant at operating condition at part load

Performance Analysis of Thermal Power Station

In order to know the performance of boilers, it is very important to test the efficiency of boilers. Testing of the boiler efficiency calculates the best possible efficiency, which drifts away from the test efficiency. Therefore, corrective action could be taken, to rectify the observed problem areas, for achieving the best efficiency. There are two methods i.e., direct method and indirect method (heat loss method), for the efficiency test of boilers. The heat loss method is more accurate than the direct method. In this method, the efficiency of the boiler is calculated, by subtracting all the heat losses in a boiler from 100 [6].

Following losses are considered in the analysis of the boiler performance

Dry flue gas loss

This is the heat loss from the boiler in the dry component of flue gases to the stack [4].

Dry flue gas loss: $(Q_{df}) = m_{df} \times c_{pdf} \times (t_{fgo} - t_{ai})$ 　　(1)

Moisture in fuel loss

Compared to bituminous coals, which have less moisture, this reduces the thermal efficiency of the power plant boiler because a considerable amount of the energy from burning the coal is used for in-furnace drying. One opportunity to improve the performance of low-rank coals is to dry the coal using low energy methods such as mechanical thermal expression or steam fluidized bed drying [7].

This is the loss of heat from the boiler in the flue gases due to water vapours which was present initially as moisture in the coal burnt. Moisture that enters the combustion chamber as a part of fuel causes a heat loss [5].

$Q_{mfuel} = m_m [c_{pw}(100 - t_{ai}) + 2257 + c_{ps}(t_{fgo} - 100)]$ 　　(2)

Moisture in combustion loss due to H_2 in coal

Coal contains hydrogen which burns to form water. This loss is due to the heat carried in flue gases by the water which is formed by H_2 [4].

$Q_{mH2} = 9H[c_{pw}(100 - t_{ai}) + 2257 + c_{ps}(t_{fgo} - 100)]$ 　　(3)

Loss due to unburnt carbon

This loss is due to small amount of carbon which remains as a residue in the ash from boiler. This loss is a function of % ash in fuel and % carbon in ash from boiler. The fineness of pulverized fuel influences this loss [3].

$Q_{uc} = m_{uc} \times CV_c$ 　　(4)

Unaccounted losses

Unaccounted losses include moisture in air loss, unburnt gas loss,
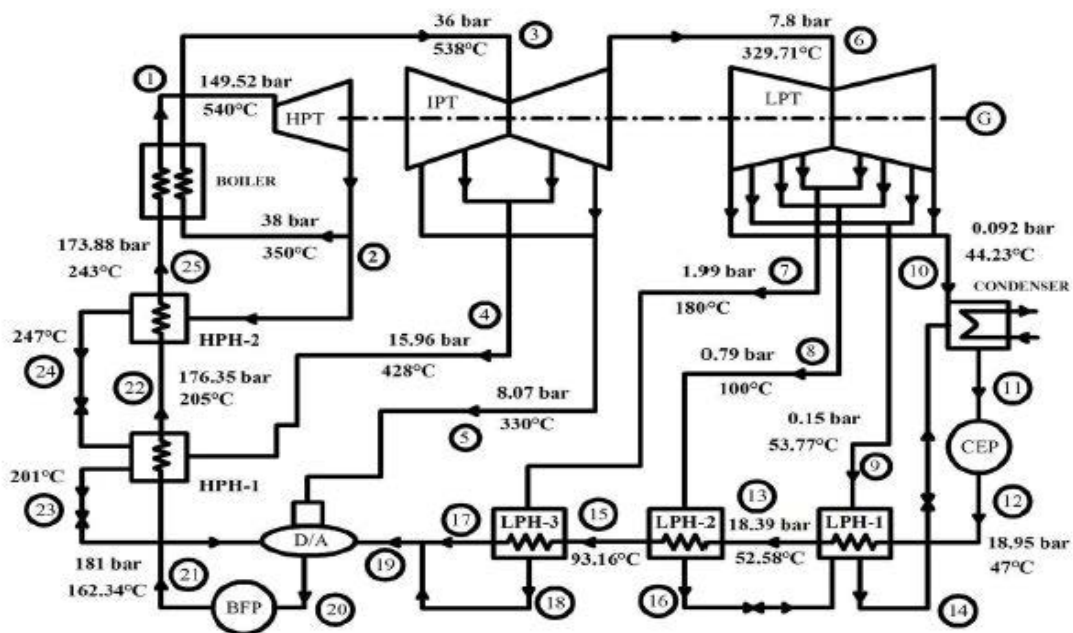

