Performance of Thermal Power Plant on System Based

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Abstract - The steam is used for rotate the turbine in thermal power plant. In India power generation is largely depends upon thermal power plant which having share of 71% of total generation. In view of energy conservation and possibility of scarcity of fuel there is need to check the performance of thermal power plant.

The Energy audit generally carried out by equipment and devices based energy efficiency improvements by way of testing in operation and on field i.e. load variation. The system based energy audit would indicate the practice system efficiencies and its integration for whole power plant performance such approaches have not be considered so far and must be tried. The actual performance of thermal power vary due to quality of used fuel, excess air control, viscosity of working fluid, turbulence, environmental impacts.

An effort is made in this work for developing methodology of energy audit in thermal power plant on system based. The paper shows all the performance equation of component involves in the thermal power plant according to the system base.

Key Words: Energy Audit, Thermal Power Plant, Energy conservation.

1. Introduction

The thermal power plant mainly consists of boiler, turbine, generator, condenser and pumps. The steam is generated in the boiler by combustion fuel and given to the turbine for rotation of turbine blades which can result in conversion of steam energy into mechanical energy and is given to the generation for the production of electricity. It works on the principle of thermal power plant. The figure 1 shows an overview of thermal power plant.

For conservation of fuel it is required to carry out energy audit of thermal power plant otherwise scarcity of fuel in future occurs. Painstaking task work with much people's had done the works on performance of thermal power plant according to the equipment based. But system based work hadn't found for auditing the thermal power plant. There is potential of energy conservation on the basis of system based audit. The thermal power plant mainly consists of following systems
1) Air and flue gas system
2) Feed water and steam system
3) Cooling water system
4) Fuel and ash handling system
5) Electrical System
6) Compressed air system
7) Lightening system
8) Insulation system

The equipments are involves in the system of thermal power plant shows in table no. 1

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Systems</th>
<th>Equipment</th>
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<tbody>
<tr>
<td>1</td>
<td>Air &amp; Gas</td>
<td>(i) FD Fan</td>
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<td>(ii) ID Fan</td>
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<td>(iii) PA Fan</td>
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<td>(iv) Airheater</td>
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<td>(vi) Chimney</td>
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<td>(vii) Coal Mill</td>
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<td>2</td>
<td>Feed water &amp; steam</td>
<td>(i) Hot well</td>
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<td>(ii) CEP</td>
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<td>(iii) Drain Coolers</td>
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<td>(iv) HP Heaters</td>
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<td>(xi) superheaters</td>
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<td>(xii) HP Turbine</td>
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<td>(xiii) Reheater</td>
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<td>(xiv) IP turbine</td>
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<td>(xv) LP Turbine</td>
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<td>(xvi) Condenser</td>
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</tbody>
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Table - 1: Thermal Power Plant System

II) Methodology

In view of EnmS 50001:2011, the study of thermal power plant system is done. According to study list of various performances equation of equipment according to system is carried out.

1) Performance of Air and flue gas system.

Air is required for combustion purpose in thermal power plant and due to combustion of fuel, flue gas is formed which is used for heating purpose. The equipment are involves in the system are shown in figure 2.

The performance of flue gas system can be calculated as follows.

\[
\eta(\%) = a) \text{ Performance efficiency of FD, PA, ID fan can be calculated as follows.} \\
\eta = \frac{\text{Heat Transfer}}{\text{Heat Transfer in kcal/hr}} \\
\eta = \frac{Q}{U \times A \times \text{LMTD}} \\
\eta = \frac{100}{102} \times \frac{\text{Power input to the motor}}{\text{Power input to the fan shaft}} \\
\eta = \frac{100}{102} \times \frac{\text{Number of motor in corresponding loading}}{\text{Transmission system}} \\
\]

b) Performance of APH can be calculated as follows.

\[
Q = \frac{\text{Heat Transfer}}{U \times A \times \text{LMTD}} \\
\text{Where,} \\
Q = \text{Heat Transfer in kcal/hr} \\
A = \text{Heat Transfer surface area in m2} \\
\text{LMTD} = \text{Log mean Temp difference in } ^\circ \text{C} \\
U = \text{Overall heat transfer coefficient} \\
kcal/hr/m2/\circ \text{C} \\
\]

LMTD can be calculated as follows

For Counter Flow

\[
\text{LMTD} = \frac{\left(\frac{T_i - t_i}{T_0 - t_i}\right)}{\ln \left(\frac{T_i - t_i}{T_0 - t_i}\right)} \\
\]

