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Energy Cost Analysis of Incorporating a Heat Recovery Steam Generator in Omotosho Phase 1 Thermal Power Plant

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Abstract

In simple gas turbine power plant, only a small portion of fuel energy is converted into electricity and the rest is lost as waste heat. To improve the performance of the plant the waste heat needs to be utilized. This paper analyzes the incorporation of a steam cycle to the existing gas turbine cycle in Omotosho Phase I power station (combined cycle). Operating data was obtained from existing Omotosho Phase I gas turbine and Egbin steam thermal plant. Preliminary analysis showed an additional 16.389 MW of power output and efficiency increase from 30.11% for simple gas cycle to 45.75% for the combined cycle. The energy cost saving per year summed up to Three billion, six hundred and fifty million naira (N3.646184 billion). This result shows that retrofitting the existing gas turbine power plant with Heat Recovery Steam Generator is a good system performance and will be an attractive investment opportunity.

Keywords: Energy, Cost Analysis, Power Output, Efficiency, Incorporating, Waste Heat

Nomenclature

$Cp_{, a, exh,}$	Specific heat capacity at constant pressure of air, exhaust gas (kJ/kgK)
CF	Cost of Fuel
EC	Energy Charge per MWH
FS	Fuel Saving
LF	Load Factor
LHV	Lower heating value (kJ/kg)
MSCF	Mass per Therm
$\dot{m}$	Mass flow rate (kg/s)
OH	Operational Hours
PCS	Power Cost Saving
p	Pressure (bar)
P	Power (MW)
Q	Heat supplied/removed rate (MW)
t	Temperature (^{0}C)
T	Absolute temperature (K)
η_m	Mechanical efficiency
η_g	Generator efficiency
$\eta_{thermal}$	Thermal efficiency
η_o	Overall efficiency
η_{oc}	Overall combined cycle efficiency

1.0 Introduction

Gas turbines have established an important role in Nigeria power generation because they are used in most current power projects in the country. The gas turbines power plants are very useful in industrial production of mechanical energy owing to the very high power –to- weight ratio achievable with simple cycle configurations. The growing demand of gas turbines in

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recent years is attributed to the rapid changes in this technology, which have led to the improvements in the design of both the individual components and the system as whole.

In simple cycle only small portion of the fuel energy is converted into electricity and the remaining is lost as waste heat. Exhaust heat from gas turbines can be recovered externally or internally to cycle itself [1- 4]. For external heat recovery various technology options, the combined gas – steam power plant is far the most effective and commonly used word wide [5]

In order to fully realize the potential benefit of the fuel in the gas turbine, it is necessary to capture and use the exhaust heat from the flue gas of the turbine. In the combine cycle application, this energy is converted into steam for expansion in a steam turbine. The conversion of this otherwise waste heat energy is accomplished in a Heat Recovery Steam Generator (HRSG) which is an adaptation of conventional water in tube boiler design. The stem turbine is attached to an electric generator to produce additional electricity.

In addition to high efficiencies, combined cycle plants have many other advantages, include in [6]:

- Low emission, since natural gas produces no ash or SO_X and smaller quantities of volatiles hydrocarbons, CO and NOx than oil and coal;
- Low capital cost and short construction time (often 2-3 years);
- Smaller space requirements than equivalent coal or nuclear power plant;
- Flexibility in plant, ranging from 10 to 750 MWe per combined cycle unit;
- Fast start up, making it easier to respond to change in demand.

The significant increase in the use of combined cycle power plants has shown that, despite the higher fuel cost compared to conventional steam power plants, are currently the best choice in terms of cost per unit of electricity [5].

The installation of Heat Recovery Steam Generator (HRSG) and steam power plant equipment to achieve a combined cycle configuration is more attractive since it does not require modification to the existing gas turbines and the construction of the steam power plant will not interfere with the operation of the turbines resulting in minimum plant down time and loss in productive capacity.

The gas turbine exhaust, typically at a temperature of 500 – 600 ^{0}C is used to raise steam in the HRSG. This steam is then used in the steam turbine to drive a generator. Normally, the gas turbine exhaust has unused oxygen content and it is possible to burn additional fuel in the boiler to raise steam output; this supplementary firing is most likely used with gas turbines operating at a relatively low exhaust gas temperature [7]. The exhaust from the HRSG may be used in a process such as paper drying, brewing, heating of building, sterilizing or for preheating combustion air for the furnace at a carbon baking facility, and this is referred to as cogeneration or combined heat and power (CHP).

