International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 02 Issue: 04 | July-2015 www.irjet.net p-ISSN: 2395-0072

Process Design and cost Analysis of Captive Power Plant While Converting it in to a Combined Cycle

Syamdeep.C[1], Prof.D.K.Narayanan[2]

[1]P.G Scholar, Electrical Engineering Department, Nehru College of Engineering and Research Centre, Kerala, India
[2]Proffesor, Electrical Engineering Department, Nehru College of Engineering and Research Centre, Kerala, India

---***---

Abstract - *The rate of exploitation of the energy resources are expanding over time and resulted in depletion of fossil fuel reserves. Efficient utilization fossil fuel resources is crucial both in environmental and economic sense. A captive power plant in an industry is utilized for the power which required for running the plant as well as the supplier of the steam which required for the process in the industry. The use of very critical equipments and critical operating conditions in the industry makes the need of captive power plant essential because it need a continuous power supply without fluctuation in load. The captive power plant studied here is a steam power plant where LNG is used as a fuel. About 10.7MW power and 153 TPH steam is generated in the plant. The efficiency of steam power plant is between 35% to 40%. The power and steam production is done with the help of steam turbines which is works on simple Rankine cycle. The use of power plant has became uneconomical, because it has lot of disadvantages like variable heat losses, unaccounted losses due to aging etc.The conversion of steam turbine to gas turbine with a heat recovery generator will put the plant in to a combined cycle. The gas turbine with a heat recovery steam generator is a form of highly efficient energy technology that combines a gas fired turbine with a heat recovery steam generator. The combined cycle improves the efficiency of plant considerably and also gives more profit for the plant.*

Key Words: *captive power plant, gas turbine, Brayton cycle, liquefied natural gas (LNG), Heat recovery steam generator, cost calculation*

1. INTRODUCTION

The captive power plants are an important part of the industry which produces steam and power. The steam from the captive power plant after the power production is utilized for the process in the industry. The conventional steam power plants are less efficient since they face many problems. The conversion of conventional steam power Plants in to a combine's cycle will improve the efficiency of the plant. The gas turbine is characterized by relatively low capital cost compared with the conventional steam turbines. It has environmental advantages and short construction time. One of the technologies adopted in the industries for efficiency improvement is also combined cycle. The combined cycle system utilizing the Brayton cycle gas turbine and Rankine cycle steam system with air and water as working fluid achieve high efficient, reliable economic power generation.

Suitable modification possible in the gas turbine combined cycle such as reheat cycle, heat exchange cycle etc which will improve the efficiency. The captive power plant run as a steam power plant is taken for analysis. The power is produced by means of steam generating boilers and turbo generator. The power requirement in the plant is 10.7 MW and 153 TPH steam is generated in a day. Three boilers at a capacity of 60 TPH are used to generate the steam. The pressure is 110ATA at a temperature of 520^{o}C.The turbo generator has a capacity of 16MW.The steam generated is divided in to three sub levels through four header consisting pressure of 110 ATA, 41ATA, 14ATA&5ATA by means of pressure reducing super heater.110ATA is used for power production and 41 ATA, 14 ATA and 5 ATA for process plant and steam requirement for the operation of the boiler.

1.1 Methodology

The cost analysis has done in existing plant by conducting a full load test and by evaluating the amount of LNG required for the production of steam. The process design has been done by analyzing the simple gas turbine cycle and calculating the steam produced by the heat recovery generator.

1.2 Cost Calculation of LNG utilized in Existing Plant

The cost of production steam in captive power plant is found out by conducting a full load test for 72 hours using LNG as a fuel.

Table -1: Steam production and LNG consumption in full load test

Date	Steam Production(MT)	LNG Consumption(kg)
22/5/15	656.1	41303
23/5/15	1452	90843
24/5/15	1452	90880
25/5/15	780	48465

Average steam produced =1085.25 MT

Average LNG consumption= 67872.85 KG

LNG required for production of 1MT steam=67872.85/1085.25=62.54 KG

Density of LNG=.7741 KG/SCM

Gross calorific value of LNG=10000 KCAL/SCM

Required MMBTU of LNG for production of 1MT steam=volume × gross calorific value
=62.54×10000× (3.9685/.77411)×1000000
=3.2 MMBTU

Cost of LNG for 1MMBTU=$19.5=RS 1209

Cost of LNG for production of 1MT steam=3.2×1209
= RS 3808.

