Efficiency assessment and improvement measures for thermal power plant in India

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Abstract. Usage of conventional energy resources has high limitations and constrains now a days. The thermal efficiency of the equipments in the modern thermal based power plant is mandatory for effective power generation with low production cost and pollution. The systems and equipments in the thermal power plant should be operated with optimum efficiency. An assessment of these system performance and comparing it with the design value is necessary for its improvement. This paper presents the findings of the observations and trials carried out on thermal power plant energy equipments. The main objective of this work is to assess the performance of various thermal power plant systems in respect of efficiency and determining the main factors which contribute to the efficacy of the power plant by indirect method. Further, suitable measures are recommended to enhance the energy performance with cost benefits. While making the measurements, care is taken to maintain the accuracy and wherever any discrepancy is found, the readings were again taken to ensure the best possible results.

Keywords: Conventional energy, Thermal power plant, Indirect method
1. Introduction

Thermal power plants play the major role in electricity production in India. Performance assessment and consecutive improvement measure can lead to large contribution in monetary terms, which can be further exploited for capacity addition [1]. In the past period of time the power plant efficiency saw a surge from around 5-45%. The growing cognizance about the greenhouse gases further encourages the efficiency enhancement in the thermal power plants [2]. The efficiency of the power plant gradually deteriorates over a period of time. Retrofits can significantly increase the performance of older power plants. The maximum efficiency can be attained by regular monitoring and control of the sources where the energy loss takes place by appropriate methods [3]. The various losses in the components of the thermal power plant are assessed to identify the process irreversibility [4]. Researchers assessed the avoidable and unavoidable energy losses for investigating the cost associated with compressor, turbine, heat exchanger and combustion chambers [5]. Researchers proposed different energy resources to integrate with the coal based thermal power plant to enhance the efficiency such as utilizing the ocean thermal energy [6], solar power to pre-heat the feed water before the economizer of the boiler [7] and biomass for co-firing operations [8]. Research is done in various components of the coal based power plant such as boiler, turbine, condenser, etc. Among the various components of the thermal plant, the boiler plays a vital equipment and also it plays a significant role in the total efficiency of the power plant. So, the boiler is to be operated with optimal efficiency. Efficiency testing of the boiler is crucial and any deviations from the design value (norms) are easily identified and rectified [9]. Different work is proposed by researchers to assess and improve the efficiency of the boiler [10-11]. The turbine is another vital part of the thermal power plant and to enhance the efficiency different researcher proposed different techniques. An Artificial Neural Network (ANN) has been applied to control the important variables of turbine such as pressure, temperature, speed and humidity for effective operation of the turbine [12]. The condenser is yet another important system in the thermal power plant where the heat input to the condenser is just ejected into the atmosphere through the water cycle, which makes it the most inefficient part of the plant and research has been done to replace the coolant water to refrigerant which gets vaporized in the condenser section and used as a prime mover for a secondary turbine generator to produce additional electricity [13]. Before investigating different methods for energy enhancement of the power plants, certain considerations should be taken into account to minimize the energy loss in the basic stage. These energy saving precautions can avoid energy loss to a greater extent with very low investment. In this paper the performance assessment of thermal power plant in India, which has a production capacity of 1100 MW is considered and the assessment is done by indirect method where the heat losses are subtracted from 100 to assess its operating efficiency and energy savings opportunities. The performance and efficiency of the power plant is evaluated which then leads to the system optimization, simple modification and renovation of equipment. The general complications related with design, process and fuel inputs are examined and suitable solutions are recommended to improve the efficiency.

