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Determination Of The Central Gas Turbine Efficiency And Reliability, Edjeba, Delta State, Nigeria.

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Abstract

The oil and gas industry commonly use gas turbines to drive pumps and compressors. Process industries use them to drive compressors and other large mechanical equipment, and many industrial and institutional facilities use turbines to generate electricity for use on-site. Information data were obtained from Edgeba power station Delta state, Nigeria. These are inventory records of monthly energy generation between 2002 and 2012 and operational statistics. The data were used to determine the efficiency and reliability of the power station. Consequently, the average reliability of the plant was 39.76% (8.36% minimum in 2008 and 49.49% maximum in 2005) as against stations target of 60-80% and efficiency was 15.79% (3.4% minimum in 2008 and 23.5% maximum in 2011) as against ISO 3977-2-1997 (Gas Turbine Procurement, Conditions and Ratings, 1997) ratings of 28.8%.

1. Introduction

The performance of a power plant by way of its efficiency and reliability, and other operating factors has definite socio-economic significance both on the company operating the plant as well as the nation at large. Obodeh and Isaac,(2011) reported that the long-term strategic intent of Nigeria is stated as to become "top 20 World economy in terms of size of gross domestic product (GNP) by the year 2020". Whilst this aspiration is long running, the goal post for its attainment has been shifted on a number of occasions (from 2000, to 2010, to 2015, to 2020) (Arikenbi, 2008; Sambo, 2007). However, without adequate and reliable electricity supply, socioeconomic transformation would remain a mirage. A gas turbine power plant essentially brings together air that it compresses in its compressor module, and fuel, that are then ignited. Resulting gases are expanded through a turbine. That turbine's shaft continues to rotate and drive the compressor which is on the same shaft, and drives also a generator coupled to the turbine shaft as well and thereby generating electrical energy. A separate starter unit is used to provide the first rotor motion, until the turbines rotation is up to design speed and can keep the entire unit running. A gas turbine, also called a combustion turbine, is a rotary engine that extracts energy from a flow of hot gas produced by combustion of gas or fuel oil in a stream of Compressed air. It has an upstream air compressor with radial or axial flow mechanically coupled to a downstream turbine and a combustion chamber in between.

According to Essien Etop, 2012; Gas turbine may also refer to just the turbine element. Energy is released when compressed air is mixed with fuel and ignited in the combustor. The resulting gases are directed over the turbine blades, spinning the turbine, and mechanically powering the compressor. Finally, the gases are passed through a nozzle, generating additional thrust when accelerating the hot exhaust gases by expansion back to atmospheric pressure. Energy is extracted in the form of shaft power, compressed air and thrust, in any combination, and used to power aircraft, trains, ships, electrical generators. The principle described is referred to as the *Brayton cycle.* Gas turbine power plants are in two categories: Open cycle turbine in which the exhaust heat is not recovered and the Closed cycle turbine power plant in which the exhaust heat is recovered using a heat recovery system. The Central Power Plant (CPP) Edgeba consist of four open cycle gas turbine generator of 2.8 MW nominal capacity each. Figure 1 is the layout of an open cycle gas turbine plant operation. Two units of the turbine are housed in a single support structure and enclosure, same with the other two units. Each units comprises of a gas generator (compressor, combustion and turbine module making up the engine system) attached to an electrical generator. Also attached to each unit are the lubricating oil cooling systems, the electrical system, the instruments and control system, the fuel system as well as the air system.

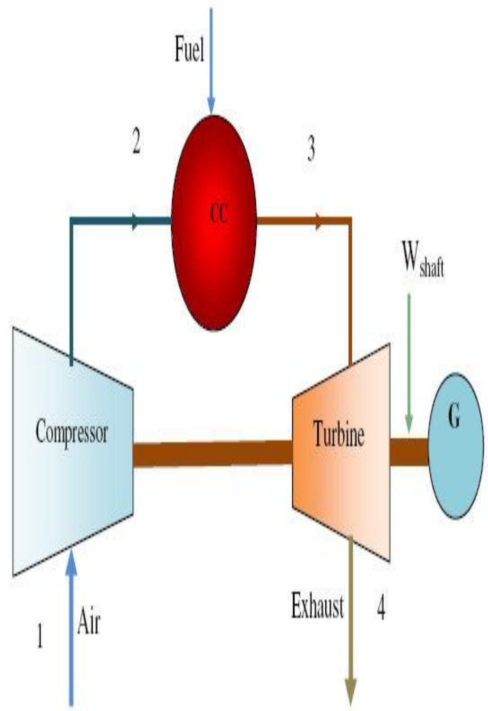

Figure 1: Layout of an Open Cycle Gas Turbine Plant Operation

Figure 2 shows the schematic drawing to give a guide on how gas is supplied through the block valve to the burners. When a turbine start up is initiated at the control room, the block diagram sequences apply to the supply of gas to the turbine burners. Figure 3 shows the block diagram of a gas turbine power plant as obtained from Sarkar et. al (2012).