Cost of LNG for the production of 153TPH in day=3868.2×153×24=142062.33 RS

2. ANALYSIS OF COMBINED CYCLE
2.1 The Simple Gas Turbine

A gas turbine is also called a combustion turbine which is a type of internal combustion engine. The basic difference in operation of gas turbine is that air is used instead of steam. Brayton cycle is an ideal cycle for the gas turbine. The First process in a gas turbine cycle is compression. The working fluid is expanded directly in to the turbine and there were no losses in either component. The power developed by the turbine will be just equal to that absorbed by the compressor. The gas turbine works on both open cycle and closed cycle. Fresh air at ambient conditions is drawn in to the compressor where its temperature and pressure are raised .The high pressure air move in to the combustion chamber where the fuel is burned at constant pressure. The resulting high temperature gas enters the turbine where they expand to atmospheric temperature while producing power. The exhaust Gas leaving the turbine are thrown out giving the name open cycle. But in the case of closed cycle the combustion process is replaced by a constant heat addition process from an external source. The exhaust process is replaced by a constant heat rejection process to the ambient air.

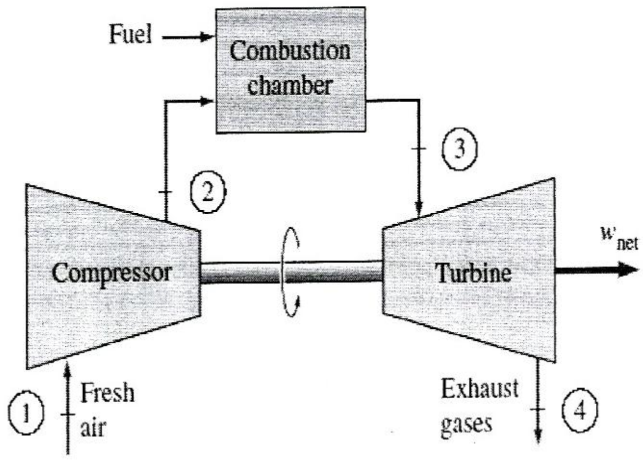

Fig -1: open cycle gas turbine

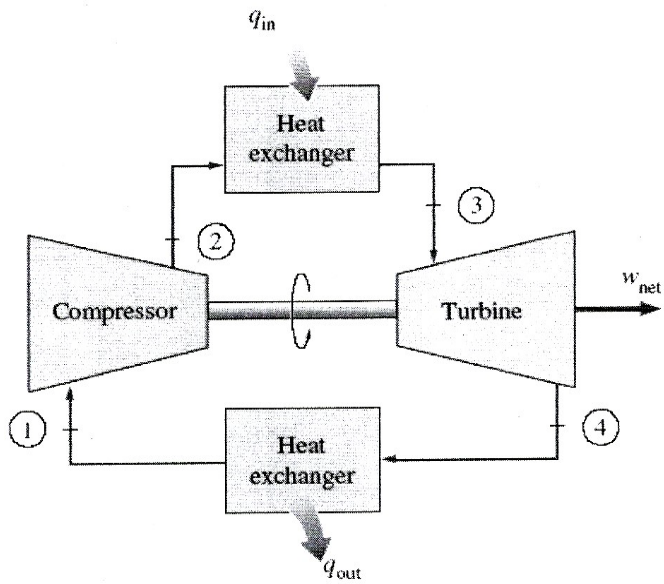

Fig -2: closed cycle gas turbine

The ideal cycle used for gas turbine is Brayton cycle. The Brayton cycle is made up of four internally irreversible processes.

