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Energy Cost Analysis of Incorporating Air Intake Cooling System in Omotosho Phase 1 Thermal Power Plant

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Abstract

The gas turbine power plants in Nigeria are sited in locations where the standard ambient air temperature condition of 15^0 C rarely occurs. This off – rated temperature condition brings about a low thermal performance of the power plants. One method that can be used to improve the thermal performance of gas turbine power plants is to reduce the temperature of air entering them by using combustion turbine air – inlet cooling technology. This paper presents the energy cost analysis of incorporating air – intake cooling system in Omotosho Phase I Thermal Power Station. Data obtained from the power station were used for the economic analysis. The analysis indicates that four hundred and ninety eight million, one hundred and thirty eight thousand, seven hundred naira and sixty kobo only as profit. Thus retrofitting the existing gas turbine power plant with air – intake cooling system is economically viable. It also provides a better system performance and is an attractive investment opportunity.

Keywords: Energy, cooling, ambient air temperature, cost analysis, profit, efficiency, power output.

1. Introduction

In order to substantially reduce the large deficit between the demand and supply of electricity in Nigeria, the federal, state and local governments, through the Niger Delta Power Holding Company (NDPHC) have built or are building gas turbine power plants in various locations in the country. The gas turbine or combustion turbine power plants were primarily preferred to other thermal power plants because of their low capital cost, short installation period and abundant availability of natural gas (Abam and Moses, 2011). Nigeria has on a number of occasions been referred to by informed commentators on the oil and gas industry as a natural gas province with some oil in it (Bademosi, 1989). This is because of her abundant reserves of natural gas which is substantially more than the oil reserves in the country.

The power output capacity of all gas or combustion turbines varies with ambient air temperature and site elevation (ASHRAE, 2008). The rated capacities of all combustion turbines are based on standard ambient air at 15^0 C, 60% relative humidity, 101.325 kPa at sea level and zero inlet and exhaust pressure drops, as selected by the International Organization for Standardization (ISO). Virtually, all the gas turbine power plants in Nigeria are sited at locations where the frequency of occurrence of ambient air temperature at 15^0 C or lower, in terms of the number of hours, is very low on yearly basis. The very high frequency of occurrence of ambient air temperature above 15^0 C implies that the gas turbines operate at off - ISO conditions virtually all the time.

Whenever a gas turbine operates at site ambient conditions that differ from the stipulated ISO conditions, there is a deviation from the plant design performance rating. For all gas turbines, increased ambient air temperature or site elevation decreases power output, increase ambient air temperature also reduces fuel efficiency (i.e. increases the heat rate defined as the fuel energy required per unit of electric energy produced) (ASHRAE, 2008).

Several methods exist for improving the performance of gas turbine power plants. These include:

i) Designing the various components to reduce internal losses (i.e. designing compressors and turbines with higher isentropic efficiencies, more efficient combustion systems and minimizing friction losses),
ii) Increasing turbine inlet temperature
iii) Recovering waste heat from the exhaust of the gas turbines and
iv) Reducing the air inlet temperature to the compressor (El – Wakil, 1984; Eastop and McConkey, 2011).

The enhancement of the performance of gas turbines through the application of combustion turbines inlet cooling (CTIC) technology has been investigated by various researchers (Abam and Moses, 2011; Egware, 2013; Cortes and Williams, 2003; Abam et al, 2012; Brooks 2000, Al – Ibrahim et al, 2002). Al – Ibrahim and Varnham (2010) have carried out a detailed review of air – cooling technologies for enhancing the performance of combustion turbines in Saudi Arabia. They stated that ambient air temperature are typically reduced by using the following techniques: wetted media evaporative cooling, high – pressure fogging evaporative cooling, absorption chiller cooling, refrigerative cooling using vapour compression and thermal energy storage. ASHRAE (2008) has outlined the economic and environmental benefits provided for plant owners, rate payers and the general public by the application of CTIC technologies on gas turbine power plants.

