PERFORMANCE ANALYSIS OF CCGT POWER CYLCE USING MAT LAB CODING

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ABSTRACT

A combined cycle is a synergistic combination of two or more power cycles operating at different temperatures running independently. Normally the cycles are classified as a 'topping' and a 'bottoming' cycle. Presently, the gas steam combined cycle is widely accepted, where Brayton Cycle has high source temperature and rejects heat at suitable temperature that is conveniently used as the energy source for the Rankine Cycle. The performance of combined cycle depends upon number of parameters like TIT, component efficiencies, turbine exhaust temperature, degree of supplementary firing and condition of steam generation. Our work is to find specific work output and optimize the thermal efficiency of combined cycle by reheating without supplementary firing and reheating with supplementary firing when steam is generated at 12 bar 325^{0}C for a given set of parameters like temperature, pressure ratio and A/f ratio. MAT lab coding has been used for validation of research work.

Keywords: Combined Cycle, Optimization, Steam turbine, Gas turbine, Efficiency, Supplementary heating, , A/F ratio, Pressure ratio.

I. INTRODUCTION

The introduction of combined cycle had opened new avenues in the field of power generation. The gas turbines that were initially used in peak load power generation and emergency conditions could be used in base load power generation. Combined Cycle is a synergistic combination of gas cycle and power cycle. Thus performance of combined cycle depends upon the performance of gas cycle and steam cycle. So in order to achieve this objective the parameters that affect the performance of gas turbine (maximum temperature, component efficiency, a/f ratio and pressure ratio) the limitations that restrict the performance of gas turbine (space, cost and metallurgical limitations) were determined .One of the major limitations of gas cycle is the unavailability of materials that could withstand high temperature. So, gas turbines are provided with high a/f ratio to maintain the temperature of turbine blades. Due to this turbine exhaust have high amount of unused oxygen in which additional fuel can be burnt. Thus concept of supplementary heating comes into picture.

S. De and P.K. Nag[1] has been done the exergy analysis of various components at different degree of supplementary heating . It is found that the most favorable benefit of supplementary heating is for a low temperature ratio only and for higher temperature ratio gain in work output is at an expense of overall efficiency of the plant. .Louis JF Hirao Ka K and E.I. Masri M.A [2] have proposed the comparative study of the influence of different means of turbine cooling on gas turbine performance G.CARRY et. Al. [3] has discussed the effect of steam cycle regeneration on combined cycle. They find out that efficiency could rise for low turbine pressure ratio and for small regeneration degree and regeneration degree causes an increase in efficiency when it is small enough .Considerable work on comparative evaluation of advanced combined cycle alternatives is reported in literature [4].IG RICE [5] have discussed the effect of pressure ratio and firing temperature on power output, thermal efficiency, turbine exit temperature. According to this reheat cycle gas turbine efficiency is degrade slightly over the simple cycle for equal firing temperature and the reheat cycle gas turbine output is increased significantly. It has been also mentioned that as the pressure ratio is increased the compressor discharge temperature also increase. However gas generator exit temperature decreases with increase in pressure ratio. He emphasize on the role of pressure ratio on specific power output and thermal efficiency. And find that as the pressure ratio for compression increases the specific work output for gas turbine increases whereas work output in steam turbine is decrease .M.A. Da Cunha et. Al. [6] has discussed the concept of inter cooling and reheat for gas turbines and the effect of position of inter-cooling and reheating on gas turbine performance. In our analysis we discuss the optimized efficiency of the combined cycle with given sets of constraints and variables. The optimized result will give the maximum efficiency of the Combined Cycle which defines the running conditions of both the Gas Turbine and Steam Turbine Cycles. In 2012 Thamir K. Ibrahim 2(7) has discussed the effect of compression ratio on performance of Combined Cycle Gas Turbine. R-I Crane [8] has discussed the critical analysis of the thermodynamic advantages of reheat in Gas Turbines.

In the present analysis, the specific work output and thermal efficiency of combined cycle is determined at different a/f ratio in the range of 50-130 and pressure ratio in the range of 4-40. It is observed that specific work output and thermal efficiency improve at lower a/f ratio and higher-pressure ratio.