Although the characteristic compactness of the gas turbine is sacrificed in binary cycle plants, the efficiency is much higher than is obtainable with simple cycle that such turbines are now widely used for large – scale electricity generating station [8,9]. Research work by [10] revealed that 66.98% of the fuel input at is lost to the environment as waste heat from flue gas in Omotosho Phase I, thereby makes it necessary to incorporate HRSG in the plant to obtain the benefit of combined cycle. Thus, this paper studies the energy cost analysis of incorporating HSRG in the existing Omotosho Phase I gas thermal power plant in Ondo state, Nigeria.

2.0 Methodology

2.1 Data Collection

Two performance data scenario will be considered for this analysis. Data obtained from a research work by [10] for the gas turbine section and data from [9, 11] for the steam turbine section. The analysis applied existing plant parameters of the steam (Rankine) cycle to accomplish the HRSG function. Omotosho Phase I power station has eight gas turbine units.

2.2 Description of Model

A combined cycle gas turbine is a fossil fuel plant that combines the Brayton cycle of the gas turbine with the Rankine cycle of the steam turbine. The schematic diagram, shown in Figure 1, the gas cycle consists of air compressor, combustion chamber, gas turbine and generator, while steam cycle consists of HRSG, Steam turbine, generator, condenser and feed pump. Exhaust heat from the gas turbine, passing through a heat recovery steam generator (HRSG), produces steam that evolves in the bottoming steam cycle (Rankine). This is direct method, because the heat is transferred directly to the working fluid of the other system. Since there is water supply from a close by river and chemical treatment plant in the station the there will no problem of clean water supply for the HSRG. The power was initially designed for combined cycle.

3.0 Analysis and Result

3.1 Preliminary Analysis of the HRSG Combined Cycle.

Data obtained from research works on Egbin Thermal Station by [9, 11] is used in this analysis.

At full load condition of Omtosho Phase I, the mass flow rate of the exhaust gas is 143.85 kg/s at a temperature of 537^0C and mass flow rate of fuel is 2.2 kg/s. Low Heat Value (LHV) of fuel is 55326.5 kJ/kg or 55.32565 MJ/kg [12].
Assuming a dual pressure heat recovery system generator which can reduce the exhaust gas temperature to 170^0 C is incorporated, the heat recovered from the flue gases Q_{exh} will be given by

$$Q_{exh} = \dot{m}_{exh} \times c_{pexh} \times (T_{exh} - T_{out}) \qquad (1)$$

Where, $\dot{m}_{exh}$ = mass flow rate of exhaust gases (kg/s)
c_{pexh} = specific heat capacity of flue gases (kJ/kgK)
T_{exh} = temperature of exhaust gases from gas turbine (^{0}C)
T_{out} = temperature of exhaust gases from heat recovery steam generator (^{0}C)
From Equation (1), Q_{exh} is calculated as:
Q_{exh} = 143.85 x 1.148 x (537 – 170) = 60.606 MW
Assume the HRSG has a gas to steam heat transfer efficiency of 0.88; the heat transferred to the steam Q_s is thus:

$$Q_s = 0.88Q_{exh} = 0.88 \times 60{,}606 = 53.333 \text{ MW} \qquad (2)$$

Data from Egbin Thermal Station:
Steam turbine cycle thermal efficiency ($\eta_{thermal}$) = 32%
Mechanical efficiency (η_{mech}) = 99%
Generator efficiency (η_{gen}) = 97%
The power available at the steam turbine generator terminal (P_{steam}) is given as:

$$P_{steam} = \eta_{thermal} \times \eta_{mech} \times \eta_{gen} \times Q_s = 0.32 \text{ X } 0.99 \text{ X } 0.97 \text{ X } 53.333 = 16.389 \text{ MW} \qquad (3)$$

The overall combined cycle efficiency of the station η_{oc} is given by Equation (4) which was obtained from [13].

$$\eta_{oc} = \left(\frac{P_{gas} + P_{steam}}{Q_{fuel}}\right) \qquad (4)$$

(Assuming no supplementary firing is carried out)
P_{steam} = power output from steam turbine generator terminal (MW)
P_{gas} = power output from gas turbine generator terminal (MW)
Q_{fuel} = Heat supplied by fuel to turbine

$$Q_{fuel} = \dot{m}_f \times LHV = 2.22 \times 55326.5 = 122.825 \text{ MJ/S} \qquad (5)$$

$$\eta_{oc} = \frac{39.8 + 16.389}{122.825} = 0.4575 = 45.75\%$$

Equation (6) used for fuel saving per annum was obtained from [14 – 16]

$$\text{Fuel Saving per annum (FS)} = \left(\frac{1}{\eta_o} - \frac{1}{\eta_{oc}}\right) \times P \times OH \times \frac{LF}{LHV} \times \frac{CF}{MSCF} \qquad (6)$$