Evaporative cooling systems have the lowest capital costs among CTIC systems, and are the most common type in use (ASHRAE, 2008). In the direct method of evaporative cooling, the inlet air is cooled by contacting a fluid such as atomized water spray, fog or a combination of both (Wang et al, 2009). This cooling method has been extensively studied and successfully implemented for reducing the temperature of air entering the compressor of combustion turbine power plants in dry hot regions (Ameri et al, 2004; 2007; Alhazmy et al, 2006). Apart from the simple and inexpensive nature of the cooing method, the water spray it utilizes cleans the inlet air stream of airborne particulates and soluble gases (ASHRAE, 2008). For most applications, evaporative coolers having a saturation effectiveness of 85% to 90% provide the most economic benefit (Brooks, 2000).
The gas turbine differs from other prime movers in being particularly sensitive to ambient air temperature. The output for a given turbine inlet temperature increases markedly at lower air temperatures, the efficiency also improves but less markedly; this is mainly because the compressor, at a given speed, aspirates a mass of air roughly proportional to the density (Wood, 1981). The density of air reduces with increase in ambient air temperature (ASHRAE, 2008). Thus , the paper advocates the use of an evaporative cooling system to enhance the performance of the existing Omotosho Phase I Gas Turbine Power plant and analyses the energy cost implications of incorporating an – intake cooling system in the plant.

2. Methodology

2.1 Data Collection

Data used for this study were obtained from a research work carried out on Omotosho Phase I Thermal Power Plant and reported by Egware (2013). The thermal power plant consists of eight (8) gas turbine units with each unit having an ISO rating of 42 MW. In his research work, Egware (2013) used the performance data obtained for the power plant for the period January 2008 – December 2011.
Table 1 shows some performance data of gas turbine unit 1(GT1) when it operated at the lowest recorded ambient air temperature for the period covered in the study. Table 2 shows similar data when GT1 operated at the average of the ambient air temperatures for the same period. Table 3 shows some plant operational data obtained from the log book of the power utility (PHCN[1]).

Table 1: Performance Data of GT1 when Operating at Lowest Temperature

Ambient Temperature, t_1 (^{0}C)	21.0
Power Output, P_1 (MW)	39.8
Overall efficiency,η_0 (%)	32.4

Table 2: Performance Data of GT1 when Operating at Average Temperature

Ambient Temperature, t_{av1} (^{0}C)	26.140
Power Output, P_{av1} (MW)	35.325
Overall efficiency,η_{0av} (%)	30.22
Air mass flow rate ,$\dot{m}_a$ (kg/s)	139.22

Table 3: Plant Operational Data from Log Book

Load factor (%)	58.57
Cost of fuel (N/kg)	228/20.3
Low Heating Value, LHV (MJ/kg)	55.3265

2.2 Model Description

The schematic diagram of the incorporated air – intake cooling system in the existing simple open – cycle gas turbine plant is shown in Figure 1. The plant consists of a cooling tower, pumps, spray cooler, compressor, combustion chamber, turbine and generator.
Cold water from the cooling tower enters the spray cooler where it contacts the air entering the plant and reduces its dry bulb temperature to a value close to its initial wet bulb temperature. The water from the sump of spray cooler is returned to the cooling tower where it is cooled to ensure the continuation of the process.
The advantages of utilizing the evaporative cooling system as outlined by Al - Ibrahim and Varnham (2010) include very low unit capital cost, simple and reliable design, and operation, no limitation on time or duration of inlet – cooling operation, low parasitic power consumption, low operational costs as well as quick delivery and installation. However, the disadvantages include the high consumption of large amounts of treated water and high maintenance cost due to scaling and water treatment.