II. THERMODYNAMIC MODELING OF COMBINED CYCLE

In the present analysis of combined cycle, the effect of various parameters like a/f ratio), pressure ratio on specific work output and thermal efficiency. The effect of reheat, supplementary heating and condition of steam generation i.e. pressure and temperature on specific work output and thermal efficiency are also analyzed.

To analyze the present study the methodology adopted are

Firstly calculate worknetl, work net2 and efficiency 1, efficiency 2 at different a/f ratio and pressure ratio for

a) Reheat , inter-cooling without supplementary firing

b) Reheat , inter-cooling with supplementary firing

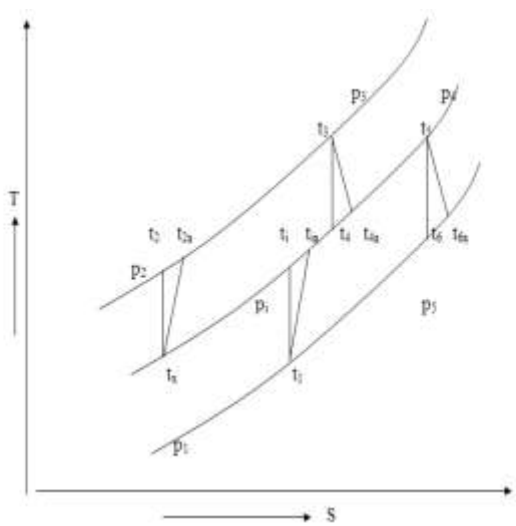
when the steam is generated at 12 bar and 325°C

Once the exhaust gas has temperature higher than the temperature needed for steam generation, the steam cycle would contribute.

Thus we can calculate work3 and efficiency3. Here,

work 3 = work net 1 + work net 2

efficiency 3 = efficiency 1 + efficiency 2



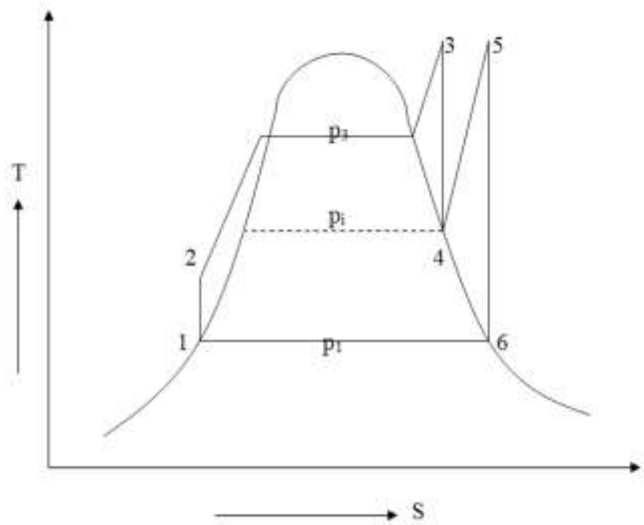


Fig. 1 Gas Turbine Cycle (Brayton Cycle) without Supplementary heating with Reheat and with Inter-cooling.

Fig. 2 Rankine Cycle without Supplementary heating with Reheat and with Inter-cooling.

