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Exergetic Appraisal of Delta IV Power Station, Ughelli

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Abstract
In this study, exergy is used to measure the performance of Delta IV power station located in Ughelli, Delta State, Nigeria. The choice of exergy as a means for performance appraisal is based on the fact that it provides a birds eye view of the sources of the major losses in the system, thus giving us a clue on how best to optimize the system under observation. Analyses are done using the first and second law of thermodynamics and results are presented in tables. In the exegetic analyses, mass and energy conservation laws were applied to each component. The compressor was seen to have the largest exergetic efficiency while that of the total plant was 45.7%. The combustion chamber had the largest exergetic destruction (56%) while that of the total plant was 58.5%.

Keywords: exergy, power station, performance appraisal, thermodynamics, Ughelli,

INTRODUCTION

Exergy is defined as a measure of energy quality (Ighodaro, 2006). It is the maximum quantity of work extractable from the flow of material and energy, which are brought under a state of equilibrium with the environment. Exergy generally is not conserved but destroyed in a system, the destruction is a measure of irreversibilities i.e. sources of performance losses, thus the essence of an energy analysis is primarily for optimization, if properly done, it reveals the point of greatest energy losses in the plant. Exergy analysis thus predicts the thermodynamic performance of an energy system (Goran W et al, 2002) and the efficiency of the system components by accurately quantifying the entropy generation of the components (Ebadi and Gorgi- Brandy, 2005).

Exergy analysis thus helps us assess the magnitude of energy destruction, identifies its location and magnitude and finally the source of thermodynamic inefficiencies in thermal system (Ofodu et al, 2002).
This study is carried out on the Delta IV gas power station, Ughelli, Nigeria. Power generation in Nigeria is highly unreliable and epileptic. Existing power stations are known to operate below fifty percent (50%) installed capacity, thus studies to identify location, magnitude and source of inefficiencies and unreliabilities becomes necessary with a view to improving efficiency and reliability.

DELTA IV POWER PLANT

The Delta IV power plant was first fired in 1990. It consists of six gas turbine units each having an installed generating capacity of 100MW. The units GT15, GT16, GT17, GT18, GT19, and GT20 are so named in the order of their arrangement in the power stations each of which is fired with natural gas. They are arranged in parallel in a single turbine hall, and each of them drives a generator with an output of 11.5kV, which is then stepped up to 330kV and fed to the national grid.

The plants operate on an open cycle and its shaft's rotational speed is 3000rpm.A schematic diagram of the 100MW gas turbine unit is given below. It shows the main work and energy flow and the state points which is accounted for in this analysis.

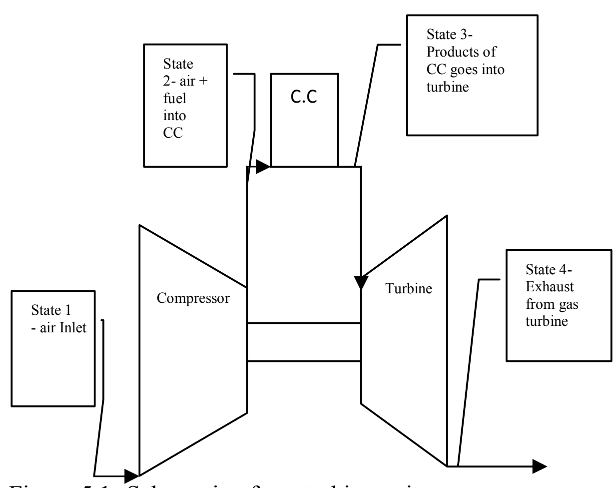

Figure 5.1- Schematic of gas turbine unit

DATA COLLECTION AND ANALYSIS

The data used for this analysis are both design parameters for the gas turbines and measured values recorded in the stations' operational log book for the period of January 2000- March 2005 for each of the gas turbines at various load set points and operational conditions. These data are then used to calculate the exergy balance for the power plant. The results of these calculations are presented in tables and on a Sankey diagram.

Formulation of the Exergy Balance Equation

A general exergy balance equation, applicable to any component of a thermal system can be formulated by utilizing the first and second laws of thermodynamics. The thermo- mechanical exergy stream may be broken down into its thermal and mechanical components (Ebadi and Gorji- Brandy).