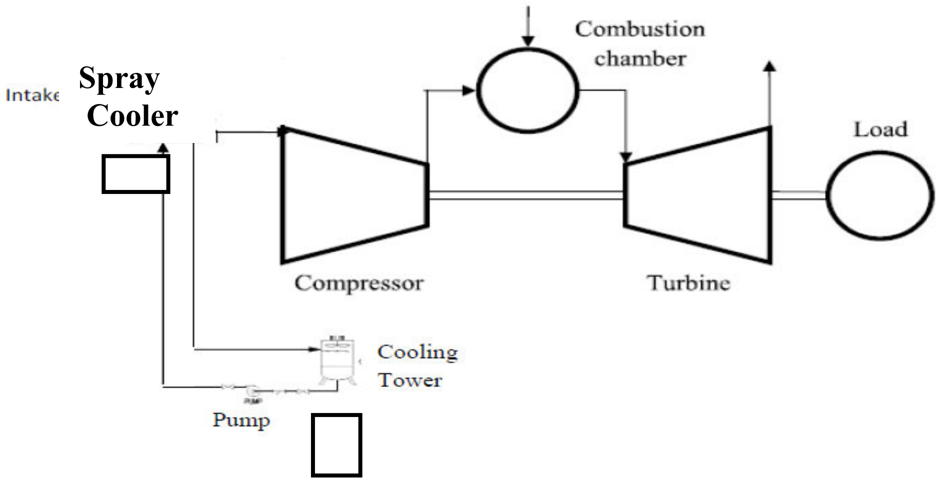

Figure 1: Schematic Diagram of Omotosho Phase I with Incorporation of an Intake Air – Cooling System

3. Preliminary Analysis of Incorporating an Intake Air – Cooling System

3.1 Economic Analysis

The economic analysis carried out here is based on the assumption that the air – intake cooling system reduces the ambient air dry bulb temperature from 26.14 ^{0}C to 21.0 ^{0}C. The formula, expressed in Equation 1, for computing the fuel savings per annum arising from the reduction of ambient air temperature is stated in Rogers and Mayhew (1992) and Salami (2004).

Fuel Savings per Annum

$$= \left(\frac{1}{\eta_{0av}} - \frac{1}{\eta_0}\right) \text{ x Power x Operational hours x } \frac{\text{load factor}}{\text{LHV}} \text{ x } \frac{\text{cost of fuel}}{\text{mass per therm(MSCF)}} \quad (1)$$

Where, η_0 = Overall efficiency at lowest ambient temperature

η_{0av} = overall efficiency at average ambient temperature.

The fuel savings is calculated using values taken from Tables 1 – 3 and using Equation 1.

$$\text{Fuel saving per annum} = \left(\frac{1}{0.3028} - \frac{1}{0.324}\right) \text{ x } 39.80 \text{ x } 3600 \text{ x } 24 \text{ x } 365 \; \frac{0.5857}{55.3265} \text{ x } \frac{228}{20.3}$$

= ₦ 32,248,201.2

$$\text{Power savings} = P_1 - P_{av}, \quad (2)$$

Where, the values for P_1 and P_{av} are obtained from Tables 2 and 3.

= (39.80 – 35.328) MW = 4.472 MW

Using the Tariffs projected for electricity generation for the year 2012 by Multi – Year Tariff Order (MYTO) the energy charge per MWH = ₦1660.9 (MYTO 2008).

Operational hours for December 2011 = 663 hours (PHCN[2])

Power cost savings for 12 months =

(Power savings) x (Operational hours) x unit cost of energy generated (3)

(Cengel and Boles 2006)

= 4.472 x 663 x 12 x 1660.9

= ₦59, 093,546.43

Total savings for intake air – cooling = Fuel saving cost + Power savings cost (4)

= ₦ 32,248,201.2 + ₦ 59,093,546.43

= ₦ 91,341,747.63

Jones (1985) has stated the formula for calculating the specific heat capacity of moist air, C_{pma}, it is given by

$$C_{pma} = C_{pda} + WC_{ps} \quad (5)$$

Where C_{pda} = specific heat capacity of dry air (1.005 kJ/kgK)

W = moisture content of air (kg/kg of dry air)

C_{ps} = specific heat capacity of water vapour (1.88 kJ/kgK)

For a value of W = 0.013 kg of water vapour/kg of dry air

C_{pma} = 1.005 + 0.013(1.88)

= 1.02944 kJ/kgK

The average air mass flow rate is taking from Table 2 as, $\dot{m}_a$ = 139.22kg/s

Cooling power (Q_c) required will be, $Q_c = \dot{m}_a C_{pma}(t_{av1} - t_1)$ (6)

Where $t_1 = 21^0$C and $t_{1a} = 26.14^0$ C

Q_c = 139.22 x 1.02944 x (26.14 – 21)

= 736.6578 kW

Central Bank of Nigeria (CBN) exchange rate at July 11, 2013, $1 = N156.0 (The Nation 2013:12)

The unit capital cost for incorporating the air – cooling system is U$230/kW (Sue et al 2002).

