Performance Assessment of 2X250 MW Coal Based Thermal Power Plant

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Abstract – Coal, being the least costly and most accessible fuel in India, is used abundantly in power generation. Coal based thermal power plants play a dominant role in energy production in our country. Assessment of efficiency of power plant is the first step towards plant performance improvement. In the present study the performance of a 500 MW coal based thermal power plant comprising of 2X250 MW units is assessed in terms of the plant availability factor, plant load factor, planned and forced outage rate, reliability, overall unit efficiency, thermal efficiency, operational efficiency and economic efficiency.

Keywords: coal, efficiency, power plant, 250 MW

1. INTRODUCTION

Coal is the least costly and most accessible fuel for some of the most dynamic developing countries. In the past coal fired power plants have made a significant contribution in meeting energy demands of India and would continue to play a dominant role in the coming two to three decades. To maximise the utility of coal use in power generation, plant efficiency is an important performance parameter; furthermore, it is the first step towards plant efficiency improvement practices. The purpose of the performance test is to arrive at the efficiency parameters for the power plant as a whole and also the various components of the power plant. Performance of a power plant is normally judged by the plant availability factor, plant load factor, planned and forced outage rate, and reliability, while the efficiency of the plant is expressed in terms of overall unit efficiency, thermal efficiency, operational efficiency and economic efficiency.

2. MATERIAL AND METHODS

The present analysis was conducted on a coal based thermal power plant of 500 MW capacity comprising of 2X250 MW units and the following parameters were recorded:-

(a) Plant Availability Factor (PAF)

To calculate PAF of a power plant the amount of time that it is able to produce electricity over a certain period is divided by the amount of the time in that period.

PAF (%) = (operation Hours / total hours for period under review) x100

(b) Plant Load Factor (PLF)

Plant load factor is a measure of the output of a power plant compared to the maximum output it could produce, thus measuring average capacity utilization. Plant Load Factor is calculated as the ratio between the actual energy generated by the power plant to the maximum possible energy that can be generated by the plant working at its rated power and for duration of an entire year.

PLF (%) = (no. of hours electricity generated in a year/no. of hours in a year) X100

(c) Planned Outage Rate

Planned outages of power plants are taken for annual/capital maintenance or monthly, weekly routine checks; and are calculated using the following formula:

Planned outage rate (%) = (outage hours /hours in period under review) x100

(d) Forced Outage Rate

Forced outage is the removal of a generating unit from service availability for emergency reasons or a condition in which the equipment is unavailable due to unanticipated failure; and is calculated using the following formula:

Forced outage rate (%) = (forced outage hours/hours in period under review) x100

(e) Reliability

Reliability is an indication of how well maintenance management programmes are being executed at the power plant and is calculated as follows:

Reliability (%) = 100%- forced outage rate

(f) Overall unit efficiency

The overall unit efficiency (η) is calculated using the following formula:
η = η_{Boiler} \times η_{Turb} \times η_{Gen}

Where:

η_{Boiler} – boiler efficiency
η_{Turb} – turbine efficiency
η_{Gen} – generator efficiency

The efficiency of boilers is measured by measuring all the losses occurring in the boilers and subtracting it from 100.

Various losses from boiler are

L_1 = Dry flue gas loss (%)
L_2 = Loss due to moisture in fuel (%)
L_3 = Loss due to hydrogen in fuel (%)
L_4 = Loss due to unburnt carbon bottom ash (%)
L_5 = Loss due to unburnt carbon fly ash (%)
L_6 = Loss due to moisture in air (%)
L_7 = Sensible heat loss from fly ash (%)
L_8 = Sensible heat loss from bottom ash (%)
L_9 = Radiation loss (%)

Turbine cycle efficiency is defined as the amount of electricity produced to the heat input to the turbine.

Turbine cycle efficiency (%) = \left( \frac{860}{\text{Turbine heat rate}} \right) \times 100

Turbine heat rate is defined as the amount of heat input to the turbine in kcal for generating one unit of electricity.