The balance is given by:

$$E_i^M - E_o^M = \left(E_i^T - E_o^T\right) + \left(E_i^P - E_o^P\right) \ldots\ldots\ldots\ldots\ldots 1$$

Where; i = exergy flow stream entering plant component

o= exergy flow stream leaving plant component

M= material/component under study

T= thermal property

P= mechanical property

The thermal and mechanical components of the exergy stream for an ideal gas with constant specific heat capacity may be written as:

$$E^T = mc_p\left[\left(T - T_{ref}\right) - T_{ref}\ln\frac{T}{T_{ref}}\right] \ldots\ldots\ldots 2$$

$$E^P = mRT_{ref}\ln\frac{P}{P_{ref}} \ldots\ldots\ldots\ldots 3$$

The entropy for each state is given by:

$$S = {}^1\!/_2\left(c_p\ln\frac{T}{T_{ref}} - R\ln\frac{P}{P_{ref}}\right. \ldots\ldots\ldots 4$$

With the separation formula defined by equation 9.1, the general exergy balance equation can be expressed as:

$$E^{CHE} + \left(\sum_{inlet} E_i^T - \sum_{outlet} E_o^T\right) + \left(\sum_{inlet} E_i^P - \sum_{outlet} E_o^P\right) + T_{ref}\left(\sum_{inlet} S_i - \sum_{outlet} S_o + \frac{Q_{CV}}{T_{ref}}\right) - E^W \ldots 5$$

Where; E^{CHE} - denotes the rate of exergy flow of fuel in the plant

Q_{CV} – denotes the heat transfer component from the environment (Ebadi and Gorji- Brandy, 2005)

Exergy Balance Equation for the Delta IV Power Plant

The exergy balance equation fir each component in Delta IV power station can be derived from the general exergy balance equations for each of these components are as follows:

1. Air Compressor

$$(E_1^T - E_2^T) + (E_1^P - E_2^P) + T_0(S_1 - S_0) = W_{AC} \ldots\ldots\ldots 6$$

2. Combustion Chamber

$$E^{CHE} + \left(E_2^T + E_f^T - E_3^T\right) + \left(E_2^P + E_f^P - E_3^P\right) + T_0\left(S_2 + S_f - S_3\right) + Q_{CC} = 0 \ldots\ldots 7$$

3. Gas Turbine

$$(E_3^T - E_4^T) + (E_3^P - E_4^P) + T_0(S_3 - S_4) - W_{GT} \ldots\ldots\ldots\ldots 8$$

4. Exergy Loss or Destruction

$$E^W + E^{CHE} + E^T + E^P = E^D \ldots\ldots\ldots\ldots\ldots 9$$

Exergy Calculations for Gas Turbine

The exergy at each state in the gas power cycle is calculated from empirical thermodynamic analysis using state 1 as the reference state in equations 6- 9. The properties of the working fluid are gotten from Thermodynamic and Transport Properties of Fluids (Rogers and Mayhew, 1981).The results are presented in table 1a below:

Table 1a: Rated conditions for Gas Turbine

State	m (kg/s)	T (K)	P (bar)	E^{CHE} (MW)	E^T (MW)	E^P (MW)	S (MW)
1	432.6	310	1.013	0.00	0.00	0.00	0.00
2	432.6	642.9	9.82	0.00	46.43	87.43	0.04
F	9.10	310	17.5	450.25	0.00	3.59	-0.128
3	441.61	1244	9.54	0.00	255	87.53	0.49
4	441.61	782.93	1.32	0.00	94.16	10.51	0.47

Using the above-tabulated results for entropy, mechanical and chemical exergies in equations 6- 8, we develop exergetic results for each components of Gas Turbine. The net flow rates of the various exergies crossing the boundary of each component in the Gas Turbine at rated conditions is shown in Table 1b together with the exergy destruction in each component.

Positive values indicate the exergy flow rate of products while negative values indicate the exergy flow rate of resources or fuel.

The sum of the exergy flow rates of products, resources and destruction equals zero for each component and for the total plant. This zero sum indicates that exergy balances are exactly satisfied.