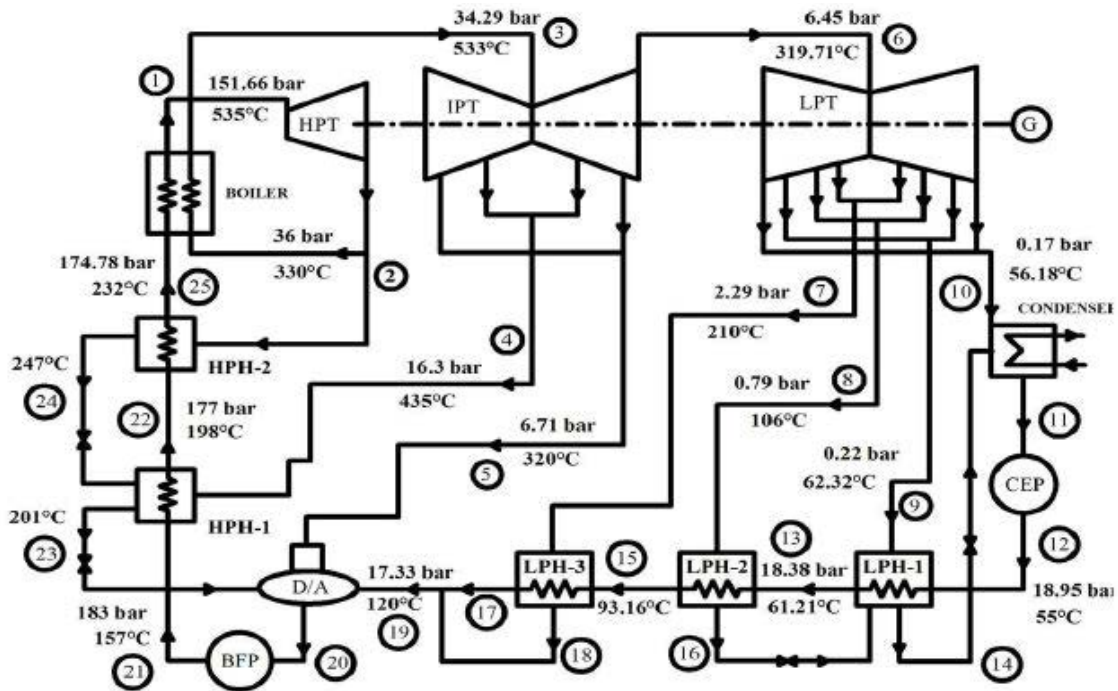**Figure 1:** Schematic diagram of operating power plant at full load.

Figure 2: Schematic diagram of operating power plant at part load.

Mill reject loss, Radiation loss, sensible heat loss in bottom ash, fly ash loss and duct ash [4].

Turbine efficiency

Turbine efficiency is the ratio of sum of the actual work done to the sum of isentropic work done of the power plant cycle. Mathematically turbine efficiency is given by:

$$\text{Turbine Efficiency}(\eta T) = \frac{Wat}{Wit} \times 100\% \qquad (5)$$

Total actual work done of turbine (*Wat*) is sum of the actual work done of high pressure, intermediate pressure and low pressure turbines determined on the basis of actual enthalpy drops in different stage and reducing mass flow rates. Total isentropic work done of turbine (*Wit*) is sum of the isentropic work done of high pressure, intermediate pressure and low pressure turbines [5].

Overall station efficiency

It is the ratio of the electrical energy sent out to the grid to the heat energy of the fuels fired in boiler [5].

$$\text{Overall Efficiency} = \frac{\text{Load available at generator terminal}}{\text{coal flow} \times \text{GCV}} \qquad (6)$$

Heat rate

Heat rate is the ratio of the heat added to steam in boiler to the electrical energy sent out to the grid. The unit of heat rate kJ/kWh or kcal/kWh. In other words, the heat rate is defined as the heat input to the working substance in boiler required producing one unit of electricity.

$$\text{Heat Rate}(HR) = \frac{\text{heat added to steam in boiler}(\text{kJ})}{\text{electrical energy sent out}(\text{kWh})} \qquad (7a)$$

$$\text{Net cycle heat rate} = \frac{\text{heat added to steam in boiler}}{\text{Net cycle work output}} \qquad (7b)$$

Specific fuel consumption (SFC)

It is defined as the amount of fuel consumed per unit of output (power developed) per hour. It is clear indication of the efficiency with which the plant develops capacity (power) from fuel [8].

$$SF = \frac{\text{Fuel consumed in kg / h}}{\text{Power developed in kW}} \qquad (8)$$

Results

Table 3 shows the results which are calculated at the operating conditions of the steam power plant at full load of 210 MW and part load of 195.86 MW.

