# Performance Evaluation of Olorunsogo Gas-Fired Power Plant Phase I

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.*

*Original Research Article*

## ABSTRACT

**Aim:** The aim of this research is to evaluate the performance of the Olorunsogo gas-fired power plant phase 1, examines the reason(s) for not operating at full capacity, and proffers possible solution(s).
**Study of the Design:** The power plant comprises of eight (8) numbers of 42MW unit gas turbine capable of evacuating 277MW.
**Methodology:** To obtain electrical parameters from the gas turbine, a mathematical model for pressure using a simple open-cycle gas turbine was developed. The pressure was further converted to energy using principles of kinetic theory of gases. Hence, the efficiency and other performance indicators were calculated.
**Results:** The study revealed an average operating capacity of 31.28MW. The average efficiency of the power plant in the period under review was 50.88%, as compared to the international standard practice of 65% and above. The average load factor and capacity factor was 11.25% and 11.54% respectively as compared to international standard practice of 50-80%, while the average reliability was 55.79%, as compared to international standard practice of 95%.

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**Conclusion:** The study further reveals that wastage of gas, downtime, and inadequate gas supply are the major factors against the full capacity operation of the power plant. The proffered possible solutions articulated in this study if implemented, will optimize the power plant's full-capacity operation.

*Keywords: Performance evaluation; efficiency; gas plant; reliability; installed capacity.*

# 1. INTRODUCTION

The erratic power supply in Nigeria is no longer a story and is generally believed to be the bane of economic and industrial development in Nigeria [1]. In Nigeria, irregular power, or simply "a power outage", has reached a very high level of embarrassment. There are various regions in a country where a power outage should never occur, however, power outages lasting several days are typical in Nigeria and can occur everywhere. In 2009, the presidential palace was not spared of this power outage [2]. Nigeria is not an exception to this trend rotating around the world as electricity is the most used and desired energy source because it is a vital driver for economic development and helps raise the standard of living for humans generally [3].

Gas power generating station accounts for twenty-three power stations out of the thirty power stations generated for the national grid in Nigeria, which account for 65% of the total power generated in Nigeria. Nigeria has been incredibly fortunate to have natural resources (gas) but has not utilized these resources for its energy supply [4]. Gas turbines nowadays are essential components of combined power plants, Gas turbine process, and exhaust gas parameters play a major role in both the operation of the combined power plant's steam component and all of its constituents [5]. With Twenty (23) gas-fired plants out of thirty generation stations in Nigeria, only 25% of the electricity generated is delivered to the end user [6]. This simply indicates that the Olorunsogo gas-fired plant phase 1 is not operating at full capacity including other gas-fired plant in Nigeria. Therefore, the need to evaluate the Olorunsogo gas-fired plant phase 1 has become very urgent and imperative, to ascertain the reason(s) for non-full capacity functionality.

This paper focuses on evaluating the performance of Olorunsogo gas-fired power plant phase 1 from 2015 to 2021, know why the power plants is not functioning at full capacity, and proffer possible solution(s) to the discovered problem(s).

# 2. LITERATURE REVIEW

The Olorunsogo gas-fired power plant is located within longitude $3^0 15' 0''$ E to $3^0 20' 0''$ E and latitude $6^0 50' 0''$ N to $6^0 55' 0''$ N and is 17km from Papalanto in Owode Local Government Area of Ogun State. The plant was required in boosting the stability of the electric power generation in the country within the shortest possible time. The construction works of Olorunsogo gas-fired power plant phase 1 commenced on 28th November 2005, and was completed in April 2007 with a capacity of 277MW, comprising of eight (8) numbers GT (gas turbine) unit of 42MW. The Olorunsogo gas power plant phase 1 project was built by the NIPP (as a joint investment of the three tiers of governments of Nigeria).

Okoye et al. [7] presented a study and performance assessment of the Olorunsogo gas-fired power plant phase 1 which shows that the power generated in 2016 was far below what was generated in 2013. This suggests that rather than helping Nigeria's energy situation, the gas power plant made things worse, as the original intention of the establishment of the gas power plant.

Joel and Taiwo [8] show that Nigeria's electrical industry is largely natural gas-based thermal power plants, and fossil fuel (gas) consists of 65% of the grid-connected power plants. The research shows that the average operational capacity of the Olorunsogo gas power plant is low. The basic motive of their study was a systematic investigation of the relationship between energy generation and real aggregate output in Nigeria, based on annual data between 1980 and 2017. The reason why the operating capacity of the power plant is low was not mentioned or discussed in the research.

