PERFORMANCE BASED COMPARATIVE ANALYSIS OF THERMAL POWER PLANT: A REVIEW

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Abstract
Coal based thermal power stations are the leaders in electricity generation in India. In this paper, the author attempts to investigate the gap between demand & supply and cost reduction in order to make the existing power plants more efficient. Efficient power generation is expected to make more power available at a lower cost for economic and other activities, which in turn shall make the country more competitive. The focus of the study is on the coal fired thermal power plants in the country. The performance calculation and rectification measures are essential for performance evaluation and efficiency enhancement.

Keywords: Thermal Power Plant, Performance Evaluation, Efficiencies, Energy

1. Introduction
Electricity is essential in the economic development of any nation. Due to rapid growth of economy and industrial development in India, the demand for use of electricity has increased rapidly. Power generation capacity in India is 70 percent thermal, with the remaining being hydro and nuclear. Thermal generation is mainly based on steam generation using a coal-fired boiler. Power Plant play very important role in improving the economic condition, competitive advantage, lifestyle, so on, of people in any country. Many research studies have been carried out on specific subsystems of the Power Plant, for example, turbine, boilers and turbo generators, in a bid to improve the reliability, safety, security, efficiency, productivity, and availability of the subsystems individually and therefore of the plant as a whole. Some researchers have tried to develop models for subsystems working in series/parallel combination. Commercial software for evaluating the performance of a subsystem is also available. The authors are, however, not aware of any study that integrates all the subsystems and systems of a power plant.

It has been shown by a number of researchers that the performance of any system is a function of the structure of the system. The understanding of the structure, that is, system and connectivity between different systems and down to component level, is useful for estimating the contribution of different attributes of the performance of the system. Any Production system should be kept failure free (as far as possible) under the given operative conditions to achieve the set goals of economical production and long run performance. A highly reliable system tends of increases the efficiency of production.

According to Behera and Dash (2010) study non-parametric Data Envelopment Analysis (DEA) to estimate the relative technical efficiency and scale efficiencies of coal-based power plant in India. Distribution of the less efficient plants in different sectors, regions, their peer groups and the return to scale properties are analysed [1].

Behra et al. (2009) attempts to investigate to estimate the relative performance of the coal fired power-generating plants in India and explore the key determinants of the inefficient units [2].

Chitkara (1999) applied Data Envelopment Analysis (DEA) to evaluate the operational inefficiencies of generating units. Three parameters viz. generation per unit of coal consumed, generation per unit oil consumed and generation per unit of auxiliary power consumption have been considered as indicators of performance [3].

Shanmugar and Kulshreshtha (2005) employ the stochastic frontier production function methodology for panel data to measure the technical efficiency (TE) of coal-based thermal power plants [4].

Mohan et al. (2003) developed a methodology for optimum selection, benchmarking sensitivity analysis, plant modification-replacement/reconfiguration, maintenance strategy analysis, selection and outage planning, and performance [5].

Gupta et al. (2009) discusses the development of a Markov model for performance evaluation of coal handling unit of a thermal power plant using Probabilistic approach. Coal handling unit consists of two subsystems with two possible states i.e. working and failed. This developed model helps in comparative evaluation of alternative maintenance strategies.
Gupta and Tewari (2009) discuss the stochastic analysis and performance evaluation of condensate system of a thermal power plant. On the basis of this study performance of each subsystem of condensate system is evaluated and then maintenance decisions are made for subsystems.

Gupta and Tewari (2009) developed a Probabilistic model, considering some assumptions. The proposed model provides an integrated modelling and analysis frame work for performance evaluation of the flue gas and air system of the thermal plant [6-8].

Mandal (2008) highlights some of design improvements which target reduced emissions and expanded operability, and explores some of the boiler implications for the ultra-supercritical conditions, needed to achieve the high cycle efficiencies for the future [9].

Prasad et al. (1999) developed a simulation for investigation purposes. The twin key aspects of the performance monitoring, i.e. monitoring of performance indices and controllable parameters are addressed in more effective and novel ways [10].