1-2 isentropic compression (in a compressor)

2-3 constant pressure heat addition

3-4 isentropic expansion (in a turbine)

4-1 constant pressure heat rejection

Gas turbines are also used as stationary power plants to generate electricity as stand-alone units or in conjunction with steam power plants on the high-temperature side. In these plants, the exhaust gases of the gas turbine serve as the heat source for the steam. The gas-turbine cycle can also be executed as a closed cycle for use in nuclear power plants. This time the working fluid is not limited to air, and a gas with more desirable characteristics (such as helium) can be used. Heat recovery generators are used to recover the heat from the hot gas stream and this heat is used for the production of steam and used for the process in captive power plant.

2.2 Calculation of Air Required For Combustion of LNG

The chemical composition of LNG used is given below

Composition	Hydrocarbons					C_{02}	N_2	H_2
	CH_4 methane	C_2H_6 ethane	C_3H_8 Propane	C_4H_{10} Butane	C_5H_{12} Pentane			
Mol%	88.51	7.72	2.33	6.49	0.02	nil	0.19	nil

Amount of oxygen required for carbon
$C+O_2 \rightarrow CO_2$
$12+32 \rightarrow 44$
$1+2.67 \rightarrow 3.67$
1kg Carbon needs 2.67 kg oxygen

$2H_2+O_2 \rightarrow 2HO$
$4+32 \rightarrow 36$
$1+8 \rightarrow 9$
There for 1kg of hydrogen needs 8kg of oxygen

1. Combustion of methane (CH_4)
$CH_4+2O_2 \rightarrow CO_2+2H_2O$
$16+64 \rightarrow 44+36$
$1+4 \rightarrow 2.75+2.25$
1kg methane requires 4KG of oxygen

2. Combustion of ethane (C_2H_6)
$2C2H_6+7O_2 \rightarrow 4CO_2+6H_20$
$60+224 \rightarrow 176+204$
$1+3.73 \rightarrow 2.93+3.4$
1kg ethane requires 3.73 KG oxygen

3. Combustion of Propane (C_3H_8)
$C_3H_8+5O_2 \rightarrow 3CO_2+4H_2O$
$44+160 \rightarrow 132+72$
$1+3.63 \rightarrow 3+1.8$
1kg propane requires 3.63KG oxygen

4. Combustion of butane (C_4H_{10})
$2\ C_4H_{10}+13O_2 \rightarrow 8CO_2+10H_2O$
$116+416 \rightarrow 352+180$
$1+3.58 \rightarrow 3.034+1.55$
1kg of butane requires 3.58 kg of oxygen for burning

5. Combustion of pentane (C_5H_{12})
$C_5H_{12}+8O_2 \rightarrow 5CO_2+6H_2O$
$72+256 \rightarrow 220+108$
$1+3.556 \rightarrow 3.056+1.5$
1kg pentane requires 3.556 kg oxygen for burning

Total oxygen required for the burning of LNG =(4×0.8851)+(3.73×0.0772)+(3.63×0.0233)+(3.58×0.069) +(3×.0002)=3.54+0.287+0.08450.232+0.00071=4.14kg

Amount of oxygen required for burning of 1kg of LNG=4.14 kg

1kg of air consist 23% of oxygen

Therefore air required for burning of 1KG of LNG=4.14/.23=18kg of air

Total amount of air with excess air=18*1.05
=18.9 kg of air
Total amount of air required for burning of 1 kg of LNG=18.9 kg

2.3 Cycle Analysis

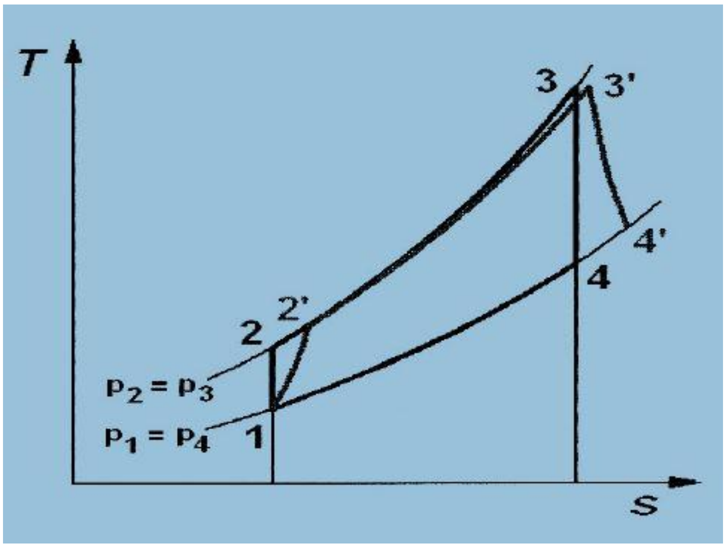

Fig -2: T-S diagram of a simple gas turbine

Process 1-2 (at compressor)

