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case study on gas turbine power generation in Nigeria.

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CERTIFICATION PAGE

This report is certified as an original research work conducted by African Energy Research (AER) in accordance with approved research standards, methodologies, and ethical guidelines.

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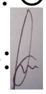
Signature & Date:  27/03/2026

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DECLARATION

This research report has not been submitted to any other institution for any purpose and all sources of data and references have been duly acknowledged.

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LIST OF ACRONYMS & ABBREVIATIONS

NERC	Nigerian Electricity Regulatory Commission
GenCos	Generation Companies
GW	GigaWatt
GWh	GigaWatt-hour
MW	MegaWatt
TCN	Transmission Company of Nigeria
MCDM	Multi-Criteria Decision Making
NNPC	Nigerian National Petroleum Corporation
NGC	Nigerian Gas Company
NISO	Nigerian Independent System Operator
ISO	International Organization for Standardization

Executive Summary

Nigeria's electricity sector remains a critical constraint on economic growth and development despite the country's vast natural gas resources. Although Nigeria has an installed generation capacity of over 13,000 MW, actual available capacity typically ranges between 4,000 and 5,500 MW, far below national demand estimated at over 20,000 MW. While simple-cycle gas turbines are designed to achieve efficiencies of 28–35%, many Nigerian plants operate at only 15–23%, reflecting substantial performance gaps.

A comparative analysis reveals that while gas turbine generation is more cost-effective than diesel and petrol generators, unreliable supply forces businesses and households to rely on these expensive alternatives. Diesel generation costs (₦1,622–₦1,650/kWh) are significantly higher than gas turbine generation (₦400–₦600/kWh), imposing a heavy economic burden on consumers and reducing industrial competitiveness.

This study examines the performance, challenges, and operational efficiency of gas turbine power generators, which form the backbone of Nigeria's electricity generation system.

CHAPTER ONE: INTRODUCTION

1.1 Background to the Study

Substantial expansion in quantity, quality and access to infrastructure services, especially electricity, is fundamental to rapid and sustained economic growth, and poverty reduction. Yet, for the past three decades, inadequate quantity and quality and access to electricity services have been a regular feature in Nigeria. Nigeria's electricity sector is predominantly reliant on thermal power generation, with natural gas-fired plants accounting for the majority of installed and operational capacity. Natural gas serves as the backbone of the national grid, accounting for approximately 80% of Nigeria's total electricity generation infrastructure. Despite abundant natural gas reserves, the country continues to face persistent electricity shortages due to inadequate generation capacity, poor infrastructure, and operational inefficiencies.

In Nigeria, a significant proportion of grid-connected power plants such as Afam, Geregu, and Sapele, are gas-fired thermal plants utilizing turbine technology, making up a large portion of all thermal plants and mostly operating on the open-cycle simple-cycle configuration. Simple-cycle gas turbines have design thermal efficiencies typically in the range of 28–35%, yet operational data from several Nigerian plants reveal actual efficiencies dropping below 25% of international benchmark. Their performance has been constrained by factors such as inconsistent gas supply, aging infrastructure, and maintenance deficiencies (Nigerian Electricity Regulatory Commission, 2023). This study therefore explores the operational performance and challenges associated with gas turbine power generators in Nigeria.

1.2 Problem Statement

Despite substantial investment in gas turbine infrastructure and Nigeria's position as a major natural gas producer, the power sector over the years has been in a deplorable state due to inadequate maintenance of equipment, poor funding and inadequate infrastructural development, with available capacity often less than 40% of installed levels. This inefficiency is driven by several critical factors:

- *Environmental Impact*

The increase in inlet air temperature, especially pronounced in dry season, causes a significant decrease in gas turbine power output. It occurs because the power output is inversely proportional to the ambient temperature and because of the high specific volume of air drawn by the compressor.

- *Infrastructure and Supply*

Inadequate gas pipeline networks and frequent "gas restrictions" prevent plants from reaching their Maximum Continuous Ratings (MCR).

- *Operational Losses*

Factors such as grid instability, poor maintenance cultures, and high exergy destruction in combustion chambers lead to frequent unplanned downtimes and an average plant reliability of only.