Turbine heat rate (kCal/kWh) = \frac{[Q1(H1-h2)+Q2(H3-H2)]}{\text{Gross Generator Output}}

Where

Q1 = Main steam flow, kg/hr
H1 = Main steam enthalpy, kcal/kg
h2 = Feed water enthalpy, kcal/kg
Q2 = Reheat steam flow, kg/hr
H3 = Hot reheat enthalpy, kcal/kg
H2 = Cold reheat enthalpy, kcal/kg

In most of the thermal power stations generator efficiency is not independently calculated as rotor shaft work (WT) is not estimated (Niwas, 2014); however at the plant the turbogenerators (BHEL make) has reported efficiency of 98 per cent.

(g) Thermal efficiency

Thermal efficiency is an indication of how well the power plant is being operated as compared to the design characteristics of the plant; and is calculated as follows:

Thermal efficiency η = \left( \frac{\text{Energy generated} \times \text{time}}{\text{MC} \times \text{CV}} \right) \times 100

Where:

MC – quantity of coal consumed
CV- calorific value of coal

(h) Operational efficiency

Operational efficiency is calculated using the following formula:

Operational efficiency = \left( \frac{E}{E_{100\%}} \right) \times 100

where:

E = energy output from the power plant in the period
E_{100\%} = potential energy output from the power plant operated at 100% in the period

(i) Economic efficiency

Economic efficiency is the ratio between productions costs of electricity and energy output from the power plant for a period of time and can be calculated as follows:

Economic efficiency = \frac{\text{Production cost for a period}}{\text{Energy output from the power plant in the period (kWh)}}

3. RESULTS

Plant Availability Factor (PAF, %)

Mean value of the PAF for unit I was reported to be 77.91 per cent, while for the unit II it was 66.80 per cent. The mean value of the PAF for the plant from January 2017 to December 2017 was 72.36 per cent.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Month</th>
<th>PAF (%)</th>
<th>Unit I</th>
<th>Unit II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>January 2017</td>
<td>16.13</td>
<td>48.39</td>
<td></td>
</tr>
</tbody>
</table>
Plant Load Factor (PLF, %)

Mean value of the PLF for unit I was reported to be 52.51 per cent, while for the unit II it was 44.74 per cent. The mean value of the PLF for the plant from January 2017 to December 2017 was 48.62 per cent.

Table 2. Plant Load Factor (PLF) during January 2017 -December 2017

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Month</th>
<th>PLF (%)</th>
<th>Unit I</th>
<th>Unit II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>January 2017</td>
<td>10.07</td>
<td>30.78</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>February 2017</td>
<td>48.83</td>
<td>34.73</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>March 2017</td>
<td>8.76</td>
<td>60.09</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>April 2017</td>
<td>56.13</td>
<td>67.68</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>May 2017</td>
<td>68.29</td>
<td>70.72</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>June 2017</td>
<td>65.25</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>August 2017</td>
<td>31.76</td>
<td>59.9</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>September 2017</td>
<td>76.44</td>
<td>12.72</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>October 2017</td>
<td>68.76</td>
<td>11.86</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>November 2017</td>
<td>66.85</td>
<td>36.04</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>December 2017</td>
<td>66.13</td>
<td>66.75</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>52.51</td>
<td>44.74</td>
<td>48.62</td>
</tr>
</tbody>
</table>

Forced Outage Rate (FO, %)

Mean FO for the unit I was found to be 22.78 per cent, while the same for the unit II was 31.40 per cent. The mean FO for the plant during the study period was reported to be 27.09 per cent.

Table 3. Forced Outage Rate (FO) during January 2017 -December 2017

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Month</th>
<th>FO (%)</th>
<th>Unit I</th>
<th>Unit II</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>January 2017</td>
<td>86.62</td>
<td>53.29</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>February 2017</td>
<td>21.88</td>
<td>42.78</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>March 2017</td>
<td>89.05</td>
<td>7.09</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>April 2017</td>
<td>13.20</td>
<td>70.50</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>May 2017</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>June 2017</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>July 2017</td>
<td>6.67</td>
<td>98.77</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>August 2017</td>
<td>55.96</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>September 2017</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>10.</td>
<td>October 2017</td>
<td>0.00</td>
<td>58.40</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>November 2017</td>
<td>0.00</td>
<td>45.91</td>
<td></td>
</tr>
<tr>
<td>12.</td>
<td>December 2017</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>22.78</td>
<td>31.40</td>
<td>27.09</td>
</tr>
</tbody>
</table>

Reliability

The average reliability of unit I was 77.22 per cent, while for unit II it was 68.61 per cent. The overall plant reliability during the study period was 72.91 per cent.