To assess the efficiency of thermal plant the various sections of the plant is considered such as boiler system, turbine system, unit auxiliaries, ash handling plant, pumping system, chiller, cooling tower, air compressor, lighting system, motor load and thermal insulation. Before the assessment of the various systems, the overall efficiency of the plant considered for a period of a year where the maximum efficiency is found to be 37.95% and the minimum efficiency is found to be 37.64% as shown in Fig. 1.
2. Efficiency assessment and recommendation of boiler system

During the assessment, the boiler is operated at 1485 tonnes per hour (TPH). The boiler efficiency trial is conducted as per the running load and the readings of all the parameters were recorded for a period of 3 hrs. Efficiency study involves in quantification of all the losses inherent to the boiler system and accordingly operating efficiency is calculated. During the trials, the key parameters, namely unit load, coal flow, coal analysis total air flow, combustibles in bottom ash and fly ash, flue gas analysis were recorded. The sample of fuel and ash is sent to the proximate analysis to the in-house chemical laboratory. During the trials, all relevant parameters, namely, coal, air, flue gas, water and steam were collected and efficiency assessment is carried out. The various losses of the boiler and its percentage in the overall boiler loss is shown in the table 1. The overall efficiency of the boiler is 88.25 and the remaining percentage is encountered as losses.

Table 1 Boiler losses and its percentage

| S No | Description                        | Calculation                                                                 | Energy loss in percentage |
|------|------------------------------------|-----------------------------------------------------------------------------|---------------------------|
| 1    | Unburnt carbon losses              | Total combustibles (Combustibles in fly ash + Combustibles in bottom ash) x Calorific value of coal | 0.82                      |
| 2    | Heat loss due to dry flue gas      | $\left[ 24 \times \text{Dry flue gas} \times (\text{flue gas temperature(FGT)} - \text{combustion air temperature (CAT)}) \right] / \text{Higher heat value (HHV) of fuel}$ | 6.05                      |
| 3    | Heat loss due to moisture in fuel  | $M \times [584 + C_p \times (T_f - T_a)] \times 100 / \text{GCV}$          | 0.71                      |

M - kg of moisture in 1kg of fuel
$C_p$ - Specific heat of superheated steam (0.45 J/K/kg°C) 584 is the latent heat (J/kg) corresponding to the partial pressure of water vapour
|   |   |
|---|---|
|4  | Heat loss due to burning of hydrogen |
|   | $T_f$ - Flue gas temperature |
|   | $T_a$ - Ambient air Temperature |
|   | GCV – Gross calorific value |
|   | $[900 \times (h_g - h_f)] / \text{HHV}$ |
|   | $h_g$ (Specific enthalpy of saturated vapor) = $1055 + (0.467 \times \text{FGT})$ |
|   | $h_f$ (Specific enthalpy of saturated liquid) = $\text{CAT} - 32$ |
|5  | Heat loss due to moisture in air |
|   | AAS x humidity Factor x $C_p$ x $(T_f - T_a)$ x 100 / GCV |
|6  | Heat loss due to sensible heat of bottom ash |
|   | Total ash collected per kg of Fuel Burnt x GCV of bottom Ash x 100 / GCV of fuel |
|7  | Heat loss due to sensible heat of fly ash |
|   | Total ash collected per kg of Fuel Burnt x GCV of Fly Ash x 100 / GCV of Fuel |
|8  | Heat loss due to radiation and convection |
|   | Obtained from the standard chart available from the American Boiler Manufacturers Association (ABMA) |

The various losses in the boiler such as heat loss due to dry flue gas, heat loss due to burning of hydrogen in fuel, heat loss due to moisture in fuel, heat loss due to moisture in the air, unburnt carbon loss, heat loss due to sensible heat of bottom ash and heat loss due to radiation and convection are calculated.

It is observed from the figure 2 that the dry flue gas loss is a majority of all losses and this can be controlled by reducing the combustion air. This loss can also be controlled by keeping air leakage or ingress across ash handling.
plant (AHP) to a significant extent and ascertaining that the air supplied by the force draft fan (FDF) is fully utilized for combustion. Second major loss is the heat loss due to water evaporation due to hydrogen in the fuel, this loss is purely depends on the fuel composition and have no relevance to the operations of the boiler. Third major loss is heat loss due to moisture in the fuel and mainly incurred due to usage of high moisture content in the fuel. All though the coal quality is good and moisture present in fuel also is less compared to design coal values. All the other losses are inevitable and incurs due to various factors. It has been observed that the boiler efficiency is 88.25% as against the design efficiency of 89.02%.