Discussion and Recommendations

Several technical factors affect the amount of CO_2 emissions from power plants. These include coal type, boiler efficiency, excess air etc. Therefore, for improvements in plant efficiency, it is desirable the operational levels are close to the design levels of parameters. However, that is not the case for several power plants in India. For instance, in a survey carried out by the Indo-German Energy Network, it was found out that almost 25% of the 210 MW units operated at a boiler efficiency of less than 80% and almost 42% of these operated at less than 82% boiler efficiency. Similarly, close to 22% of the 210 MW units operated with an auxiliary consumption of more than 10%. Due to these factors, higher amount of losses occur, which lead to more coal consumption and therefore higher CO_2 emissions. Thus, most old units should be renovated and modernized to achieve higher efficiency [9].

According to losses in boiler it is concluded that dry flue gas loss is within the design range at part load but at full load it deviates. Moisture in fuel loss and H_2 in fuel loss is not in the desired range. Therefore boiler efficiency deviates from the design value. Other losses are little bit near to design value. Unburnt carbon loss also reduces the boiler efficiency.

Comparison between the actual performance and design conditions would be important to evaluate whether the plant is operating according to the design conditions or not. Itemized comparison of various boiler loses is done below. Boiler performance is tabulated below and the deviations are discussed. Summary of results shown in Table 3 is given in Table 4 below.

In the Table 4, design condition of steam generator is recommended by American Society of Mechanical Engineers performance test codes-4 (PTC-4). This Code provides rules and instructions for conducting performance tests of fuel fired steam generators. PTC 4, on Fired Steam Generators, is the ultimate comprehensive document for defining, calculating and testing for the efficiency of Fired Steam Generators by the Energy Balance Method as well as other significant performance parameters. A major feature of the Code is that it includes the methodology for correcting test conditions to guarantee/reference conditions based upon actual unit performance [10].

Actual various losses of boiler at full and part loads are compared with the ASME PTC 4. After that it has concluded whether they are satisfactory or unsatisfactory.

Reasons of higher boiler losses

Though the losses in the boiler are not completely preventable, but they can be minimized but before minimizations of losses, there is need to find the critical area where these losses are maximum so that maximum savings can be done. Some of reasons for higher boiler losses are explored and discussed below.

Dry flue gas loss: Flue gas temperature at the boiler exit is 1550C as against design value of 1400C and incidentally oxygen content at APH outlet is 5%, which is much higher than design value of 3.2% at full load. These factors increase the losses at full load. But these parameters are within the design range at part load. Also the excess air at full load is 31% whereas at part load it is 22%, therefore, loss at full load is more as compared to part load.

Wet stack loss: Wet stack loss is because of moisture and hydrogen in fuel. The total moisture in the coal is 8% as against design value of 6.17% at full load and the total moisture in the coal is 12.5% as against design value of 7.5% at part load. Hydrogen content is slightly deviating from design value. This loss could be reduced by reducing moisture content in the coal as follows.

- Coal must be dried before reaching the combustion chamber so that moisture does not enter the combustion chamber.
- Proper amount of secondary air should be supplied for proper combustion.
- Consistent quality coal by blending the proper mixing to achieve a minimum range of variation in calorific value, volatile matter and moisture.

Unburnt carbon loss: It is observed that unburnt carbon loss is higher than the design value because of unburnt carbon in bottom ash is 3% higher than the design value at full load. But at part load, unburnt carbon fly ash is 1.2% as against design value of 0.4%. It could be due to poor mill performance and less secondary air for proper combustion due to heavy air leakage from the air heater. This loss should be maximum 1.5% on a better run unit. This loss can be controlled by controlling air supplies and assessing air ingress to mills. This loss can also reduce by proper washing of the coal can reduce the percentage of ash in the coal.