III. ANALYSIS OF GAS TURBINE CYCLE

3.1 With Reheat Without Supplementary Heating

$$\frac{t_i}{t_1} = \left(\frac{p_i}{p_1}\right)^{\gamma-1/\gamma}$$

where

$$\frac{\gamma-1}{\gamma} = 0.2857$$

Also, $p_i = \text{sqrt}(p_1 \times p_2)$, where Sqrt = Square Root

Now,

$$\frac{t_i - t_1}{t_{ia} - t_1} = \eta_c$$

$$t_{ia} = \frac{t_i - t_1}{\eta_c} + t_1$$

Now, similarly

$$t_{2a} = \frac{t_2 - t_x}{\eta_c} + t_x$$

Here, for perfect inter-cooling, $t_x = t_1$

So $$t_{2a} = \frac{t_2 - t_1}{\eta_c} + t_1$$

Now, to calculate t_3

$$m_f \times L.C.V = (m_f + m_a) \times C_{pg} \times (t_3 - t_{2a})$$

$$m_a = 1 \times a/f$$

$$t_3 = \frac{m_f \times L.C.V}{(m_f + m_a) \times C_{pg}} + t_{2a}$$

$$\frac{t_3}{t_4} = \left(\frac{p_3}{p_4}\right)^{0.2857}$$

and $p_4 = \text{sqrt}(p_3 \times p_5)$

$$t_4 = \frac{t_3}{(p_3 / p_5)^{0.2857}}$$

and $t_5 = t_3$

$$t_6 = \frac{t_5}{(p_4 / p_5)^{0.2857}}$$

$$\eta_t = \frac{t_5 - t_{6a}}{t_5 - t_6}, \quad t_{6a} = t_5 - \eta_t (t_5 - t_6)$$

Here,

$$w_t = (m_f + m_a) \times C_{pg} \times (t_3 - t_{4a} + t_5 - t_{6a})$$

and

$$w_c = m_a \times C_{pa} \times (t_{2a} - tx + t_{ia} - t_1)$$

Now,

$$\text{Thermal Efficiency} = \frac{\text{Work 1}}{m_f \times L.C.V + (m_f + m_a) \times C_{pg} \times (t_5 - t_{4a})}$$

3.2 Reheat With Supplementary Heating

We have,

$$w_t = Z \times (m_f + m_a) \times C_{pg} \times (t_3 - t_{4a} + t_5 - t_{6a})$$

IV ANALYSIS OF STEAM CYCLE

4.1 With Reheat Without Supplementary Heating

Mass of steam generated by utilization of waste energy.

$$\text{Work (steam)} = m_s \times (h_3 - h_2)$$

Now to calculate 'm_s'

$$m_s = \frac{(m_f + m_a) \times C_{pg} \times (t_8 - t_9)}{(h_3 - h_2)}$$

Also,

$$\text{work net } 2 = \frac{(\text{work } 2)}{(m_f + m_a)}$$

$$\textit{Efficiency } 2 = \frac{(\textit{work } 2)}{m_f \times L.C.V + (m_f + m_a) \times C_{pg} \times (t_5 - t_{4a})}$$

4.2 With Supplementary Heating With Reheat With Inter Cooling

To calculate mass of steam

$$m_s(h_1 - h_{f3}) = Z \times (m_f + m_a) \times C_{pg} \times (t_8 - t_9) + Z_a \times m_f \times L.C.V$$

Here $Z_a = 1 - Z$,

Where Z is supplementary fuel fired.

$$m_s = \frac{Z \times (m_f + m_a) \times C_{pg} \times (t_8 - t_9) + Z_a \times m_f \times L.C.V}{(h_3 - h_2)}$$

$$\text{work net2} = \frac{\text{work2}}{(m_f + m_a)}$$

Here,

$$\textit{Efficiency 2} = \frac{\textit{work2}}{m_f \times L.C.V + (m_f + m_a) \times C_{pg} \times (t_5 - t_{4a})}$$