The flue gas analysis is carried out at various locations in the flue gas path to arrive at the composition and temperature and in-leakage profile across the respective locations.

3. Efficiency assessment of turbine system

Steam turbine with a surface type condenser is used in the power plant and to assess the performance of the turbine, the various components are evaluated such as condenser, turbine heat rate and high pressure (HP)/Intermediate pressure (IP) of cylinder efficiency. The Table 2 shows the efficiency calculations of various parameters of turbine system.

| S No. | Description                          | Efficiency calculation                                      |
|-------|--------------------------------------|-------------------------------------------------------------|
| 1     | Condenser Performance                | Qc = m_w x C_p x Δ_t                                        |
|       |                                      | Qc - Heat rejected in condenser through circulating cooling |
|       |                                      | water (kCal/h)                                              |
|       |                                      | m_w - water flow rate (kg/h)                                |
|       |                                      | Δ_t - Average CW temperature rise (T_OUT – T_IN )            |
|       |                                      | T_OUT – CW outlet temperature (°C)                           |
|       |                                      | T_IN - CW inlet temperature (°C)                             |
| 2     | Turbine Heat Rate                    | W_s x c x Δ_t                                               |
|       |                                      | W_s – Steam flow                                            |
|       |                                      | c – Specific heat capacity                                  |
|       |                                      | Δ_t – Temperature difference                                |
| 3     | HP and IP cylinder efficiency        | Actual enthalpy drop / Isentropic enthalpy drop             |

The condenser performance is found to be 53% and to calculate the turbine heat rate the relevant parameters of the steam turbine (Main steam Pressure, Temperature, Flow, Cold reheat pressure, Temperature, Hot reheat pressure, Load etc.) were recorded for a period of 3 hours and the turbine heat rate are found to be 1944.5 kCal/kWh. The condenser is a water-cooled type with natural draft cooling tower. The design inlet water temperature of the condenser is 36 °C, at a turbine exhaust steam pressure of 0.107 kg/cm²a, saturated steam temperature of 46.75°C at Turbine Continuous Maximum Rating (TMCR) of 1496.8 TPH.

It is found that the terminal temperature difference (TTD) of water cooled condenser (WCC) (steam saturation temperature - water outlet temperature) in as-run conditions is at 7.97°C at 30.7 °C inlet cooling water temperature, 39.9 °C outlet temperature, condenser vacuum of 0.113 kg/cm²a against the design value of 0.75°C at 36 °C inlet CW temperature, 46 °C outlet cooled water temperature, condenser vacuum of 0.107 kg/cm²a. This occurrence of high TTD and lower vacuum in spite of lower than design cooling water inlet temperature could be due to, condenser
leakages, reduced heat transfer effectiveness due to scale and fouled heat transfer area and drop in ejector performance. It is envisaged that a TTD of 5 °C should be targeted for, in day to day operations, which could enhance the unit output by around 1.66 MW. It is recommended to carry out helium leak test on condenser and rectify any leakages. Further, improving the heat transfer effectiveness by ensuring clean and unscaled/unfouled heat transfer area of chemical descaling treatment to remove the existing deposits. Incorporate the online condenser cleaning system is preferred.

4. Efficiency assessment of unit auxiliaries

Performance assessment of key plant auxiliaries is conducted and the auxiliaries include primary air (PA) fans, forced draft (FD) fans, induced draft (ID) fans, mills and pumps. The operating efficiencies of the PA, FD and ID fans were found by measuring various parameters such as flow, static head at the suction and discharge and their respective motor power consumption. The overall efficiency of the PA and FD fans is around 52 % and ID fan is 58%. The coal milling system is a critical area relating to plant operation and utmost care is accorded to their upkeep and operation. Measurements were undertaken to assess the performance of the mills and associated subsystem, this includes electrical measurements (kW, PF, Amps, and V) of operating mills. It is observed that the specific energy consumption of mill is in the range of 9.38 - 12.28 (kWh/Ton). To assess the performance of the pump, the electrical as well as flow parameters has been looked into and the overall efficiency is found to be 75.62 %.