1.3 Aim and Objectives of the Study

The main aim of this study is to evaluate the performance, challenges, and operational efficiency of gas turbine power generators in Nigeria.With the objectives of:

- Analyzing the impact of gas supply reliability on power generation output.
- Assessing the performance efficiency of selected gas turbine generators.
- Identifying the major challenges affecting their operation and maintenance.
- Evaluate the economic implications of underperformance in gas turbine plants, including revenue losses, and generation cost penalties.

1.4 Scope of the Study

The study focuses on grid-connected gas turbine power plants in Nigeria. It examines selected thermal power plants that utilize gas turbines, analyzing their operational performance, efficiency levels, and associated challenges.

The study is limited to technical, operational, and supply-related aspects of gas turbine systems and does not extensively cover other forms of power generation such as hydroelectric or renewable energy sources. Geographically, the study is confined to Nigeria, with case-specific insights drawn from selected power plants where relevant data is available.

1.5 Significance of the Study

This research will provide actionable insights for policymakers, regulators (including NERC), generation companies (GenCos), and investors seeking to optimize Nigeria's gas turbine fleet, the dominant source of thermal power. By quantifying performance gaps and their economic costs, the study offers practical recommendations for optimizing the performance and maintenance of gas turbine systems.

CHAPTER TWO: LITERATURE REVIEW

2.1 Conceptual Review

2.1.1 Nigeria's Energy Landscape

Nigeria is sub-Saharan Africa's largest economy and most populous nation, with a population exceeding 200 million. Nigeria's grid-connected power plants have an installed generation capacity of approximately 13,625 MW as consistently reported by the Nigerian Electricity Regulatory Commission (NERC) through 2025–2026.

Average available capacity in early 2026 hovered between 4,000–5,500 MW (Plant Availability Factor often 32–38%), with hourly generation around 4,100–5,500 MWh in recent months. A record peak of approximately 5,802 MW was achieved in March 2025, reflecting some grid improvements, but this is still well below latent demand (estimated >20,000 MW).

Electrification stands at approximately 55–65% of households (2023), with stark rural-urban divides. Even connected users face frequent outages, leading to widespread reliance on costly diesel generators and traditional biomass. Transmission and distribution losses remain high, and many industries operate captive power plants. Recent reforms under the Electricity Act 2023 have enabled state-level markets and greater private participation, contributing to modest gains in 2025. The World Bank's survey of 2,916 Nigerian firms recorded an average of 32 outages per month, each averaging 11.6 hours.

2.1.2 Gas Turbine Power Generation

A gas turbine power generator is a thermal power system that converts the chemical energy of fuel (typically natural gas) into mechanical energy and subsequently into electrical energy. The process operates on the Brayton cycle, involving air compression, combustion, and expansion through a turbine to produce power.

CHAPTER ONE: INTRODUCTION

The ideal Brayton cycle comprises four processes: isentropic compression of inlet air, constant-pressure heat addition during combustion, isentropic expansion through the turbine, and constant-pressure heat rejection to atmosphere. Real turbines deviate from this ideal due to irreversabilities and component inefficiencies, making performance optimization a central engineering challenge in any deployment context, particularly Nigeria's.

Gas turbines are widely used in Nigeria due to the country's heavy reliance on natural gas for electricity generation. Studies show that over 70% of Nigeria's electricity generation is gas-fired, highlighting the importance of this technology in national energy.

2.1.2 Types of Gas Turbine Systems

- **Single-Cycle Gas Turbine**

A single-cycle (simple-cycle) gas turbine system operates on a straightforward thermodynamic process in which air is compressed, mixed with fuel, and combusted to produce high-temperature gases that drive a turbine for electricity generation. This system is characterized by its operational simplicity, rapid start-up capability, and relatively low capital cost.

- **Combined-Cycle Gas Turbine**

A combined-cycle Gas Turbine uses both gas and steam turbines together to produce more electricity from the same fuel than traditional single-cycle plants. The waste heat from the gas turbine is routed to the nearby steam turbine, which generates extra electrical power. A Combined Cycle Power Plant produces high power outputs at high efficiencies (up to 60%) and with low emissions. A conventional power plant has efficiency of about 33% electricity only and remaining 67% as waste.