The following data were obtained from [17]
Load Factor (LF) = 58.57% Cost of fuel (CF) = N228, Mass per Therm (MSCF) = 20.3kg

$$FS = \left(\frac{1}{.3011} - \frac{1}{0.4575}\right) \times 56.189 \times 3600 \times 24 \times 365 \; \frac{0.5857}{55.3265} \times \frac{228}{20.3} = \text{N}239,206{,}865.7$$

Energy saving for the combined cycle will be 16.389MW generated by the steam turbine
Using the Tariffs projected for generation for the year 2012 by Multi – Year Tariff Order (MYTO) N1660.9 Energy charge per MWH (EC) [18].
Operational hours (OH) for December 2011 = 663 hours [17]
Equation (7) was obtained from [19].

$$\text{Power cost savings per annum (PCS)} = (P_{steam}) \times (12OH) \times (EC) \qquad (7)$$

$$\text{Total saving for combined cycle } (TS_{CC}) = FS + PCS \qquad (8)$$

Results from Equations (6 – 7) are summarized in Table 1.
Assume all the other 7 GT's are working as GT1,
Total Saving for the station per annum = N 455,773,084.9 X 8 = N 3,646.185 Million

4.0 Discussion

From the value of combined cycle efficiency calculated, the installation of a hypothetical combined cycle improved the efficiency from 30.11% of gas turbine cycle to 45.75% for the combined cycle. This improvement in efficiency makes the combined cycle plant suitable for base load power generation. To avoid having one steam turbine train for each gas turbine unit, it is more economical to have two gas turbine units and a HRSG to drive one steam turbine train proposed in the design specification, which did not see the light of the day. The power output from the steam turbine generator terminal would increase the total plant power output.
The revenue from incorporating HRSG was calculated by appropriate formula as stated. The energy cost analysis for the hypothetical HRSG as analyzed for one year using one the unit GT1 which is N 455,773,084.9 as shown in Table 1. It was assumed that when all the other seven units are working similar to unit one because they have similar specifications it amount to N3, 646.184 million. The fund can supplement salary, other administrative expenses and help to recover the capital cost of

additional components. The combined cycle will utilize waste heat energy that would be been exhaust to the atmosphere, this will help to reduce the excess heat the atmosphere thereby help to control climate change.

5.0 Conclusion and Recommendation

The possibility of incorporating a steam turbine unit to utilize the high temperature flue gases from the gas turbine unit (combined cycle) was analyzed; the findings show an improved power output, efficiency and fuel savings. The incorporation of combined cycle will reduce the quantity of heat rejected thereby reducing the impact of pollution on the local environment. Therefore, it is recommended that it should be incorporated in the plant to improve the power output and plant efficiency and other advantages mentioned in literature.

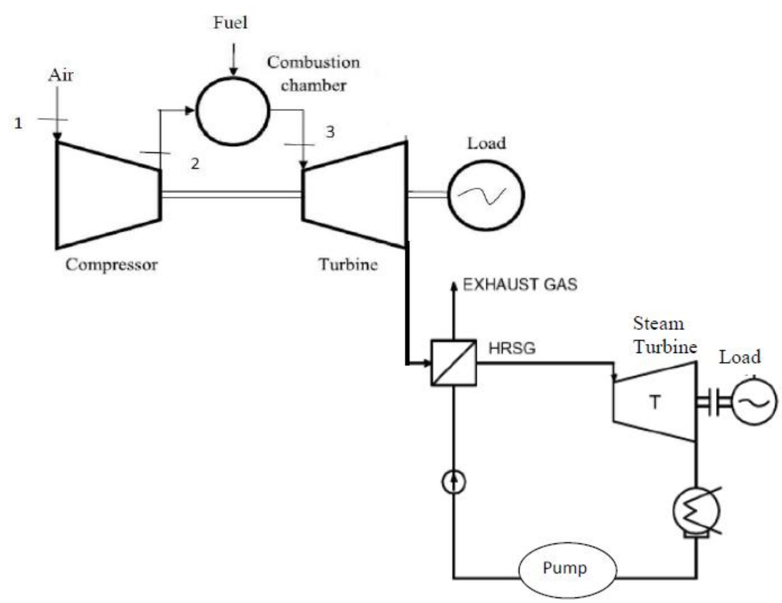

Figure 1: The Schematic Diagram of the Hypothetical HRSG Combined Cycle plant

Table 1: Results of Energy Cost Saving per annum for Incorporating HRSG in GT1

S/N	Savings	Amount (N)
1	Fuel saving per annum (FS)	239,206,865.7
2	Power cost saving per annum (PCS)	216,566,219.2
3	Total saving as Combined Cycle (TScc)	455,773,084.9

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