Liu et al. (2010) results show that the most important variable in the DEA model is the “heating value of total fuels”. Finding from this study can be beneficial in improving some of the exiting power plants and for more efficient operational strategies and related policy-making for future power plants [11].

Gupta et al. (2009) discusses performance evaluation of the steam and water system in a thermal power plant, with the help of developed probabilistic model. The system consists with two possible states: working and failed [12].

Garg et al. (2007) presents a computational methodology for a computer – based solution to the problem of evaluation and selection of an optimum power plant. This methodology is named as multiple attribute decision making (MADM) methodology and consists of elimination search and technique for order preference by similarity to ideal solution (TOPSIS) approach [13].

Look and Saur, (1986) presents that the evaluation of the performance of a thermal plant is geared basically towards the determination of the energy efficiency of the plant. A plant’s energy efficiency has definite economic significance since the heat input at high temperature represents the energy that must be purchased (oil, natural gas, etc) and the net energy output represents the returns for the purchase [14].

Utgikar et al, (1994) discussed that energy plays a vital role in a country’s economic development and it is expected to be more significant in the coming years due to increasing demand, consequently, energy conservation and efficient use of energy becomes a major supply option [15].

This paper aims at the determination of the performance of thermal plant, with the intent of appreciating those conditions favourable or unfavourable for good performance as might be common to all thermal plants of its kind, as well as such conditions that might be unique to India, also, to suggest possible means of ensuring improvements. The performance is discussed based on the plant’s overall efficiency, boiler, thermal and turbine efficiencies. An estimated overall efficiency is compared with a calculated overall efficiency.

2. Methodology

It has been observed that an energy analysis was carried out on the system as a whole as well as on the major components of the plant i.e. the boiler, turbine, and condenser. Information on the following parameters was used for the analysis of power plant [16].

i. Gross energy generated (MWH)
ii. Energy used in the plant (MWH)
iii. Energy sent out (MWH)
iv. Fuel Coal consumed (MT)
v. Running hours (hrs)
vi. Equipment availability
vii. Total number of forced and planned outages.
viii. Conditions responsible for forced outages.

Other data acquired from the plant include:
ix. The unit heat rate (KJ/KWH)
x. The unit net heat rate (K/KWH)
xi. Generator efficiency.
2.1. Assumptions [16]

As per literature survey, the following assumptions are considered for the efficient operation of power plant.

1. Net heat rate in KJ/KWH was taken to be equal for all the units in operation.
2. The thermodynamic parameters at the various state points are the same in all the units in operation.
3. In calculating the boiler and turbine efficiencies, the enthalpies at the relevant state points were taken to be equal to the initial values based on the commissioning energy balance.
4. Heat rate equals the initial value based on the commissioning energy balance.
5. Plant operated at maximum continuous rating throughout the period in review.
6. Generator efficiency is constant at 98%.
7. Efficiency is taken to be constant.

2.2. Constraints & limiting factors

1. Poor record keeping practice.
2. Constant fluctuation and irregularity of plant loading due to the constant fluctuations in the transmission efficiency of the national grid as controlled by the national control centre.
3. Breakdown of equipment.

2.3. Performance evaluation [16]

Energy analysis of the thermal plant involves the following calculations

**Estimated overall efficiency**

\[ \eta_{oe} = \frac{\text{Energy transfer to fluid}}{\text{Fuel energy Consumed}} \]  

(1)

**Boiler efficiency**

\[ \beta = \frac{\text{Heat transfer to fluid}}{\text{Fuel Energy Consumed}} \]  

(2)

Heat transfer to fluid is calculated as net heat rate (KJ/KWh)*Gross energy generated (KWh)

**Internal turbine efficiency**

\[ \tau = \frac{\text{Heat drop in turbine}}{\text{Net energy sent to turbine}} \]  

(3)

Where,

Heat drop in turbine = \([H_1-H_2] + [H_3-H_4]\)*Running time (hrs) per unit available

\[ H_1 = \text{Total heat of Steam at the stop valve (KJ/H)} \]
\[ H_2 = \text{Total heat of Steam to reheat (KJ/H)} \]
\[ H_3 = \text{Total heat of Steam to turbine from reheated (KJ/H)} \]
\[ H_4 = \text{Total heat of Steam at exhaust (KJ/H)} \]

