Performance Appraisal of The Trans - Amadi Gas Turbine Power Station

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Abstract- The performance appraisal of the Trans - Amadi Gas Turbine Power Station has been done. The studied which encompasses collection of data from actual plant operational logsheets: turbine log sheets, plant/Auxiliaries logsheets and generator logsheets for the months of February, 2011 to November 2011. Parameters which could not be directly measured or determined were derived utilizing appropriate thermodynamic equations and principles. The work also reveal that an increment of ambient temperature from 25^0C to 34^0C , the power output decreases by 0.08MW, the thermal efficiency decreases by 3.77%, the heat supplied decreases by 421KW, the air fuel ratio increases by 5.22, the specific fuel consumption increases by 0.102Kg/KWh and the heat rate increases by 0.23KCal/Wh respectively. The performance of the gas turbine plant revealed that the plant will consume much fuel for small amount of workdone: that is, there is tendency for poor power supply. It is recommended that routine maintenance should be carried out periodically and if the symptoms persist, intercoolers should be introduced in order to control the ambient temperature which is the cause.

Indexed Terms- Gas Turbine, Ambient Temperature, Performance, Effect and Power

I. INTRODUCTION

The gas turbine engine is a vital means of generating mechanical energy which is achievable through the air intake system into the compressor via the atmosphere [1]. Also, gas turbines are very vital rotary machinery which also have relationship with the internal combustion engines and are intensively utilized to accomplish the principal function of producing mechanical energy in the form of shaft via the kinetic energy of the gas created in the combustion chamber [2][3][4][5][6][7][8][9]. Meanwhile, the enhancement of the value of performance became a breakthrough through increasing of the compressor - pressure ratio and the turbine - inlet - temperature respectively. While the incremental advancement in the cooling technology and material science has resulted in the obtainment of high turbine - inlet - temperature[10][11][12]. With this high and herculean demand for energy, it becomes imperative to look at the performance of gas turbine since the plant is a major source of energy[11]. Hence, this study will look at the performance Appraisal of the Trans - Amadi Gas Turbine Power Station**.**

II. LITERATURE REVIEW

Gas turbine plant which operates on Brayton's cycle in the simplest form, has undergone tremendous modifications. These different forms of gas turbine plants were made possible as a result of researches that were carried out on gas turbine performance parameters as well as solution on how to improve the performance of gas turbine over the years. All of these researches among other things considered the compressor inlet temperature and pressure; compressor discharged pressure and turbine inlet temperature as well as turbine exhaust temperature and also proffered solutions on how to improve the performance of the gas turbine plant. Some recent works on gas turbine performance are discussed below [12][13][14].

The effect of variation of power turbine inlet temperature to the performance of a gas turbine was conducted by [15]. Data was collected from control room log sheets for a period of sixty weeks and properly analyzed. The parameters considered during the data collection were pressure, temperature and power output. The other parameters that could not be gotten directly from the log sheet were obtained using proper thermodynamics relations. The result proves that as the power turbine inlet temperature reduces from 843.44K to 799.05K, the power turbine efficiency increased from 94.65% to 94.76% and the power output from 13.28MW to 15.52MW. Hence, irreversibility reduced from 63.22% to 61.96% as the power turbine inlet temperature decreased from 732.46K to 710.26K. These show that operating a gas turbine power plant at lower power turbine entry temperature as the system approaches its rated capacity gives better performance.