Table 4. Reliability during January 2017 -December 2017

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Month</th>
<th>Reliability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Unit I</td>
</tr>
<tr>
<td>1.</td>
<td>January 2017</td>
<td>13.38</td>
</tr>
<tr>
<td>2.</td>
<td>February 2017</td>
<td>78.12</td>
</tr>
<tr>
<td>3.</td>
<td>March 2017</td>
<td>86.80</td>
</tr>
<tr>
<td>4.</td>
<td>April 2017</td>
<td>100.00</td>
</tr>
<tr>
<td>5.</td>
<td>May 2017</td>
<td>100.00</td>
</tr>
<tr>
<td>6.</td>
<td>June 2017</td>
<td>100.00</td>
</tr>
<tr>
<td>7.</td>
<td>July 2017</td>
<td>93.33</td>
</tr>
<tr>
<td>8.</td>
<td>August 2017</td>
<td>44.04</td>
</tr>
</tbody>
</table>
Overall unit efficiency

Overall unit efficiency of unit 1

(a) Boiler efficiency ($\eta_{\text{Boiler}}$)

The efficiency of boiler for the Unit 1 was calculated to be 86.56 per cent.

Table 5: Parameters for Calculation of Boiler Efficiency of Unit 1

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total moisture</td>
<td>%</td>
<td>8.72</td>
</tr>
<tr>
<td>Ash</td>
<td>%</td>
<td>36.75</td>
</tr>
<tr>
<td>V.M.</td>
<td>%</td>
<td>21.6</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>%</td>
<td>32.93</td>
</tr>
<tr>
<td>Ambient temp</td>
<td></td>
<td>28.50</td>
</tr>
<tr>
<td>Average Co2 at APH inlet</td>
<td>%</td>
<td>13</td>
</tr>
<tr>
<td>GCV of coal</td>
<td>Kcal/Kg</td>
<td>4020</td>
</tr>
<tr>
<td>Average O2 at APH inlet</td>
<td>%</td>
<td>4.00</td>
</tr>
<tr>
<td>Average N2 at APH inlet</td>
<td>%</td>
<td>83</td>
</tr>
<tr>
<td>Average load</td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>Unburnt carbon in bottom ash</td>
<td>%</td>
<td>1.43</td>
</tr>
<tr>
<td>Dry bulb</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Unburnt carbon in Fly ash</td>
<td>%</td>
<td>0.39</td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
<td>0.011</td>
</tr>
<tr>
<td>Wet Bulb Temp</td>
<td></td>
<td>16</td>
</tr>
<tr>
<td>No. of mill in service</td>
<td>No.</td>
<td>4</td>
</tr>
<tr>
<td>No. of mill in service</td>
<td>KW</td>
<td>1800</td>
</tr>
<tr>
<td>Bottom Ash temp</td>
<td>Deg C</td>
<td>1110</td>
</tr>
<tr>
<td>Coal Flow Rate</td>
<td>t/h</td>
<td>151</td>
</tr>
<tr>
<td>Average APH outlet temp</td>
<td>Deg C</td>
<td>148.5</td>
</tr>
<tr>
<td>Nitrogen % in coal</td>
<td>%</td>
<td>1.84</td>
</tr>
</tbody>
</table>