Bori et al. [9] look at the techno-economic approach to readily assess the profitability or otherwise of combined cycle power plants (CCPPs) for increased electricity production in Nigeria. The research also proposes upgrading existing gas-fired power plants in the Nigeria into

combined cycle power plants for improved electricity supply. He concluded that though Nigeria is blessed with sufficient natural energy resources, the nation has not fully utilized its natural energy resources for electricity generation to meet the demand of the nation. Modern ways of electricity generation should be implored which are more efficient, reduced installation cost and less fuel consumption.

Udeh and Udeh [10] look at the performance of thermal power plants fired by natural gas. The research pointed out that the open gas turbine power plant comprises three major components: the compressor, combustion chamber, and turbine. The first law of thermodynamics model was used in their research for predicting the thermodynamic performance of the thermal power plant. The result shows that gas turbine performance is impacted by component performance and turbine operating conditions, and the plant's efficiency, power production, precise fuel usage, and work ratio can all be used to evaluate its performance. Moreover, the investigation of their research did not provide the reason(s) why individual gas-fired power plant was not working to its full potentials.

These studies reveal that gas-fired power plant in Nigeria requires urgent attention, to know the reason(s) of their non-full capacity functionality and proffer possible solution(s).

## 3. METHODOLOGY

The power plant comprises of eight (8) numbers of 42MW unit gas turbine, capable of evacuating 277MW. The primary data collection method was implored in this research due to its uniqueness to research works. Data such as installed capacity, power generated in MWh, power exported in MWh, running time in hours and gas consumed in standard cubic feet (SCF) were collected directly performance management department of the gas power station. The collated empirical data prepared by the performance management department of the gas power station spans from 2015 to 2021.

The main data obtained from the Olorunsogo power plant phase 1 were all electrical parameters, while the parameters associated with gas turbines are pressure, volume, and temperature. Therefore, to obtain electrical parameters from the gas turbine, a mathematical model for pressure using a simple open-cycle gas turbine was developed. The pressure is further converted to energy using the

fundamental principle of the kinetic theory of gases.

Four processes take place in the Brayton cycle in a gas turbine.

(i) Process 1-2: Reversible isentropic compression
(ii) Process 2-3: Constant pressure heat addition.
(iii) Process 3-4: Reversible isentropic expansion
(iv) Process 4-1: Constant heat rejection.

$1 - 2 - 3 - 4$ ………………..... Ideal cycle
$1 - 2s - 3 - 4s$ ………….……Actual cycle

### 3.1 Ideal Cycle of The Turbine

The efficiency of the gas turbine is given as;

$$\text{Efficiency} = \text{Efficiency} \quad \eta = \frac{WD}{Q_A} \qquad (1)$$

Where,

WD is work done
$Q_A$ is heat supply or added

$$\text{Work done WD} = Q_A - Q_R \qquad (2)$$

Where,

$Q_A$ is heat added at constant pressure.
$Q_R$ is heat rejected at constant pressure.

Addition of heat at constant pressure ensures that the combustion process is efficient and complete, as it allows for a more controlled and stable reaction between the fuel and air. While rejection of heat at constant pressure ensures that the working fluid remains in a stable state throughout the cycle.

Therefore, heat added at constant pressure is given as;

$$Q_A = mCp(T_3 - T_2) \qquad (3)$$

$= Cp(T_3 - T_2)$ kJ/kg, Cp is the specific heat at constant pressure.

Similarly, Heat rejected at constant pressure is given as;