The thermodynamics analysis of a gas turbine power plant modeled with an evaporative cooler was carried out by [16]. In this study, the performance enhancement of gas turbine power plant by cooling the compressor intakes air with an evaporative cooler is studied. More so, this study looked at the effect of inlet air cooling system on the performance of an existing gas turbine power plant in Nigeria. The results after the investigation shows that for each 5℃ decline of inlet air temperature, net output power increase around 5-10% and the thermal efficiency increases around 2-5%. It proves that the amount of this increase is higher when the pressure ratio is high and turbine inlet temperature is low. Thermodynamic analysis of the gas turbine, power plant was performed by [17]. The investigation presented the parametric study of thermodynamic performance in gas turbine power plant. The variation of operating condition such as compressor ratio, turbine inlet and exhaust temperature, air fuel ratio, isentropic compressor, and turbine efficiency and ambient temperature and the performance of gas turbine with thermal efficiency, compressor work, power, specific fuel consumption and heat rate were investigated. The analytical formula for the specific work and efficiency were derived and analysized; MATLAB software were used to developed the programming of performance model for gas turbine. The results gotten shows that the compressor ratio, ambient temperature, air to fuel ratio as well as the isentropic efficiencies have strong effect on the thermal efficiency. Hence, the thermodynamic parameters on cycle performance are economically feasible and beneficial for the gas turbine operations.

III. METHODOLOGY

The research methodology involves collection of data from actual plant operational logsheets: turbine log sheets, plant/Auxiliaries logsheets and generator logsheets for the months of February 2011 to November 2011. Parameters which could not be directly measured or determined were derived utilizing appropriate thermodynamic equations and principles. The parameters investigated and considered during the data collection are the pressures, temperatures and mass flow rates at various temperature and pressure points in the gas turbine. However, in the evaluation and treatment of the data, statistical methods were used to calculate the mean values of daily parameters. This was done for a month and the average was taken at the end of every month. The actual performance of the power plant over the period of its installation was determined from their average parameters: inlet pressures, outlet pressures, inlet temperatures, mass flow rates, outlet temperatures and compressor works[11][12][13][14][15].

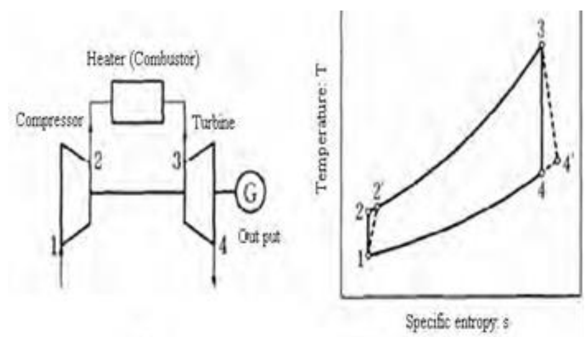

Figure 3.1: Single - Cycle, Single-Shaft Gas Turbine and T-S Diagram for Brayton cycle [18]

Heat Supplied

$$\dot{Q}_{Supplied} = \dot{m}C_p(T_3 - T_2) \quad (1)$$

Turbine Work:

$$\dot{W}_T = \dot{m}C_p(T_4 - T_3) \quad (2)$$

Compressor Work:

$$\dot{W}_c = \dot{m}C_p(T_2 - T_1) \quad (3)$$

Net Power Output:

$$\dot{W}_{Net} = \dot{W}_T - \dot{W}_C \quad (4)$$

The energy balance at the combustion chamber is expressed as [13][17]

$$\dot{m}_a C_{pa} T_2 + \dot{m}_f \times LHV + \dot{m}_f C_{pf} T_f = (\dot{m}_a + \dot{m}_f) C_{pg} \times T_3 \quad (5)$$

LHV = 47541.6kJ/kg [19]

From Equation 5; the fuel ratio, f, is expressed as:

$$f = \frac{\dot{m}_f}{\dot{m}_a} = \frac{C_{pg} \times T_3 - C_{pa} T_2}{LHV - C_{pg} T_3} \quad (6)$$

The turbine inlet temperature can be expressed as [13]:

$$T_3 = \frac{\dot{m}_a C_{pa} T_2 + \dot{m}_f LHV}{C_{pg}(\dot{m}_f + \dot{m}_a)} \quad (7)$$

Heat Added is also expressed as [14][20]

$$\dot{Q}_{added} = (\dot{m}_a + \dot{m}_f) \times C_{pa}(T_3 - T_2) = \dot{m}_f \times CV \quad (8)$$

