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Performance Analysis of Thermal Power Station: Case Study of Egbin Power Station, Nigeria

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Abstract

The performance analysis of Egbin Power Plant in terms of efficiency and reliability is herein presented. The Station consists of six units of steam turbines with a total installed capacity of 1320MW and commissioned between May 1985 and November 1987. In this paper, field data were collected from the Station records of operation and maintenance for a period under review of 2000 to 2010. This reveals that the average overall efficiency of the plant, for the review period, was 34.67% as against standards of 40-45% while the average reliability was 80.92% as against best practices of 98-100%. The shortfall in performance levels of the plant is attributable to low plant availability due to frequent breakdowns/failures, overdue overhauling of some units, obsolete technology, instability of the national grid system, aging plant equipment and disruption in gas supply among others. Measures to improve the performance indices (efficiency and reliability) of the plant were suggested

Keywords: Egbin power plant, performance analysis, efficiency, reliability.

Introduction

In the Nigerian scenario, energy demand has not been addressed with the requisite planning that would guarantee concurrent capacity growth. Indeed, there has been a long persisting shortfall especially in electric energy output as compared with the demand in the economy [1]. Electricity generation in Nigeria involves two major methods namely, thermal and hydro. These two are meant to complement each other in terms of their circumstantial difficulties. The hydro power station being cheaper to run is expected to be optimized during favourable seasons, while the thermal, at other seasons come into full blast as the water in the dams go down in hydro power stations.

The performance analysis of a thermal plant is geared basically towards the determination of the energy efficiency of the plant. A plant's energy efficiency has definite economic significance since the heat input at high temperature represents the energy that must be purchased (oil, natural gas, etc) and the net energy output represents the returns for the purchase [2]. Since energy plays a vital role in a country's economic development and it is expected to be more significant in the coming years due to increasing demand, consequently, energy conservation and efficient use of energy becomes a major supply option [3]. This paper therefore evaluate the efficiency and reliability of Egbin Power Plant (the power generation stronghold in Nigeria), over a period of eleven years (2000 to 2010) and make recommendations on how to improve its performance.

Egbin Thermal Plant

Egbin thermal plant is located at the suburb of Lagos State, Ijede area of Ikorodu. The plant was commissioned in 1985 and consists of 6 units of 220 (6X220) MW (Reheat – Regenerative). They are dual fired (gas and heavy oil) system with modern control equipment, single reheat; six stages regenerative feed heating. The plant was constructed under joint Japanese/ French financing on a turnkey contract basis and most of the equipment were Japanese supplied. The overall cost of the plant was US $ 1 billion with an expected life of 25 years. The estimate was based on the fact that the plant should run mainly on natural gas which does not give the serious boiler slag and ash problem characteristic of coal fuel [4]. Natural gas is supplied to the plant directly from the Nigerian Gas Company (NGC). Lagos operations department is the annexed to Egbin gas station of the thermal plant. Since Egbin thermal plant is located on the shores of the lagoon cooling water for the plant's condensers is pumped from the lagoon into the water treatment plant en route to the condensers.

Major Plant Components

The Boiler, Turbine and Generator (collectively known as the B-T-G system) are the most crucial equipment required for the generation of electricity in steam power plants. All other equipments in the station are termed auxiliaries and are needed for the smooth running of the boiler, turbine and generator of the units in the station. According to Egbin Design Manuals [5], the functions and operating conditions of these plant components are x-rayed as follow:

Boiler: The Boiler is designed to produce flow of main steam at temperature of 541^0C and pressure of 12,500kPa and also to reheat steam from the turbine high pressure stages, from the combustion of heavy fuel oil or natural gas.

Turbine: The Turbine is the impulse type, tandem-compound, double flow reheat, condensing tube, with maximum continuous rating of 220MW, speed 3000rpm, initial steam pressure 12.5MPa, initial steam temperature 538^oC, exhaust steam pressure

8.5kPa, twenty-four (24) stages (eight (8) high, six (6) intermediate and 10 (5*2) low pressure stages) and with three (3) low pressure heaters, two (2) high pressure heaters and one (1) de-aerator, which receives dry steam from the boiler and rotates a shaft coupled to the rotor of the generator to generate power.