Capital cost = Q_c x Capital cost x Exchange rate (7)

= 736.6578 X 230 X 156

= ₦ 26,431,281.86

Assume operating and maintenance cost of 10% per annum of capital cost

Maintenance cost = 0.1 x 26,431,281.86

= ₦ 2,643,128.186

Total cost = ₦ 26,431,281.86 + ₦ 2,643,128.186

= ₦ 29,074,410.05

Net savings (Profit) for inlet air cooling system for GT1

= Total saving cost per annum – Total cost per annum (8)

= ₦ 91,341,747.63 – ₦ 29,074,410.05

= ₦ 62,267,337.58

= $399,149.5999

Assuming the other GT's behave in a similar manner as GT1

Plant Net savings = ₦ 62,267,337.58 x 8

= ₦ 498.138, 700.6

= $3,193,196.799

3.2 Discussion

The capital cost and revenue from incorporating the air intake cooling system was calculated by appropriate formula stated. The energy cost analysis for the hypothetical air – cooling system as analyzed for one year using for gas turbine GT1 indicated a profit of sixty two million, two hundred and sixty seven thousand, three hundred and thirty seven naira and fifty eight kobo only (₦ 62,267,337.58). The incorporation of the intake – air cooling system in all the eight gas turbine units is therefore advocated as it will bring about a net savings of four hundred and ninety eight million, one hundred and thirty eight thousand, seven hundred naira and sixty kobo only(₦ 498.138, 700.6) when all the units are operating simultaneously. This shows that the incorporation is economically feasible. The additional revenue obtained will supplement salary and other expenses.

Other economic and environmental benefits that the incorporation of the air – intake cooling system would bring as stated by (ASHRAE, 2008) include;

i) Increasing power output when it is most needed and most valuable,
ii) Increasing fuel efficiency of the gas turbine (lowering the heat rate),
iii) Minimizing the usage of less efficient steam – turbine based systems thereby helping to minimize increase in electricity tariffs to consumers.

Environment benefits include allowing minimum use of inefficient and polluting power plants by allowing maximum use of efficient and cleaner combustion turbine plants thereby,

i) Conserving natural fuel resources,
ii) Reducing emissions of pollutants (So_x, NO_x, particulates and hydrocarbons),
iii) Reducing emission of global warming/climate change gas (CO_2).

5. Conclusion and Recommendation

The possibility of incorporating an inlet air – cooling system to maintain low ambient air temperature was analyzed; the findings show an improved power output, efficiency and fuel savings. It also shows that the intake air – cooling system incorporation is economically feasible. The incorporation of intake air – cooling system will reduce the quantity of heat rejected thereby reducing the emission of pollutants and global warming gases on the local environment. Therefore, it is recommended that cooling system should be incorporated in the plant to improve its power out put, efficiency and other thermal performance parameters.

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References

A. Abam D.S.P and Moses N.N (2011), "Computer Simulation of Gas Turbine Performance", Global Journal of Researches in Engineering, Vol. 11, Issue I, Version 1.0. ISSN: 0975 – 5861.

Abam F.I,Ugot I.U, Igbong D.I (2012), "Performance Analysis and Components Irreversibilities of a (25 MW) Gas Turbine Power Plant Modeled with a Spray Cooler", American Journal of Engineering and Applied Sciences; 5(1):35 – 41.

Alhazmy M.M, Jassim R.K, Zaki G.M (2006), "Performance Enhancement of Gas Turbines by Inlet Air – Cooling in Hot and Humid Climates". International Journal of Energy Research 30: 777 – 797.

