Energy & Exergy Analysis in Thermal Power Plants

Siddharth Dongre¹, Gulab Sahu²

¹Asst. Prof., Mechanical Engineering, kruti institute of technology & engineering, Raipur
Chhattisgarh swami Vivekananda University Bhilai
Siddhartha1890@gmail.com

²Asst. Prof., Mechanical Engineering, kruti institute of technology & engineering, Raipur
Chhattisgarh swami Vivekananda University Bhilai
Sahuroyalmech32@gmail.com

Abstract: The purpose of the study outlined in this is to identify major energy loss areas in india’s thermal power stations and develop a plan to reduce them using energy and exergy analysis as the tools. The energy supply to demand is narrowing down day by day around the world due to the growing demand and sometimes due to ageing of equipments. nearly all of the power plants are designed based not only on the first law of thermodynamics, for the reason that it does not distinguish between the quality and quantity of energy. The present study deal with the judgment of energy and exergy analysis of thermal power plants stimulated by coal. The project seeks to increase output from the Power Stations.

Keywords: Energy, Exergy, Efficiency, Improvement,

1. Introduction

The Asian region including India they are suffering from critical shortage of power and this has negative impact on industrial development. The expansion on the demand side resulted in over stretching of the current electricity generation capacity coupled with aging thermal plants which are still utilising old technology. The paper will focus on the energy efficiency improvement in thermal stations.

Thermal Power Stations generate electricity through a thermal power plant; its installed capacity is designed with a common range of boilers feeding into common steam receivers from where any of the turbines tape the steam. Currently only few boilers are in operation with an output of approximately 1615MW. The power plants use coal as the primary input for generating electricity. The plant use 20-30% of energy value of primary fuels and the remaining 70-80% is lost during generation, transmission and distribution of which major loss is in the form of heat. The heat rate of a plant is the amount of fuel energy input needed (Btu, higher heating value basis) to produce 1 kWh of net electrical energy output. This study was done to identify various methods to reduce the heat rate of existing coal-fired power plant in India by identifying areas that cause the most heat losses and introducing the new technologies that cater for the losses. Energy and exergy analysis is used for the identification of these losses. Energy analysis evaluates the energy generally on its quantity only, whereas exergy analysis assesses the energy on quantity as well as the quality. The aim of the exergy analysis is to identify the magnitudes and the locations of real energy losses, in order to improve the existing systems, processes or components. This study identifies specific plant systems and equipment where efficiency improvements can be realized either through new installations or modifications, and provides estimates of the resulting net plant heat rate reductions and the order-of-magnitude costs for implementation.

1.1 Aim

The main aim of the study is to identify areas where energy losses are occurring and develop them for efficient and effective improvement in a thermal power station.

1.2 Objectives

The object to satisfy this are:
- To conduct energy analysis of the overall plant and determine the efficiencies and energy losses of all the major components on the power plant.
- Select and develop the areas where energy losses are being experienced.
- Determine the costs and payback periods for the new technologies suggested for efficiency improvement.

1.3 Scope

The study scope encompasses three major tasks, energy and exergy analysis and the identification of methods to reduce the energy losses of power plant and the determination of their associated costs involved with the installation of the possible measure to cater for the problem. Energy analysis is to be done on components from the combustor to the electrical generator.

1.4 Need Justification

Electricity supply in India is becoming a shortage due to increase in demand made up of import displacement, urban expansion, expanded rural electrification program, new investments and the need of spinning reserves. The current electricity supply situation in the country is as shown in Table 1 below.
Table 1: Power Station in India

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Type</th>
<th>Year</th>
<th>Installed Capacity</th>
<th>Dependedal Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>NTPC Thermal Station</td>
<td>Thermal</td>
<td>1983</td>
<td>2600MW</td>
<td>2200MW</td>
</tr>
<tr>
<td>Indira Sagar Hydro Power Station</td>
<td>Hydro</td>
<td>2005</td>
<td>1000MW</td>
<td>750MW</td>
</tr>
<tr>
<td>Neyveli Thermal Power Station</td>
<td>Thermal</td>
<td>1962</td>
<td>600MW</td>
<td>420 MW</td>
</tr>
<tr>
<td>Talcher Super Thermal Power Station</td>
<td>Thermal</td>
<td>1995</td>
<td>3000MW</td>
<td>2400MW</td>
</tr>
<tr>
<td><strong>TOTALS</strong></td>
<td></td>
<td></td>
<td><strong>72000MW</strong></td>
<td><strong>5770MW</strong></td>
</tr>
</tbody>
</table>

Table 1 shows the installed capacity against the dependable capacity, so our goal is to work towards increasing the dependable supply to as close as possible to the installed capacity. Our power plants in the country currently provide about 80.6% of the installed capacity, a situation we intend to increase through efficiency improvement of the entire power plants.