Generator: The Generator is the radiant type, 3-phase, 2-pole, hydrogen-cooled, with output voltage of 16kV, power of 245.8MVA (221.22MW), speed 3000rpm, 0.9 power factor, exciting voltage of 440V, 50Hz frequency, armature current of 8870A and field current of 2781A, ambient temperature of 45^{o}C, armature temperature rise of 55^{o}C, field temperature rise of 65^{o}C, and with natural circulation with single reheat and duct firing.

Performance of Steam Power Plants

According to [6], the choice of a steam turbine power plant depends on its performance, which depends on five factors:

- Capacity of plant
- Plant's load factor and capacity factor
- Thermal (and overall) efficiency
- Reliability
- Availability of water for condensate.

Efficiency

The thermal efficiency of steam power plants, defined as the ratio of heat equivalent of mechanical energy transmitted to the turbine shaft is quite low (about 30%). The thermal efficiency of a power plant depends on three (3) factors which include, the pressure of steam entering turbine, the temperature of steam entering turbine and the pressure in the condenser. It increases by increasing the temperature and pressure of the steam entering the turbine, decreasing the pressure in the condenser, re-heating steam between turbine stages and by bleeding steam along the heating lines [7]. In order to increase the efficiency of steam power plants, heat/loss saving devices such as reheaters, superheaters, economizers, preheaters among others are incorporated in the design.

Thermal Efficiency ($\boldsymbol{\eta_t}$)

$$\eta_t = \frac{heat\ equivalent\ of\ mechanical\ energy}{input\ energy\ from\ fuel\ combustion} \times 100\% \tag{1}$$

$$\eta_t = \frac{overall\ efficiency}{electrical\ (generator) efficiency} \times 100\% \tag{2}$$

$$\eta_t = \frac{\eta_o}{0.98} \tag{3}$$

Overall efficiency of the plant, defined as the ratio of heat equivalent of electrical output to the heat of combustion is about 29%. In case of most modern super-critical-pressure steam plants employing many heat saving devices, the plant overall efficiency may reach the value of 50% (i.e. with a supercritical temperature of about 600^{o}C, overall efficiency could be just over 40% while with ultra supercritical temperature of around 700^{o}C, efficiency may be improved to around 50%) [7]. The overall efficiency of steam power station is low mainly due a large amount of heat (over 50%) that lost in condensers and secondly heat that wasted in other parts of the plant (boiler, alternator etc). The heat loss in the condenser is unavoidable since heat energy cannot be converted into mechanical energy without temperature difference. The greater the temperature difference, the greater is the heat energy converted into mechanical energy. This necessitates keeping the temperature of the condenser to a minimum value. But the greater the temperature difference, the greater the amount of heat lost. This explains the low efficiency of steam plants.

Overall Efficiency (η_o)

$$\eta_o = \frac{heat\ equivalent\ of\ electrical\ output}{input\ energy\ from\ fuel\ combustion} \times 100 \quad (4)$$

$$\eta_o = \frac{[energy\ generated\ (MWH) \times 1000 \times 3600]kJ}{\left[\left(\frac{gas\ consumed\ (MMSCF) \times 10^6}{35.3147}\right)m^3\ \times net\ CV\ (kJ/m^3)\right]kJ} \times 100\ \% \quad (5)$$

Where

Volume (m^3) = Volume (SCF) / 35.3147

SCF is Standard Cubic Feet

Net CV is Net Calorific Value of the Gas (Usually between 34000 – 36000 kJ/m^3 as supplied by NGC)

Reliability

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 the system that it will perform its required function under stated conditions for a specified period of time. The concept of reliability is associated, in qualitative terms, with good design, endurance, consistent quality, maintainability and dependability. With adequate maintenance, the reliability of a power plant may approach 1 (that is, 100%).

$$R = \frac{expected\ running\ hours - downtime}{expected\ running\ hours} \times 100\% \quad (6)$$

$$R = \frac{(N \times T) - (n \times t)}{(N \times T)} \times 100\% \quad (7)$$

Methodology

The data used for this work were collected from Egbin thermal station, Lagos.