The combined efficiency of the fans is lower at 52% as against 76% design value. The reason behind the poor performance of the fans are due to part loading and inefficient damper control for flow modulation. The pressure drop across the damper is a direct energy loss. This loss can be eliminated by the adoption of Variable Frequency Drive (VFD). VFD installation would also aid flow modulation without much reduction in head required, at the same time this does not create any artificial drop unlike damper.

Three condensate extraction pumps (CEP’s) with the rated capacity of 900kW are installed and normally two CEP’s are operated. The total power consumption of the two CEP’s is 1279 KW. The operating discharge pressure is 28kg/cm², whereas the de-aerator pressure is only 9.55 kg/cm² indicating a pressure drop of more than 13 kg/cm² in the control valve. It is suggested to remove one operating CEP in one stage. Even after removal, the expected pressure developed by CEP is 22 kg/cm², which is sufficient to pump feed water to the deaerator. The estimated savings would be 16.6%, worth in annual energy savings of 16 lakhs kWh.

The cooling water pumps are designed to deliver a flow rate of 19500 m³/hr at 23.5 m head and design pump efficiency is 84%. Presently pumps are operated at the efficiency from 49 to 71%, which is low compared to design and energy savings can be obtained by applying corrocoating for pumps to improve the pump efficiency. The expected efficiency improvement in pumps after corrocoating is to be 3%.

5. Efficiency assessment of pumping system

The performance of the water pumps is assessed by the measurement of flow, head and motor power. The pumps such as booster pumps, raw water pumps, fuel oil pumps are considered for performance assessment. The overall efficiency of booster pumps is found to be 67%, raw water pump efficiency is 68% and fuel oil pump is found to be 44%. The booster pumps are designed to deliver a flow rate of 1273 m³/h at 120m head, but operating at an average flow rate of 1442 m³/h at head 102 m. The higher flow rate measure Vs designed flow is due to less operating, which leads to shift in the performance curve of the pumps away from break even point (BEP) thus pumps are operating at a lesser efficiency against the design. Significant savings can be obtained by applying corrocoating for pumps to improve the pump efficiency. The expected efficiency improvement in pumps after corrocoating is to be 3%.
6. Efficiency assessment of chiller

Air conditioning is used to provide comfort and desired working conditions for the control rooms and office space, etc. The efficiency of chiller is determined by the relation \( M \times C_p \times (T_1 - T_2) / 3024 \); where, \( M \) - Water flow rate \( \text{m}^3/\text{hr} \), \( C_p \) - Specific heat of water, i.e. 1 kCal/kg °C, \( T_1 \) - Water inlet temperature, °C, \( T_2 \) - Water outlet temperature, °C and the overall efficiency is found to be 25%. There are three no’s of vapor compression refrigeration (VCR) chillers, each of 160 tons of refrigeration (TR) are installed and out of 3 chillers two is operated. Performance study revealed that both the chillers are running in part load. Operating TR of the chiller is 43 TR (25%) and 76 TR (50%). The specific energy consumption of chillers alone is 0.70 and 0.89 (kW/TR). For each chiller one chilled water and condenser pump is running. There is a possibility to switch off one chiller and run only one chiller to further reduce chiller statistical process control (SPC) and overall SPC of the system. After switching off one chiller the total TR load will be shifted to one chiller which is 119 TR (75%) so still there is 25% further loading can be done.

7. Efficiency assessment of cooling tower

Different parameters measurement is conducted to assess the performance of cooling tower such as the cooling water flow, wet and dry bulb temperature and cooling water pump performance. The efficiency of cooling tower is calculated by \( [(\text{Range})/(\text{Range} + \text{Approach})] \times 100 \), where, Range (°C) = Cooling water (CW) inlet temperature for cooling tower (CT) - CW outlet temperature from CT and Approach (°C) = CW outlet temperature from CT - Wet bulb temperature. The effectiveness of the cooling tower is 76.89%, which is a satisfactory value.