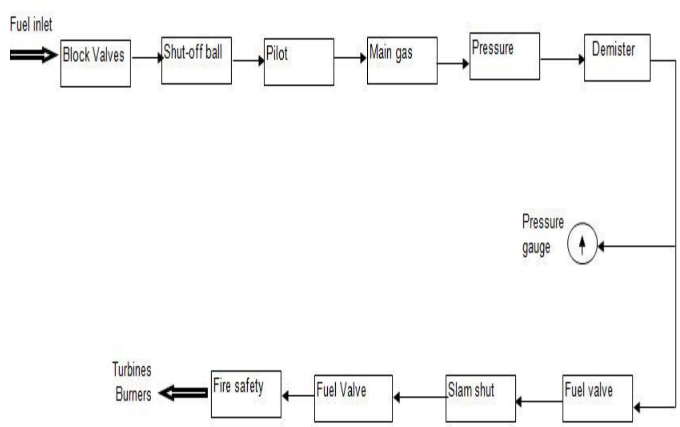

Figure 2: Gas supply Schematic from Plant Gas Skid to Turbine Burner

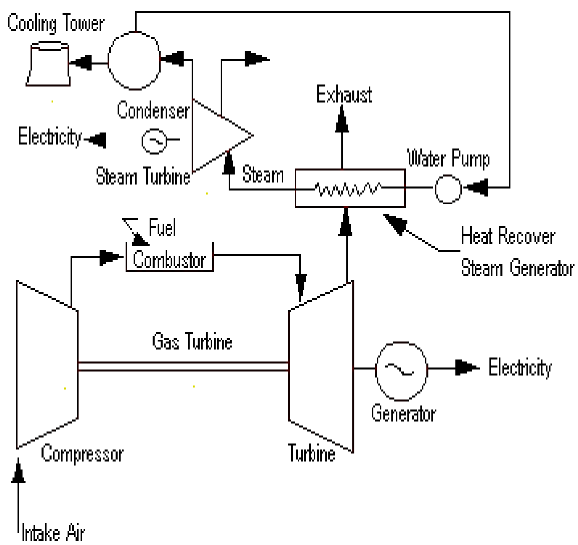

Figure 3: Block diagram of a Gas Turbine Power Plant

According to the Raja et. al. (2006), the thermal efficiency of an open cycle gas power plant is defined as he ratio of the work done by the plant to the heat supplied. Which is mostly between 25% to 35% depending on the environmental factors the plant is being operated in. For open cycle gas turbine 75% of the heat energy is usually lost through the exhaust to the atmosphere (Rahman and Ibrahim, 2011), hence the low efficiency of an open cycle power plant compared to the combined cycle gas power plant which employs the use of waste heat recovery system in recovering waste heat and using it to run another smaller plant. While the overall efficiency of the plant is defined as the ratio of heat equivalent of the electrical output to the heat of combustion of the gas fuel used. Usually the overall efficiency of a gas turbine in open cycle applications is between (32% to 35%) at base load in new and clean conditions and at rated ambient pressure temperature and ambient humidity. Reliability is the probability that a device or system will operate for a given period of time without failure, and under given operating conditions Reliability of a system is the characteristic of a system that it will perform its required function under stated conditions for a specified period of time.

2. Materials and Methods

Data were obtained from Edgeba power station's logbook. These are inventory records of monthly energy generation between 2002 and 2012 and operational statistics showing the period when each of the plant units was first commissioned, period of major outage and the time of maintenance. In processing the data, thermal efficiency, overall efficiency and reliability were obtained. Information on Fuel Gas Consumed (MMSCF) and Gross Energy Generated (MWH) were used in the analysis. The equations 1 to 9 were used to evaluate the efficiency and the reliability.

$$Overall\ Efficiency\ (\eta_o) = \frac{heat\ equivalent\ of\ electrical\ output}{input\ energy\ from\ fuel\ combustion} \times 100\% \qquad (1)$$

$$\eta_0 = \frac{[energy\ generated\ (MWH) \times 1000 \times 3600]KJ}{\left[\left(\frac{gas\ consumed\ (MMSCF) \times 10^6}{35.3147}\right) m^3 \times net\ CV\ \left(\frac{KJ}{m^3}\right)\right] KJ} \times 100\% \qquad (2)$$