If the temperature of air increases, then the density of air increases and mass flow rate decreases. So the power output of the turbine reduces because more power is required to compress warmer air. So in order to increase the efficiency of gas turbine the air is cooled to 15^oc.

T_1=15^{o}C=288K
Atmospheric pressure =1 bar
Take the pressure of air after compression P_2=5 bar
During isentropic compression we have the relation
$T_2/T_1= (P_2/P_1)^{(Ya-1)/Ya}$
Where T_2 is the temperature of air after compression and Ya is the adiabatic index of air=1.4
From the equation T_2=456K
Isentropic efficiency of the compressor= $(T_2-T_1)/(T_2'-T_1)$
The efficiency of compressor taken as .8
Therefore T_2' =498K

Process2-3(at combustion chamber)

After the combustion we have the relation,
Heat supplied by fuel=Heat taken by burning gas
m_f× calorific value of the fuel=$(m_a+m_f)\times c_{pg}\times(T3-T_2')$
m_f=mass of fuel
m_a=mass of air
c_{pg}=specific heat at constant pressure of combusted gas=1.147kj/kgk
T_3=939K

Process 3-4(at turbine)

During isentropic expansion we have the relation,
$T_4/T_3=(P_4/P_3)^{(Yg-1)/Yg}$
Yg is the adiabatic index of combusted gas=1.33
T_4=629K
Isentropic efficiency of the turbine=$(T_3-T_4')/(T_3-T_4)$
Isentropic efficiency of the turbine=0.8
T_4'=691K
Work input to the compressor,$W_{comp}=C_p(T_2'-T_1)$kj/kg of air
Where C_p specific heat at constant pressure of air=1.005kj/kgk
W_{comp}=1.005×(498-288)
=211kj/kg of air
Work output from turbine,
$W_{net}=W_{turbine}-W_{comp}$
=284-211
=73kj/kg of air
At a mass flow rate of air m_a=147kj/sec
The net work output W_{net}=147×73KW
= 10731KW
=10.7MW
Therefore work input to the compressor $W_c=m_a\times c_{pa}\times (T_2'-T_1)$
=147×1.005× (498-288)
=31.024 MW

2.4 Calculation of Steam Produced In Heat Recovery Generator (HRSG)

Total heat energy produced by the fuel at combustion chamber
$Q_{in}=m_f$ ×calorific value of fuel
=1.78×42000
=74760KW
= 74.76 MW
Out of 74.76 MW power 10.7 MW is net output power
Additional work required to overcome bearing, friction and windage loss during compression process is 10% of net work input to compressor
= (31.024×10)/100
=3.1MW
Unaccounted loss is about 5% of total input energy =
=(74.6×5)/100
=3.73MW
Therefore total energy input to HRSG=74.76-10.7-3.1-3.73
=57.23MW
=57230KW
Heat utilized by 1kg of feed water in economizer $h_{f1}=m_w\times c_w\times(t_{e2}-t_{e1})$
Where m_w=mass of feed water=1kg
C_w=latent heat of vaporization=4.18kj/kg
t_{e1}=temperature of feed water in economizer=183^{o}c(as per the condition of economizer in steam boilers)
t_{e2}=temperature of feed water leaving the economizer=210^{o}c(as per the condition of economizer in steam boilers)
h_{f1}=1×4.2× (210-183)
=113.4kj/kg of water
Heat utilized in evaporator per kg of feed water $h_e=(h_f+xh_{fg})-h_{f1}$
h_f=specific enthalpy of saturated liquid
At 40 bar pressure 210^{o}c,h_f=1087.4 kj/kg and
h_{fg}=latent heat of evaporation=1712.9kj/kg
X=dryness fraction
$=S_g-S_f/S_{fg}$
Where S_g=specific entropy of saturated vapour=6.069kj/kgK
S_f=specific entropy of saturated liquid=2.797kj/kgk
S_{fg}=specific entropy of evaporation=3.272kj/kgk
X= (6.069-2.797)/3.272
=1
Therefore h_e= (1087.4+1712.9)-113.4
=2687kj/kg

