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Short Communication

Economic and Performance Analysis of Thermal System

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Abstract

For the feasibility of any thermal system economic analysis is must. In the present work economic analysis of a cogeneration power plant is made for increasing the efficiency of cycle. From the literature it is being observe that for increased efficiency the factor which should be taken in to consideration are: air compressor efficiency, gas turbine efficiency, mass flow rate of air, turbine inlet temperature, pressure loss and size of combustion chamber, LMTD for heat transfer surfaces, cycle pressure ratio and mass of steam to be produced. Mathematical model available in literature is used and a computer program in software MATLAB is executed for the analysis. Trend observed for the increase in cost are tabulated in the results.

Keywords: GTCC, HRSG, LMTD

Introduction

The economy of India, a developing country, has grown rapidly in recent years, along with the electrical demand. In recent years, the use of gas turbine for power generation has increased dramatically worldwide. According to world energy forecasts, fossil fuels like coal, oil, and natural gas will continue to be the main energy sources for power generation in the near future in India as well as worldwide. Large-scale natural gas production in India with improved gas turbine technology has made combined cycle power plants a viable option. The thermal efficiency of gas turbine combined cycle (GTCC) power plants can reach 60% that is far more than that of conventional coal-fired steam turbine plants, which not only conserves our limited reserves but also reduces emissions and protects our lives and environment[1,2,3]. Larger gas turbines with higher power outputs are mainly used in combined cycle plants for heat and power cogeneration[4,5,6,7,8,9]. The main financial and cash flow concepts are as follows:

Initial equity: The portion of the total investment is paid by the owner's funds. The remainder is paid with borrowed money.

Years for payback of equity: The time required to recoup the initial equity put up by the plant owners from the net plant cash flow.

Net cash flow: The net amount of cash generated per year.

Cumulative net cash flow: The sum of annual net cash flows for the plant over its lifetime.

Operating income = Total revenues – total operating expenses.

Total revenues include electricity and steam revenues. In the present work purchase equipment cost of air compressor, combustion chamber, gas turbine, air preheater and heat recovery steam generator (HRSG) is calculated on the basis of different operating parameters.

Material and Methods

The following cost functions for compressor, combustor, turbine, air preheater and HRSG are used for the analysis:

$$Compressor = \frac{71.10 \times m_{air}}{0.9 - \eta_{is}} r_c \times \ln(r_c)$$

$$Combustor = \frac{46.08 \times m_{air}}{0.995 - \%\Delta P_{cc}} \times \left[1 + \exp\left(0.018 T_{\max} - 26.4\right)\right]$$

$$Turbine = \frac{479.34 \times m_{gas}}{0.92 - \eta_{is}} . \ln r_t \times \left[1 + \exp\left(0.036 T_{\max} - 54.4\right)\right]$$

$$AirPreheater = 4122\left(\frac{m_g\left(h_{in} - h_{out}\right)}{18.\Delta T_{LMTDAph}}\right)^{0.6}$$

$$HRSG = 6570\left[\left(\frac{Q_{ec}}{\Delta T_{LMTDec}}\right)^{0.8} + \left(\frac{Q_{ev}}{\Delta T_{LMTDev}}\right)^{0.8}\right] + 21276.m_{st} + 1184.4 m_g^{1.2}$$

The scheme outlined above has been numerically studied using a code developed in MATLAB.

Results and Discussion

With the increase of GT cycle output, the GTCC output increases even more, so the difference of GT and GTCC outputs increases. Therefore, larger gas turbines in combined cycle power plants will experience a greater output increase than smaller gas turbines, since the electrical efficiency of the combined cycle is higher than that of a simple cycle. The efficiencies of the smaller gas turbines are not directly related to size as with the medium and large turbines where the electrical efficiency of both the GT and GTCC increases slowly with increasing output. Therefore, large gas turbines with their higher electrical efficiencies in both simple and combined cycle systems will provide better energy conservation and utilization.

