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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.

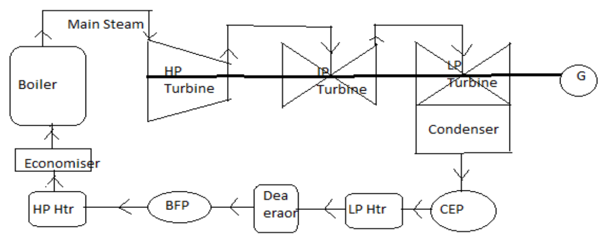

Fig -1: Overview of thermal power plant

For conservation of fuel it is required to carry out energy audit of thermal power plant otherwise scarcity of fuel in future occurs. Pains taking task work with rMany 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

Sr. No	Systems	Equipment
1	Air & Gas	(i) FD Fan (ii) ID Fan (iii) PA Fan (iv) Airheater (v) ESP (vi) Chimney (vii) Coal Mill
2	Feed water & steam	(i)Hot well (ii) CEP (iii) Drain Coolers (iv) HP Heaters (v) Deareator (vi)BFP (vii) HP Heater (viii)Economizer (ix)Drum (x) Water Wall (xi) superheaters (xii) HP Turbine (xiii) Reheater (xiv)IP turbine (xv) LP Turbine (xvi) Condenser

3	Cooling Water	(i) Cooling tower (ii) CWP
4	Fuel & Ash	(i) Conveyer Belt (ii)Feeders (iii) Crusher (v) Ash Water Pump (vi) Ash Disposal Pump
5	Electrical Systems	(i) Transformer (ii)Motors

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.

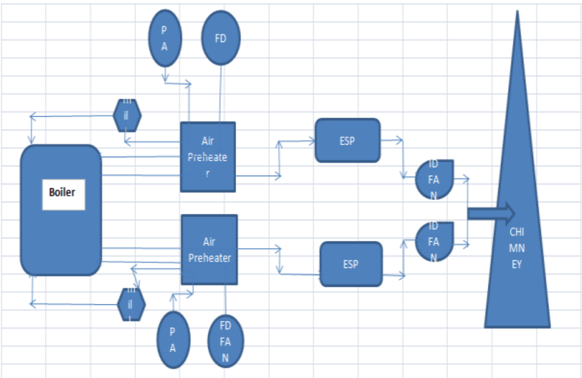

Fig -2: Air and Flue gas system

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

$$\eta(\%) = \frac{\eta \text{ of FD} \times \eta \text{ of PA} \times \text{Effectivenes of APH} \times \eta \text{ of coal mill} \times \eta \text{ of ESP} \times \eta \text{ of ID} \times \eta \text{ of chimney}}{100}$$

a) Performance efficiency of FD, PA, ID fan can be calculated as follows

$$\text{Static Fan Efficiency\%} = \frac{\text{volume in } \frac{m3}{sec} \times \text{total pessure in mmwc}}{102 \times \text{power input to the shaft in KW}}$$

$$\text{Power input to the Fan shaft} = \text{Power input to the motor} \times \eta \text{ of motor in corresponding loading} \times \text{transmission sysyem } \eta$$

b) Performance of APH can be calculated as follows.

$$Q = U \times A \times LMTD$$

Where,

Q= Heat Transfer in kcal/hr

A= Heat Transfer surface area in m2

LMTD= Log mean Temp difference in ◦ C

U= Overall heat transfer coefficient kcal/hr/m2/◦C

LMTD can be calculated as follows

For Counter Flow

$$LMTD = \frac{\left(\frac{Ti - to}{To - ti}\right)}{\ln\left(\frac{Ti - to}{To - ti}\right)}$$

For Parallel Flow

$$LMTD = \frac{\left(\frac{Ti - ti}{To - to}\right)}{\ln\left(\frac{Ti - ti}{To - to}\right)}$$

Where,

T_i = Inlet temperature of Hot air

T_0= Outlet Temperature of hot air

t_i= Inlet Temperature of cold air

t_o= Outlet Temperature of cold air

c) Performance of ESP

Performance of precipitator = $1 - [e]^{(-Aw/V)}$

Migration Velocity (w) = $\frac{r E_1 E_2}{2\pi\mu}$

Where,

A= Effective Precipitating collecting electrode area

V= Gas Flow through the precipitator

r = Radius of the particle

E_1= Strength of particle charging field (volts)

E_2= Strength of particle collecting field (volts)

µ = 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

$$\eta_{chimney} = \frac{H/_J \left[\left(\frac{ma}{ma+1}\right) \times \frac{Tg}{Ta} - 1\right]}{Cp(T1 - T2)} \times g \times 10^{-3}$$

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Where,

H= Height

J = In SI unit J is equal to 1

m_a= mass of air supplied per kg of fuel

m_a+1= mass of chimney gases

T_g = average absolute temperature of chimney gases

T_a = absolute temperature at atmosphere

T_1= Absolute temperature of flue gases leaving the chimney to create draught

T_2 = 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

$$\text{Air fuel Ratio} = \frac{\text{Air flow}\left(\frac{T}{hr}\right)}{\text{Coal Flow}\left(\frac{T}{hr}\right)}$$

$$\text{SEC of coal (kWhr/T)} = \frac{\text{Power input(kWhr)}}{\text{Caol flow}\left(\frac{T}{hr}\right)}$$