Total combustibles % 54.53

V M % of Combustibles % 39.61

Hydrogen as % of total combustibles % 5.855

Hydrogen as fired % 3.19

Sulphur % 0.4

Total Carbon (including Sulphur 0.3 %) % 39.77

Carbon % 39.370

Oxygen in coal % 9.726

Weight of dry flue gases / Kg of carbon Kg/Kg of carbon 19.385

Carbon in bottom ash Kg/Kg of fuel 0.001

Carbon if fly ash Kg/Kg of fuel 0.001

Weight of carbon consumed Kg of carbon / kg of fuel 0.366

Weight of Dry air supplied / Kg 6.458

Weight of Dry air supplied / Kg Weight of fuel burnt / Kg of fuel 0.631

Weight (W) Kg 0.070

Weight of dry flue gases / Kg of fuel Kg/Fuel 7.089

Dry Flue gas loss Kcal / Kg 204.558

Dry Flue gas loss (%) 5.088515208

Loss due to moisture in fuel Kcal / Kg 55.10832381

Loss due to moisture in fuel (%) 1.370853826

Loss due to hydrogen in fuel Kcal / Kg 181.6106257

Loss due to hydrogen in fuel (%) 4.517677256

Loss due to unburnt carbon (Bottom ash) Kcal / Kg 4.2317275

Loss due to unburnt carbon (Bottom ash) (%) 0.105266853

Loss due to unburnt carbon (Fly ash) Kcal / Kg 10.3869675
Loss Due to unburnt carbon (Fly ash) (%) = 0.175522388

Loss Due to moisture in air (%) = 0.099141541

Sensible Heat loss from fly ash Kcal / Kg = 7.056

Sensible Heat loss from fly ash (%) = 0.175522388

Sensible Heat loss from Bottom ash Kcal / Kg = 22.2572

Sensible Heat loss from Bottom ash (%) = 0.175522388

Radiation Loss (%) = 1.5

Heat Credit Kj / Kg = 40.768

Heat Credit Kcal / Kg = 9.707

Heat Credit (HC) % = 0.2415

Boiler efficiency = (100+HC) – (l₁+l₂+ l₄+ l₅+ l₆+ l₇+ l₈+ l₉)

= (100+0.24) – (5.09+1.37+4.52+0.11+0.26+0.10+0.18+0.55+1.15)

=86.56%

(b) Turbine efficiency

The turbine efficiency is calculated to be 43.46 per cent.

Table 6. Calculation of turbine efficiency of unit 1

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>Unit</th>
<th>Value</th>
<th>Ent (KJ/KG)</th>
<th>Ent (KCAL/KG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEED WATER FLOW</td>
<td>T/HR</td>
<td>HBD</td>
<td>723</td>
<td></td>
</tr>
<tr>
<td>FEED WATER PRESSURE(HP H -6 outlet pressure)</td>
<td>Kg/cm²</td>
<td>163</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPH-6 Outlet temp(Feed water temp. at ECO i/l)</td>
<td>°C</td>
<td>245</td>
<td>1062.70</td>
<td>254.23</td>
</tr>
<tr>
<td>HPH-5 Outlet temp</td>
<td>°C</td>
<td>196</td>
<td>841.07</td>
<td>201.21</td>
</tr>
<tr>
<td>HPH-6 Extraction steam pressure</td>
<td>Kg/cm²</td>
<td>35</td>
<td>3087.80</td>
<td>738.71</td>
</tr>
<tr>
<td>HPH-6 Extraction Steam Temperature</td>
<td>°C</td>
<td>343</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Turbine heat rate (kCal/kWh) = Q₁X(H₁−h₂)+Q₂X(H₃−H₄)

Gross Generator Output = 725(826.39-254.21)+652.12(842.27-741.03) = 1978.81

The turbine efficiency of Unit 1 is calculated as

Turbine cycle efficiency (%) = (860/1978.81)*100 = 43.46%

(c) Generator efficiency

Generator efficiency = 98%

(d) Overall unit efficiency, ηₜ = ηBoiler x ηTurb x ηGen

Where:

ηBoiler – boiler efficiency
ηTurb - turbine efficiency

ηGen - generator efficiency

= 86.56 X 43.46 X 98= 36.86 %

(e) Thermal efficiency = Thermal efficiency η =

((Energy generated x time) / ( MC x CV )) x100

Where:

MC – quantity of coal consumed
CV- calorific value of coal

= [100/(MC X CV/ Energy generated X time)]

= [100 / HR (kCal/kWh)] x conversion factor

Where

HR= Heat rate in kCal/kWh
Conversion factor= 1 kilo watt hour is equal to 860 kilo calorie

= (100/1978.81) X 860

=43.46 %

Overall unit efficiency of unit 2

(a) Boiler efficiency (ηBoiler)

The boiler efficiency of the Unit 2 was reported to be 86.16 per cent.