The compressor work is computed from the mass flow rate together with the enthalpy across the compressor is expressed as [13][14].

$$\dot{W}_c = \dot{m}_a C_{pa}(T_2 - T_1) = \rho_a v_a C_{pa}(T_2 - T_1) \quad (9)$$

Thermal Efficiency is expressed as:

$$\eta = \frac{\text{Net Power Output}}{\text{Total Heat Supplied}} = \frac{\dot{W}_{Net}}{\dot{Q}_{Supplied}} \quad (10)$$

The Specific Fuel Consumption is expressed as:

$$SFC = \frac{3600 \times \dot{m}_f}{\dot{W}_{net}} \quad (11)$$

The Heat Rate is expressed as:

$$HR = \frac{\text{Heat Added}}{\text{Power Supplied}} = \frac{1}{\eta_{th}} \quad (12)$$

Stoichiometric Equation at the combustion chamber for ideal combustion process: that is the minimum amount of air that is require for absolute burning and it is expressed as [12][13][14]:

$$C_m H_n + \left(m + \frac{n}{4}\right) O_2 + 3.76\left(m + \frac{n}{4}\right) O_2 \rightarrow mCO_2 + \frac{n}{2} H_2O + 3.76\left(m + \frac{n}{4}\right) N_2 \quad (13)$$

The Specific Fuel Consumption can also be expressed as:

$$SFC = \frac{3600}{AFR \times W_{net}} \quad (14)$$

The Air Fuel Ratio can be expressed as:

$$AFR = \frac{LHV}{\dot{Q}_{added}} \quad (15)$$

IV. RESULT AND DISCUSSION

- RESULTS

The parameters in Table 4.1 is the design parameter of the plant, Table 4.2 is the parameters obtained through direct measurement from the operational logsheets: turbine log sheets, plant/Auxiliaries logsheets and generator logsheets for the months of January 2012 to October 2012 and compared to [11]. The parameters which contained in Table 4.3 are values for the turbine inlet temperature (T_3), compressor work (W_c), turbine work (w_t), net work (W_{net}) heat supplied or added (Q_{add}), air fuel ratio (AFR), thermal efficiency, specific fuel consumption (SFC) and heat rate (HR) and they were obtained by calculation using equation: 7,9,2,4,8,15,10, 14 and 12 respectively. Finally, the effect of the ambient temperatures on theses parameters: mass flow rate, pressure ratio, power output, compressor work, turbine work, heat added, total workdone, air fuel ratio, thermal efficiency, specific fuel consumption and heat rate were plotted as shown in Figure 4.1 -4.4.

Table 4. 1: Design Parameters

S/N	Parameters	Unit	Design data
1	Power Output	Mw	26.8
2	Thermal Efficiency	%	28.7
3	Heat Rate (HR)	Kcal/w.h	2.833
4	Specific Fuel Consumption (SFC)	Kg/kw.h	0.308

Table 4.2: Parameters Gotten Through Direct Measurement

S/N	T_1°c	T_2°c	T_3°C	T_4°c	$\dot{m}_f$(Kg/s)	P_2=p_3 (Bar)	P_{Output} (MW)
1	25	240	860	378	3.0	18.1	11.19
2	26	245	871	382	3.0	18.1	11.19
3	27	249	877	385	3.0	18.1	11.18
4	28	279	887	389	3.0	18.1	11.17
5	29	282	891	390	2.9	18.0	11.16
6	30	285	895	392	2.9	18.0	11.14
7	31	287	895	394	2.8	17.8	11.13
8	32	288	941	415	2.7	17.8	11.12
9	33	293	966	426	2.6	17.8	11.12
10	34	294	869	383	2.6	17.6	11.11