Where:

$$Volume\ (m^3) = \frac{volume\ (SCF)}{35.3147} \quad (3)$$

SCF is Standard Cubic Feet
Net CV is Net Calorific Value of the gas (usually between 34000-36000 KJ/m^3 as supplied by National Gas Company. NGC)

Also,

$$Thermal\ Efficiency\ (\eta_t) = \frac{heat\ equivalent\ of\ mechanical\ energy}{input\ energy\ from\ fuel\ combustion} \times 100\% \quad (4)$$

$$\eta_t = \frac{Overall\ efficiency}{electrical\ (generator) efficiency} \times 100\% \quad (5)$$

$$\eta_t = \frac{\eta_o}{0.90} \quad (6)$$

Where electrical/ generator efficiency is constant at 90%

And

$$Reliability\ (R) = \frac{expected\ running\ hours - downtime}{expected\ running\ hours} \times 100\% \quad (7)$$

$$R = \frac{actual\ running\ hours}{expected\ running\ hours} \times 100\% \quad (8)$$

$$R = \frac{(N \times T) - (n \times t)}{(N \times T) - Planned\ Outage} \quad (9)$$

Where:

(N×T) is the expected total running hours = 24hrs×3659(days) ×4(units) = 35040 hrs

(n×t) is the summation of all the unplanned outages for the four units in a year

Planned outage = standby time + maintenance period.

3. Results and Discussion

3.1 Efficiency

The efficiencies (thermal and overall) of the central power plant evaluated from plant data with equation (2) and (6), are presented in Table 1 and Figure 4.It is obvious that for the years under review the overall efficiency of the plant varies between 3.5 to 23.5% (with minimum in 2008 and maximum in 2009), with an average of 16.04% while the thermal efficiency hovers between 3.4 – 23.45% (with minimum in 2008 and maximum in 2011) with an average of 15.79%.

Table 1: Central Power Plant Energy and Efficiency Profile

YEAR	ENERGY GENERATED (MWH)	FUEL GAS CONSUMED (MMSCF)	NET CALORIFIC VALUE (KJ/m3)	OVERALL EFFICIENCY (%)	THERMAL EFFICIENCY (%)
2002	16,845.52	499.321	34500	12.50	13.90
2003	21.004.62	509.362	34500	15.20	16.90
2004	17,088.30	513.434	34500	12.60	14.00
2005	31,212.80	683.134	34500	16.80	18.60
2006	30,701.90	679.982	34500	16.60	18.40

2007	12,130.34	512.127	34500	8.69	15.90
2008	2,928.03	411.521	34500	3.40	3.70
2009	26,940.44	429.736	34500	23.10	25.60
2010	28,123.40	491.287	34500	21.10	23.40
2011	27.127.21	428.003	34500	23.50	26.10
2012	22,519.78	411.82	34500	20.20	22.45
AVERAGE				15.79	17.52