For Parallel Flow

\[
\text{LMTD} = \frac{\left(\frac{T_i - t_i}{T_0 - t_i}\right)}{\ln \left(\frac{T_i - t_i}{T_0 - t_i}\right)} \\
\]

Where,

\[
T_i = \text{Inlet temperature of Hot air} \\
T_0 = \text{Outlet Temperature of hot air} \\
t_i = \text{Inlet Temperature of cold air} \\
t_0 = \text{Outlet Temperature of cold air} \\
\]

c) Performance of ESP

Performance of precipitator = 1 - \left[ e^{-\frac{A w}{V}} \right] \\
Migration Velocity (w) = \frac{r E_1 E_2}{2 \mu} \\
Where,

\[
A = \text{Effective Precipitating collecting electrode area} \\
V = \text{Gas Flow through the precipitator} \\
r = \text{Radius of the particle} \\
E_1 = \text{Strength of particle charging field (volts)} \\
E_2 = \text{Strength of particle collecting field (volts)} \\
\mu = \text{Viscosity of frictional coefficient of the gas} \\
\]

d) Performance of chimney

For the performance purpose of chimney the efficiency can be carried out as follows

\[
H = \frac{C \times [\frac{m^3}{s}] \times [\frac{T_0 - 1}{T_i - 1}] \times [\frac{T_i}{T_0 - 1}]}{10^3} \\
\]

Fig - 2: Air and Flue gas system
Where,

\( H = \text{Height} \)

\( J = \text{In SI unit } J \text{ is equal to 1} \)

\( m_a = \text{mass of air supplied per kg of fuel} \)

\( m_{a+1} = \text{mass of chimney gases} \)

\( T_g = \text{average absolute temperature of chimney gases} \)

\( T_a = \text{absolute temperature at atmosphere} \)

\( T_1 = \text{Absolute temperature of flue gases leaving the chimney to create draught} \)

\( T_2 = \text{Absolute temperature of flue gases leaving the chimney in case of artificial draught} \)

e) Performance of coal mill

In the performance of coal mill air fuel ratio and Specific energy consumption of coal can be check. It can be calculated as follows

\[
\text{Air fuel Ratio} = \frac{\text{Air flow (m}^3/\text{sec})}{\text{Coal Flow (hr)}}
\]

\[
\text{SEC of coal (kWhr/T)} = \frac{\text{Power input (kWhr)}}{\text{Coal flow (hr)}}
\]

2) Performance of Feed water and steam system

The feed water is required for generating the steam in boiler and is given to the turbine. After the work done in turbine steam is dumped in condenser and conversion of steam to water takes place. The equipment involves in this system is shown in figure no. 3

![Feed Water and steam system](image)

Fig -3: Feed Water and steam system

The performance of feed water and steam system can be calculated as follows

\[
\eta_{\text{boiler}} = \frac{\eta_{\text{boiler}} \times \eta_{\text{turbine}} \times \eta_{\text{condenser}}}{100}
\]

a) Performance of CEP and BFP

\[
\text{Pump Efficiency} = \left( \frac{\text{Hydraulic Power Ph}}{\text{Power input to the shaft}} \right) \times 100
\]

Where,

\[
\text{Hydraulic Power Ph (kW)} = \frac{Q \times (H_d - H_s) \times g \times \rho}{1000}
\]

Where,

\( Q = \text{mass flow rate (m}^3/\text{sec}) \)

\( \rho = \text{Density of fluid (kg/m}^3) \)

\( g = \text{acceleration due to gravity (m/s}^2) \)

\( H_d \text{- Total Head in meters} \)

b) Performance of HP & LP heaters

For the performance purpose of LP & HP heaters effectiveness can be carried out

\[
\text{Effectiveness}(\%) = \left( \frac{T_i - t_o}{(T_i - t_i)} \right) \div \left( \frac{T_o - t_i}{T_o - t_d} \right)
\]

Where,

\( T_i = \text{Inlet temperature of condensate} \)

\( T_o = \text{Outlet Temperature of condensate} \)

\( t_i = \text{Inlet Temperature of extracted steam} \)