$$Q_R = mCp(T_4 - T_1) \qquad (4)$$

$= Cp(T_4 - T_1)$ kJ/kg

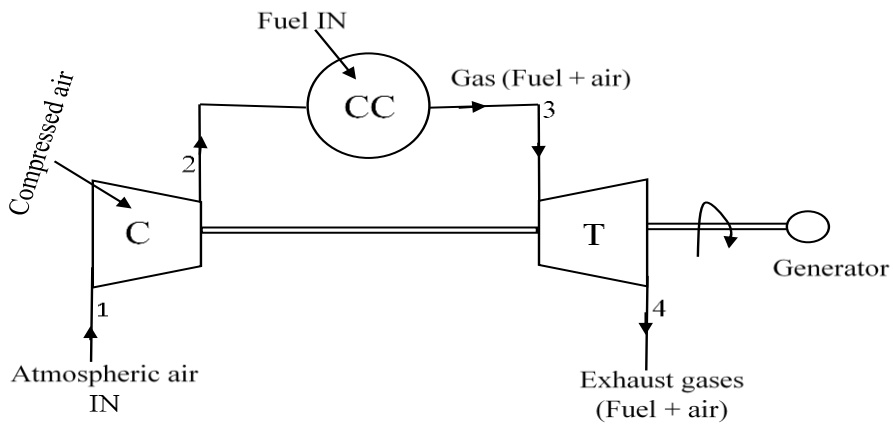Substitute equations (3) and (4) in equation (2)

**Fig. 1.  A schematic diagram for a simple open-cycle gas turbine**
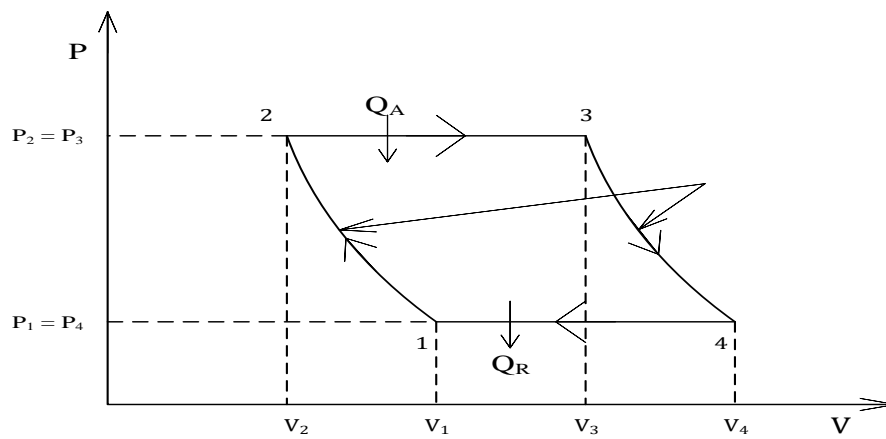*C is compressor; CC is the combustion chamber; T is turbine*
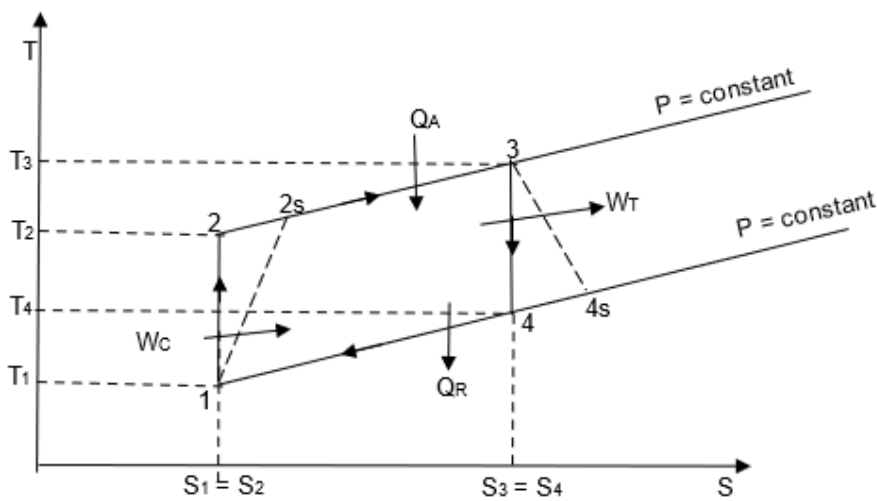


**Fig. 2. Pressure-volume (P-V) graph**



**Fig. 3. Temperature-Isentropic (T-S) graph**

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Therefore,

$$WD = C_p(T_3 - T_2) - C_p(T_4 - T_1) \text{ kJ/kg} \qquad (5)$$

Substitute for WD in equation (v) and $Q_A$ in equation (iii) into equation (i)

$$\therefore \text{ Efficiency } \eta = \frac{C_p(T_3 - T_2) - C_p(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$= \frac{C_p(T_3 - T_2)}{C_p(T_3 - T_2)} - \frac{C_p(T_4 - T_1)}{C_p(T_3 - T_2)}$$

$$= 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)} \qquad (6)$$

For processes 1 to 2; reversible isentropic compression process and using the PVT (pressure, volume, temperature) relationship,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} \qquad (7)$$

$$= (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\therefore T_2 = T_1(r_p)^{\frac{\gamma-1}{\gamma}} \qquad (8)$$