Table 4: 3: Parameters Gotten Through Computation

S/No.	W_c (kw)	W_t (kw)	Q_{add} (kw)	W_n (kw)	AFR	η_{th} (%)	SFC (Kg/kwh)	HR (kcal/w.h)
1	734	1670	2148	478	21.42	43.07	0.352	2.32
2	660	1694	2169	475	21.21	43.13	0.357	2.32
3	669	1691	2072	381	22.20	42.99	0.425	2.33
4	757	1726	2107	381	21.83	40.63	0.433	2.46
5	737	1678	2040	362	22.55	40.72	0.441	2.46
6	743	1685	2043	358	22.52	40.67	0.447	2.46
7	720	1620	1966	346	23.40	40.30	0.445	2.48
8	695	1640	2036	396	22.59	41.35	0.402	2.42
9	679	1622	2021	399	22.76	41.61	0.396	2.40
10	679	1429	1727	298	26.64	39.30	0.454	2.55

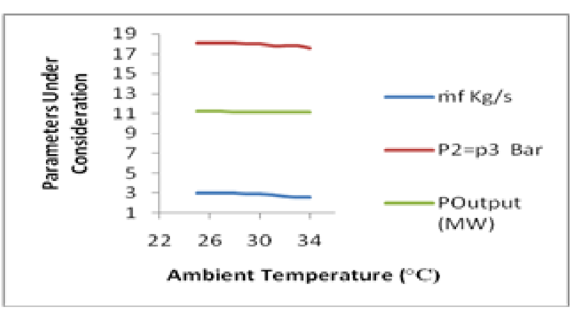

Figure 4. 1: Effect of Ambient Temperature on the Mass flow Rate, Pressure Ratio and Power Output

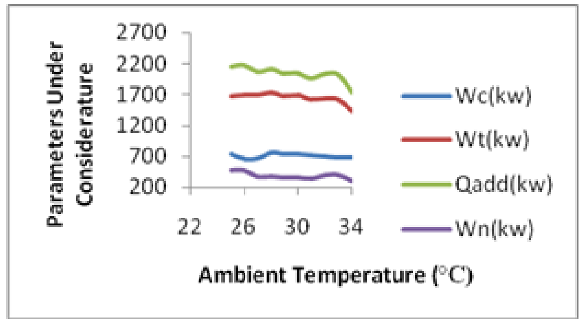

Figure 4.2 : Effect of Ambient Temperature on Compressor Work, Turbine Work, Head Added and Total Workdone by the Gas Turbine Plant.

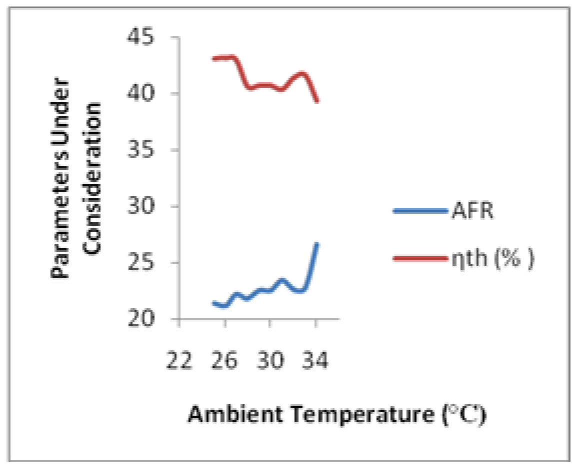

Figure 4.3: Effect of Ambient Temperature on the Air - Fuel Ratio and the Thermal Efficiency.

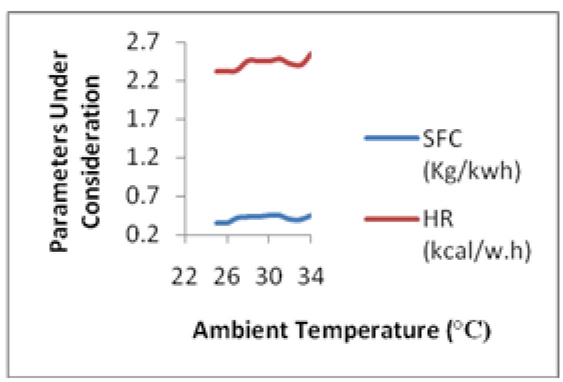

Figure 4.4: Effect of Ambient Temperature on the Specific Fuel Consumption and the Heat Rate.

