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EVALUATION OF OUTPUT AND HEAT RATE OF THE SIMPLE CYCLE GAS TURBINE DURING THE BASE LOAD CONDITION

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ABSTRACT:- *The gas turbine is a power plant, which produces a great amount of energy for its size and weight. Performance monitoring of gas turbine constitutes a key practice to ensure plant profitability, with considerable cost savings related to maintaining maximum fuel efficiency and availability. Environmental considerations play effective roll in the performance of the gas turbine. The gas turbine is a complex machine, and its performance and reliability are governed by many factors. In present work, the tests were run on a frame type single shaft gas turbine unit. The performance test for the gas turbine was conducted with HRSG while gas turbine was in cogeneration cycle mode. During the base load performance of the gas turbine, the gas turbine was operated on full load (100% load). Evaluation of the gas turbine parameters (output and heat rate) by considering the factors affecting the gas turbine performance like air temperature, ambient pressure, humidity, inlet and exhaust losses, frequency and degradation. In accord with industry standards, the gas turbine performance is generally quoted at 15^{0}C ambient temperature, 60% relative humidity, sea level site conditions i.e. 1.01325 bar ambient pressure and zero inlet and outlet losses. In the real world, however, ambient air temperature, site elevation, inlet and exhaust pressure drop all have impact on installed gas turbine site performance. Since the gas turbine is an air-breathing engine, its performance is changed by anything that affects the density and mass flow of the air intake to the compressor. Ambient weather conditions are the most obvious changes from the reference conditions. This affects the gas turbine parameters i.e. output and heat rate. So correction to be considered for the factors affecting the gas turbine performance like air temperature, ambient pressure, humidity, inlet and exhaust losses, frequency and degradation. The present work discuss the variation in power as well as heat rate, compared to the gas turbine unit at ISO conditions, with the help of simple correction curve, which are usually supplied by the manufacturer.*

***KEYWORDS*:** Output power, Heat rate, Ambient temperature, Atmospheric pressure, Humidity, Inlet and exhaust losses, Frequency, Degradation

I. INTRODUCTION

Performance monitoring of gas turbine constitutes a key practice to ensure plant profitability, with considerable cost savings related to maintaining maximum fuel efficiency and availability. Environmental considerations play effective roll in the performance of the gas turbine. The gas turbine is a complex machine, and its performance and reliability are governed by many factors. The present work describes the evaluation of output and heat rate of the simple cycle gas turbine during the base load condition. The tests were run on a frame type single shaft gas turbine unit. The exhaust steam energy from this unit was recovered in a heat recovery generator (HRSG), which without supplementary gas firing. In accord with industry standards, the gas turbine performance is generally quoted at 15^{0}C ambient temperature, 60% relative humidity, sea level site conditions i.e. 1.01325 bar ambient pressure and zero inlet and outlet losses. In the real world, however, ambient air temperature, site elevation, inlet and exhaust pressure drop all have impact on installed gas turbine site performance. The main objective of this test was to prove the output and heat rate of the gas turbine unit. Also to evaluate the gas turbine parameters i.e. output and heat rate by considering the factors affecting the gas turbine performance like air temperature, ambient pressure, humidity, inlet and exhaust losses, frequency and degradation. Figure 1 is a schematic of the simple cycle gas turbine in cogeneration mode.

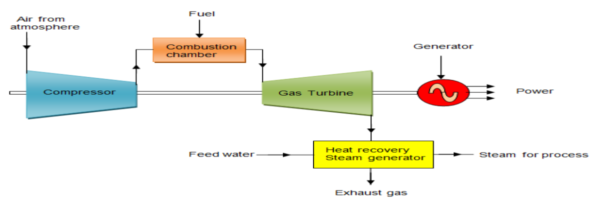

Figure 1. Schematic of simple cycle gas turbine based cogeneration system

II. EXPERIMENTAL INVESTIGATION

The gas turbine compressor was cleaned before the test using off-line compressor cleaning procedure with the recommendation of the manufacturer. The turbine, compressor and duct work area also were inspected to ascertain whether the plant is in proper condition. The gas turbine was thermally stable prior to the initiation of test. The test was conducted (base load) when the gas turbine was operating on or near its limiting exhaust temperature characteristic.