Where,

$\gamma$ is the specific heat ratio ($\frac{C_p}{C_v}$)
$C_p$ is the specific heat at constant pressure
$C_v$ is the specific heat at a constant volume

For processes 3 to 4, the reversible isentropic expansion process

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\left(\frac{\gamma-1}{\gamma}\right)} \qquad (9)$$

$$= (r_p)^{\frac{\gamma-1}{\gamma}}$$

$$\therefore T_3 = T_4(r_p)^{\frac{\gamma-1}{\gamma}} \qquad (10)$$

Substitute for $T_2$ and $T_3$ in equation (vii)

Efficiency $\eta = 1 - \dfrac{(T_4 - T_1)}{T_4(r_p)^{\frac{\gamma-1}{\gamma}} - T_1(r_p)^{\frac{\gamma-1}{\gamma}}}$

$$= 1 - \frac{(T_4 - T_1)}{(r_p)^{\frac{\gamma-1}{\gamma}}(T_4 - T_1)}$$

$= 1 - \dfrac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$ = The efficiency of the gas turbine, (Ideal cycle) (11)

Where,

$r_p$ is pressure ratio ($\frac{P_2}{P_1}$)

$\gamma$ is the specific heat ratio ($\frac{C_p}{C_v}$)
$P_1$ is the input pressure of the compressor.
$P_2$ is the exhausting pressure of the compressor.
$C_p$ is the specific heat at constant pressure.
$C_v$ is the specific heat at constant volume.

Based on the kinetic theory of gases, it is known that the pressure exerted by gas molecules on the walls of the container depends on: (i) the mass of the molecules, (ii) the molecules' rate of motion, and (iii) how many molecules are present in the container [11].

Mathematically, it is expressed as;

$$P = \frac{1}{3}Sc^2 \qquad (12)$$

Where,

P is the pressure
S is the density
c is the r.m.s velocity of gas molecules.

Since the molecules of gases are in constant motion, they possess kinetic energy. The value of the kinetic energy can be determined using a formula derived from the ideal gas equation as will be shown in this section [11].

Mathematically, the mean kinetic energy of translation per unit volume of the gas is;

$$E = \frac{1}{2}Sc^2 \qquad (13)$$

Where E is kinetic energy

Dividing equation (14) by (15), we have;

$$\frac{P}{E} = \frac{Sc^2}{3} \times \frac{2}{Sc^2}$$

$$= \frac{2}{3}$$

$$\therefore P = \frac{2E}{3} \qquad (14)$$

This implies that;

$$P_1 = \frac{2E_1}{3} \text{ and } P_2 = \frac{2E_2}{3} \qquad (15)$$

Where,

$P_1$ is the input pressure of the compressor
$P_2$ is exhausting pressure of the compressor
$E_1$ is energy installed in MW
$E_2$ is energy generated in MW

But $r_p$ = pressure ratio = $\frac{P_2}{P_1}$

$$\therefore r_p = \frac{\frac{2E_2}{3}}{\frac{2E_1}{3}}$$

$$= \frac{2E_2}{3} \div \frac{2E_1}{3}$$

$\therefore r_p$ = pressure ratio = $\frac{E_2}{E_1}$       (16)

Heat capacity ratios for gases $\left(\frac{C_p}{C_v}\right)$

The equipartition theorem states that any quadratic energy term such as kinetic energy contributes equality to the internal energy of a system in thermal equilibrium. This means that for a gas each degree of freedom contributes ½ RT to the internal energy on a molar basis (R is the ideal gas constant) [11,12].

Assuming an atom of a monoatomic gas that moves in three independent directions, the gas has three degrees of freedom due to its translational motion. The rotation of gas molecules adds additional degrees of freedom. A linear molecule rotates along two independent axes. Assuming a linear molecule, it is therefore means that a linear molecule has two rotational degrees of freedom. The total number of degrees of freedom for a linear molecule is 5 so its internal energy is e = 5/2 RT, its molar heat capacity at constant volume is $C_v$ = 5/2 R and its molar heat capacity at constant pressure will be $C_p$ = 7/2 [11,13].