Table 7: Parameters for Calculation of Boiler Efficiency of Unit 2

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>VALUE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total moisture</td>
<td>%</td>
<td>8.92</td>
</tr>
<tr>
<td>Ash</td>
<td>%</td>
<td>38.61</td>
</tr>
<tr>
<td>V.M.</td>
<td>%</td>
<td>22.61</td>
</tr>
<tr>
<td>Fixed Carbon</td>
<td>%</td>
<td>29.86</td>
</tr>
<tr>
<td>Ambient temp</td>
<td>%</td>
<td>28.50</td>
</tr>
<tr>
<td>Average coxat APH inlet</td>
<td>%</td>
<td>13</td>
</tr>
<tr>
<td>GCV of coal</td>
<td>Kcal/Kg</td>
<td>4020</td>
</tr>
<tr>
<td>Average O2 at APH inlet</td>
<td>%</td>
<td>4.2</td>
</tr>
<tr>
<td>Average N2 at APH inlet</td>
<td>%</td>
<td>82.8</td>
</tr>
<tr>
<td>Average load (MW)</td>
<td></td>
<td>243</td>
</tr>
<tr>
<td>Unburnt carbon in bottom ash</td>
<td>%</td>
<td>1.46</td>
</tr>
<tr>
<td>Dry bulb</td>
<td></td>
<td>21</td>
</tr>
</tbody>
</table>

Unburnt carbon in FLy ash % 0.42
Moisture % 0.011
Wet Bulb Temp % 16
No of mill in service No. 4
No of mill in service KW 1800
Bottom Ash temp 1110
Coal Flow Rate t/h 150
Average APH outlet temp Deg C 149.5
Nitrogen % in coal % 1.83
Total combustibles % 52.47
Vn as % of combustibles % 43.09
Hydrogen as % of total combustibles % 5.953
Hydrogen as fired % 3.12
 Sulphur % 0.4
Total Carbon (including Sulphur 0.3 %) % 37.61
Carbon % 37.209
Oxygen In Coal % 9.909
Weight of dry flue gases / Kg of carbon Kg/Kg of carbon 19.390
Carbon in bottom ash KGg/Kg of fuel 0.001
Carbon if fly ash KGg/Kg of fuel 0.001
Weight of carbon consumed Kg of carbon / kg of fuel 0.384
Weight of Dry air supplied / Kg 6.835
Weight of fuel burnt / Kg 0.612
Weight (W) 0.075
Weight of dry flue gases / Kg of fuel Kg/Fuel 7.447
Dry Flue gas loss Kcal / Kg 216.69
Dry Flue gas loss (l1) % 5.390407
Loss due to moisture in fuel Kcal / Kg 56.41475238
Loss due to moisture in fuel (l1) % 1.403352049
Loss Due to hydrogen in fuel Kcal / Kg 177.7818951
Loss Due to hydrogen in fuel % 4.422435203
| Loss Due to unburnt carbon (Bottom ash) | Kcal / Kg | 9.078350914 |
| Loss Due to unburnt carbon (Bottom ash) | % | 0.225829625 |
| Loss Due to unburnt carbon (Fly ash) | Kcal / Kg | 10.4463216 |
| Loss Due to unburnt carbon (Fly ash) | % | 0.259858746 |
| Loss Due to moisture in air | Kcal / Kg | 4.332262097 |
| Loss Due to moisture in air | % | 0.107767714 |
| Sensible Heat loss from fly ash | Kcal / Kg | 7.475 |
| Sensible Heat loss from fly ash | % | 0.185942687 |
| Sensible Heat loss from Bottom ash | Kcal / Kg | 23.3837604 |
| Sensible Heat loss from Bottom ash | % | 0.581685582 |
| Radiation Loss (I₉) | % | 1.5 |
| Heat Credit | Kj / Kg | 41.040 |
| Heat Credit | Kcal / Kg | 9.771 |
| Heat Credit (HC) | % | 0.2431 |

Boiler efficiency = (100 + HC) - (l₁ + l₂ + l₃ + l₄ + l₅ + l₆ + l₇ + l₈ + l₉)
= (100 + 0.24) - (5.39 + 1.40 + 4.42 + 0.23 + 0.26 + 0.11 + 0.19 + 0.58 + 1.5)
= 86.16%

(b) Turbine efficiency

The heat rate of the Unit 2 was calculated to be 1989.79. Thus the turbine efficiency is calculated to be 43.22 per cent.

