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PART LOAD PERFORMANCE ASSESSMENT OF SINGLE SHAFT GAS TURBINE IN COGENERATION CYCLE MODE

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Abstract

The evaluation of the new generation of gas turbines is complicated and presents new problems, which have to be addressed. The complete unit will give the required performance when running at the design point (base load performance); that is, when it is running at the particular speed, pressure ratio and mass flow for which the components were designed. The problem then remains to find the variation of performance of the gas turbine over the complete operating range of speed and power output, i.e. part load performance. In practice it is found that the gas turbine operates at various load as per the requirement of power and process steam in a cogeneration mode. So it is necessary to analyze the off-design performance of the gas turbine in cogeneration mode. The on line monitoring of the gas turbine performance is important for the plant engineers to achieve their goals of maintaining high availability of the machinery, minimizing degradation and maintaining operation near design efficiencies. Present work is related the off design performance assessment *of the single shaft gas turbine in cogeneration cycle mode.*

KEYWORDS: Compressor efficiency, turbine inlet temperature, turbine efficiency, thermal efficiency, overall efficiency

I. INTRODUCTION

The present work describes the online performance of the single shaft gas turbine in cogeneration mode. The tests were run on a frame type single shaft gas turbine unit. The exhaust energy from this unit was recovered in a heat recovery steam generator(HRSG), which without supplementary gas firing. The main objective of this test is to determine the thermodynamic performance of the gas turbine in cogeneration system. Also the purpose of the test was to determine the component performance and efficiency of the gas turbine at part load and full load condition.

Performance tests for the gas turbine were conducted with HRSG while gas turbine was in cogeneration cycle mode. The part load performance assessment was carried out by the gas turbine was operated from about 20% load to full load. Full load was determined to be when the turbine's automatic controls took over. These controls are actuated by the exhaust temperature. The gas turbine must be thermally stable prior to the initiation of any test. This stability is achieved when turbine wheel space temperatures change no more than five degrees Fahrenheit in fifteen minute period. The test was conducted (base load) when the gas turbine is operating on or near its limiting exhaust temperature characteristic. Figure 1 is a schematic of instrumentation for the gas turbine based cogeneration system.

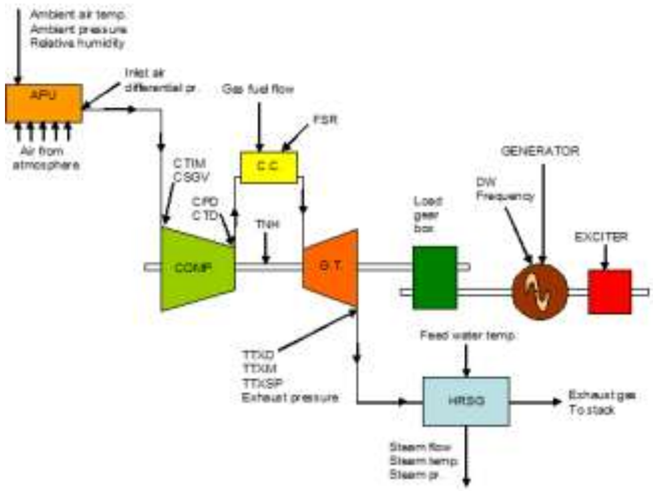

Figure 1. Schematic of instrumentation for the gas turbine based cogeneration system

- Two thermocouples (CTIF-1, 2) are situated in the compressor inlet duct to measure gas turbine compressor inlet air temperature.
- Gas turbine speed (TNH) is indicated by the gas turbine control system through magnetic pickups.
- Generator output and frequency are taken from generator control panel. Gas turbine output is also indicated by the gas turbine control system through MW transducer.
- The gas fuel flow is measured with the fuel flow meter.
- Eighteen thermocouples (TTXD-1 to 18) are situated in the gas turbine exhaust plenum to measure the temperature of exhaust gas.

The data which were logged from gas turbine control system (Speed Tronic Mark-IV) are

- Gas turbine output (DW)
- Gas turbine shaft speed (TNH)
- Inlet guide vane position (IGV)
- Compressor inlet air temperature (CTIM)
- Compressor discharge air temperature (CTD)
- Compressor discharge pressure (CPD)

- Fuel stroke reference (FSR)
- Turbine exhausts gas temperature (TTXM)
- Turbine exhaust gas temperature spread (TTXSP)
- Gas turbine total firing hours

The data which were logged from Distributed Control Systems (DCS) in the control room are

- Fuel gas flow
- Steam flow
- Steam temperature
- Steam pressure

The data which were recorded manually are given below

- Differential pressure of inlet duct at air puffing unit
- Pressure of exhaust gas at turbine outlet
- Frequency of power at generator control panel
- The ambient pressure (IBP), temperature and relative humidity was noted from nearest laboratory at utility and environmental control.

