Thermoeconomic Analysis Of Combine Cycle Power Plant

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Abstract

In this research paper thermoeconomic analysis of the combine cycle power plant is carried out. The aim of this new methodology is to find out Exergy Production Cost (EPC) of the combine cycle power plant under study. The exergy analysis of this plant is carried out with the simulator software "Cycle-Tempo". Exergy analysis shows that maximum exergy destruction occurs in the combustion chamber followed by gas turbine, LP steam turbine, compressor, Heat Recovery Steam Generator (HRSG) and condenser. HP steam turbine is having maximum exergetic efficiency while combustion chamber is having second highest exergetic efficiency among all components. Pressure ratio of compressor and gas turbine, turbine inlet temperature and mass flow are considered as decision variables for calculating capital cost of components and Exergy Production cost. With the help of thermoeconomic analysis EPC of plant comes 6.315 Rs/kWh.

1. Introduction

Generally, the performance of thermal power plants is evaluated through energetic performance criteria based on first law of thermodynamics, including electrical power and thermal efficiency. In recent decades, the exergetic performance based on the second law of thermodynamics has found as useful method in the design, evaluation, optimization and improvement of thermal power plants. The exergetic performance analysis can not only determine magnitudes, location and causes of irreversibilities in the plants, but also provides more meaningful assessment of plant individual components efficiency. These points of the exergetic performance analysis are the basic differences from energetic performance analysis. Therefore, it can be said that performing exergetic and energetic analyses together can give a complete depiction of system characteristics. Such a comprehensive analysis will be a more convenient approach for the performance evaluation and determination of the steps towards improvement [1-3].Combined Cycle Power Plants (CCPP) and related technologies have been mature enough due to almost three decades of experience and implementation in power production field. The development of heat recovery steam generators (HRSG) with more than one pressure level and with reheating sections meets the need to exploit better the enthalpy available at the gas turbine exhaust, reducing the exergy losses in heat exchange between hot gases and water [4,5].

The design of CCGT power plants is commonly complex due to the presence of two different power cycles which are coupled through the heat recovery steam generator (HRSG). As common practice, gas and steam turbines are selected within a set of commercially available ones, while the HRSG is the only component of a combined cycle which can be tailored specifically for each gas turbine unit and for each specific plant. Improvement of the HRSG for a combined cycle can be conducted by many approaches [6].

Thermoeconomics is nowadays a powerful tool to study and optimize an energy system. In its application filed is the evaluation of utility costs as products or supplies of production plants, the energy costs between process operations or of an energy converter. Those costs are applicable in feasibility studies, in investment decisions, on comparing alternative techniques and operating conditions, in a cost-effective section of equipment during an installation, an exchange or expansion of an energy system [7].Exergetic production cost (EPC) is a new method developed for the analysis of thermal systems. The developed technique has as objective to find out total operating costs of the plant (EPC), assuming a fixed rate of electricity production and process steam [8].

The objective function is to find out thermoeconomic analysis of combine cycle power plant with Exergy Production cost of the product of the plant. Pressure ratio of compressor and gas turbine, turbine inlet temperature and mass flow are considered as decision variables for calculating capital cost of components and

Nomenclature

m	mass flow rate (kg/s)
E	energy (kJ/kg)
Ex	exergy (kJ/kg)
e	exergy of matter (kJ/kg)
h	enthalpy (kJ/kg)
s	entropy (kJ/kg*K)
Q	heat (kJ)
W	work (kJ)
PEC	purchase equipment cost ($/kW)
P	pressure (MPa)
T	temperature (^{0}C)
f	annuity factor
CP	construction period
k	annuity factor (years)
c	specific cost value ($/kWh)
P_{ele}	purchased electricity cost ($/kWh)
H	operation hour (h)
Z	equipment cost rate ($/h)
ri	rate of inflation (%)
η	efficiency
φ	maintenance factor
E_p	power developed (kW)

Subscripts

i	inlet
o	outlet
0	atmospheric conditions
k	component
d	destruction
ac	air compressor
cc	combustion chamber
gt	gas turbine
HRSG	heat recovery steam generator
st	steam turbine
gen	generator
cond	condenser
ex	exergy based
el	electricity
s	steam
req	required
p	product
x	constituent

Superscript

ph	physical
ch	chemical

Exergy Production cost. Those parameters areselected because of their effect over the power generated and the purchase costs of the components. The EPC equation is developed as a function of these operating parameters.

2. Methodology

Assumptions were made for calculations are system operates in steady state, ideal gas equations are applied to air and combustion products, complete combustion reaction.