1.5 Methodology

The plan is going to cover the following areas:

- A description of the facilities and their principal operation on the plant.
- A discussion of all major energy consuming systems.
- A description of all recommended Energy Conservation Measures (ECMs) with their specific energy impact.
- Energy and exergy analysis of the whole plant.
- A review on the implementation costs, benefits and payback period.
- Specific conclusions and recommendations.

2. Description of the plant

A schematic diagram of a plant with its various significant components is shown in Figure 2. The continuous supply of de-mineralized water is ensured to the condenser hot well for the normal running of the plant at a constant load. The condensate extraction pump (EXP) feeds the feed water to the ejector from the hot well. After the ejector exit, the feed water passes through the gland steam cooler, and the low pressure heater (LP). From the outlet of the low pressure heater (LP) the condensate enters into the boiler feed pump (BFP) where the condensate is pumped from the high pressure heater one (HP1) to high pressure heater three (HP3). Then the condensate passes through the economizer, and then enters into the boiler drum. There is a continuous circulation of water between the drum and the water walls and a part of the feed water is converted into steam. The steam is separated in the super heater section and enters into the turbine through the turbine stop valve and then rotates the electrical generator. After expansion in the turbine the exhaust steam is condensed in the condenser and is used for the closed cycle as shown in Figure 2.
turbine, generating power. The temperature decreases and pressure drops, and condensation can take place may occur.

- **Process 4-1: Isobaric heat rejection (Condenser)**: An isobaric process, in which the pressure of working fluid remains constant. The wet vapour then enters a condenser where it is condensed at a constant temperature to become a saturated liquid.

### 3.2 Energy analysis

In an open flow system there are three types of energy transfer across the control surface namely working transfer, heat transfer ($Q_k$), and energy associated with mass transfer and/or flow. The temperature ($T_k$) from the heat source and the network ($W$) developed by the system are used for the analysis of open flow systems and to analyze plant performance whilst kinetic and potential energy changes are ignored. The energy or first law efficiency of a system is defined as the ratio of energy output to the energy input to the system.

### 3.3 Exergy analysis

Exergy is a generic term for a group of concepts that define the maximum possible work potential of a system, a stream of matter or heat interaction; the state of the environment being used as the datum state. In an open flow system there are three types of energy transfer across the control surface namely working transfer, heat transfer, and energy associated with mass transfer or flow. The work transfer is equivalent to the maximum work, which can be obtained from that form of energy (Naterer et al, 2010). Exergy analysis is based on the first law of thermodynamics, which is related to the conservation of energy. Second law analysis is a method that uses the conservation of mass and degradation of the quality of energy along with the entropy generation in the analysis, design and improvement of energy systems. Exergy analysis is a useful method; to complement but not to replace energy analysis, (Bajan, 2002). The irreversibility maybe due to heat transfer, through limited temperature difference; mixing of fluids at different temperature and mechanical friction. Exergy analysis is an effective means, to identify losses due to irreversibility in a real situation.

### 3.4 Operational Efficiency

Operational efficiency is the ratio of the total electricity produced by the plant during a period of time compared to the total potential electricity that could have been produced if the plant operated at 100 percent in the period.

\[
\text{Operational efficiency} = \frac{E}{E_{100\%}} \times 100 \quad \text{eqn.8}
\]

Where: $E =$ energy output from the power plant in the period (kWh)
E100% = potential energy output from the power plant operated at 100% in the period (kWh)

- **Economic Efficiency**

Economic efficiency is the ratio between production costs, including fuel, labor, materials, and services, and energy output from the power plant for a period of time.

\[
\text{Economic efficiency} = \frac{\text{production costs for a period}}{\text{energy output from the power plant in the period (kwh)}}
\]

\[\text{…eqn. 9}\]

5. Discussion of Results

From the energy analysis, the overall plant energy loss is calculated as 81.72%. The comparison of energy losses between different components is given in Figure 4. It is observed that the maximum energy loss (47.79%) occurred in the condenser, this is due to the reason of heat energy expulsion from the condenser. Thus the energy analysis diverts our attention towards the condenser for the plant performance improvement. Approximately half of the total plant energy losses occur in the condenser only and these losses are practically useless for the generation of electric power. Thus the analysis of the plant based only on the First law principles may mislead to the point that the chances of improving the electric power output of the plant is greater in the condenser by means of reducing its huge energy losses, which is almost impracticable.