- Two thermocouples (CTIF-1, 2) are situated in the compressor inlet duct to measure gas turbine compressor inlet air temperature. The arithmetic average of thermocouples reading (CTIM) is indicated by the gas turbine control system (Speed Tronic Mark-IV) which is located in control room
- 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. These instruments are located in control room near 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. The gas fuel flow is indicated by Distributed Control Systems (DCS) in the control room.
- Eighteen thermocouples (TTXD-1 to 18) are situated in the gas turbine exhaust plenum to measure the temperature of exhaust gas. The arithmetic average of thermocouples reading (TTXM) is indicated by the gas turbine control system.

Figure 2 is a schematic of instrumentation for the gas turbine based cogeneration system. The data which were logged from gas turbine control system (Speed Tronic Mark-IV) are given below.

- 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 exhaust 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 given below.

- 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

Part of the above data was logged through gas turbine control system (Speed Tronic Mark-IV) printouts and rest ware recorded manually. The ambient pressure (IBP), temperature and relative humidity was noted from nearest laboratory at utility and environmental control.

The test was conducted over a period of one hour. The readings were taken at an interval of 10 minutes. The test was conducted (base load) when the gas turbine is operating on or near its limiting exhaust temperature characteristic, i.e. average exhaust gas temperature 565 ^{0}C. Calculations involving corrections to standard condition was done using stated equipment characteristics provided by manufacturer.
The following steps are followed to evaluate the correction factors for corrected output power and heat rate.

- Barometric pressure correction: The output of the gas turbine unit is proportional to the barometric pressure at site. The guarantees are given based on site average barometric pressure. The correction factor would be the ratio of ambient pressure to ISO pressure.
- Temperature and frequency correction: The output power and heat rate of the gas turbine unit is dependent upon the compressor inlet temperature and the speed (and hence the frequency) at which it is operated. The correction for frequency and compressor inlet temperature can be obtained from the curves.
- Relative humidity correction: The output and heat rate of gas turbine unit are dependent on relative humidity. Hence, a correction is to be applied for the difference in humidity at design relative humidity and the humidity at the time of test.
- Inlet and exhaust pressure loss correction: The gas turbine output and heat rate are also affected by pressure losses occur in the inlet and exhaust duct system. So gas turbine output and heat rate both are to be corrected.
- Degradation correction: The gas turbine has been in operation for more than 6000 firing hours thus degradation loss should be applied to the gas turbine output and heat rate.
- The output power and heat rate are to be multiplied with appropriate correction factors to arrive at the corrected output power and heat rate.

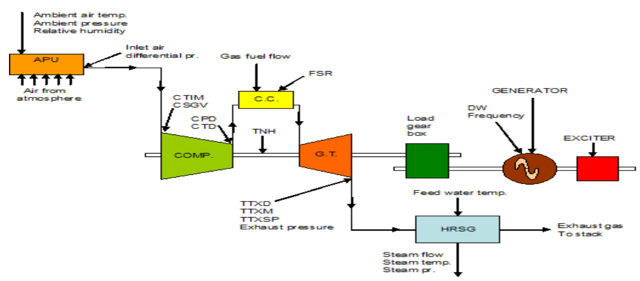

Figure 2. Schematic of instrumentation for the gas turbine based cogeneration system

III. OBSERVATIONS

TABLE 1

Atmospheric temperature	32.13 ^{0}C
Atmospheric pressure	1006 mbar
Relative humidity	29 %
Differential pressure at APU	4.2 in H_2O
main oil pump discharge pressure	4.3 kg/cm^2
Lube oil header pressure	2.05 kg/cm^2
Hydraulic oil pressure	90 kg/cm^2
Compressor air pressure	8.7 kg/cm^2
Lube oil tank temperature	54 ^{0}C
Inlet guide vane opening	83 DGA
Loading gear box bearing temp.	69 ^{0}C
Fuel gas pressure after control valve	11 kg/cm^2
Exhaust gas pressure	325 mm H_2O
Leg cooler temperature	42 ^{0}C
Cooling water inlet temperature	19.5 ^{0}C
Cooling water outlet temperature	32 ^{0}C
Gas conditioning skid out let pr.	20 kg/cm^2
Specific gravity of fuel gas (NG)	0.5719
Net calorific value of NG	35621 kJ/m^3
GT fired time	69371 hrs
GT starts	1080 nos