V. ANALYSIS THROUGH MATLAB CODING

5.1 – Analysis Of Combined Cycle With Reheat Without Supplementary Heating

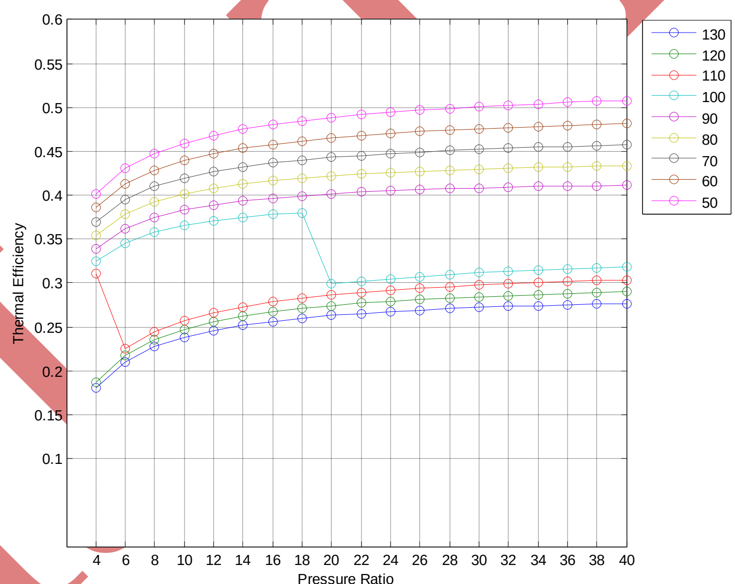


Fig. 3: Thermal Efficiency v/s Pressure Ratio at Different A/F Ratio with Reheat without Supplementary Heating When Steam is generated at 12 bar 325^{0}C

The Optimized Value of Efficiency at Air/Fuel Ratio 50.00 and Pressure Ratio 40.00 is 0.508.

1) Steam cycle become effective for A/F ratio 110 and lower.

2) At A/F ratio of 100 Efficiency 3 increases from pressure ratio 4 to pressure ratio 18. Efficiency 3 decreases sharply in the range of 18 to 20 bars. From 20 bar onward Efficiency 3 continuously increase with pressure.

3) At a particular pressure ratio the Efficiency 3 increases with lowering of A/F ratio.

4)It is also seen that Efficiency 3 continuously increases with pressure for all A/F ratio.

5)The optimized value of Efficiency 3 is at A/F ratio 50 and pressure ratio 40.

5.2 – Analysis Of Combined Cycle With Reheat With Supplementary Heating.

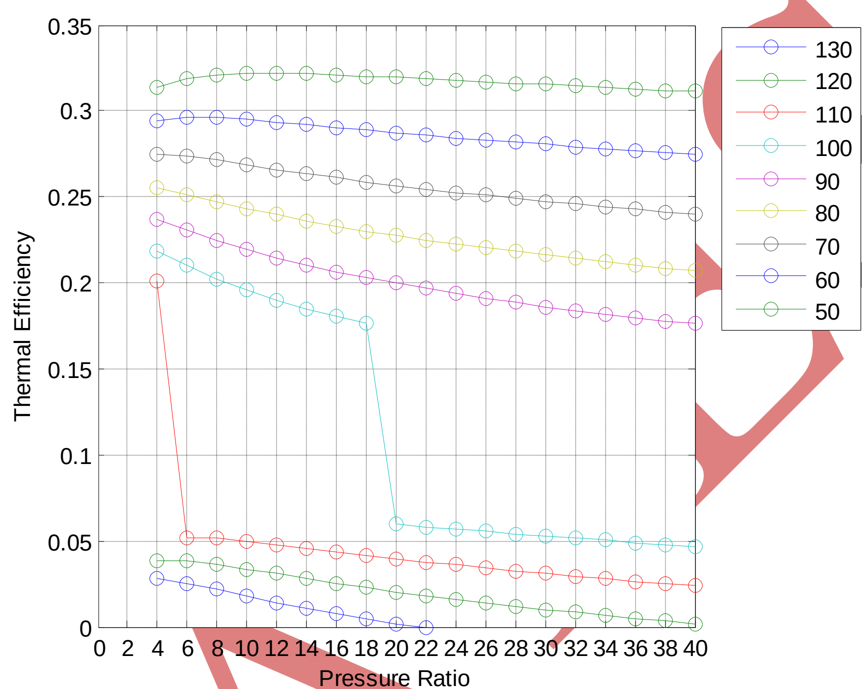


Fig.4 : Thermal Efficiency v/s Pressure Ratio at Different A/F Ratio with Reheat with Supplementary Heating When Steam is generated at 12 bar 325^{0}C

The Optimized Value of Efficiency at Air/Fuel Ratio 50.00 and Pressure Ratio 10.00 is 0.322.

1) The steam cycle becomes effective for A/F ratio 110 and lower.

2) It is seen that when steam is generated at high pressure and temperature, Efficiency 3 increases.