Al – Ibrahim A, Al – Rubaian A, Smiai M, Abusas G (2002), "Combustion Turbine Inlet Air – Cooling Technologists and in – situ Performance in the Climate Conditions of Saudi Arabia", Proceedings of the Energy Conservation and Cogeneration Exchange Meeting (ECON 2002) Nov. 2 -3, 2002, Saudi Aramco, Dammam.

Al – Ibrahim A, Varnham A (2010), "A Review of Inlet Air – Cooling Technologies for Enhancing the Performance of Combustion Turbines in Saudi Arabia", Applied Thermal Engineering, Volume 30, pp 1879 – 1888.

Ameri M, Nabati H, Keshtgar A. (2004), "Gas Turbine Power Augmentation Using Fog Inlet Cooling System", Proceedings ESDA 04 7th Biennial Conference of Engineering Systems design and Analysis. Manchester UK, ESDA 2004 – 58101.

Ameri M, Shahbazian H.R, Nabizadeh M. (2007), "Comparison of Evaporative Inlet Air Cooling Systems to Enhance the Gas Turbine Generated Power". Int. J. Energy Res 31: 483 – 503.

ASHRAE (2008), "2008 Handbook – HVAC systems and Equipment". SI Edition, Chapter 17.

Bademosi F. (1989), "Gas Utilisation in the Domestic Market", NAPECTOR Magazine Volume 10 No.4, Fourth Quarter.

Brooks F.J (2000), "GE Gas Turbine Performance Characteristics", GE Power systems, New York. GER3567H.

Cengel Y.A and Boles M.A (2006), "Thermodynamics – An Engineering Approach", 5th edition, McGraw – Hill, Boston,

Eastop T.D and McConkey A.(2011), "Applied Thermodynamics for Engineering Technologist", 11th Impression, Pearson Education Ltd.

El – Wakil M.M (1984), "Power Plant Technology", 1st Edition, McGraw – Hill Book Company.

Egware H.O (2013), "Exergy Analysis of Omotosho Phase I Gas Thermal Power Station", Unpublished M.Eng Project, University of Benin, Benin City, Nigeria.

Jones W.P (1985), "Air Conditioning Engineering", 3rd Edition, Edward Arnold.

Nigerian Electricity Regulation Commission: Multi – Year Tariffs Order (MYTO) "(July 2008 – June 2013) for the Determination of Charges and Tariffs for Electricity Generation, Transmission and Retails Tariffs".

PHCN[1]: "Omotosho Power Station Phase I Gas Turbine and Generator Running Record". 2008 -2011.

PHCN[2]: (December 2011): "Omotosho Power Station Phase I Monthly Generation Analysis".

Rogers G.F.C and Mayhew Y.R (1992), "Engineering Thermodynamics": Work and Heat Transfer, 4th edition, Pearson Education Ltd, England,.

Rogers G.F.C and Mayhew Y.R (1995), "Thermodynamics and Transport Properties of Fluids", 5th edition, Oxford Basic Blackwell publishers, Britain.

Salami L.A (2004), "Thermal Power Engineering 1", Lecture Note, Department of Mechanical Engineering, University of Benin. Benin City, Nigeria.

Sue D.C, Chuang C.C and Lin P.H (2002), "Performance Improvement for Gas Turbine Combined Cycle Power Plant (GTCCPP) in Taiwan", In Johnson D1 editor, Electric Power 2002 4th Annual conference and Exhibition, Vol. 4A, Missouri (USA), America Center St. Louis; pp 1- 15.

The Nation, Friday (2013), "CBN Exchange Rate as at 11/07/2013", July 12, Vol. 8 No. 2544 pp 11.

Wang T, Li X and Pinneti V. (2009), "Simulation of Mist Transportation for Gas Turbines Inlet Air – Cooling", ASME Int. Mec. Eng Congress, November 13 – 19, Anaheim, Ca. USA.

Wood B. (1981), "Gas Turbine", Kempe's Engineers Year – Book, Vol. 1,Morgan – Grampian Book Publishing CO.Ltd, 30 Calderwood Street, London SE6QH Chapter F4 pp 8.