II. PROCEDURE OF CALCULATION

The following procedure was followed to calculate the performance of the gas turbine.
The efficiency of the compressor is based on the following equation:

$$\eta_c = \frac{T_{t1}\,[(P_{t2}/P_{t1})\,(\gamma\text{-}1)/\,\gamma - 1]}{\Delta_{Tact}}$$

Where:
T_{t1} = temperature at compressor inlet
P_{t1} = pressure at compressor inlet
P_{t2} = pressure at compressor outlet
Δ_{Tact} = actual temperature rise in compressor
γ = average specific heat ratio for compressor

The turbine efficiency calculation is more complex. The first part is the calculation of the turbine inlet temperature. The calculation is based on the following equation:

$$T_{t3} = \frac{[\,(ma \text{ x } C_{p2} \text{ x } T_{t2}\,) + (\,\eta_b \text{ x } m_f \text{ x LHV of natural gas}\,)\,]}{[\,C_{p3} \text{ x } C_{p2}\,(\,m_f + m_a\,)\,]}$$

Where:
T_{t2} = temperature at the out let of the compressor
C_p = specific heat at constant pressure
m_f = mass flow rate for the fuel gas
m_a = mass flow rate of the air
η_b = combustion efficiency
LHV = lower heating value of the fuel supplied

The mass flow value of the air was obtained from the technical information provided by the manufacturer regarding the operating conditions of the gas turbine. For the performance computation of the gas turbine, the lower heating value the fuel being burned is considered. The turbine efficiency can now be calculated with the use of the following relationship:

$$\eta_t = \frac{\Delta_{Tact}}{T_{t3}\,\{\,1 - [\,1\,/\,(P_{t3}/P_{t4})\,(\gamma\text{-}1)\,/\,\gamma\,]\,\}}$$

Where:
Δ_{Tact} = temperature drop in the turbine
T_{t3} = turbine inlet temperature
P_{t3} = turbine inlet pressure
P_{t4} = turbine exhaust pressure
γ = average specific heat ratio for turbine

The gas turbine is coupled with a heat recovery steam generator (HRSG). The exhaust gas from the turbine is used as a source of heat in the boiler.
The thermal efficiency of the gas turbine alone (simple cycle efficiency) was calculated by using the following relationship:

$$\eta_{th} = \frac{W_{load} \text{ x } K}{(LHV) \text{ x } Q_{ft}}$$

Where:
W_{load} = gas turbine output,
K = 3600 kJ/kW-hr
LHV = lower heating value of the fuel gas
Q_{ft} = volume flow rate of the fuel gas to the turbine,

The overall system efficiency, i.e. cogeneration system is based on the following equation:

$$\eta o = \frac{W_{load} \text{ x } K}{[\,(LHV) \text{ x } Q_{ft}\,] - [\,ms\,(\,h_s - h_{fw}\,)\,]}$$

Where:
W_{load} = gas turbine output
K = 3600 kJ/kW-hr
LHV = lower heating value of the fuel
Q_{ft} = volume flow rate of the fuel gas to the turbine
m_s = mass flow of steam from HRSG
h_s = enthalpy of the superheated steam
h_{fw} = enthalpy of the feed water