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

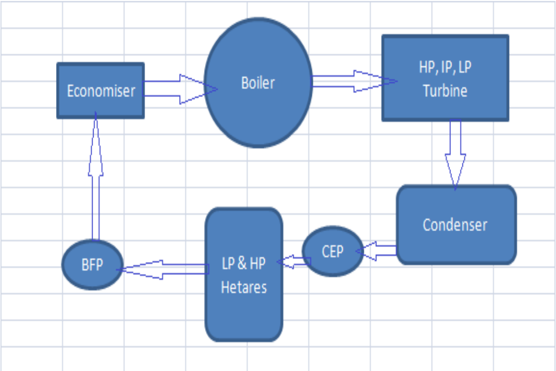

Fig -3: Feed Water and steam system

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

$$\eta\ (\%) = \frac{\eta \text{ of CEP} \times \text{Effectiveness of LP } HP \text{ heater} \times \eta \text{ of BFP} \times \eta \text{ of economiser} \times \eta \text{ of boiler} \times \eta \text{ of turbine} \times \eta \text{ of condenser}}{100}$$

a) Performance of CEP and BFP

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

Where,

$$\text{Hydraulic Power Ph(Kw)} = \frac{Q \times (Hd - Hs) \times g \times \rho}{1000}$$

Where,

Q= mass flow rate (m^3/sec)

ρ= Density of fluid (kg/m^3)

g= acceleration due to gravity (m/s^2) Hd-Hs= Total Head in meters

b) Performance of HP & LP heaters

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

$$\text{Effectiveness}(\%) = \frac{\left(\frac{Ti - to}{To - ti}\right)}{\ln\left(\frac{Ti - to}{To - ti}\right)}$$

Where,

Ti = Inlet temperature of condensate

To= Outlet Temperature of condensate

ti= Inlet Temperature of extracted steam

to= 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

$$\text{Boiler efficiency } (\eta) = \frac{Q \times (hg - hf)}{q \times GCV} \times 100$$

Where,

hg– Enthalpy of saturated steam in kCal/kg of steam

hf – Enthalpy of feed water in kCal/kg of water

Q – Quantity of steam generated per hour (Q) in kg/hr.

q– Quantity of fuel used per hour (q) in kg/hr

GCV – 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=[(11.6×C)+{34.8×(H_2 – O_2/8)}+(4.35×S)]/100

Where C, H_2 O_2 and S are the percentage of carbon, hydrogen, oxygen and sulphur present in fuel

b. % Excess Air Supplied (EA) = $\frac{O2\,\%}{21-O2\%} \times 100$

c. Actual mass of air supplied /kg of fuel (AAS)= {1+EA/100}×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

$$L1 = \frac{m \times Cp \times (Tf - Ta)}{GCV\ of\ fuel} \times 100$$

Where,

L1 = % Heat loss due to dry flue gas

m = Mass of dry flue gas in kg/kg of fuel

= Combustion 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 (%)

$$L2 = \frac{9 \times H2 \times \{584 + Cp\,(Tf - Ta)\}}{GCV\ of\ fuel} \times 100$$

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

$$L3 = \frac{M \times \{584 + Cp\,(Tf - Ta)\}}{GCV\ of\ fuel} \times 100$$

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

$$L4 = \frac{AAS \times humidity\ factor \times Cp \times (Tf - Ta) \times 100}{GCV\ of\ fuel}$$

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

$$L5 = \frac{\%CO \times C \times 5744}{(\%\ CO + \%\ CO2) \times GCV\ of\ fuel} \times 100$$

Where,

L5 = % Heat loss due to partial conversion of C to CO

CO = Volume of CO in flue gas leaving economizer (%)

CO2 = Actual Volume of CO2 in flue gas (%)

C = Carbon content kg / kg of fuel

6. Heat loss due to radiation and convection:

L6 =0.548 x [(Ts / 55.55)^4- (Ta / 55.55)^4] + 1.957 x (Ts - Ta)1.25 x sq.rt of

[(196.85 V_m + 68.9) / 68.9]

Where

L6 = Radiation loss in W/m2

Vm = Wind velocity in m/s

Ts = Surface temperature (K)

Ta = Ambient temperature (K)

7. Heat loss due to unburnt in fly ash :

$$L_7 = \frac{\text{Total Ash collected/kg of fuel} \times \text{GCV of Fly ash} \times 100}{\text{GCV of Fuel}}$$

8. Heat Loss due to unburnt in bottom ash

$$L_8 = \frac{\text{Total Ash collected/kg of fuel} \times \text{GCV of bottom ash} \times 100}{\text{GCV of Fuel}}$$

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.