CHAPTER ONE: INTRODUCTION

2.1.3 Efficiency and Performance Concepts

Thermal Efficiency: Ratio of useful energy output to energy input.

Heat Rate: Measure of fuel consumption per unit of electricity generated.

Exergy Efficiency: Evaluates energy losses within system components.

2.1.4 Energy Supply Chain Framework

Gas turbine power generation depends on an integrated system involving:

- Gas production and supply,
- Power generation,
- Transmission and distribution.

Disruptions in any part of this chain, especially gas supply directly affect power output and system reliability.

2.2 Theoretical Framework

- **Thermodynamic Theory (Brayton Cycle)**

The operation of gas turbines is based on thermodynamic principles governing energy conversion. The Brayton cycle explains how air is compressed, heated, and expanded to generate mechanical work.

- **Energy Efficiency Theory**

This theory emphasizes optimal utilization of energy resources to minimize waste and maximize output. It is relevant in analyzing performance gaps in gas turbine systems.

- **Systems Theory**

Gas turbine power generation is viewed as part of a broader interconnected system involving fuel supply, generation, and grid infrastructure. A failure in one subsystem (e.g., gas supply disruption) affects the entire system.

2.3 Empirical Review

Nigeria's electricity supply deficit is one of the most extensively documented in sub-Saharan Africa. NERC Annual Reports and TCN System Operator Monthly Reports establish that as of 2023, installed generation capacity of approximately 13,000 MW yielded actual daily generation of only 3,500–5,000 MW, against a population of over 200 million and estimated unmet demand exceeding 18,000 MW. Some studies emphasize that gas turbine plants are crucial for addressing Nigeria's electricity deficit due to the country's abundant natural gas reserves, yet their potential remains underutilized.

Other studies such as Emovon, I. et al. (2018) applied MCDM methods to maintenance prioritisation applied multi-criteria decision-making techniques to maintenance prioritisation at the Sapele Power Plant, providing insights that are applicable to gas turbine subsystem management.

2.4 Knowledge Gaps Identified

Despite existing research, several gaps remain, some of them are:

- Limited Plant-Specific Analysis
- Insufficient Real-Time Operational Data
- Integration of Modern Technologies
- Gas Supply Chain Optimization

CHAPTER THREE: METHODOLOGY

3.1 Research Design

This study adopts a mixed-methods research design, combining a quantitative and analytical approach to evaluate the performance of gas turbine power generators in Nigeria. The design is structured as an explanatory case study, which is appropriate given the study's aim to not only give an in-depth examination of specific gas-fired power plants such as Afam, Geregu, and Sapele, which are representative of Nigeria's thermal generation fleet.

The study also incorporates a descriptive and diagnostic framework, aimed at identifying operational inefficiencies, performance gaps, and the underlying causes affecting gas turbine performance. Quantitative analysis is employed to evaluate efficiency metrics such as thermal efficiency, heat rate, and availability factors.

3.2 Data Sources

Primary data for this study are obtained directly from operational and technical records of selected gas turbine power plants. Other data sources include:

- Annual reports from Nigerian Electricity Regulatory Commission
- International energy datasets from International Energy Agency
- Academic journals, conference papers, and prior research studies

3.3 Data Collection Methods

Data collection was conducted through systematic document review and content analysis. Document Review is the primary method for collection. Operational logs, regulatory filings, system operator reports, and published studies are systematically reviewed and extracted into structured data templates. Content analysis techniques are applied to qualitative documents to identify recurring themes related to performance constraints.

3.4 Analytical Tools and Models

The analysis employs a combination of qualitative and conceptual analytical tools, including:

- **Economic Impact Quantification**

This is used to estimate the financial cost of underperformance.

- **Multi-Criteria Analysis**

This is used to rank and prioritise identified operational challenges, drawing on the MCDM framework applied by Emovon et al. (2018) at Sapele, adapted to the broader plant sample of this study.

- **Comparative Analysis**

This is used to compare Performance metrics of Nigerian gas turbines with other sources for power generation to identify efficiency gaps.