Table 1b: Exergy flow rates and Exergy Destruction in Gas Turbine

COMPONENT	$\dot{E}^W(MW)$	$\dot{E}^{CHE}(MW)$	$\dot{E}^T(MW)$	$\dot{E}^P(MW)$	$\dot{E}_D(MW)$
Compressor	-142.26	0.00	46.34	87.43	12.4
Combustion Chamber	0.00	-450.25	208.57	3.49	245.17
Turbine	244.06	0.00	-160.84	-77.02	6.2
Total Plant	**97.8**	**-450.25**	**94.07**	**13.9**	**263.77**

EXERGY EFFICIENCY

The exergy efficiency is given by:

$$\eta_{ex} = \frac{useful\ exergy}{exergy\ supplied}$$

From Table 1b, we compute the exergetic efficiencies of the individual components and for the entire plant.

$$Compressor: \eta_{ex.c} = \frac{46.34 + 87.43}{146.26} = 0.915$$

$$Combustion\ Chamber: \eta_{ex.cc} = \frac{208.57 + 3.49}{45.25} = 0.471$$

$$Turbine: \eta_{ex.t} = \frac{160.84 + 72.02}{244.06} = 0.954$$

$$Total\ Plant: \eta_{ex.tp} = \frac{97.8 + 94.07 + 13.9}{450.25} = 0.457$$

Figure 2 shows the exergetic efficiency of components of the gas turbine plant. The exergetic efficiency of the entire plant amounts to 45.7%. The exergetic efficiency of the combustion chamber and of the entire plant are quite low, this is attributed to the high energy degradation emanating from the combustion chamber and its high irreversibilities.

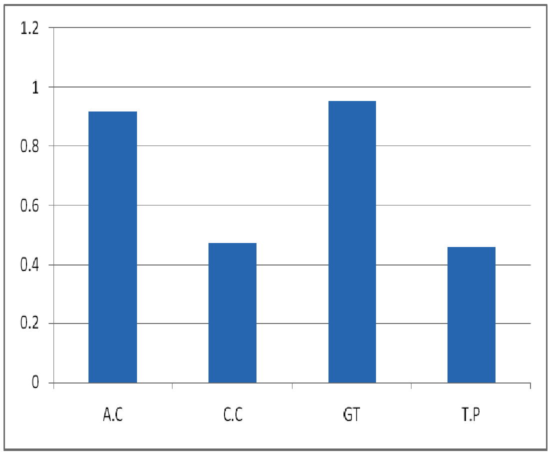

Figure 2: Exergetic efficiency of components and of total plant

EXERGY DESTRUCTION

In comparison with other plant components, the combustion chamber destroys the largest amount of total inlet energy into the plant as shown in figure 3 below. This large amount of exergy losses are traced to the high firing temperatures, incomplete combustion and possible mechanical losses in the combustion chamber. The figure shows also that 58.6% of the total inlet exergy is destroyed in the plant.

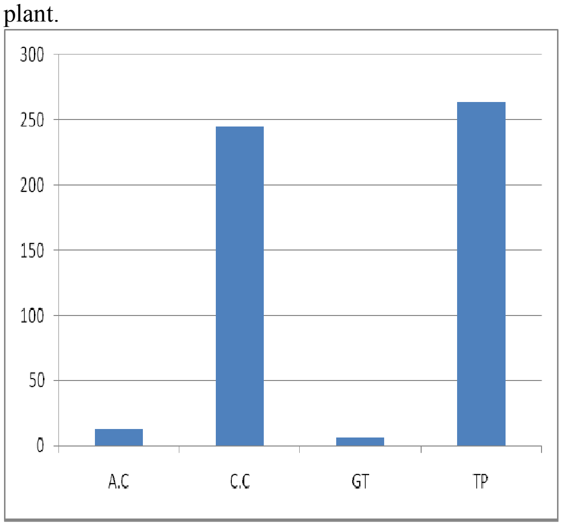

Figure 3: Exergy destruction in components and in the total plant

CONCLUSION

The exergy balance applied to the power station revealed how much of the usable work potential or exergy, supplied as the input to the system under consideration has been consumed (irretrievably lost) by the process, the exergy losses or irreversibilities thus provides a generally applicable quantitative measure of process inefficiencies thus enhancing optimization.

The exergy study showed that considerably exergy destruction occurs in the combustion chamber only and therefore, both the exergy efficiency and exergy destruction in the power station are affected mostly by the turbine inlet temperature.

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