But $\gamma$ = specific heat ratio = $\frac{C_p}{C_v}$

$$\therefore \gamma = \frac{7R/2}{5R/2} \quad (17)$$

$$= \frac{7R}{2} \times \frac{2}{5R}$$

$$= \frac{7}{5} = 1.4$$

$\therefore$ Efficiency $\eta = 1 - \frac{1}{(r_p)^{\frac{1.4-1}{1.4}}}$

$$1 - \frac{1}{r_p^{0.286}} \quad \text{(Ideal cycle)} \quad (18)$$

## 3.2 Actual Cycle of The Turbine

An actual cycle of the gas turbine has to be considered since there is no ideal machine anywhere.

Efficiency $\eta$ = $\frac{Actual\ work\ done}{Ideal\ work\ done}$ X 100%    (19)

$$= \frac{C_p(T_3 - T_{4s})}{C_p(T_3 - T_4)}$$

$$= \frac{(T_3 - T_{4s})}{(T_3 - T_4)} \quad (20)$$

Process 3-4s reversible adiabatic process

$\therefore P^{1-\gamma}T^\gamma$ = constant

$$P_3^{1-\gamma}T_3^\gamma = P_4^{1-\gamma}T_4^\gamma \quad (21)$$

Also, $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}$   (22)

Again, $P_4 = P_1$ and $P_3 = P_2$

$$\therefore \frac{P_2}{P_1} = r_p \quad (23)$$

Now,

$$\text{Efficiency } \eta = \frac{(T_3 - T_{4s})}{T_3\left(1 - \frac{T_4}{T_3}\right)}$$

$$= \frac{T_3\left(1 - \frac{T_{4s}}{T_3}\right)}{T_3\left(1 - \frac{T_4}{T_3}\right)}$$

$\therefore$ Efficiency $\eta = \frac{1-(r_p)^{\frac{\gamma-1}{\gamma}}}{1-\left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}}$    (24)

Rationalizing the denominator

$$\text{Efficiency } \eta = \frac{1-(r_p)^{\frac{\gamma-1}{\gamma}}}{\left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}-1} \quad \text{(Actual cycle)}$$

$$= \frac{1-(r_p)^{\frac{1.4-1}{1.4}}}{\left(\frac{1}{r_p}\right)^{\frac{1.4-1}{1.4}}-1}$$

$\therefore$ Efficiency $\eta = \frac{1-(r_p)^{0.286}}{\left(\frac{1}{r_p}\right)^{0.286}-1}$ X 100%    (25)

Where,

$r_p$ is the pressure ratio $\left(\frac{E_2}{E_1}\right)$
$E_1$ is the energy installed in MW.
$E_2$ is the energy generated in MW.

## 3.3 Reliability

Reliability is the probability that a device or system will operate for a given period

without failure, and under given operating conditions.

Reliability R(t) = $\frac{\text{Expected running hours} - \text{downtime}}{\text{Expected running hours}}$ X 100%  (26)

## 3.4 Load Factor

The load factor measures the variation in the loads a plant draws and the load it is capable of drawing. It is essential in evaluating the cost per unit generated since it shows how well the plant is using its capacity [14].

Load factor (LF) = $\frac{\text{Energy exported in MWh}}{\text{Installed capacity in MW X actual running time}}$ X 100%  (27)

## 3.5 Capacity Factor

The capacity factor serves as a gauge for the plant's level of utilization. It measures the amount of the potential energy created at full capacity during the same time period in relation to the net electricity generated during that time [14].

Capacity Factor (CF) = $\frac{\text{Energy generated in MWh}}{\text{Installed capacity in MW X actual running time}}$ X 100%  (28)

## 4. RESULTS AND DISCUSSION

Table 1 shows the collated data from Olorunsogo gas-fired power plant phase 1 as compiled by the record management department. Fig. 4 shows the graphical representation of the key performance indicators, calculated from the collated data for the year 2015 – 2021 under review.

The average percentage of efficiency, load factor, capacity factor, and reliability are 50.88%, 11.25%, 11.54% and 55.79% respectively. It shows that all the key performance indicators are low compared to the gas power plant standard practice.

A gas-fired power plant's acceptable standard practice load factor is 50-80% [15]. The standard practice reliability and availability of a gas-fired power plant is 95% and above [14]. A gas-fired power plant's acceptable standard practice efficiency is 65% and above [7]. The research reveals that all the key performance indicators are low compared to the gas power plant international standard practice.