TABLE 2

Sr. No.	Time	GT Load DW MW	GT Meter Reading MW	Freq Hz.	Shaft speed rpm	Comp inlet temp CTIM ^{0}C	Comp dis pr CPD bar	Comp dis tem. CTD ^{0}C	Fuel stroke ratio FSR %	Fuel flow m^3/hr	GT Exh temp TTXM ^{0}C	Temp spread TTXSP ^{0}C	Max. vibration MAX VIB mm/s
1	10.30	28.81	56931	49.6	5053	28	9.04	347	56.9	10750	565	20.3	7.2
2	10.40	28.66	56936	49.0	5056	29	9.04	356	56.3	10700	565	20.1	7.3
3	10.50	28.87	56941	49.7	5073	29	9.11	359	56.5	10800	564	19.6	7.5
4	11.00	28.41	56946	49.5	5057	29	9.01	360	56.0	10625	565	19.4	7.4
5	11.10	28.10	56950	49.4	5047	29	8.95	360	55.6	10585	565	19.0	7.1
6	11.20	28.06	56956	49.4	5040	29	8.92	359	55.5	10580	565	19.5	7.0
7	11.30	28.39	56960	49.6	5067	29	9.02	361	56.1	10625	565	19.0	7.4

IV. PROCEDURE OF CALCULATION

Corrected output power

Measured output power = final reading – initial reading

Correction factor for ambient pressure: F1
F1 = 0.9925
Correction factor for ambient temperature: F2
F2 = 0.885
Correction factor for humidity: F3
F3 = 0.9996
Correction factor for inlet pressure drop: F4
F4 = 0.9843
Correction factor for exhaust pressure drop: F5
F5 = 0.9840
Correction factor for frequency: F6
F6 = 1.02
Correction factor for degradation: F7
F7 = 0.947

$$\text{Corrected power} = \frac{\text{actual power measured x F6}}{\text{F1 x F2 x F3 x F4 x F5 x F7}}$$

Corrected heat rate:

$$\text{Calculated heat rate} = \frac{\text{fuel consumption x LHV of fuel gas}}{\text{output power}}$$

Correction factor for ambient temperature: F1
F1 = 1.03
Correction factor for humidity: F2
F2 = 1.001
Correction factor for inlet pressure drop: F3
F3 = 1.0053
Correction factor for exhaust pressure drop: F4
F4 = 1.0159
Correction factor for frequency: F5
F5 = 0.997
Correction factor for degradation: F6
F6 = 0.975

$$\text{Corrected heat rate} = \frac{\text{heat rate x F5 x F6}}{\text{F1 x F2 x F3 x F4}}$$

Figure 3 to Figure 10 shows the various correction curves for output and heat rate supplied by the manufacturer.