3) The optimization point-shift downward if we opt for lower A/F ratio and is located at A/F ratio 50 and pressure ratio 10.

VI. CONCLUSION

Turbine exit temperature is decreasing as pressure ratio is increased keeping A/F ratio constant because turbine maximum temperature does increase with pressure ratio but this effect is marginalized by the increase of expansion ratio owing to higher pressure ratio. At a particular pressure ratio if a higher A/F ratio is optimized then turbine maximum temperature goes on decreasing as the mass of fuel is constant and at higher A/F ratio the heat released due to combustion of same mass of fuel is used for raising the temperature of higher quantity of flue gas resulting in low temperature of turbine inlet temperature. In the gas turbine cycle the efficiency first increase and then decreases with increasing pressure ratio when steam is generated at, 12 bar 325^{0}C with reheat .A steam cycle does not effective at higher A/F ratio. Generally steam cycle is effective at A/F ratio 110 and less than it. Efficiency of steam cycle is decreases as pressure ratio increases when steam is generated at 12 bar 325^{0}C, with or without reheating and with or without supplementary heating. In combined cycle for A/F 130 to A/F 100 the turbine exit temperature is less than 325^0 C i.e. (the condition of Steam generated)so steam cycle does not contribute and, Efficiency = Efficiency 1.Steam cycle became effective at A/F ratio of 100 and lower. Here Efficiency = Efficiency 1 + Efficiency 2.At a particular pressure ratio the efficiency of combined cycle is increases at lower A/F fuel ratio.

NOMENCLATURE

m_f	Mass of fuel
m_a	Mass of Air
a/f	Air Fuel Ratio
η_c	Isentropic compressor efficiency
η_t	Isentropic turbine efficiency
h_1	Enthalpy of steam at turbine Inlet temperature
h_2	Enthalpy of steam after expansion in turbine.
h_{f3}	Enthalpy of feed water after considering pump work.
Work 1	Work output in gas turbine per kg of fuel burnt.
Work net 1	Work output in gas turbine cycle per kg of flue gas.
m_s	Mass of steam
Work 2	Work output (steam cycle.) per kg of fuel burnt.
Work net 2	Work output (steam cycle.) per kg of flue gas.
Efficiency 1	Thermal efficiency for gas turbine cycle.
Efficiency 2	Thermal efficiency for steam cycle.
Work 3	Specific work output for combined cycle.
Efficiency3	Thermal efficiency for combined cycle.
p_2	Compressor exit pressure.
t_2	Compressor exit temperature.
t_3	Turbine Inlet Temperature
t_4	Isentropic Turbine Exit Temperature (w/o Reheating)
t_5	Temperature after Reheated.
t_6	Isentropic Turbine exit temperature (with Reheating).
p_3	Pressure in combustion chamber for gas turbine cycle.
p_4	Reheat Pressure.
t_i	Isentropic Temperature of air after intercooler.
p_i	Intercooler Pressure.

T.I.T	Turbine Inlet Temperature
w/o	Without
H.R.S.G	Heat Recovery Steam Generator
H.P.C	High Pressure Compressor
L.P.C	Low Pressure Compressor
H.P.T	High Pressure Turbine
L.P.T	Low Pressure Turbine
t_i	Actual temperature of air after passing low pressure Compressor
t_{2a}	Actual temperature of air after passing high pressure Compressor
t_{4a}	Actual temperature of flue gas after passing high pressure Turbine
t_{6a}	Actual temperature of flue gas after passing low pressure Turbine
t_x	Temperature of air after passing through intercooler.
w_t	Work output of turbine.
w_c	Work required in the compressor.
t_{ia}	Actual temperature after compression
L.C.V	Lower Calorific Value.
.p_1	Ambient pressure.
t_1	Ambient temperature.
C_{pg}	Specific heat of flue gas.
C_{pa}	Specific heat of air.
Z	The percentage of fuel that is burnt in Combustion Chamber when supplementary heating is considered.
Z_a	The percentage of fuel that bypass the Combustion Chamber when supplementary heating is considered.

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