The amount of energy or electricity generated from a cubic volume of gas depends on the generator's efficiency and the efficiency of the
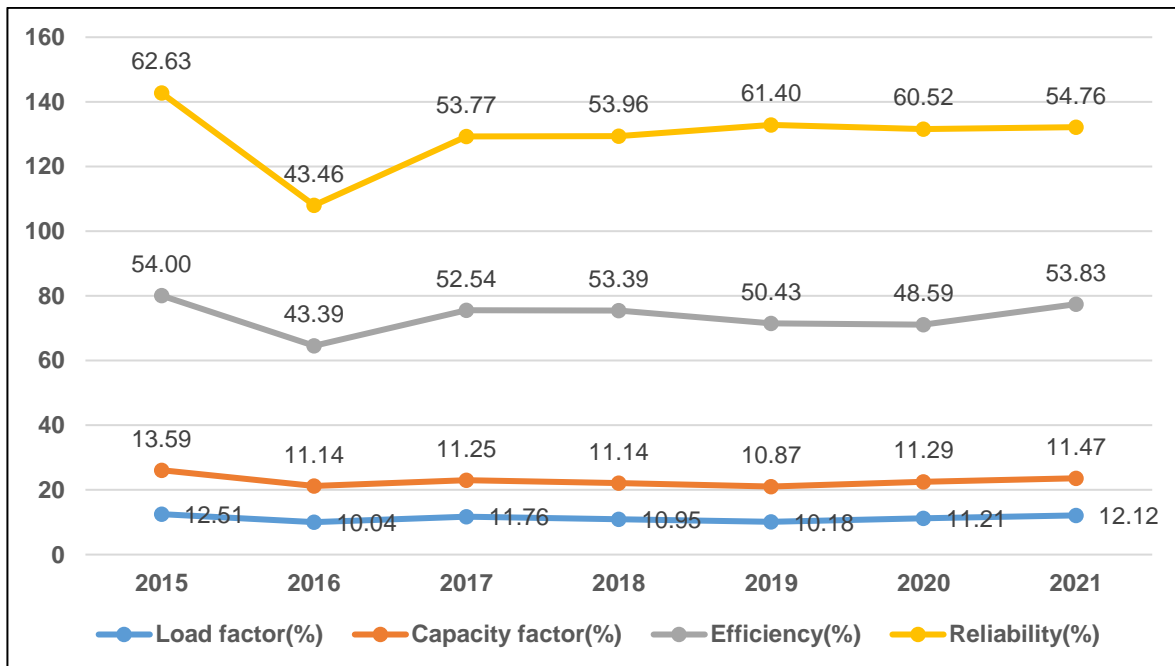


**Fig. 4. Key performance indicators**

**Table 1. Olorunsogo power plant collated data with installed capacity of 277MW**

| Year | Running time (hrs) | Power generated (MWh) | Power generated (MW) | Power exported (MWh) | Power exported (MW) | Gas consumed (SCF) | Expected running time (hrs) | Downtime (hrs) |
|---|---|---|---|---|---|---|---|---|
| 2015 | 48,100.10 | 1,544,073.71 | 32.10 | 1,533,138.00 | 31.87 | 17,884,801,666.68 | 70,080.00 | 21,979.90 |
| 2016 | 30,458.70 | 939,946.89 | 30.86 | 931,360.45 | 30.58 | 11,043,403,382.85 | 70,080.00 | 39,621.30 |
| 2017 | 37,679.80 | 1,174,654.90 | 31.17 | 1,165,017.14 | 30.92 | 13,138,237,184.95 | 70,080.00 | 32,400.20 |
| 2018 | 37,812.90 | 1,167,184.71 | 30.87 | 1,157,295.56 | 30.61 | 12,702,525,006.21 | 70,080.00 | 32,267.10 |
| 2019 | 43,028.00 | 1,331,199.58 | 30.94 | 1,320,780.58 | 30.70 | 15,335,453,079.13 | 70,080.00 | 27,052.00 |
| 2020 | 45,218.10 | 1,413,971.51 | 31.27 | 1,403,532.71 | 31.04 | 13,293,565,660.79 | 70,080.00 | 24,861.90 |
| 2021 | 40,479.40 | 1,286,253.53 | 31.78 | 1,276,542.66 | 31.54 | 13,375,361,490.86 | 70,080.00 | 29,600.60 |

conversion. This ranges from 30% for a combustion engine or old single-cycle turbines to over 60% for the most modern gas turbine. On the norms, 1kWh of energy is generated by burning from 0.083 to 0.125 standard cubic feet (SCF) [16].