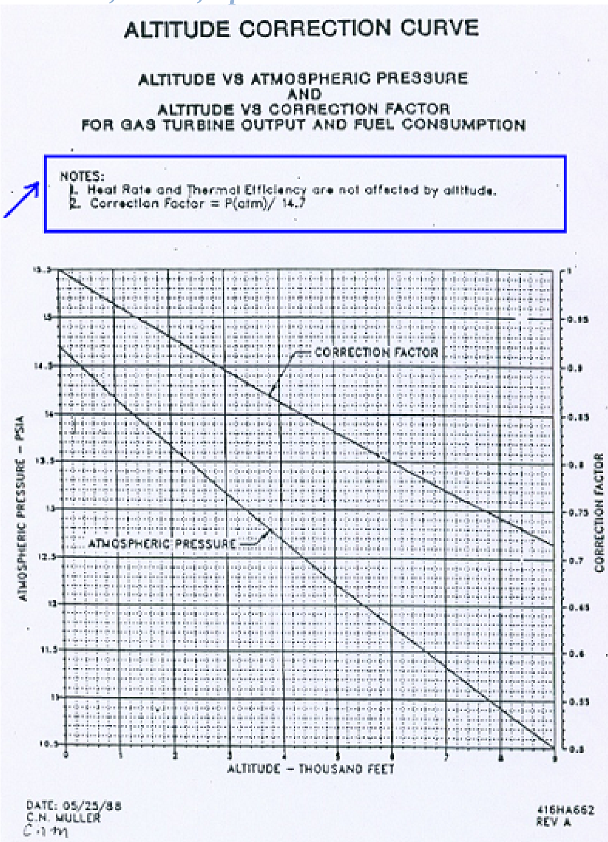

Figure 3. Correction curve for ambient pressure

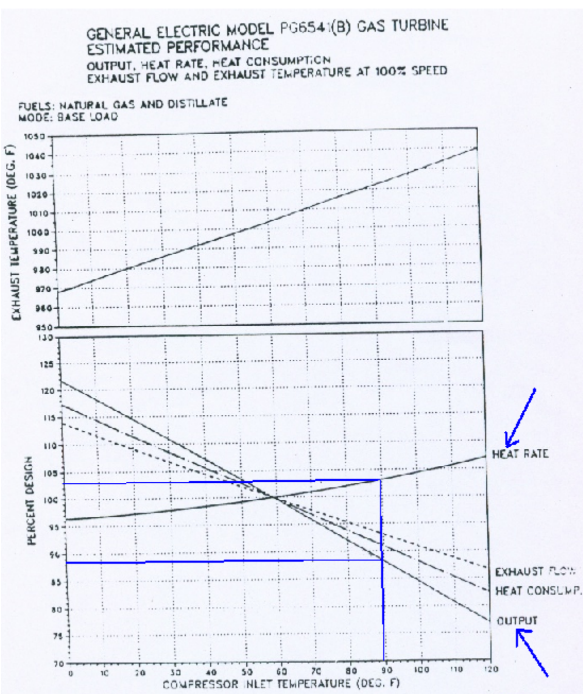

Figure 4. Correction curve for ambient temperature

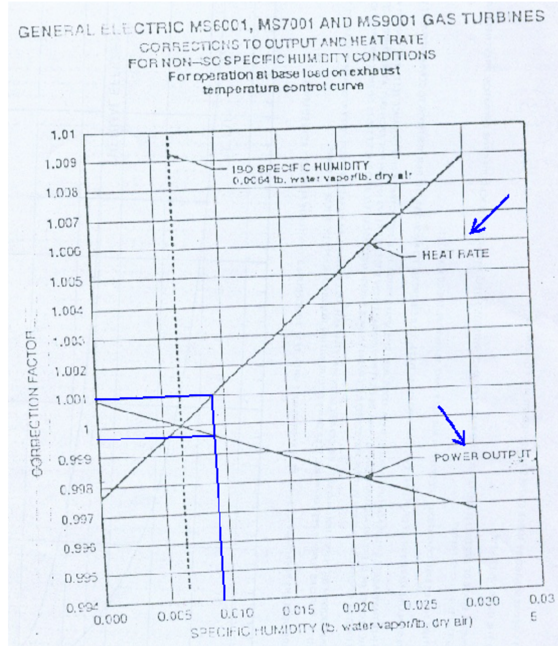

Figure 5. Correction curve for humidity

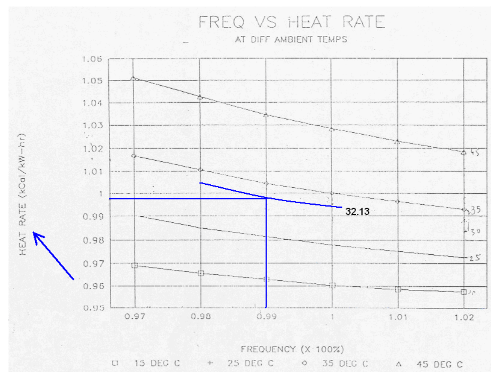

Figure 6. Correction curve for frequency

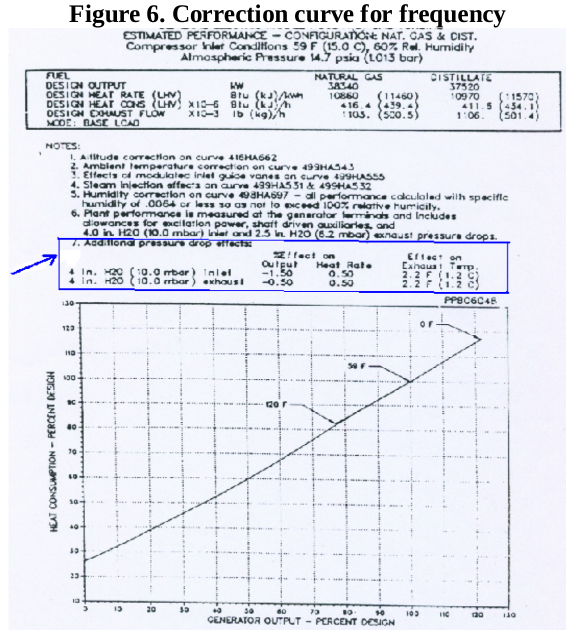

Figure 7. Correction curve for inlet & exhaust pr. Losses

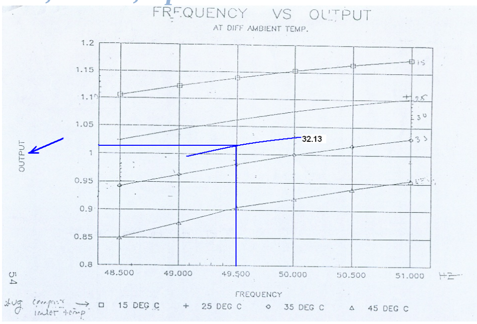

Figure 8. Correction curve for frequency

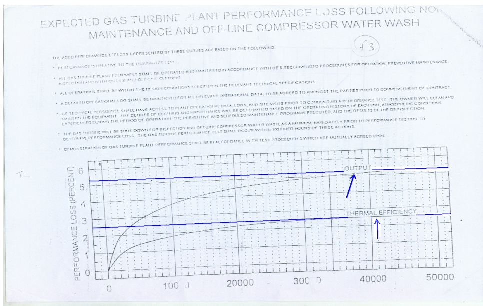

Figure 9. Correction curve for degradation

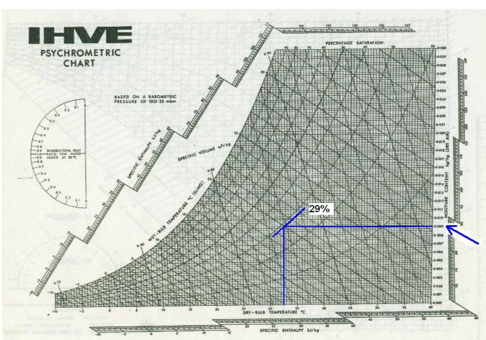

Figure 10. Psychrometric chart

V. RESULTS AND DISCUSSION

Design output power	= 38340 kW
Design heat rate	= 11460 kJ/kWh
Measured output power	= 29000 kW
Corrected output power	= 36730 kW
Calculated heat rate	= 13101 kJ/kWh
Corrected heat rate	= 12094 kJ/kWh

Since the gas turbine is an air-breathing engine, its performance is changed by anything that affects the density and mass flow of the air intake to the compressor. Ambient weather conditions are the most obvious changes from the reference conditions. This affects the gas turbine parameters i.e. output and heat rate. So correction to be considered for the factors affecting the gas turbine performance like air temperature, ambient pressure, humidity, inlet and exhaust losses, frequency and degradation. The reduction in power, compared to the gas turbine unit at ISO conditions, can be described by simple correction curve, which are usually supplied by the manufacturer.

Inserting air filtration, silencing, ducting into the inlet of gas turbine, heat recovery devices (HRSG), silencing, and ducting in the exhaust, all these system causes pressure drops, i.e., at the gas turbine actually an inlet pressure that is lower than ambient pressure and an exhaust pressure is higher than ambient pressure. These inevitable pressure losses cause a reduction in power of the gas turbine.

After evaluating corrections to actual conditions, however, the designed output power and heat rate differ from the corrected output power and heat rate as it does not include generator loss, gear box loss and auxiliary loss.