8. Efficiency assessment of air compressor

The plant has separate air compressors for plant air system and instrument air system. The instrument air compressed system is used for control systems, solenoid valve operations, etc. and the service air compressed system is used for atomization, cleaning, maintenance, general service applications, etc. The main plant compressed air system comprises of two instrument air compressors operate parallel in tandem, between an operating discharge pressure window of 7.1 kg/cm² to 8.1 kg/cm², (ie., the air compressor cuts in at 7.1 kg/cm² and cuts out at 8.1 kg/cm²). The instrument air from the compressor at 7 kg/cm² is finally used at all end-users at less than 4 kg/cm² through FRL (filter - regulator - lubricator) side control. It is recommended to rationalize the compressor cut-in and cut-out pressure settings from existing 7.1 kg/cm² cut-in and 8.1 kg/cm² cut-out to 6.0 kg/cm² cut-in and 7.0 kg/cm² cut-out and thus avoid downstream throttling. The mean generating pressure reduction will be 1.10 kg/cm².

9. Efficiency assessment of lighting system

Extensive study of lighting is conducted during the course of study in the following areas such as control rooms, workplaces, boiler area, turbine area, pump houses and chiller area. The lighting fixtures installed in the plant are FTLs (Fluorescent Lamp), MVs (mercury-vapor lamp), SVs (Special Vehicle Lights) and LEDs (Light Emitting Diode) for indoor and outdoor lighting. FTLs and MVs fixtures have low efficacy. Already plant has replaced few of the lamps to LEDs so suggested to replace the remaining lamps to LEDs to achieve energy savings. There are about 4074 no’s of 36 W FTL. It is recommended to replace these 36W FTL’s with LED tube lights in a phased manner.
10. Efficiency assessment of motor load

From the motor load survey, it is seen that most of the motors are drawing power between 50 to 90% of their rated capacity, which is a good sign of good maintenance practices.

11. Efficiency assessment of thermal insulation

The infrared thermal scanning of equipment having high surface temperature areas is carried out on hot surfaces including boiler, steam turbine, and steam pipe lines to identify hot spots/heat loss areas towards insulation review/upgrades. The thermography scanning is carried by infrared thermal imager. All the hot zone temperatures greater than 65°C were noted down for further analysis. The heat losses were calculated only for those areas, where the temperature is higher than recommended norm. The formula used for heat loss estimation is given as  \( Q = \left(10 + \frac{(T_s - T_a)}{20}\right) \times (T_s - T_a) \) in kCal / m²/hr where, \(T_s\) = Surface temperature in °C, \(T_a\) = Ambient temperature in °C, Heat loss = \(Q \times \) Area of the surface (m²) and the heat loss are found to be 70,563kCal/hr. It is recommended to improve the insulation level in the heat loss areas in order to minimize steam and subsequent fuel savings.

12. Conclusion

The overall efficiency of the thermal power plant is calculated by multiplying the thermal efficiency with the electrical efficiency. The key step to enhance the efficiency of the thermal power plant is the detailed study of the plant and then the efficiency calculation. The efficiency calculation by indirect method is the best way to account all the losses in the thermal power plant. From the detail study the following conclusions can be made:

- The dry flue gas loss is a majority of all losses in the boiler and this can be controlled by decreasing the dry gas. This is achieved by optimizing the amount of oxygen in the flue gas. Quality burners and accurate combustion are necessary for good results.
- In the condenser section it is recommended to carry out helium leak test and rectify any leakages. Further, the surface should be unsealed/unfouled to remove the deposits and achieve the effective energy transfer.
- Corroding and optimal design of pumps such as providing the accurate clearance inside the pump can improve the efficiency and also significant savings can be obtained by replacing pumps with energy efficient pumps.
- Optimal utilization of chiller plant can improve energy savings to a greater extent.
- It is recommended to replace these FTL’s with LED tube lights in a phased manner to optimize the energy utilization.

13. Reference

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