\( t_o = \text{Outlet Temperature of extracted steam} \)

c) Performance of Boiler

The performance of boiler can be calculated as by direct method and indirect method

i. Direct Method

\[
\text{Boiler efficiency (Ƞ)} = \left( \frac{Q \times (h_g - h_f)}{q \times GCV} \right) \times 100
\]

Where,

\( h_g = \text{Enthalpy of saturated steam in kCal/kg of steam} \)

\( h_f = \text{Enthalpy of feed water in kCal/kg of water} \)

\( Q = \text{Quantity of steam generated per hour (Q) in kg/hr.} \)

\( q = \text{Quantity of fuel used per hour (q) in kg/hr} \)

\( GCV = \text{gross calorific value of the fuel in kCal/kg of fuel} \)

ii. Indirect Method

In indirect method, efficiency is the difference between the losses and energy input

The following losses are applicable to coal fired Boiler

L1. Loss due to dry flue gas (sensible heat)

L2. Loss due to hydrogen in fuel (H2)

L3. Loss due to moisture in fuel

L4. Loss due to moisture in air
L5. Loss due to carbon monoxide (CO)
L6. Loss due to surface radiation, convection and other unaccounted
L7. Unburnt losses in fly ash (Carbon)
L8. Unburnt losses in bottom ash (Carbon)

Boiler Efficiency by indirect method = 100 - (L1 + L2 + L3 + L4 + L5 + L6 + L7 + L8)

Calculation procedure For Indirect Method

Theoretical (stoichiometric) air fuel ratio and excess air supplied are to be determined first for computing the boiler losses

a. Theoretical air required for combustion=
\[
\frac{(11.6 \times C) + \{34.8 \times (H_2 - O_2/8)\} + (4.35 \times S)}{100}
\]

Where C, H₂O₂ and S are the percentage of carbon, hydrogen, oxygen and sulphur present in fuel

b. % Excess Air Supplied (EA) =
\[
\frac{\text{Actual mass of air supplied /kg of fuel (AAS)}}{\text{theoretical air}} \times 100
\]

c. Actual mass of air supplied /kg of fuel (AAS)=
\[
(1+\text{EA/100}) \times \text{theoretical air}
\]

The various losses associated with the operation of a boiler are discussed below with Required formula

1. Heat loss due to dry flue gas
\[
L1 = \frac{m \times Cp \times \{Tf - Ta\}}{GCV \text{ of fuel}} \times 100
\]

Where,
L1 = % Heat loss due to dry flue gas
m = Mass of dry flue gas in kg/kg of fuel

Combiustion products from fuel: CO₂ + SO₂ + Nitrogen in fuel +Nitrogen in the actual mass of air supplied + O₂ in flue gas.
(H₂O/Water vapour in the flue gas should not be considered)
Cp = Specific heat of flue gas in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C

2. Heat loss due to evaporation of water formed due to H₂ in fuel (%)
\[
L2 = \frac{9 \times H2 \times [584 + Cp \times \{Tf - Ta\}]}{GCV \text{ of fuel}} \times 100
\]

Where
L2=Heat loss due to evaporation of water formed due to H₂ in fuel
H₂ = kg of hydrogen present in fuel on 1 kg basis
Cp = Specific heat of superheated steam in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C
584=Latent heat corresponding to partial pressure of water vapour

3. Heat loss due to moisture present in fuel
\[
L3 = \frac{M \times \{584 + Cp \times \{Tf - Ta\}\}}{GCV \text{ of fuel}} \times 100
\]

Where
L3 = Heat Loss due to moisture present in fuel
M = kg moisture in fuel on 1 kg basis
Cp = Specific heat of superheated steam in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C
584 =Latent heat corresponding to partial pressure of water vapour

4. Heat loss due to moisture present in air
\[
L4 = \frac{AAS \times \text{humidity factor} \times Cp \times \{Tf - Ta\} \times 100}{GCV \text{ of fuel}}
\]

Where
L4=Heat loss due to moisture present in air
AAS = Actual mass of air supplied per kg of fuel
Humidity factor = kg of water/kg of dry air
Cp = Specific heat of superheated steam in kCal/kg°C
Tf = Flue gas temperature in °C
Ta = Ambient temperature in °C (dry bulb)