2.1. Thermodynamic analysis

Fig.1 shows the process flow diagram of the combine cycle power plant under consideration. Thermodynamic

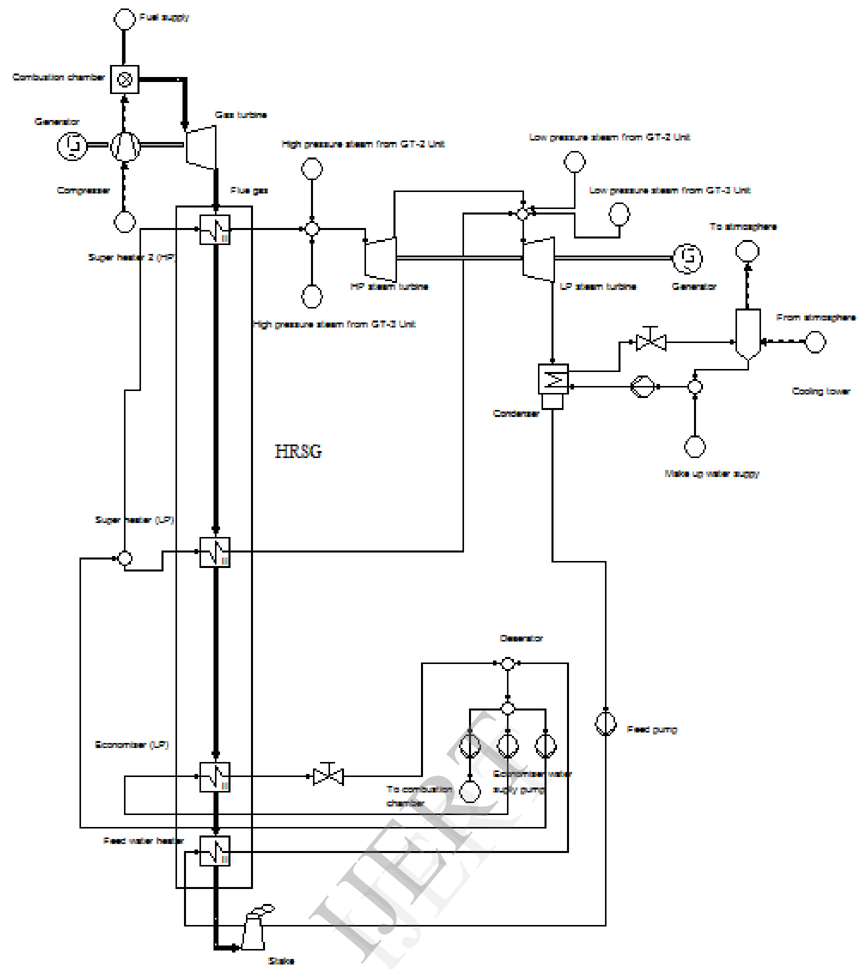

Fig-1: layout of combine cycle power plant

analysis of plant considered following balances like mass, energy and exergy. The parameters and data are based on actual plant data for 660 MW combine cycle power plant being installed by National Thermal Power co. Ltd, Bharuch, India.

For steady state process, the mass balance for control volume system,

$$\sum m_i = \sum m_o \qquad 1.$$

The energy balance for control volume system,

$$\sum E_i + Q = \sum E_o + W \qquad 2.$$

The exergy balance for control volume system,

$$\sum E_{x,i} + \sum \left(1 - \frac{T_0}{T_k}\right) * Q = \sum E_{x,o} + W + E_{x,d} \qquad 3.$$

Where, $E_x = m * e_x$

$$m * e_x = m * (e^{ph} + e^{ch})$$

$$e^{ph} = (h - h_0) - T_0 * (s - s_0) \qquad 4.$$

Exergy efficiency of power plant,

$$\eta_{exergy} = 1 - \left(\frac{E_{x,d}}{E_{x,i}}\right) \qquad 5.$$

2.2 Economic analysis

In this method, cost associated with purchase and operating cost of each component. The expression for purchase cost of components and amortization factor are presented here [9], but some coefficients were adapted to quotation made by manufacturers. The new coefficients also take into account installation, electrical equipment, control system, piping and local assembly.