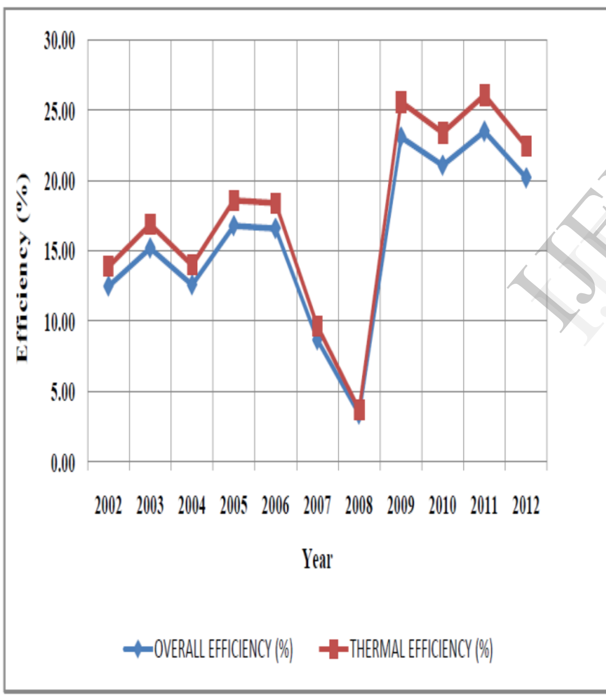

Figure 4: Variation of Thermal and Overall Efficiency with Year

For the period under review, as shown in Table 1 and Fig 4, efficiency averaged 14.4% from 2002 to 2004, and lightly went up to an average of 16.7% in 2005 and 2006. The year 2007 saw a decline of efficiency to 8.69% that lead to an even more shaper decline in 2008 with an efficiency of 3.4%. Efficiency picked up again from 2009 to 2011 with an average of 22.5%. Presently as at the end of the third (3rd) quarter in 2012 the Central Power Plant has maintained an efficiency of 20.20%. Low efficiency is mostly characterized by the periods of unplanned outages as efficiency is dependent on total power output. In 2002 unit 2 was down on faulty gas generator while unit 1 was undergoing pre commissioning checks, leaving only unit 3 and 4 running on 1.4MW maximum load. In 2004 unit 1 went on unplanned outage due to fire outbreak in the combustion chamber. In 2007 only unit 4 was available for running on 1.5MW maximum load. As at 2008 unit 2 and 3were being overhauled while unit 1 was out of service leaving only unit 4 running, this explains the steep fall of efficiency between 2006 and 2008. The year 2009 saw a rise to highest Efficiency as unit 2 and 3 were back on line having undergone overhauling. 2010 saw a slight drop in efficiency due to unit 4 being down on faulty alternator bearings. Repair and overhaul of unit 1 commenced in October 2010 and completed in December 2011 also unit 4 was back on in 2011, hence the rise of efficiency to 23.5% in 2011 and 20.22% presently as at the end of the 3rd quarter in 2012.(CPP, daily and monthly report 2002- 2012).

According to *ISO 3977-2-1997* (Gas Turbine Procurement, Conditions and Ratings, 1997), the efficiency of an open cycle gas turbine power plant rated *12.532 MW* for a unit operated in ISO conditions of *80.6℉(27℃)* ambient temperature, topography at *sea level 75%* relative humidity excluding inlet and exhaust losses is *28.8%*. This ISO conditions only slightly vary with the environmental and operating conditions at Central Power Plant, Edgeba hence its being adopted as a standard for efficiency in this paper. The short fall from this efficiency level especially between 2002 to 2008, is attributed to aged equipment, lack of maintenance and inadequate skilled man power. These are some of the problems hindering desired output (efficiency), from the plant.

3.2 Reliability

Equation (8) was used to generate reliability for the period under consideration and the results are presented in Table 2 and Figure 5. The plant had an average of 39.75% with the lowest reliability of 8.36% in 2008 and a maximum of 49.49% in 2005 as against a target of 60 – 80% set by the management of the plant. (CPP Annual Report, 2002 – 2012).

Table 2: Reliability Profile of CPP, Edgeba

YEAR	ACTUAL RUNNING HOURS (H)	EXPECTED RUNNING HOURS (H)	RELIABILITY (%)
2002	11,230.40	35,040	32.73
2003	11,336.60	35,040	32.35
2004	11,372.54	35,040	32.35
2005	17,340.00	35,040	49.49
2006	16,706.26	35,040	47.67
2007	10,108.33	35,040	28.84
2008	2,928.99	35,040	8.36
2009	14,966.67	35,040	42.71
2010	15,623.89	35,040	44.59
2011	15,670.38	35,040	44.73
2012	15,610.13	34,950	44.79
AVERAGE	12,708.56	35,038	39.79

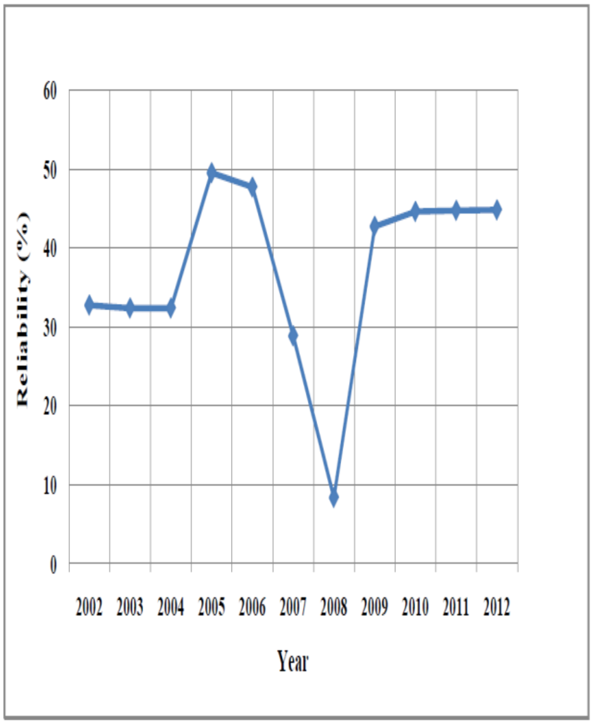

Figure 5: Variation of Reliability with Year

Reliability is a function of running time, hence the higher the number of unplanned outages the lower the reliability of the plant. The Central Power Plant (CPP) from designed usually run three (3) units and keep one (1) on standby, so to effectively determine the reliability of the plant table 3 illustrates the hours spent on Planned outages, Unplanned outages and the stand by the Plant experienced within the year under review and Figure 6 shows the variation of the Station Outage and Standby time with Year.