**Table 8. Calculation of turbine efficiency of unit 2**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEED WATER FLOW</td>
<td>T/Hr</td>
<td>692</td>
</tr>
<tr>
<td>FEED WATER PRESSURE(HPH-6 outlet pressure)</td>
<td>Kg/c m²</td>
<td>163</td>
</tr>
<tr>
<td>HPH-6 Outlet temp(feed water temp. at eco inlet)</td>
<td>°C</td>
<td>245</td>
</tr>
</tbody>
</table>

Turbine heat rate (kCal/kWh) = Q₁[H(H₂-H₂)+Q₂(H₂-H₂)]

Generator Output

= 723.94(822.87-255.33)+665.38(845.48-739.28)

= 242
=1989.79 kCal/kWh
The turbine efficiency of Unit 2 is calculated as
Turbine cycle efficiency (%)=(860/1989.79)*100
=43.22%

(c) Generator efficiency
Generator efficiency= 98%

(d) Overall unit efficiency,
η= η_{Boiler} x η_{Turb} x η_{Gen}
Where:
η_{Boiler} – boiler efficiency
η_{Turb} - turbine efficiency
η_{Gen} - generator efficiency
= 86.16 X 43.22 X 98= **36.49 %**

(e) Thermal efficiency = Thermal efficiency η = ((Energy generated x time) / (MC x CV)) x100
Where:
MC – quantity of coal consumed
CV- calorific value of coal
= [100/(MCX CV/ Energy generated X time)]
= [100/ HR (kCal/kWh)] x conversion factor
Where
HR= Heat rate in kCal/kWh
Conversion factor= 1 kilo watt hour is equal to 860 kilo calorie
= (100/1989.79) X 860
=43.22 %

Operational efficiency
Operational efficiency = (E/E_{100%}) x 100
where:
E = energy output from the power plant in the period
E_{100%} = potential energy output from the power plant operated at 100% in the period

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Month</th>
<th>Energy output (MU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>January 2017</td>
<td>75.98</td>
</tr>
<tr>
<td>2</td>
<td>February 2017</td>
<td>140.38</td>
</tr>
<tr>
<td>3</td>
<td>March 2017</td>
<td>128.06</td>
</tr>
<tr>
<td>4</td>
<td>April 2017</td>
<td>222.85</td>
</tr>
<tr>
<td>5</td>
<td>May 2017</td>
<td>258.56</td>
</tr>
<tr>
<td>6</td>
<td>June 2017</td>
<td>234.44</td>
</tr>
<tr>
<td>7</td>
<td>July 2017</td>
<td>155.15</td>
</tr>
<tr>
<td>8</td>
<td>August 2017</td>
<td>170.47</td>
</tr>
<tr>
<td>9</td>
<td>September 2017</td>
<td>160.50</td>
</tr>
<tr>
<td>10</td>
<td>October 2017</td>
<td>149.95</td>
</tr>
<tr>
<td>11</td>
<td>November 2017</td>
<td>185.18</td>
</tr>
<tr>
<td>12</td>
<td>December 2017</td>
<td>247.15</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>2128.67</strong></td>
</tr>
</tbody>
</table>

E= 2128 MU
Potential energy output from the power plant operated at 100% in the period-
Plant capacity 500 MW/h
In one day = 500 MW X 24 h
= 12000 MWh
In one year = 12000 MWh X 365
= 43800000 MWh
= 4380000000 kWh
= 4380 X 10^6 Unit
Thus E_{100%} = 4380 MU
Thus, operational efficiency = (2128/4380) X100
= 48.58%

Economic efficiency
For calculation of economic efficiency the total energy output and total cost required to generate the electricity for the financial year 2017-18 were recorded and economic efficiency was calculated to be Rs. 4.91/kWh.