3.5 Assumptions and Limitations

The study is based on several assumptions:

- Available data from power plants are accurate and reliable.
- Gas supply volume data from NGC/NNPC is assumed to be representative of actual deliveries to individual plants.

Key limitations include:

- Data Availability Constraints
- Findings from selected case study plants may not fully represent all gas turbine plants in Nigeria.

3.6 Ethical Considerations

This study adheres to standard ethical research principles. All data used are obtained from publicly available, credible, and verifiable sources. Sources are appropriately acknowledged, and interpretations are presented objectively, without political or institutional bias. The research maintains analytical independence, ensuring that conclusions are driven by evidence rather than advocacy, in line with best practices for policy and industry research.

CHAPTER FOUR: DATA PRESENTATION & ANALYSIS

4.1 Data Description

The data used in this study are structured as a hybrid dataset combining plant-level operational indicators and sector-wide performance statistics to provide a realistic representation of gas turbine performance within Nigeria's electricity system.

It is organized around thematic areas that correspond directly to the study's objectives: gas supply volumes and constraint frequency; plant availability and capacity factors; thermal efficiency and heat rate performance; operational and maintenance challenges; and comparative cost and reliability metrics across electricity supply options in Nigeria. To account for performance variations, the study incorporates environmental and operating variables such as:

- Ambient temperature ranges across major generation regions
- Seasonal variations affecting turbine inlet air conditions
- Grid frequency fluctuations and load instability

While the datasets are derived from credible institutional sources, they reflect system-level averages rather than unit-level precision, which is appropriate for the scope of this study.

4.2 Analysis and Interpretation

4.2.1 Gas Turbine Assessment

Power Plant	Installed Cap. (MW) Avg. Availability	Avg. Availability	Key Performance Issue
Transcorp Ughelli	1,020	Approximately 54%	Output loss 9.3% at 31°C inlet temp
Geregu (GE SGT5-2000E)	435	Approximately 58%	Ambient temperature degrades compressor
Afam VI (Niger Delta)	776	Approximately 52%	Capacity factor average 20.1%; gas supply
Omotosho (Ondo)	500	Approximately 50%	Single-Cycle gas turbine efficiency penalty.
Egbin Thermal (Lagos)	1,320	Approximately 45%	Ageing infrastructure, and forced outages

Table 1: Key Nigerian Gas Turbine Plants

4.2.1.1 Root Causes of Gas Turbine Underperformance

- Gas Supply Insecurity:

Insufficient, unreliable, or interrupted natural gas delivery is the dominant root cause, repeatedly cited in NERC, NISO, and industry reports as the reason for plants going offline or operating at reduced capacity. Nigeria generates 4,500 MW for a population of 200 million people, and more than 50% of the population has no electricity access. Gas disruptions reduced available generation to just 2,830 MW from a potential 8,700 MW, a 67.5% effective capacity loss.

- Deferred Maintenance

Many plants, some decades old, suffer from inadequate routine and preventive maintenance, leading to mechanical failures and frequent unplanned outages. Studies show high exergy destruction in combustion chambers due to poor combustion, defective burners, and fuel quality issues. Mean time between failures is often low, with long repair times. Progressive degradation of compressor blades, hot section components, and auxiliary systems driven by constrained maintenance budgets reduces achievable output and efficiency over time.

- Ambient Conditions

Nigeria's hot, humid climate causes significant derating of gas turbines, which are sensitive to inlet air temperature and density. Higher ambient temperatures reduce air density, increasing compressor work and lowering power output (output can drop noticeably above ISO conditions of 15°C). Fouling from dust/humidity and off-design operation further degrade performance. Simple-cycle plants (common in Nigeria) are particularly affected compared to more efficient combined-cycle setups.