$$PEC_{ac} = \left[\frac{75*m_{air}}{0.9-\eta_{ac}}\right] * \left[\frac{P_{ac,o}}{P_{ac,i}}\right] * \ln\left[\frac{P_{ac,o}}{P_{ac,i}}\right] \qquad 6.$$

$$PEC_{cc} = \left[\frac{48.75*m_{air}}{0.997-\frac{P_{ac,o}}{P_{cc,o}}}\right] * [1+\exp(0.018*T_{cc,o}-26.4)] \qquad 7.$$

$$PEC_{gt} = \left[\frac{1536*m_{gas}}{0.92-\eta_{gt}}\right] * \ln\left[\frac{P_{gt,i}}{P_{gt,o}}\right] * [1+\exp(0.036*T_{cc,o}-54.4)] \qquad 8.$$

$$PEC_{HRSG} = 4745*\left[\frac{h_s}{\log*(T_{gt,o}-T_{HRSG,i})}\right] + (11820*m_s) + (658*m_{gas}) \qquad 9.$$

$$PEC_{st} = 6000*E_{P,s}^{0.7} \qquad 10.$$

$$PEC_{gen} = 60*E_P^{0.95} \qquad 11.$$

$$PEC_{cond} = 1773*m_s \qquad 12.$$

$$f = \left[\frac{q^{(k+CP)}-1}{(q-1)*q^{(k+CP)}} - \frac{q^{(CP)}-1}{(q-1)*q^{(CP)}}\right]^{-1} \qquad 13.$$

$$q = \left(1+\frac{in}{100}\right) + \left(1+\frac{ri}{100}\right) \qquad 14.$$

$$EPC_{ex} = (E_P*c_{el,ex}) + (E_s*c_{s,ex}) + (E_{req}-E_P)*P_{ele} \qquad 15.$$

Where,

$$c_{el,ex} = \frac{f*\varphi*(PEC_{ac}+PEC_{cc}+PEC_{gt}+PEC_{st}+PEC_{gen})}{H*E_P} + \frac{C_{fuel}}{E_P} \qquad 16.$$

$$c_{s,ex} = \frac{f*\varphi*(PEC_{HRSG})}{H*E_P} + \frac{C_{fuel}}{E_P} \qquad 17.$$

3. Case study

The present method is applied to 660 MW combine cycle power plant being installed by National Thermal Power co. Ltd, Bharuch, India. This plant has three gas turbine unit and one steam turbine unit. This steam turbine unit has two types of steam turbine; one is high pressure and second is low pressure turbine. Water type cooling tower is used to condense steam coming out of low pressure steam turbine.

Table-1.

Input parameters

$m_{air}, kg/s$	465.5	E_P, MW	583
$m_{gas}, kg/s$	491.7	E_P, s, MW	156.58
$m_s, kg/s$		CP	1
$[\frac{P_{ac,out}}{P_{ac,in}}]$	1.33	ri	5
$[\frac{P_{gt,in}}{P_{gt,out}}]$	67.3	φ	1.06
$T_{cc,out}, ^0C$	1069	$C_{fuel}, \$/h$	22.01
$P_{cc,out}, MPa$	7	$P_{ele}, \$.kWh$	7.9
η_{ac}	0.6	H, h	8000
η_{gt}	0.6		
E_{req}, MW	660		

Table-2

Natural gas composition

Component	Mole (%)
CH_4	81.39
N_2	14.82
C_2H_6	3.01
C_3H_8	0.78
Total	100

4. Results and discussion

The exergy analysis of combine cycle power plant is carried out with the help of the software "Cycle-Tempo" [10]. Fig-2 shows the exergy destruction from different components of the plant. Results shows that maximum exergy destruction occurs in combustion chamber which followed by gas turbine, LP steam turbine, compressor, Heat Recovery Steam Generator (HRSG) and condenser. It is interesting to observe that condenser is having least exergy destruction.

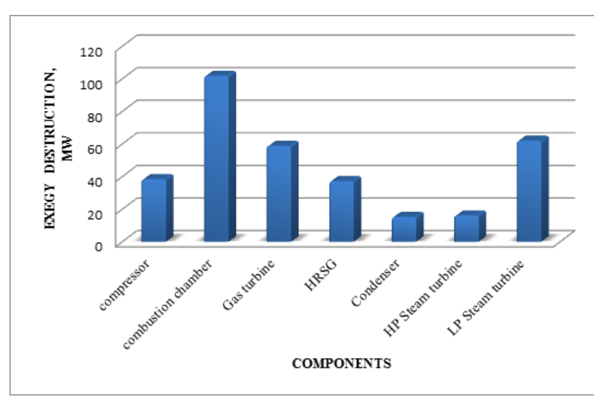

Fig-2: exergy destruction from components of plant

Fig-3 shows the exergetic efficiency of components of plant. It is observed that HP steam turbine have highest exergetic efficiency while condenser is having lowest exergetic efficiency. It is very interesting to observe that though combustion chamber and gas turbine have maximum exergy destruction but it have second and third highest exergetic efficiency respectively.