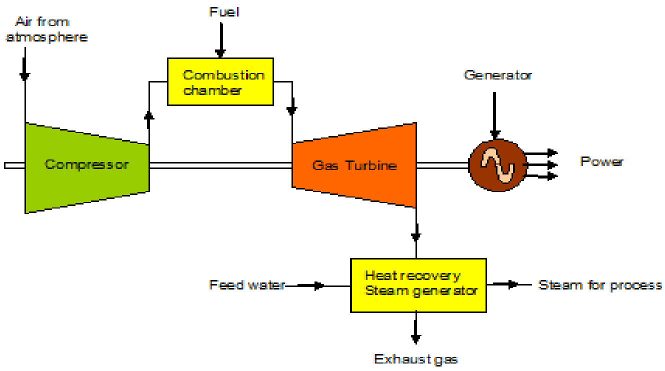

Figure 2 Schematic of gas turbine based cogeneration system

III. OBSERVATION TABLE

Sr no	GT output DW MW	Turbine Shaft speed TNH Rpm	Comp inlet temp T_{t1} CTIM °C	Comp inlet pr.P_{t1} (abs) bar	Comp outlet temp (T_{t2}) CTD °C	Comp outlet pr.P_{t2} (g) CPD bar	Fuel gas flow m^3/hr	Exh.gas temp (GT) T_{t4} TTXM °C	Steam flow t/h	Steam pr kg/cm^2	Steam temp °C	Stack temp °C
1	5.56	4994	31	1.002	292	5.49	4650	363	0	-	-	200
2	8.01	5005	31	1.002	303	5.97	5400	400	0	-	-	200
3	9.90	5015	31	1.003	307	6.12	6300	437	0	-	-	200
4	12.97	5028	31	1.003	312	6.37	7000	471	39	36.50	348	160
5	15.19	5032	31	1.004	316	6.63	7800	502	41	36.60	347	156
6	16.99	5038	30	1.004	323	6.80	8200	526	43	36.70	346	153
7	17.62	5042	30	1.003	321	6.77	8400	534	46	36.80	347	143
8	21.25	5049	29	1.003	328	7.24	9050	560	50	36.90	345	140
9	23.95	5058	28	1.003	337	7.64	9600	559	56	36.80	346	138
10	27.25	5075	27	1.002	356	8.71	10700	565	62	36.90	347	135
11	30.07	5125	27	1.002	363	9.12	11500	565	67	37.00	347	131

IV. RESULTS AND DISCUSSION

Sr. no	GT output W_{load} MW	GT output %	Comp pr ratio r	Air-fuel ratio f	Spec Fuel Consump SFC kg/kWhr	TIT. T_{t3} °C	Exh gas temp °C	Steam flow m_s t/h	Comp eff η_c %	Turbine eff η_t %	Thermal eff η_{th} %	Overall eff η_o %
1	5.56	19	6.7	100.56	0.66	595	363	0	84.02	72.38	12.04	12.04
2	8.01	27	7.0	86.59	0.53	665	400	0	82.89	74.16	14.93	14.93
3	9.90	33	7.1	74.22	0.50	740	437	0	82.81	77.88	15.82	15.82
4	12.97	43	7.4	66.80	0.42	800	471	39	83.21	78.73	18.65	34.55
5	15.19	51	7.6	59.95	0.40	866	502	41	83.88	81.08	19.60	34.65
6	16.99	57	7.8	56.85	0.38	906	526	43	82.49	81.01	20.86	36.79
7	17.62	59	7.7	55.50	0.37	920	534	46	82.90	81.49	21.12	38.56
8	21.25	71	8.2	51.51	0.33	977	560	50	83.48	82.23	23.64	43.48
9	23.95	80	8.8	50.57	0.31	998	559	56	84.13	83.78	25.11	48.47
10	27.25	91	9.7	48.95	0.31	1038	565	62	83.42	84.14	25.64	49.17
11	30.07	100	10.3	48.49	0.30	1051	565	67	84.44	84.53	26.32	50.74

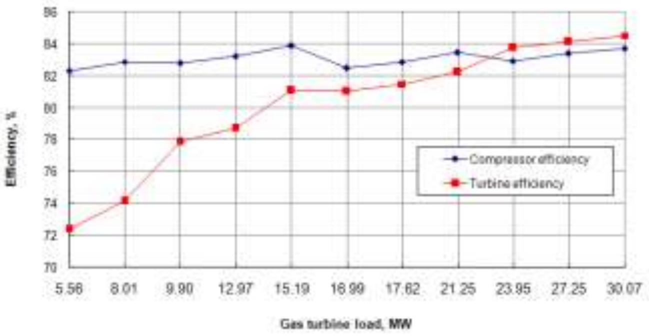

Figure 3 Compressor and turbine efficiency as a function of gas turbine load

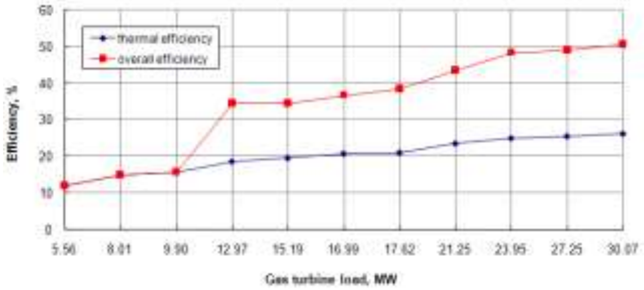

Figure 4 Thermal efficiency and overall efficiency as a function of gas turbine load