Materials Used

Performance analysis was carried on the plant as a whole. Empirical data were obtained from plant records from 2000 to 2010 prepared by the Efficiency department and the Performance management department of the plant. Information on the following was used in the analysis.

- Gross energy generated (MWH)
- Energy used in the plant (MWH)
- Energy sent out (MWH)
- Fuel gas consumed (MMSCF)
- Running Hours
- Faults records

Assumptions

- Plant ran only on natural gas throughout the period under review
- Generator efficiency is constant at 98%

Constraints and Limiting Factors

- Irregularities in figures for some data obtained from the plant.
- Constant fluctuation and irregularity of plant loading due to constant fluctuations in the transmission efficiency of the national grid as controlled by the National Control Centre (NCC), Oshogbo.
- Unavailability of some records for some of the period under review (2000 - 2004) as the Performance Management Department of the Plant was only set up in 2005.
- Breakdown of equipment, as some of the units were out of service during the period under review.

Results and Discussion

The efficiencies (thermal and overall) of Egbin Power Plant, evaluated from plant data with equations (2) and (5), are presented in Table 4.1 and Fig. 4.1. From these, it is obvious that for the years under review, the overall efficiency of the plant vary between 30.30 – 36.60% (with minimum in 2009 and maximum in 2007) while the thermal efficiency hover between 30.92 – 37.35% (with minimum in 2009 and maximum in 2007).

Table 4.1: Summary of Egbin Power Plant Energy and Efficiency Profile.

Year	Energy Generated (MWH)	Fuel Gas Consumed (MMSCF)	Net Calorific Value (kJ/m^3)	Overall Efficiency (%)	Thermal Efficiency (%)
2000	5,603,227.76	57,262.511884	34,508.07	36.05	36.79
2001	6,941,104.98	76,341.971380	34,795.54	33.22	33.90
2002	6,876,965.25	67,448.384790	35,827.35	36.18	36.92
2003	6,810,113.71	72,639.578640	34,871.21	34.18	34.88
2004	7,962,664.29	80,455.037360	34,748.39	36.21	36.95
2005	8,592,097.13	81,929.037220	36,820.60	36.21	36.95
2006	5,004,369.08	50,523.236670	34,989.23	35.99	36.72
2007	3,636,676.32	35,601.394820	35,482.53	36.60	37.35
2008	4,386,854.92	47,874.795900	34,836.79	33.44	34.12
2009	3,383,990.30	35,794.627360	39,666.75	30.30	30.92
2010	5,385,475.96	58,878.258820	35,195.50	33.04	33.71

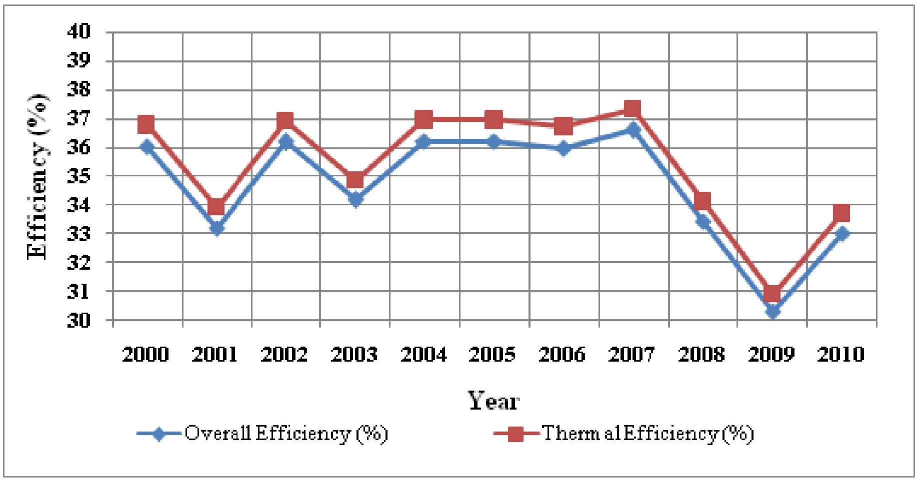

Figure 4.1: Variation of Thermal and Overall Efficiencies with Year.