DISCUSSION

Figure 4.1 display the effect of ambient temperature on the mass flow rate, power output and the pressure ratio of the gas turbine plant. It reveals that as the ambient temperature increases from 25^0C to 34^0C; the mass flow rate decreases by 0.4Kg/s, the pressure ratio decreases by 0.5bar and the power output decreases by 0.08MW respectively. The decrement mostly in the power output indicate that there is a short fall in power supply by the gas turbine plant. Figure 4.2 show the effect of ambient temperature on the compressor work, turbine work, heat supplied and total workdone by the gas turbine power plant. It is observe that as the ambient temperature increases from 28^0C to 34^0C; the compressor work decreases by 78KW, the turbine work decreases by 297KW , the total workdone decreases by 83KW and the heat supplied decreases by 380KW. This indicate that less work is done by the gas turbine power plant. Figure 4.3 show the effect of ambient temperature on the air fuel ratio and thermal efficiency. It shows that as the ambient temperature increases from 25^0C to 34^0C; the air fuel ratio increases by 5.22 while the thermal efficiency decreases by 3.77%. This indicate that higher fuel is required for a smaller workdone by the gas turbine power plant. Furthermore, Figure 4.4 display the effect of ambient temperature on specific fuel consumption and heat rate. It depicts that as the ambient temperature increases from 25^0C to 34^0C; both the heat rate and the specific fuel consumption increases by o.23KCal/Wh and 0.102Kg/KWh respectively. This increment in these parameters indicate that the gas turbine power plant will consume much fuel.

CONCLUSION

This study shows that the ambient temperature has great effect on the performance of the gas turbine. The work also reveal that an increment of ambient temperature from 25^0C to 34^0C , the power output decreases by 0.08MW, the thermal efficiency decreases by 3.77%, the heat supplied decreases by 421KW, the air fuel ratio increases by 5.22, the specific fuel consumption increases by 0.102Kg/KWh and the heat rate increases by 0.23KCal/Wh respectively. The performance of the gas turbine plant revealed that the plant will consume much fuel for small amount of workdone: that is, there is the tendency for poor power supply. It is recommended that routine maintenance should be carried out periodically and if the symptoms persist, intercoolers should be introduced in order to control the ambient temperature which is the cause.

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NOMENCLATURE

T = Temperature {Degree Celsius (^{0}C) or Degree Kelvin (K)}
h = Specific Enthalpy (KJ/KgK)
s = Specific Entropy (KJ/KgK)
m_a = Mass flow rate of air (Kg/s)
m_g = Mass flow rate of gas (Kg/s)
η_{th} = Thermal Efficiency (%)
W_c = Compressor Work (KJ/Kg)
W_T = Turbine Work (KJ/Kg)
W_N = Turbine Net Work (KJ/Kg)
Q_{added} = Heat Added or Heat Supplied (KJ/Kg)
C_{pa} = Specific Heat of Air at Constant Pressure (KJ/KgK)
C_{pg} = Specific Heat of Gas at Constant Pressure (KJ/KgK)
P_{atm} = Atmospheric Pressure (bar)
GT = Gas Turbine
P = Pressure (bar)
LHV = Lower Heat Value (KJ/Kg)
AFR = Air Fuel Ratio
MW = Meggawatts
SFC = Specific Fuel Consumption (Kg/KW.h)
HR = Heat Rate (Kcal/KW.h)
P_1= Compressor Inlet Pressure (Atmospheric Pressure) {bar}
P_2= Compressor Outlet Pressure (bar)
P_3= Turbine Inlet Pressure (bar)
P_4 = Turbine Outlet Pressure (bar)
T_1 = Ambient Temperature (^{0}C)
T_2 = Compressor Exit Temperature (^{0}C)
$\dot{m}$ = Mass Flow Rate (Kg/s)
ρ_a = Density of Air (Kg/m^3)
v_a = Volume of Air (m^3)