Hence the First law analysis (energy analysis) cannot be used to pinpoint prospective areas for improving the efficiency of the electric power generation. However, the Second law analysis serves to identify the true power generation inefficiencies occurring throughout the power station.

The exergy loss in the boiler is mainly due to the combustion reaction and to the large temperature difference during heat transfer between the combustion gas and steam. Factors that contribute to high amount of irreversibility’s are tubes fouling, defective burners, fuel quality, inefficient soot blowers, valves steam traps and air heaters fouling. The exergy loss in the turbines is due to the frictional effects and pressure drops across the turbine blades as well as the pressure and heat losses to the surroundings. The HPT and LPT contribute 6.36% of the total exergy destruction which indicates a need for reducing its irreversibility’s. Other factors that may contribute to the irreversibility’s are most likely due to the throttling, losses at the turbine governor valves, silica deposited at the nozzles. Overhauling the turbine maybe needed to check the real causes for improving plant performance.

The exergy losses in the FWH, from the thermodynamic point of view are due to the finite temperature difference between the streams, which interchange heat loss to the atmosphere and also due to the pressure drop. HP3 shows the highest exergy loss, so tubes inspection should be recommended during plant outage to determine the real cause. Other causes include wrong venting operation, high percentage of plugged tubes, poor maintenance and wrong operating water level.
The Second law efficiency (the exergy efficiency) of different components is also calculated and their comparison is depicted in Figure 7. It is noted that the exergy efficiency of the turbine, the feed water heaters and the heat pumps are 90.07%, 77.23%, and 83.63% respectively. The exergy efficiency of the boiler and the condenser are calculated as 69.53% and 84.20% respectively. The overall plant exergy efficiency is 18.28%. Thus the exergy analysis of the plant pinpoints that the prospective improvement in the combustor can improve the overall plant efficiency.

6. Challenges

- Worker morale is very low due to the current economic situation of economic recovery in the country.
- The human resource base is another impending issue a situation which saw many qualified technical personnel including engineers and journey men left the country for greener pastures during the era 2007 and 2008 economic meltdown.
- Vandalism of machinery has proven a major challenge as the security is having a tough time as one can’t tell whether it’s an internal or external job which is in operation.

7. Recommendations

The research recommends that results from this study be used as a guide in determining future process improvement actions. Using exergy analysis, the boiler was found to have the highest percentage of exergy destruction (48.92%) of the overall plant (81.66%). To reduce this loss retrofitting and replacement of some boiler elements is necessary for the overall plant efficiency improvement. The Power Station should also include the concepts of an bright power plant, the concepts include:

- Process Monitoring, Optimization and Management
- Real-time Process data collection
- Real-time process statistics
- Real-time process monitoring
- Schematics visualization and study
- Reports Generation
- Performance Calculation and Analysis, this should be done on the following areas: Plant Performance, Unit Performance, Mass and Energy Balance (Boiler, Turbine, Feedwater Heater, Condenser, Cooling Tower, Air Preheater, Feedwater Pump, Condensing Pump, Circulating Pump, Induced Draft Fans, Force Draft Fans, and Primary Air Fans).
- Economical analysis and optimal operation guidance
  Calculate and compare between the actually controllable parameters and expected parameters to obtaining the energy losses
  - Analyze the reasons of deviation hypert system, and providing the operation direction
  - Primary Controllable Losses
    - Main Steam Pressure
    - Main Steam Temperature
    - Reheat Steam Temperature
    - Carbon Content of Fly Ash
    - Primary uncontrollable Losses
    - RH Pressure Loss
    - Fuel Thermal Value
    - HP Turbine Efficiency
  - Advanced Control Technology, for example:
    - To optimize the surplus air in the combustion process to decrease CO emission
    - Calculate the best relationship between oxygen, air flow, coal supply, main steam flow and so on
  - Online Performance Test
    - Boiler Performance Test
    - Turbine Performance Test
    - Condenser Performance Test
    - Air Preheater Leakage Test
    - Vacuum Leakage Test

8. Conclusion

The paper set to show the weakness of depending on energy analysis only power plants as a performance measure that will help improve efficiency. Exergy analysis was undertaken at the thermal power plant which highlighted the areas that could be addressed to improve the efficiency. A recommendation of retrofitting and replacement was done for the system. On going work in development of intelligent power plant is expected to improve stability of steam headers, responsiveness to steam demand, increase power
generation flexibility, minimize operations cost, improve overall plant efficiency, increase fuel cost savings and reduce CO2 Emission.

References