Table 3: Standby Outage/ Standby Log

	HOURS OF OUTAGES/STANDBY				PLANNED OUTAGES/STANDBY		
YEAR	HOURS OF PLANNED OUTAGE (H)	HOURS OF UNPLANNED OUTAGES (H)	HOURS ON STANDBY (H)	TOTAL HOURS (H)	PLANNED OUTAGE (%)	UNPLANNED OUTAGE (%)	STANDBY (H)
2002	8760	8760	10	35040	25.00	25	0
2003	200	8760	38	35040	1.00	25	0
2004	8760	8760	100	35040	25.00	25	0.3
2005	9585	8760	17	35040	27.40	25	0
2006	632	10491	725	35040	2.00	30	8.28
2007	8	26280	4	35040	0.00	75	0
2008	17520	8760	10	3504	50.00	25	0

				0			
2009	8760	8760	10	35040	25.00	25	0
2010	4	8760	7	35040	0.00	25	0
2011	8760	24	8745	35040	25.00	0	24.90
2012	612	300	6128	26208	33.40	1.1	23

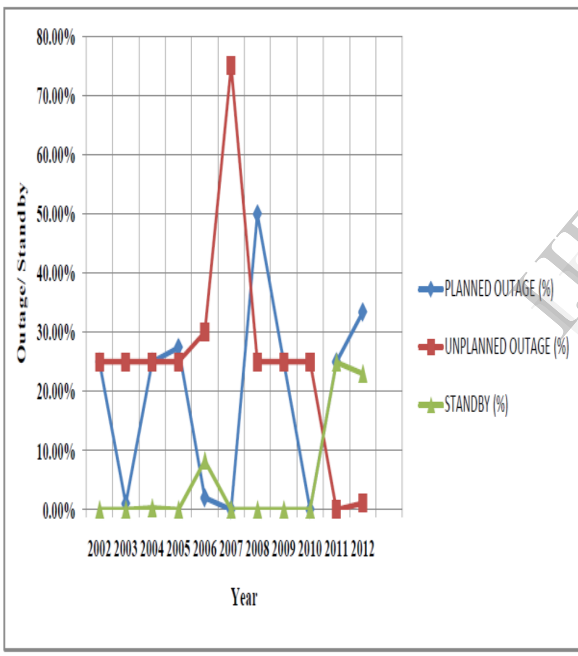

Figure 6: Variation of Station Outage and Standby Time with Year

As shown in table 3 and Figure 6, no unit was really on standby until in 2011 and 2012 and this was due to the high level of unplanned outages that occurred within 2002 and 2008), unplanned outages become prevalent due to the ageing of plant equipment as the plant is a 31 year old plant and also due to instability of load connected to the busbar. By design, Ruston TB 5000 Model gas turbine, which is being used in the Plant, is meant to undergo thorough maintenance after every 8000 hours of running and overhauled after 30000 hours according Ruston TB 5000 operation manual,(1981). Unit one (1) was overhauled in 2011 after being down from 2004 to 2010, while units two (2) and three (3) where last overhauled in 2008. Unit four (4) was down on faulty gas generator in 2003 and was fixed and overhauled in 2003 and has since been running and maintenance carried out periodically as at when due. Presently all units are functional and running with unit four (4) being kept on standby. With unit one (1) being overhauled recently the Plant reliability index has improved from 8.36% in 2008 to 44.73% in 2011 and already 44.8% in 2012.

4. Conclusion

Performance analysis of the Central Power Plant (CPP), Edgeba has been carried out with specific emphasis on the three key performance indicators: overall Efficiency, Thermal Efficiency and Reliability. For the twelve years under review (2002-2012), the study revealed that the average overall efficiency was 15.79% (3.4% minimum in 2008 and 23.5% maximum in 2011) as against ISO 3977-2-1997 (Gas Turbine Procurement, Conditions and Ratings, 1997) ratings of 28.8%, while the thermal efficiency had an average of 17.52% (8.36% minimum in 2008 and 26.1 maximum in 20011). The average reliability of the plant was 39.76% (8.36% minimum in 2008 and 49.49% maximum in 2005) as against stations target of 60-80%.

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