Air cooled electric generators operate at 97 to 98% efficiency. Equivalent to a 2 to 3% penalty in available power and heat rate at the electric generator output terminal. Reduction gearbox losses typically result in a 1.5% reduction in available power (at the gear box output) and 1.5% increase in heat rate. A small amount of electrical and mechanical output goes to power engine auxiliaries. Typically costs about 0.6% penalty in net power output and heat rate.

VI. 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 base load performance of the gas turbine in cogeneration plant. Also evaluate what the effect of changes in ambient temperature, barometric pressure, inlet and exhaust losses, relative humidity, degradation or changes in frequency on the gas turbine output power and heat rate. The performance assessment tests have following conclusion.

- The gas turbine is an air-breathing engine. The performance of the gas turbine distinctly depends on ambient and operating conditions. its performance is changed by anything that affects the density and mass flow of the air intake to the compressor. It is not only influenced by site elevation, ambient temperature and relative humidity but also by the pressure losses occurred at inlet and exhaust, the fuel (LHV of the gas), the frequency and load conditions. The impact of component degradation on individual component performance also influences the overall gas turbine performance. Proper application of the gas turbine requires consideration of these factors.
- Changes in ambient temperature have an impact on base load power output and heat rate. If the ambient temperature changes, the air density also changes. Therefore the mass flow through the turbine changes. The power output is directly proportional to the mass flow. Increased ambient temperature reduces the power output, therefore increases the heat rate. Similarly, humid air, which is less dense than dry air, also affects output and heat rate.

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