Net heat energy sent to the turbine = net heat rate* gross energy generated per unit available

**Condenser effectiveness**

\[ C = 1 - \exp(-Ntu) \]  

(4)

Where,

\[ Ntu = \frac{t_2-t_1}{\text{LMTD}} \]

T1 = Inlet temperature of condenser cooling water (°C)
T2 = Outlet temperature of condenser cooling water (°C)
LMTD = Logarithmic mean temperature difference
Thermal efficiency

\[ \eta_t = \frac{3412}{\gamma \cdot \text{heat rate}} \]  
(5)

Where, \( \gamma \) = generator efficiency
Heat rate is in Btu/Kwh, 1 Kwh = 3412 Btu

Calculated overall efficiency

\[ \eta_{oc} = \eta_t \cdot \beta \cdot \tau \cdot \gamma \]  
(6)

The estimated overall efficiency, \( \eta_{oe} \), would be compared with the calculated overall efficiency, \( \eta_{oc} \), using statistical testing.

\[ T = \frac{X - \mu_o}{s/\sqrt{n}} \]  
(7)

Where, the mean estimated overall efficiency \( \eta_{oe} \) is taking as our hypothesis (null hypothesis, \( \mu_o \)). We shall accept the hypothesis if the test suggests that it is true, except for a small error probability, \( \alpha \), called the significance level of the test, otherwise the hypothesis is rejected. Where,

\[ X = \frac{1}{n} \sum_{j=1}^{X} \]  
\[ S^2 = \frac{1}{(n-1) \sum_{j=1}^{1/(X_j-X)^2}} \]

Using the t-distribution with \( n-1 \) degrees of freedom (\( n \)=number of years under consideration). \( X \) and \( S \) are the mean and standard deviation respectively of the calculated overall efficiency. Choosing a significance level of 5% (\( \alpha=5\% \)) from the t- distribution table, we obtained a critical value, \( \alpha \), such that,

\[ P(T \leq \alpha) = \alpha = 5\% \text{ or } P(T \leq \alpha) = 1- \alpha = 95\% \]

So that \( \alpha \) because of the symmetry of the distribution
If the hypothesis is true, we have a chance of only \( \alpha \) (=5%) that we observe a value \( t \) of \( T \) (calculated from our sample) that will fall between – \( \alpha \) and \( -\alpha \). Nevertheless we do observe such a \( t \), we assert that the hypothesis (mean estimated overall efficiency) cannot be true and we reject it. Then we accept the alternative (mean calculated overall efficiency). If however, \( t \leq \alpha \), we accept the hypothesis.

2.4 Discussion

From the literature review the following recommendations needs to be incorporated to improve the performance and efficiency of the plant have been made for each of the units covering maintenance and operational aspects. The recommendations have been divided into three categories viz short term, medium term and long term respectively.

The short term recommendations are those which can be implemented immediately at a low cost. These relate to improving vacuum, mill operation, boiler operation, ESP (better housekeeping, on time deashing to avoid ash carry over and electrical maintenance) etc and all other equipment and systems as are considered important for improvement of plant efficiency.

The medium term recommendations pertain to those works which can be taken up during major shut down or during overhauling. These recommendations relate to attending to coal firing system, air dampers, flue gas system, cooling towers etc.

The long term recommendations cover renovation and modernization aspects of the plant considering the available poor quality coal for power generation.

2.5 Suggestions for system improvement

By extensive literature survey and interaction with project personnel at power plants spread all over the country suggested that substantial improvements in their performance are feasible with improvements in management systems. These are indicated below which may be analyzed from case to case and unit to unit.

- Each unit should have a “Performance Monitoring schedule all Major systems in power plant including the auxiliaries (Coal handling plant, ash handling plant, water treatment plants and compressors). Monthly performance tests should be conducted to evaluate boiler efficiency, condenser performance, turbine cylinder
efficiency, LP/HP heater performance, turbine heat rate etc. These figures should be checked with the design, last month’s performance, best performance of the unit and best performance of similar other units in the station.