Assuming 0.125 standard cubic feet (SCF) of gas to generate 1kWh of energy.

$$\therefore 1 \text{ SCF} = \frac{1}{0.125} = 8\text{kWh} = 0.008\text{MWh} \quad (29)$$

This research reveals that the total gas consumed for the years under review is 96,773,347,471.47 SCF while the total energy generated is $0.00886 \times 10^8$MWh

The expected energy generated by the power plant is 96,773,347,471.47X 0.008. Therefore, the expected energy to be generated is $7.7429 \times 10^8$MWh.

From this analysis, the total energy generated for the years under review is $0.00886 \times 10^8$MWh which is extremely low compared to the expected energy generated of $7.7429 \times 10^8$MWh by the Olorunsogo gas-fired power plant phase 1.

Also, the expected running time for the years under review is 490,560.00 hours, but the actual running time is 282,777.00 hours. This gives a total downtime of 207,783.00 hours. This indicates that the downtime of the power plant is very high.

## 4.1 Findings

Interviews with some staff, and the results from the analysis of the performance of the Olorunsogo gas-fired power plant phase1, the following findings were obtained.

(i) Wastage of gas: It was observed from the results that, there is a lot of gas wastage as the energy generated from the consumed gas for the years under review is very low compared to what is expected to be generated from the consumed gas. The wastage of gas has been attributed to inefficient combustion, poor maintenance, turbine gas leakage, and inadequate control system.

(ii) Downtime: The downtime period of the Olorunsogo gas-fired power plant phase 1 is very high for the years under review. The downtime was a result of system breakdown, inadequate gas supply, and maintenance activities.

(iii) Inadequate gas supply: The volume or quantity of gas supplied to the gas plant from NGC (Nigeria Gas Company) is insufficient for running the generation plant. This is due to the frequent shutdown of the gas plant as a result of the vandalization of the gas pipeline by the militant group in response to the government's failure to give them employment and provide basic amenities for their communities.

(iv) Poor maintenance culture: Lack of maintenance culture has been a big problem in Nigeria. Most of the equipment in the power plant is outdated and needs to be upgraded especially phase II which is still managed by the federal government. Even if maintenance were eventually carried out, it is corrective maintenance instead of preventive maintenance.

(v) Inadequate staff training: Staff is not exposed to state-of-the-art technology through local and oversea training for the optimal day-to-day running of gas-fired power generation systems.

## 4.2 Possible Solutions

(i) The management of the Olorunsogo gas-fired power plant phase 1 must do everything possible to reduce gas wastage. This can be achieved by making sure that, the fuel-air mixture is properly balanced and the combustion process optimized. Also, regular cleaning of turbine blades and prompt replacement of worn-out parts.

(ii) Urgent and necessary maintenance should be given to the gas turbines in other to reduce downtime periods.

(iii) There should be an adequate, sufficient, and regular supply of gas from the Nigeria Gas Company. This can be achieved by reducing or eliminating the activities of the Militants or agitators of pipeline vandalization.

(iv) There must be proper maintenance of gas turbines and other facilities. The surveillance, monitoring, and maintenance units should be equipped with modern technological gadgets to detect and rectify faults on time and probably reduce the incidence of the vandalization of power plant facilities.

(v) There should be on-time staff training both local and international. This will always introduce the staff to modern technology in power generation, which also serves as a motivating factor for the staff.

## 5. CONCLUSION

Performance evaluation of the Olorunsogo gas-fired power plant phase 1 for the years under review (2015 to 2021) shows that the power plant had an overall poor performance; the results shows that the average efficiency of the power plant for the years under review is 50.88%, compare to the standard practice of 65% and above. The average reliability is 55.79%, compare to the standard practices of 95% and above. Several reasons were added to be responsible for these shortfalls in performance. These include; wastage of gas, inadequate gas supply, low staff morale, poor maintenance culture, and inadequate staff training. The proffered possible solutions articulated in this study if implemented, will optimize the power plant's full-capacity operation.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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