4.2.2 Gas Turbine vs. National Grid, Petrol and Diesel Generators

Metric	National Grid	Petrol/Diesel Generators	Gas Turbines
Reliability	Low (32–36% PAF; frequent collapses)	High (on-demand)	High
Cost per kWh (₦)	Band A: ₦206.80/kWh-₦225/kWh. Band B: ₦100–₦175/kWh	Diesel: Approximately ₦1,622 – ₦1,650 Petrol: Approximately ₦1,270 – ₦1,350 (fuel price dependent)	₦400–600+/kWh (fuel-dependent)
Efficiency	Grid-dependent	25–35%	35–52%
Emissions	Mostly gas/hydro	High (CO_2, NOx, particulates)	Moderate (cleaner than diesel)
Scalability	Constrained by transmission	Small–medium loads	Medium–large (captive or utility)
Lifespan	Infrastructure dependent	3–5 years for petrol generators and 10–20 years for diesel generators	25–35 years

Table 2: Comprehensive Comparison

The public grid remains the lowest-tariff option on paper but is undermined by extreme unreliability. Mismanagement, corruption, and insufficient maintenance reduces the grid's effective availability, resulting in Transmission & distribution losses of approximately 15–25%.

4.3 Key Findings

Based on the analysis, the following key findings are identified:

- Gas turbine plants in Nigeria operate far below their design efficiency, leading to increased fuel consumption and operational costs.
- Inadequate and unreliable gas supply is the most significant constraint affecting turbine performance and output.
- Underperformance results in substantial revenue losses and increased cost of electricity generation.

CHAPTER FIVE: DISCUSSION OF RESULTS

5.1 Interpretation of findings

The analysis in Chapter Four indicates that Nigerian gas turbine plants operate substantially below their design capacities, with average availability factors ranging from 45% to 58%.

The data establishes unambiguously that gas supply insecurity is the dominant constraint on gas turbine output in Nigeria. The finding that gas disruptions reduced available generation from a potential 8,700 MW to just 2,830 MW.

The comparative analysis in Chapter Four between gas turbines, the national grid, and petrol/diesel generators provides the economic context within which gas turbine underperformance must be assessed. The finding that diesel generation costs approximately ₦1,622–₦1,650/kWh, roughly three to four times the cost of gas turbine generation at ₦400–600/kWh, illustrates the economic penalty that Nigerian households and businesses absorb as a substitute for unavailable grid and gas turbine power. The World Bank's survey finding of 32 outages per month averaging 11.6 hours each is not merely a reliability statistic; it represents a recurring economic cost borne disproportionately by those who can least afford it.

In Nigeria, gas generators dominate thermal generation because the country has abundant natural gas reserves. However, underperformance is widespread due to gas supply insecurity, deferred maintenance, aging infrastructure, and hot-humid ambient conditions. This results in much lower output than design capacity, as reflected in plant availability and efficiency statistics.

CHAPTER SIX: CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusion

Despite Nigeria's position as one of Africa's largest natural gas producers, the power sector has been systematically unable to access sufficient, reliable, and quality gas supply to operate its turbine fleet at anywhere near installed capacity. Gas disruptions alone have been shown to reduce available generation from a potential 8,700 MW to as low as 2,830 MW, a 67.5% effective capacity loss that dwarfs the contribution of any purely technical failure mode. This is a structural supply chain failure, not a generation-side problem, and it renders plant-level technical interventions insufficient on their own.

Actual thermal efficiencies of 15–23% across the Nigerian fleet, against design benchmarks of 28–35%, represent a performance deficit of 8–15 percentage points attributable to a combination of ambient temperature derating, compressor fouling, deferred hot section maintenance, and combustion system deterioration. These efficiency losses are not inevitable, they are largely recoverable through targeted investment in maintenance, inlet air cooling, and operational discipline. The fact that they persist reflects an institutional and financing failure as much as a technical one.

6.2 Recommendations

- Upgrade to Combined-Cycle Systems
- Prioritize investment in turbine refurbishment, pipeline reliability, and auxiliary systems to reduce outages.
- Integrate Gas Turbine Performance Targets into National Energy Transition Planning.

6.3 Areas for Further Research

While this study provides integrated assessment of Nigeria's gas turbines several areas warrant deeper investigation to further enhance operational performance, reliability, and economic efficiency.

Firstly, developing predictive models that account for high ambient temperatures, humidity, dust, and fuel quality variations specific to Nigerian gas turbine plants. Such models can inform proactive maintenance schedules and extend equipment lifespan.

Finally, evaluating the technical and economic viability of retrofitting existing simple-cycle plants to combined-cycle systems, considering site-specific factors such as space, infrastructure, and fuel availability.

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