Table 10. Parameters for calculation of economic efficiency of the plant for FY 2017-18
<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Particulars</th>
<th>Cost (Crores)</th>
</tr>
</thead>
</table>

Table 9. Energy output from the power plant during January 2017- December 2017
Energy output = 2978.40 MU
Economic efficiency = Production cost for a period/Energy output from the power plant in the period (kWh)

= 1462.39 Cr/2978.40 MU
= Rs. 4.91/kWh

4. DISCUSSION

During the study period from January 2017 to December 2017 the mean value of PAF was reported to be 72.36 per cent. The availability of a power plant varies greatly depending on the type of fuel, the design of the plant and how the plant is operated. Everything else being equal, plants that are run less frequently have higher availability factors because they require less maintenance. Most thermal power stations, such as coal, geothermal and nuclear power plants, have availability factors between 70% and 90%. Newer plants tend to have significantly higher availability factors, but preventive maintenance is as important as improvements in design and technology [1]. The mean value of PLF was reported to be 48.62 per cent. According to the Executive Summary, CEA (2017) the average PLF of all India coal and lignite based power plants were 63.48 and 60.37 per cent for January 2016 and January 2017; respectively [2]. The average PLF of all India private sector coal and lignite based power plants were 62.60 and 56.45 per cent for January 2016 and January 2017; respectively. PLF determines the exact load ability of the thermal power plant. Indirectly, it gives the performance of the power plant. If the PLF is 100%, it means plant is running on full load as per installed capacity. As the PLF approaches 100%, the performance of the thermal power plant also increases. Among various advantages of higher PLF, one of the major one is reduction in the planned or forced outages, that finally optimises auxiliary power consumption. On higher load, all the respective auxiliaries also run on full load, which results in utilisation of various auxiliaries at higher efficiency. Ultimately life of the auxiliary also increases. Hence PLF is found to be the key indicator for the analysis of performance of any power plant [1].

Planned outages of generating units are taken for annual/capital maintenance or monthly, weekly routine checks. Inadequacies in the annual planned/ capital maintenance carried out by power stations resulted into known defects in various systems of power stations remained unsolved during regular annual planned maintenance of units causing subsequent forced outages and loss of power generation; moreover delayed receipt of new or repaired parts during scheduled annual maintenance period resulted in a subsequent additional outage for replacement of parts. Power stations suffered loss of 35.97 million units of power generation during 2006 to 2014 due to subsequent avoidable forced outages on account of above reasons [3]. In the present study the planned outage during the study period is not reported as it had already been carried out in December 2016. In the present study the FO was 27.09 per cent, the reasons for this being coal shortage (36.36 per cent) and equipment problem (63.64 percent), with about 90.91 per cent shut down of more than 24 hours. The reliability was calculated to be 72.91 per cent. As per the Performance Review of Thermal Power Stations 2011-12 the loss of generation due to non-availability of thermal units because of forced outages during 2011-12 increased to 11.46 per cent as compared to 10.32 per cent during 2009-10. The increased forced outage was due to increased forced shutdown of units due to coal supply problem and transmission constraints and equipment problems of some new units. The study revealed that 59.87 per cent of the total forced shut down were of duration up to 24 hours. 38.67 per cent outages were of duration varying from 1 to 25 days and only 1.45 per cent of shut downs were for more than 25 days [4]. The boiler efficiencies of Unit 1 and Unit 2 were 86.56 and 86.16 per cent; respectively. The heat rate and turbine efficiency of Unit 1 were reported to be 1978.81 and 43.46 per cent; while these values for Unit 2 were 1989.79 and 43.22 per cent; respectively. The overall unit efficiency of Unit 1 and Unit 2 were 36.86 and 36.49 per cent; respectively. The operational efficiency of the plant during the study period was 48.58 per cent. The economic efficiency of the plant for FY 2017-18 was calculated to be Rs. 4.91/kWh.

5. CONCLUSION

Assessment of performance parameters plays a major role in economics of generation from a power plant. Better efficiency of the plant and its components result in less consumption of resources required for energy production. The differences in the calculated efficiency from the designed efficiencies indicate the urgent need to control the parameters within the designed ratings and to evolve measures to improve the efficiency of the plant.

REFERENCES

Executive summary


BIOGRAPHIES

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