5. Heat loss due to incomplete combustion
Where,  
\[ L_5 = \frac{\% \text{CO x C x 574}}{(\% \text{CO} + \% \text{CO}_2) \times \text{GCV of fuel}} \times 100 \]

\[ L_5 = \% \text{Heat loss due to partial conversion of C to CO} \]
\[ \text{CO} = \text{Volume of CO in flue gas leaving economizer} \ (\%) \]
\[ \text{CO}_2 = \text{Actual Volume of CO}_2 \text{ in flue gas} \ (\%) \]
\[ C = \text{Carbon content kg / kg of fuel} \]

6. Heat loss due to radiation and convection:
\[ L_6 = 0.548 \times \left[ \left( \frac{T_s}{55.55} \right)^4 - \left( \frac{T_a}{55.55} \right)^4 \right] + 1.957 \times \left( T_s - T_a \right) \times \text{sq.rt} \left( \frac{196.85 V_m + 68.9}{68.9} \right) \]
Where
\[ L_6 = \text{Radiation loss in W/m}^2 \]
\[ V_m = \text{Wind velocity in m/s} \]
\[ T_s = \text{Surface temperature (K)} \]
\[ T_a = \text{Ambient temperature (K)} \]

7. Heat loss due to unburnt in fly ash:
\[ L_7 = \frac{\text{Total Ash collected / kg of fuel x GCV of Fly ash} \times 100}{\text{GCV of Fuel}} \]

8. Heat Loss due to unburnt in bottom ash:
\[ L_8 = \frac{\text{Total Ash collected / kg of fuel x GCV of bottom ash} \times 100}{\text{GCV of Fuel}} \]

d) Performance of Turbine
Steam turbine is a mechanical device that extracts thermal energy from pressurized steam, and converts to useful mechanical work. The steam turbines are split into three separate stages, High Pressure (HP), Intermediate Pressure (IP) and Low Pressure (LP) stage.

e) Performance of Condenser
Condenser performance can deteriorate with time, offdesign operations and other interferences such as fouling, scaling etc
\[ Q = U \times A \times \text{LMTD} \]
Where,
\[ Q = \text{Heat Transfer in kcal/hr} \]
\[ A = \text{Heat Transfer surface area in m}^2 \]
\[ \text{LMTD} = \text{Log mean Temp difference in } ^\circ \text{C} \]

\[ U= \text{Overall heat transfer coefficient kcal/hr/m}^2/\circ \text{C} \]

LMTD can be calculated as follows

For Counter Flow
\[ \text{LMTD} = \frac{T_i - T_o}{\ln \left( \frac{T_i - T_o}{T_m - T_o} \right)} \]

For Parallel Flow
\[ \text{LMTD} = \frac{T_i - T_o}{\ln \left( \frac{T_i - T_o}{T_m - T_o} \right)} \]

Where,
\[ T_i = \text{Inlet temperature of Hot condensate} \]
\[ T_o = \text{Outlet Temperature of hot condensate} \]
\[ t_i = \text{Inlet Temperature of cold water} \]
\[ t_o = \text{Outlet Temperature of cold water} \]

3) Performance of Cooling water system
The water is required for cool the condensate in condenser. The circulation of water can be done by cooling water pump. These pumps take water from the condenser and given to the cooling tower and given back the cold water to the condenser. This can be shown in figure no. 4.

![Fig 4: Cooling water system](image-url)

Performance of Cooling water system can be calculated as follows

\[ \eta_{\text{cooling water system}} = \frac{\text{Power input to the shaft}}{\text{Power input to the shaft}} \times 100 \]

Where,

a) Performance of cooling water pump
The water is required for cool the condensate in condenser. The performance can be calculated as follows.

\[ \eta_{\text{pump}} = \frac{\text{Hydraulic Power input}}{\text{Power input to the shaft}} \times 100 \]

Where,
Where,

\[ Q = \text{mass flow rate (m}^3/\text{sec)} \]
\[ \rho = \text{Density of fluid (kg/m}^3) \]
\[ g = \text{acceleration due to gravity (m/s}^2) \]
\[ H_d - H_s = \text{Total Head in meters} \]

b) Performance of Cooling Tower

The cooling tower efficiency can be expressed as

\[ \eta = \left( t_i - t_o \right) \times 100 / \left( t_i - tw_b \right) \]

Where,

\[ \eta = \text{cooling tower efficiency (\%)} \]
\[ t_i = \text{inlet temperature of water to the tower (°C)} \]
\[ t_o = \text{outlet temperature of water from the tower (°C)} \]
\[ tw_b = \text{wet bulb temperature of air (°C)} \]