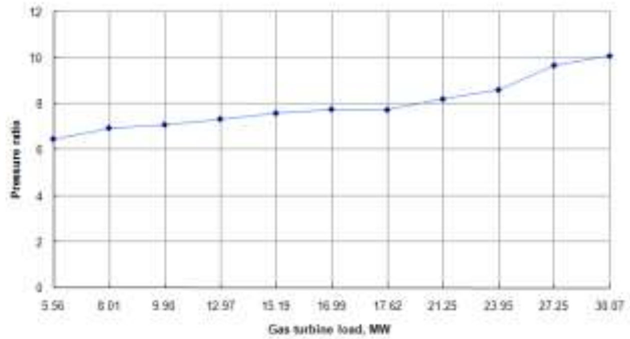

Figure 5 Pressure ratio as a function of gas turbine load

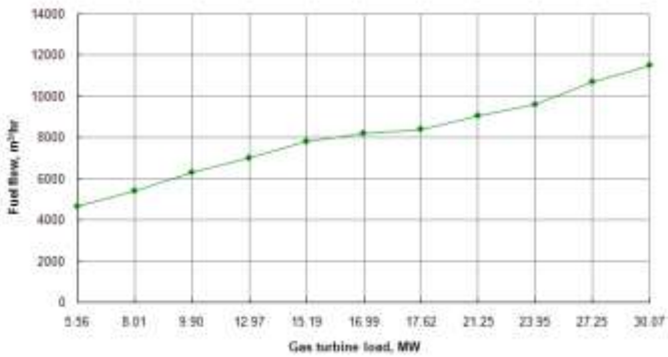

Figure 6 Fuel gas flow as a function of gas turbine load

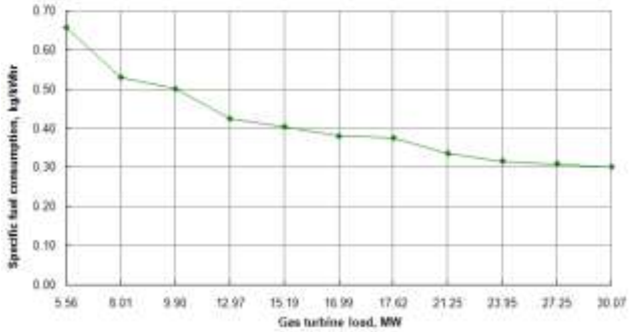

Figure 7 Specific fuel consumption as a function of gas turbine load

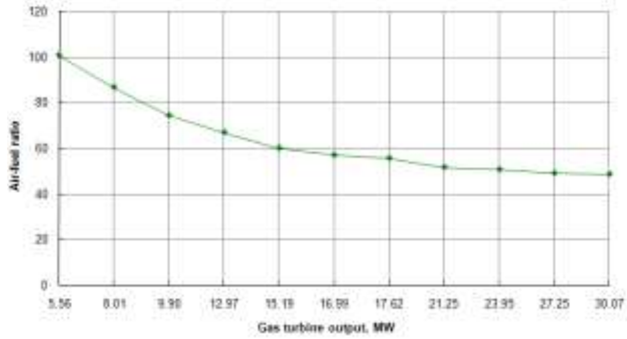

Figure 8 Air- fuel ratio as a function of gas turbine load

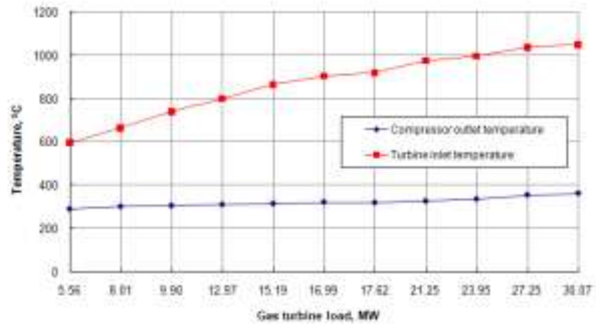

Figure 9 Temperature variations in compressor and turbine as a function of gas turbine load