For the period under review, as show in Table 4.1 and Fig. 4.1, efficiency averages around 37% except in 2001 when it was 33.22%; in 2003 when it was 34.18%; in 2008 when it was 33.44%; lowest in 2009 when it was 30.30% and in 2010 when the efficiency went up to 33.04%.

Majorly, low efficiency is characteristic of periods of forced outages as efficiency is dependent on total power output. In 2001, units 4 and 6 were out of service; in 2006, unit 6 went on forced outage due to exploded boiler furnace; in 2009, unit 1 went on forced outage due to fire incident on the turbine rotor. As at 2009, only four units were available. Units 2, 3 and 5 were available for maximum load of 220MW while unit 4 was limited to maximum load of 200MW due to heater problem. This explains the steep fall of efficiency between 2007 and 2009. With the repair of unit 1 in 2010, efficiency went up to 33.04% as five (5) units were available to maximum load of 1080MW (Egbin Annual Reports, 2000-2011). Another reason advanced for low efficiency is the restriction in gas supply. This is because the low generation experienced between 2006 and 2009, with little improvement in 2008, is as a result of restriction in gas supply. Gas supply is limiting generation output of the station and AES (an independent power plant) at the moment at 700MW while available capacity with AES stands at 1300MW (The Nation, 2009).

Moreover, what also contributes to low efficiency is low reliability of plant caused by frequent breakdown or failure of units. For the period under review, as evaluated with equation (7), the plant had the lowest reliability of 69.47% in 2007 and the maximum of 89.38% in 2010 as against the target of 100% as set by the management of the plant (Egbin Annual Reports, 2000-2010). Table 4.2 and Fig. 4.2 paint the picture clearly.

Table 4.2: Reliability Profile of Egbin Power Plant.

Year	Expected Running Time (Hours)	Downtime (Hours)	Reliability (%)
2005	52560	11258.35	78.58
2006	52560	8451.65	83.92
2007	52560	16046.57	69.47
2008	52560	10653.91	79.73
2009	52560	8183.59	84.43
2010	52560	5581.87	89.38

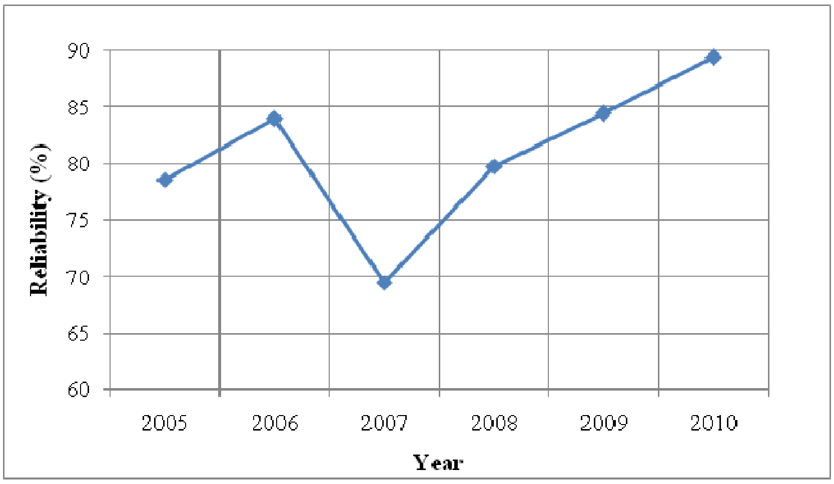

Figure 4.2: Variation of reliability with year.