The total investment includes the cost of specialized equipment, plant site infrastructure, mechanical infrastructure, buildings, etc. The specialized equipment includes the gas turbine, the steam turbine, the heat recovery boiler, the water-cooled condenser, the fuel gas compressor, the continuous emissions monitoring system, the distributed control system, and the transmission and generating voltage equipment packages. Here purchase equipment cost of air compressor, combustion chamber, gas turbine, air preheater and heat recovery steam generator (HRSG) is calculated on the basis of different operating parameters. Cost of HRSG depends upon the Log mean temperature difference (LMTD), mass of steam produced and mass of flue gases passing through it.

With increase in LMTD cost of HRSG comes down but with increase in mass of steam and flue gases cost of HRSG increases. Cost of air preheater depends upon LMTD and mass of flue gases and same trend that of HRSG is observed in it. Cost of air compressor is dependent upon the mass of air entering the compressor, compression ratio and compressor efficiency. As the value of all these three parameters increases, cost of air compressor also increases. Cost of combustion chamber (CC) depends upon the mass of air entering the combustion chamber, pressure losses in combustion chamber and combustion chamber outlet temperature. As CC outlet temperature increases, cost of material also increases. Secondly for higher mass flow rate in CC, size of CC should be large. Both these factors increase the cost of combustion chamber. For higher turbine inlet temperature (TIT), turbine blade material becomes costly. For higher mass flow rate of air, larger gas turbine is required. Same trend is observed for the case higher efficiency and higher turbine pressure ratio. However, other factors must also be taken into consideration.

Table-1
Purchase equipment cost (PEC) of HRSG

LMTD	100	115	130	145	160
PEC of HRSG	426957023	426856699	426772596	426708276	426655499
Mass of steam (Kg/s)	20000	25000	30000	35000	40000
PEC of HRSG	426957023	958629405	106500940	117138940	127776940
Mass of flue gases (Kg/s)	80	85	90	95	100
PEC of HRSG	426957023	426974197	426991579	427009153	427026913

Table-2
Purchase equipment cost of air preheater

LMTD	100	110	120	130	140	150
PEC air preheater	151236	142827	135563	129207	123587	475826
Mass of flue gases (Kg/s)	80	85	90	95	100	105
PEC air preheater	151235	156765	162234	167583	172821	177955

Table-3
Purchase equipment cost of air compressor

Mass of air (Kg/s)	80	85	90	95	100
PEC compressor	946483	1005638	1064793	1123948	1183104
Compression Ratio	8	10	12	14	16
PEC compressor	946483	1308240	1692748	2102284	2520921
Compressor Efficiency	0.8	0.82	0.84	0.86	0.88
PEC compressor	946483	1183104	1577472	2366208	4732416

Table-4
Purchase equipment cost of combustion chamber

Mass of air (Kg/s)	80	85	90	95	100	105
PEC of CC	111756	118740	125725	132710	139695	146679
Pressure loss in CC	0.10	0.09	0.08	0.07	0.06	0.05
PEC of CC	111756	124903	141557	163335	193033	235929
CC outlet temperature	1373	1423	1473	1523	1573	1623
PEC CC	45788	56266	82264	146679	301896	686058

Table-5
Purchase equipment cost of gas turbine

Mass of flue gases	80	85	90	95	100	105
PEC gas turbine	669271	711100	752930	794625	836448	878270
TIT	1373	1423	1473	1523	1573	1623
PEC gas turbine	669271	692601	833514	1681652	6832959	37321055
Turbine pressure ratio	8	10	12	14	16	18
PEC gas turbine	669271	740059	799585	849156	892121	930020
GT Efficiency	0.8	0.82	0.84	0.86	0.88	0.9
PEC gas turbine	669271	803125	1003906	1338542	2007813	4015626

The increase in the annual fuel consumption is almost proportional to the GTCC output. Then, the maximum fuel consumption and the maximum output are both from the largest system. Larger gas turbines will be better choices for Indian GTCC power plants due to their higher electrical efficiencies, shorter payback time, and lower owner's cost per MW, but their total investment cost and annual fuel needs are very high. India, therefore, needs to select suitable sized gas turbines according to the specific economic conditions.

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