$$\text{Turbine Cylindrical efficiency} = \frac{\text{Actual enthalpy drop across turbine in kcal/kg} \times 100}{\text{theoratical enthalpy drop across theturbine in kcal/kg}}$$

e) Performance of Condenser

Condenser performance can deteriorate with time, offdesign operations and other interferences such as fouling, scaling etc

$$Q = U \times A \times LMTD$$

Where,

Q= Heat Transfer in kcal/hr

A= Heat Transfer surface area in m2

LMTD= Log mean Temp difference in ◦ C

U= Overall heat transfer coefficient kcal/hr/m2/◦C

LMTD can be calculated as follows

For Counter Flow

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For Parallel Flow

$$LMTD = \frac{\left(\frac{Ti - ti}{To - to}\right)}{\ln\left(\frac{Ti - ti}{To - to}\right)}$$

Where,

T_i = Inlet temperature of Hot condensate

T_o= Outlet Temperature of hot condensate

t_i= Inlet Temperature of cold water

t_o= 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

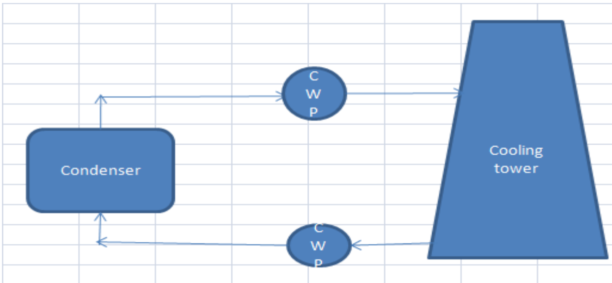

Fig -4: Cooling water system

Performance of cooling water system can be calculated as follows

$$\eta_{\text{cooling water system}}\ (\%) = \frac{\eta \text{ of cwp} \times \eta \text{ of cooling tower}}{100}$$

a) Performance of cooling water pump

The water is required for cool the condensate in condenser. The performance can be calculated as follows.

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

Where,

$$\text{Hydraulic Power Ph(Kw)} = \frac{Q \times (Hd - Hs) \times g \times \rho}{1000}$$

Where,
Q= mass flow rate (m^3/sec)
ρ= Density of fluid (kg/m^3)
g= acceleration due to gravity (m/s2) Hd-Hs= Total Head in meters

b) Performance of Cooling Tower

The cooling tower efficiency can be expressed as

$$\eta = (ti - to) \times 100 / (ti - twb)$$

Where,
η = cooling tower efficiency (%)
t_i = inlet temperature of water to the tower (oC)
t_o = outlet temperature of water from the tower (oC)
t_{wb} = wet bulb temperature of air (oC)

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

$$\eta = \frac{Pout}{Pin} = 1 - \frac{Ploss}{Pin}$$

Where,
Pout – Output power of the motor
Ploss – Losses occurring in motor
Pin – 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.

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

Where,

$$\text{Hydraulic Power Ph(Kw)} = \frac{Q \times (Hd - Hs) \times g \times \rho}{1000}$$

Where,
Q= mass flow rate (m^3/sec)
ρ= Density of fluid (kg/m^3)
g= acceleration due to gravity (m/s2) Hd-Hs= 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.

i. free air delivered Qf =

$$k \times \pi \times \frac{d2}{4} \times \frac{T1}{P1} \times \left[\frac{2 \times (P3 - P4) \times P3 \times Ra}{T3}\right]^{1/2}$$

Where,
K: Flow coefficient – as per IS
d: Nozzle diameter M
T1: Absolute inlet temperature °K
P1: Absolute inlet pressure kg/cm2
P3: Absolute Pressure before nozzle kg/cm2
T3: Absolute temperature before nozzle °K
Ra: Gas constant for air 287.1 J/kg k
P3–P4: Differential pressure across the nozzle kg/cm2

ii. $$\text{Isothermal Efficiency} = \frac{\text{Isothermal Power}}{\text{Input Power}}$$

$$\text{IsothermalPower} = \frac{P1 \times Qf \times \log_e r}{36.7}$$

Where,
P1 = Absolute intake pressure kg/ cm2
Qf = Free air delivered m3/hr.
r = Pressure ratio P2/P1

iii. Specific power consumption

$$\text{at rated discharge pressure} = \frac{\text{Power consumption , kW}}{\text{Free Air Delivered, m3/hr}}$$

iv. $$\text{Volumetric efficiency} = \frac{\text{Free air delivered m3/min x 100}}{\text{Compressor displacement,m3/min}}$$

$$\text{Compressor displacement,} \frac{m3}{min} = \frac{\pi}{4} \times D2 \times L \times S \times \chi \times n$$

Where,
D = Cylinder bore, metre
L = Cylinder stroke, metre
S = Compressor speed rpm
χ = 1 for single acting and

2 for double acting cylinders

n = No. of cylinders

6) Performance of Lightening 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 works given an idea for auditing the thermal power plant. The performance of the thermal power plant can be check on the basis of system based which brought several options that result in reduction of energy conservation.

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