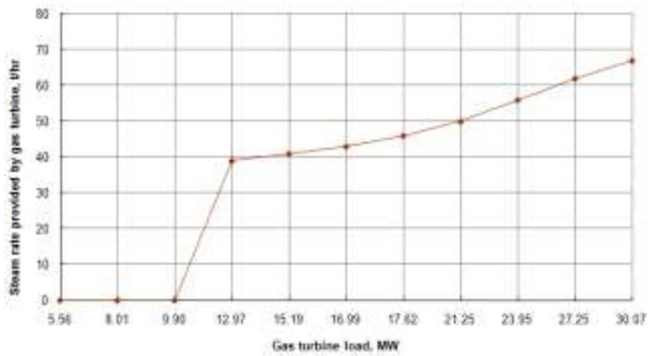

Figure 10 Steam rate provided by gas turbine as a function of gas turbine load

There are the two main factors affecting the performance of the gas turbines: component efficiencies and turbine working temperature. The higher they can be made, the better the all-round performance of the plant. In practice, losses occur in both the compressor and turbine which increase in power absorbed by the compressor and decrease the power output of the turbine.

In the case of single shaft gas turbine driving a generator, the compressor power remains essentially fixed. It should be evident from a figure 3 that the compressor operates over a smaller range of efficiency compared to the turbine in the gas turbine plant.

The thermal efficiency of the simple cycle (26% maximum) shown in the figure 4 is dependent on the turbine inlet temperate and the rapid drop in turbine inlet temperature (figure 9) with decreasing power is the basic cause of the poor part load performance of the gas turbine. While in cogeneration system the overall efficiency is increased to 51% of its maximum value.

The variations of specific fuel consumption with reduction in power (figure 7) occur at part load performance and the poor specific fuel consumption at part load is probably the biggest disadvantage of the gas turbine for the plant.

The Specific fuel consumption curve of figure 7 exhibit an increase in SFC as the power is reduced because the reduction in fuel flow (figure 6) leads to a reduction in compressor speed and turbine inlet temperature. The thermal efficiency of a real cycle falls as the turbine inlet temperature is reduced. This poor part load economy is a major disadvantage of the simple gas turbine.

Regarding the supply of waste heat to a cogeneration plant, due to the differences in exhaust flow as load is reduced, the essentially constant air flow and compressor power in a single shaft unit results in a large decrease of exhaust temperature for reduction in power at part load condition, which might necessitate the burning of supplementary fuel in HRSG under operating conditions to maintain the requirements of process steam.

V. CONCLUSIONS

The Performance assessment of the gas turbine is essential in the efficient utilization of turbo machinery in cogeneration system. These performance assessments have given some insight into the part load performance of the gas turbine in cogeneration plant. The performance assessment tests have following conclusions.

- Any gas turbine will experience a reduced efficiency at part load condition. Figure 3 shows the effect of efficiency as a function of the load for both the compressor and turbine.
- Part load turbine efficiencies are affected more than compressor efficiencies. The discrepancy results from the compressor operating at a relatively constant inlet temperature, pressure, and pressure ratio, while the turbine inlet temperature is greatly varied.
- Figure 4 shows the thermal efficiency of the gas turbine and the cogeneration cycle (gas turbine exhaust being used in the HRSG) based on the LHV of the gas. This figure shows that below 50% of the rated load, the cogeneration cycle is not effective. At full load, it is obvious the benefits one can reap from a cogeneration cycle.
- The specific fuel consumption curve of figure 7 exhibits an increase in SFC as the power is reduced. This poor part load economy is a major disadvantage of the simple gas turbine.

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REFERENCES

1. Frank J. Brooks, “GE Gas Turbine Performance Characteristics”, GE Power Systems, GER-3567H, 2000, Schenectady, NY, USA.
2. Rainer Kurz, “Gas Turbine Performance”, Proceedings of the thirty-fourth turbomachinery symposium, 2005, California, USA.
3. S. Can Gulen, Patrick R. Griffin and Sal Paolucci, “Real-Time On-Line Performance Diagnostics of Heavy Duty Industrial Gas Turbines”, International Gas Turbine & Aero engine Congress & Exhibition, 2000, Munich, Germany.
4. Meherwan P. Boyce, Gas Turbine Engineering Handbook, third edition, 2006. Elsevier Inc., USA.
5. Training Manual, Operations & Maintenance Of Gas Turbines, BHEL-GE Gas Turbine.
6. Gas Turbine World, Performance Specs, 23rd Edition, January 2005, Vol. 34 No. 6
7. C. Wilkes,” Gas Fuel Clean-up System Design Considerations For GE Heavy Duty Gas Turbine”, GE Power Systems, GER-3942, 1996, NY, USA.
8. L.B. Davis and S.H. Black,” Dry Low NOx Combustion Systems for GE Heavy-Duty Gas Turbines”, GE Power Systems, GER-3568G, 2000, Schenectady, NY, USA.