Forced outages are as a result of the various faults at the station. These have effects on the efficiency and reliability of the plant and can be classified as: plant faults, gas supply faults, operational faults and system faults. Analysis of these faults, for the years under review, is presented in Table 4.3 and Fig. 4.3.

Table 4.3: Station Faults log.

Year	Number of Failures					Percentage of Failures			
	System Fault	Plant Fault	Gas Fault	Operational Fault	Total	System Fault (%)	Plant Fault (%)	Gas Fault (%)	Operational Fault (%)
2000	52	32	10	5	99	52.53	32.32	10.10	5.05
2001	45	30	8	10	93	48.39	32.26	8.60	10.75
2002	78	33	15	4	130	60.00	25.38	11.54	3.08
2003	125	77	11	6	219	57.08	35.16	5.02	2.74
2004	88	62	16	5	171	51.46	36.26	9.36	2.92
2005	116	75	18	4	213	54.46	35.21	8.45	1.88
2006	95	55	13	1	164	57.93	33.54	7.93	0.61
2007	89	36	29	4	158	56.33	22.78	18.35	2.53
2008	95	38	20	0	153	62.09	24.84	13.07	0.00
2009	91	43	21	1	156	58.33	27.56	13.46	0.64
2010	134	54	6	2	196	68.37	27.55	3.06	1.02

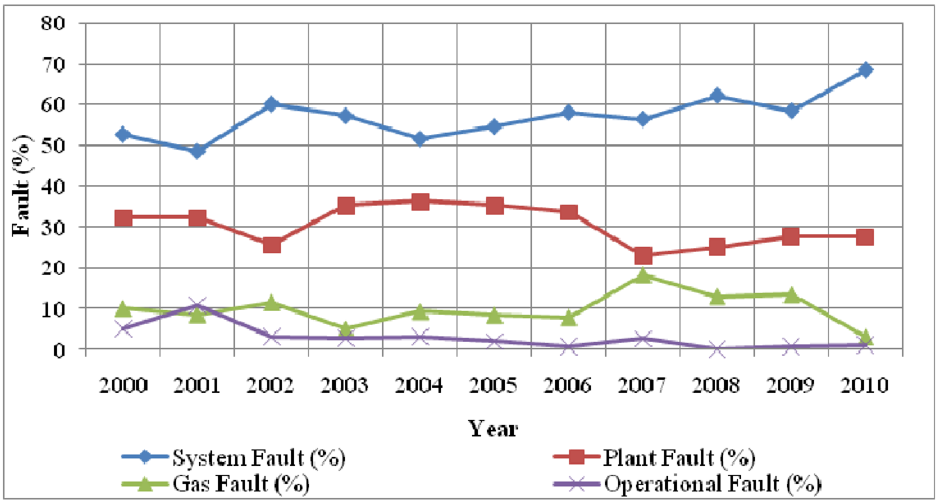

Figure 4.3: Variation of Station faults with year.

The high incidence of faults or failures in the station is an indication of low plant reliability index, frequent unit trips during operation leading to grid system instability, reduction in available plant capacity over time and poor efficiency.

Conclusion

Performance analysis of Egbin Thermal Plant has been carried out with specific emphasis on the Efficiency and Reliability of the plant. For the eleven (11) years under review (2000-2010), the study revealed that the average overall efficiency was 34.67% (30.30% minimum; 36.60 maximum) as against expected values of 40-45%. The average reliability of the plant, for the period under review, was 80.92% (69.47 minimum; 79.73 maximum) as against best practices/target of 98-100%. A number of reasons were adduced to be responsible for this shortfall in performance. These include: low plant availability due to breakdowns/failures, overdue overhaul of units, obsolete technology, instability of the national grid system, aging plant components, disruption in gas supply among others. Measures to improve the performance indices (efficiency and reliability) of the plant have been suggested and this include: overhaul maintenance of due plant equipment/units, training and re-training of operation and maintenance (O&M) personnel, upgrading obsolete technology, ensuring security of gas supply and rehabilitation of failed equipment.

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