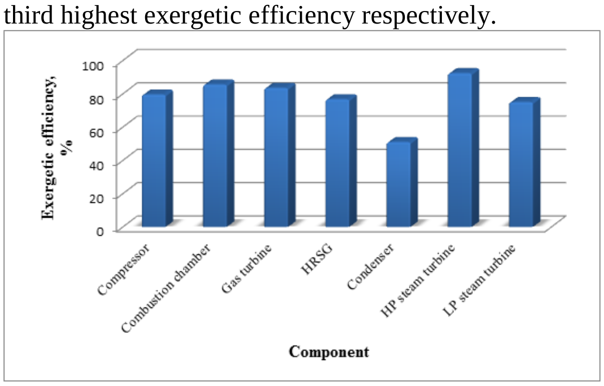

Fig-3: Exergetic efficiency of components of plant

Economic analysis is carried out with help of the software "EES" by generating code in this software. The result of purchase equipment cost and one year calculation of EPC is shown in the table-3.

Table-3
Result for k = 1 and in = 8%

q	1.134	$Z_{st}, (US\$/kWh)$	4427
f	1.286	$Z_{cond}, (US\$/kWh)$	21.45
$Z_{ac}, (US\$/kWh)$	682.5	$Z_{gen}, (US\$/kWh)$	4.338
$Z_{cc}, (US\$/kWh)$	4.796	$EPC, (US\$/h)$	66988
$Z_{gt}, (US\$/kWh)$	1693	$EPC, (RS/kWh)$	6.315
$Z_{HRSG}, (US\$/kWh)$	7603		

The variation in EPC as a function of amortization period is shown in fig-4.

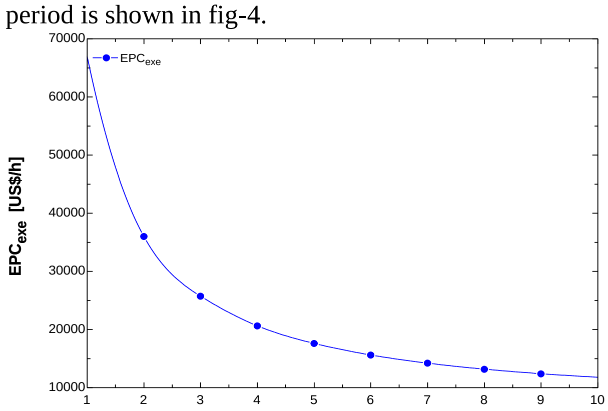

Fig-4: effect of amortization period on EPC (US$/h)

Fig-4 shows the effect of amortization period on EPC (Rs/kWh). From fig-3 and 4 it can be observed that EPC in both cases decreased as amortization period

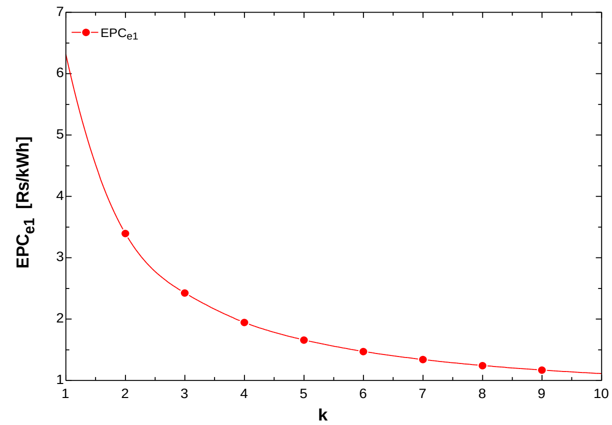

Fig-5: effect of amortization period on EPC (Rs/kWh)

5. Conclusion

It is observed that there is significant amount of loss ofexergy from components of the power plant which should be reduced so that power produced by plant can be improve. Combustion chamber have highest exergy destruction but it also have second highest exergetic efficiency. In the economic analysis, the method developed to find out EPC is very good tool to carry out economic analysis of the combine cycle power plant.The advantage of this method is its lowest computational time, because it is a direct algebraic method, easy to handle and to change its parameters. The study was applied to combine cycle systems and cost of electricity produced comes 6.315 Rs/kWh.

6. References

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