Parameter	Full Load	Part Load	Unit
Dry flue gas loss, %	5.29	4.32	-
Moisture in fuel loss, %	1.56	2.03	-
H2 in fuel loss, %	4.386	5.54	-
Unburnt carbon loss, %	1.603	1.382	-
Unaccounted Loss, %	1.245	1.22	-
Boiler efficiency, %	85.91	85.51	-
Turbine efficiency, %	88.30	88.05	-
Overall efficiency, %	34.34	30.21	-
Gross cycle heat rate	7493.28	7659.95	kJ/kWh
Specific fuel consumption	0.69	0.66	kg/kWh
Energy lost per annum	3.66×10^{10}	1.2×10^{11}	kJ
Extra coal consumption/year	2681	7519	tons
Annual extra loss of electricity	53.62×10^6	62.65×10^6	units

Table 3: Summary of results.

Parameters	Full Load	Part Load	Design condition	Conclusions
Losses	%	%	%	
Dry flue gas loss	5.29	4.32	4 - 5	Satisfactory at part load; unsatisfactory at full load
Moisture in fuel loss	1.56	2.03	0.5 - 1	Unsatisfactory
H$_2$ in fuel loss	4.386	5.54	3 – 3.5	Unsatisfactory
Unburnt carbon loss	1.603	1.382	1	Unsatisfactory
Unaccounted Loss	1.245	1.22	Max.1.5	Satisfactory

Table 4: Comparison of various boiler losses.

Conclusions

Performance of the coal based power plant, like boiler efficiency and specific fuel consumption reduces with time, due to poor combustion, heat transfer fouling and poor operation and maintenance. Deterioration of fuel quality and water quality also leads to poor performance of plant. Efficiency testing helps us to find out how far the boiler efficiency drifts away from the best efficiency. Any observed abnormal deviations could therefore be investigated to pinpoint the problem area for necessary corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a pre requisite for energy conservation action in industry.

The purpose of the performance test is to determine actual performance and efficiency of the boiler and compare it with design values or norms. It is an indicator for tracking day-to-day and season-to-season variations in boiler efficiency and energy efficiency improvements.

On the basis of results and discussion done in previous articles, the performance of a coal based power plant at full and part loads is compared with the design values and deviations have been found.

Because of deviation of actual efficiency from the design value, the coal consumption increases, power produced decreases, and there is corresponding monetary loss during the operation of the power plant. These quantities are given below for full load as well as on part load.

Following conclusions are drawn at full load of 210 MW coal based thermal power plant on the basis of the results given in the Table 2.

The design boiler efficiency is 86.1% while the actual efficiency 85.91%. Thus, the deviation from design value is 0.19% due to which 3.66×10^{10} kJ of energy is lost per year at full load.

1. Approximately 2681 tons of extra coal is consumed per year and corresponding to this around 6.7 million rupees are lost due to deviation in boiler efficiency from the design value.

2. Specific fuel consumption (SFC) is 0.69 kg/kWh as against design value of 0.64 kg/kWh due to which 53.62×10^6 units are wasted.

3. Around 18.77 crores rupees are losses in profit due to deviation in SFC from the design value.

Following conclusions are drawn at part load of 195.85 MW coal based thermal power plant on the basis of the results given in the Table 3.

Boiler efficiency deviation from design value is 0.59% due to which 1.2×10^{11} kJ of energy is lost per year at part load.

1. Approximate 7519 tons of extra coal is consumed per year and corresponding this around 18.8 million rupees are lost due to deviation in boiler efficiency from the design value.

2. Specific fuel consumption (SFC) is 0.66 kg/kWh as against design value of 0.54 kg/kWh due to which 62.65×10^6 units are waste.

3. Around 21.93 crores rupees are losses in profit due to deviation in SFC from the design value.

It is clear from above result and conclusions that, beside the revenue loss at part load operation, there is an annual monetary loss of 19.44 crores at full load and 23.81 crores at part load. Therefore it is better to run this power plant at full load.

On the basis of performance of coal based power plant it can be concluded that a significant amount of energy is going as a waste and a large amount of money is lost. Therefore, it is highly desired to check the performance of power plant at regular interval so that boiler losses as well as the specific fuel consumption can be monitored for satisfactory performance of the power plant.

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