Heat utilized by 1kg of feed water in super heater $h_{sup}=(1-X)h_{fg}+C_{ps}(T_{sup}-T_s)$
At 40 bar pressure
Saturated temperature T_s=250.3^{o}c
Super heated temperatue T_{sup}=390^{o}c
Specific heat of super heated steam C_{ps}=2.3kj/kg
Therefore,h_{sup}=(1-1) ×1712.9+2.3(390-250.3)
=321.31kj/kg

Total heat energy utilized by 1kg of feed water $h_t=h_{f1}+h_e+h_{sup}$

=113.4+2687+321.31

=3121.71kj/kg

Take thermal efficiency of HRSG=0.9

Total heat energy available for economizer, evaporator and super heater=0.9×57230

=51504 kj/sec

Therefore mass of steam produced by HRSG=51504/3121.71

=16.49 kg/sec

=59TPH

Therefore maximum steam can be produced by HRSG is 59 TPH. The total steam demand of industry is 122 TPH. So remaining steam requirement is equal to 63TPH.So the remaining steam requirement can be met by running the three captive boilers available within the plant. The three boilers will run at an average load of 20.6TPH with the plant. This will increase the reliability of the plant and provide a continuous supply of steam if some problem like tripping of gas turbine happens to the plant.

2.5 Cost Calculation of LNG in Combined Cycle

Mass of LNG used as fuel in gas turbine m_f=1.78kg/sec

Heat liberated by the LNG during compression

=m_f × calorific value of fuel

=1.78×42000

=74760kj/sec

=74760/ (1.05×10^6) MMBTU/sec

=6151.68MMBTU/day

Present cost of 1 MMBTU LNG=$19.5

Take1$=62Rs

So the cost of fuel=19.5×62×6151.68

=Rs 7437381.12

We have cost of LNG for the production of 1MT steam in captive boilers.

=Rs 3868.8

Cost of LNG for production of 63TPH steam in a day

=3868.8×63×24

=Rs.5849625.6/day

Therefore total cost of LNG=7437381.12+5849625.6

=Rs.13287006.28/day

Profit of the company gas turbine with HRSG installed

=Running cost at present situation-Running cost while installing gas turbine with HRSG

=14206233.6-13287006.28

=Rs 919227.32/day

4. CONCLUSIONS

After the installation of gas turbine combined cycle, the overall requirement of steam for captive power plant will reduce from 153TPH to 122 TPH , total steam load of complex will come down by total condensing load of both turbines. The gas turbine with a power rating of 15MW will satisfy the power requirement in the plant.

3 captive boilers with a capacity of 60TPH will run with the combined cycle in order to satisfy the steam requirement in the plant. The conversion of captive power plant in to combined cycle will improve the efficiency of the plant, reduce the size of the plant and also lead to a sustainable growth.

REFERENCES

1. A.k Tiwari,M.M.Hassan and Mohd islam," Effect of operating parameters on the performance of combined cycle power plant", open access scientific reports, volume 1,issue7,2012.
2. Mr.Vikas singhal and Mr.deepak Bhardwaj,"A research paper on study the analysis of combined cycle power plant with change in gas turbine operating parameter", vol 3,issue7, pp:(171-178), July 2014.
3. P K Nag. Power Plant Engineering". Tata McGraw-Hill Education Private Limited, Vol 2, pp : (772 - 794), June 2004.
4. P.K Nag. "Engineering Thermodynamics". Tata McGraw-Hill Publishing Company Limited, Vol.2, pp :(462 - 474), December 2001.
5. Lee S. Langston and George Opdyke. "Introduction to Gas Turbines for Non-Engineers", Global Gas Turbine News, Vol 37, pp : 1-9, June 1997.