4) Fuel and ash system

a) Fuel handling system

The fuel handling plant mainly consists of equipment like crusher, feeder, and conveyor. So for the purpose of performance of this equipment motors performance can be carried out as follows:

Efficiency of motor is given by

\[ \eta = \frac{\text{Pout}}{\text{Pin}} = 1 - \frac{\text{Ploss}}{\text{Pin}} \]

Where,

\[ \text{Pout} = \text{Output power of the motor} \]
\[ \text{Ploss} = \text{Losses occurring in motor} \]
\[ \text{Pin} = \text{Input power of the motor} \]

Motor Loading can be calculated as

\[ \text{Motor Loading\%} = \frac{\text{Actual operating load of motor}}{\text{Rated capacity of the motor}} \times 100 \]

b) Ash handling system

In ash handling plant mainly consist of pumps. So the performance of pump can be carried out as follows:

Pump Efficiency = \[ \frac{\text{Hydraulic Power} Ph \times 100}{\text{Power input to the shaft}} \]

Where,

\[ \text{Hydraulic Power} Ph \times 100 \]
\[ \text{Where,} \]
\[ Q = \text{mass flow rate (m}^3/\text{sec)} \]
\[ \rho = \text{Density of fluid (kg/m}^3) \]
\[ g = \text{acceleration due to gravity (m/s}^2) \]
\[ H_d - H_s = \text{Total Head in meters} \]

5) Performance of Compressed air system

In thermal power plant Compress Air is required for Instrumentation and service. The performance of compressor can be calculated as follows.

\[ \text{free air delivered} Q_f = \frac{k \times \pi \times d^2 \times \frac{T_1}{P_1} \times \left[ \frac{2 \times (P_3 - P_4) 	imes P_3 \times R_a}{T_3} \right]^{1/2}} {4} \]

Where,

\[ K: \text{Flow coefficient – as per IS} \]
\[ d: \text{Nozzle diameter M} \]
\[ t_i = \text{Absolute inlet temperature °K} \]
\[ P_1 = \text{Absolute inlet pressure kg/cm}^2 \]
\[ P_3, P_4 = \text{Absolute Pressure before nozzle kg/cm}^2 \]
\[ T_3 = \text{Absolute temperature before nozzle °K} \]
\[ R_a = \text{Gas constant for air 287.1 J/kg k} \]
\[ P_3 - P_4 = \text{Differential pressure across the nozzle kg/cm}^2 \]

ii. Isentropic Efficiency = \[ \frac{\text{Isentropic Power}}{\text{Input Power}} \]

\[ \text{Isentropic Power} = \frac{P_1 \times Q_f \times \log r}{36.7} \]

Where,

\[ P_1 = \text{Absolute intake pressure kg/ cm}^2 \]
\[ Q_f = \text{Free air delivered m}^3/\text{hr.} \]
\[ r = \text{Pressure ratio P2/P1} \]

iii. Specific power consumption

\[ \frac{\text{at rated discharge pressure}}{\text{Free Air Delivered, m}^3/\text{hr}} = \text{Power consumption , kW} \]

iv. Volumetric efficiency

\[ \frac{\text{Compressor displacement m}^3/\text{min}}{\text{Power consumption, m}^3/\text{min}} \]

Where,

\[ D = \text{Cylinder bore, metre} \]
\[ L = \text{Cylinder stroke, metre} \]
\[ S = \text{Compressor speed rpm} \]
\[ \chi = 1 \text{ for single acting and} \]
2 for double acting cylinders

n = No. of cylinders

6) Performance of Lighting system

Lighting is provided in Thermal Power plant for providing comfortable working environment. The performance can be calculated as follows.

Calculate the Room Index

\[ RI = \frac{L \times W}{Hm(L + W)} \]

Where,

L = length of interior;
W = width of interior;
Hm = the mounting height

7) Insulation system

Insulation is given to the heating surfaces of the thermal power plant.

Heat loss from a surface is expressed as

\[ H = h \times A \times (Th - Ta) \]

Where,

h = Heat transfer coefficient, W/m²·K
H = Heat loss, Watts
Ta = Average ambient temperature, ºC
Ts = Desired/actual insulation surface temperature, ºC
Th = Hot surface temperature

III) Conclusion

This work gives an idea for auditing the thermal power plant. The performance of the thermal power plant can be checked on the basis of system based which brought several options that result in reduction of energy conservation.

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