- Milling system maintenance and air preheated maintenance should be given the top priority based on the performance monitoring parameters and ensure timely replacement of worn out parts to ensure reliable output.
- Grid monitoring of Oxygen and CO to ensure a complete combustion and control combustion air to limit the dry gas losses.
- Installation of reliable rotary gravimetric feeders to ensure the coal quantity feed into the mill and indirectly to boiler to get an online assessment of boiler performance.
- Upgradation of C&I system to replace the obsolete technology and installation of more close loop controls to avoid manual interference.
- Major maintenance of CW system and cooling towers to achieve quality and Retrofitting of Electro hydraulic control system with auto starting of turbine system with motorized drains to meet the new grid codes and fast response to variation in demand and auto operation.
- Shift wise monitoring of operating controllable parameters and merit order operation concept to gain efficiency and availability.
- The results of monthly performance monitoring of the station should be discussed in a meeting taken by the Head of the plant and remedial action plan including action on urgent financial issues, should be decided in the meeting.
- Provision of computer software for performance monitoring, maintenance planning and for simulation studies at the plant site may be considered. Spare planning and inventory management tools to be incorporated to avoid the delay in maintenance duration and non availability of spares.
- Annual overhaul of units and auxiliaries should be done regularly based on the performance deterioration. Assessment to be made before and after to access the techno economical gain as far as possible. Activities to, be planned as far as possible on account of system demands.
- Manufacturer’s maintenance manuals for different equipments and operating guide lines should be available in plant office. Senior officers during their inspections should ascertain that the instructions of the manuals are being followed.
- Retrofitting energy efficient hydro drive system for conveyors more than75 KW capacity
- Important work instructions pertaining to particular equipments should be displayed close to the equipment at an appropriate place.
- CFD modeled ducts to reduce the duct pressure losses and implementing VVF drives to reduce the auxiliary power consumption to be incorporated to update the unit performance to meet the latest demands.
- Retrofitting dry rotary compressors with HOC (heat of compressor for regeneration) drier in place of old compressors to maintain better instrument air and service air to meet the modern pneumatic instruments.
- Retrofitting the latest development in purification like RO system etc to make quality DM water from the deteriorated input water available.
- Retrofitting the dry bottom ash system with recirculation to reduce the water consumption and utilization of bottom ash.
- Charging the auxiliary header from CRH at rated load condition to reduce the energy loss of conversion to low pressure steam.
- Utilizing the waste heat to retrofit the VAM (Vapor absorption machines) refrigeration system in place of HVAC system.
- Energy efficient lighting system to utilize the latest LEDs to reduce the life cycle cost.
- One of the major causes for the poor performance is the poor housekeeping which needs immediate attention and close monitoring by top management. It has already proven that this will reduce the maintenance cost and increase the availability.
- Establishing a separate company at loading point or a centralized location (coal conditioning company) to condition or blend the coal and supply the proper size coal (1mm to 5mm size) in ensured quality (without stones and controlled calorific value and ash content) can reduce the losses to minimum and reduce the auxiliary power consumption. They can do the blending and first grinding and separation; This Company can utilize the low calorific reject coal in the low capacity CFBC/PFBC technology and meet the heat and power requirement for coal conditioning. This will ensure reliability and availability of high capacity.
- Most efficient units and reduce the partial and force outage to minimum. Major partial outages were observed due to variation and non availability of coal for bigger capacity high efficiency units. This will reduce the high quality grinding media consumption and outage of high capacity units.

3. Conclusion
In this paper, a review on energy analysis of the thermal power station has been carried out using the methods of thermodynamic analysis by considering the ratio of energy generated per annum to the amount of the fuel consumed and the other involves products of the plants thermal efficiency and the efficiencies of the boiler,
turbines and generator. In this paper, the various performance evaluation parameters are suggested which are mentioned in section 2.3. Based on these parameters, three categories of recommendations are incorporated which are short term, medium term and long term. The short term, medium term and long term categories of recommendations suggests the overall working performance of the plant. Lesser consumption of input will not only reduce the cost of electricity generation there by enhancing the competitiveness but also make available the scarce inputs to generate more and more electricity.

**References**


