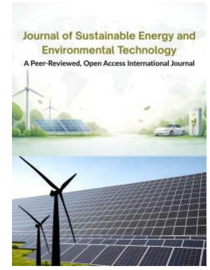
Journal of Sustainable Energy and Environmental Technology

E-ISSN: 3122-0630
P-ISSN: 3121-9454

Volume 2, Issue 1, March, 2026
(An Academians Publishers of Research & Academic Resources)



Electric Power Generating Units TG1 and TG2 Dependability: Kwale Gas Recycling Plant

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Abstract: This study examines the dependability and operational performance of electric power generating units TG1 and TG2 at the Kwale Gas Recycling Plant, Nigeria. In the context of increasing industrial demand for higher production efficiency with minimal capital expenditure, enhancing equipment reliability, availability, and maintainability has become essential for sustainable operations. The research evaluates the relationship between equipment failure rates, maintenance strategies, and the economic implications of power generation losses due to system unavailability.

Using reliability engineering principles, key performance indicators such as Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR), and operational availability were analyzed to assess system effectiveness. The study also highlights the role of modern maintenance approaches, including Reliability-Centered Maintenance (RCM), Total Productive Maintenance (TPM), and Computerized Maintenance Management Systems (CMMS), in improving plant performance and reducing downtime.

Findings indicate that over time, the cost associated with lost power generation due to equipment failure significantly exceeds the initial capital investment of the generating units. This underscores the importance of adopting proactive and data-driven maintenance strategies to enhance dependability and optimize lifecycle costs. The study concludes that integrating advanced reliability models and continuous maintenance improvement frameworks can significantly improve operational efficiency, safety, and long-term economic performance of gas turbine power plants.

Keywords: *Dependability; Costs reduction; Performance; Kwale gas plant; Safety; Maintainability.*

1. Introduction

In the context of increasing industrial demand for higher production efficiency with minimal capital expenditure, enhancing equipment reliability, availability, and maintainability has become essential for sustainable operations. Dependability may be defined in relation as the capacity of an equipment to fulfill its intended function. It is commonly measured as the mean time between failures (MTBF) of each system (Dunn, 2022). Ensuring that any physical asset continues to function as intended is the aim of reliability-centered maintenance, i.e., to be dependable. The objectives of reliability engineering are to forecast and prevent every failure as well as to estimate the costs if the failure is allowed to occur. Workers are in charge of making sure that the equipment is upgraded or designed to be more maintainable, that technical problems with ongoing maintenance are investigated, and that the required corrective and improvement measures are put into place (Dunn, 2022).

This study examines the dependability and operational performance of electric power generating units TG1 and TG2 at the Kwale Gas Recycling Plant, Nigeria. The research evaluates the relationship between equipment failure rates, maintenance strategies, and the economic implications of power generation losses due to system unavailability.

2. Literature Review

2.1 Maintenance Management and Dependability

Received 05 January, 2026; Accepted 16 February, 2026; Available Online: 25 March, 2026

Schedule compliance is one of the most crucial metrics for monitoring and controlling maintenance. It is always less than or equal to 100% and is usually expressed as a percentage. It is calculated by dividing the total number of scheduled work orders for a given time period (typically one week) by the number of scheduled work orders completed during that time. Alternatively, it can be expressed as a percentage of installed or actual capacity used during a 12-month period. The scheduled restoration task is a maintenance task to restore a component at a predetermined, specified frequency, regardless of the component's condition at the time of replacement. One example is the routine turbine overhaul that takes place every 170,000 operating hours. The frequency of a planned maintenance activity depends on the component's useful life.

The factory operator participation in equipment redesign, maintenance, and ongoing process improvement is emphasized by the total productive maintenance (TPM) program. A new asset value engineering is utilized to methodically make sure that the user needs are satisfied but not surpassed. It mostly entails getting rid of new equipment's "non-value-adding" characteristics. Total asset management (TAM) is an emerging trend in the strategy to maintain equipment reliability. It is an integrated approach to asset management that incorporates elements such as Reliability-Centered Maintenance (RCM), Total Productive Maintenance (TPM), Design for Maintainability, Design for Reliability, Value engineering, Life-Cycle Costing, Probabilistic Risk Assessment, and others to arrive at the optimal Cost-Benefit-Risk asset solution to meet any given production requirements (Dunn, 2022).

This strategy must embrace total planned quality maintenance (TPQM), a management concept for integrated maintenance that promotes quality control in maintenance as well as planning all maintenance (i.e., preventive, predictive, corrective, and automatic self-fulfilling). The company can monitor scheduling, parts supply, planning, preventive maintenance programs (PM), environmental and safety compliance, statistical maintenance control functions and performance expectations, product quality, customer service, economy and efficiency of operation, control, containment, comfort, protection, and compliance with environmental regulations, structural integrity, and even the asset physical appearance by using an active computerized maintenance-management system (CMMS).

2.2 Reliability Engineering Principles

Win Smith Weibull software can be used to transform failure and repair time data into statistical format for use in reliability estimates (Fulton, 2010). One can forecast a system operational availability, dependability, maintainability, and other operating behavior using maintenance models that use real failure data and repair times (Barringer, 2000). A portion of the failure data comes from straightforward mathematical computations, while other data use Weibull databases in accordance with the recommended methodology (Abernethy, 2019). The system initial design and construction, the caliber of its installation, how cautiously it was used, and how effectively it was maintained all have an impact on the frequency of breakdowns and associated expenses, dependability, maintainability, and system performance. One can determine how expenses will change over time and the many influencing factors by using Monte Carlo simulations (Barringer, 2009). The reliability model detects unwanted alternatives and makes it possible to estimate what is affordable. The system's availability, dependability, maintainability, and performance capacity all affect its effectiveness.

For equipment dependability, the following issues need to be addressed typically: is the system accessible? Is the procedure/system dependable? What are the reasons for process breakdowns? And is the procedure consistent? These problems are addressed by analysis of a dependable process data from maintenance activity. Barringer and Roberts (2002) list the following as some of the reasons for utilization losses: (a) excessive system stress (such as temperature, pressure, flow, and chemical concentration); (b) late starts or early quits; (c) disregard for long-term optimization; (d) too frequent changes in process goals; (e) absence of a statistical process control; and (f) use of analogue rather than digital control.

In order to make the firm more profitable, problems should be identified with time and money so that everyone can comprehend them. Then, they should be fixed on a priority basis. High availability (i.e., a high percentage of uptime), predictable output, and the elimination of hidden issues are all necessary for the process. RCM involves posing the following queries: (1) In the current operating environment, what are the asset's functions and related performance standards? (2) How does it fall short in carrying out its duties? (3) What leads to every malfunction? (4) What takes place after every failure? (5) How important is every failure? (6) How can each failure be anticipated or avoided? (7) What happens if an appropriate preventative measure is not found?

2.3 The Nigerian Context

With the exception of Nigeria, electric power projects worldwide are dependable, reasonably priced per kilowatt-hour, cater to particular consumer needs, coordinate emergency response and technological advancements, maintain environmental compliance, undertake extensive modernization projects, and manage risk. Electric power plant failures cause economic losses, production losses, and downtime. When it comes to malfunctions, unplanned maintenance, and extended downtime, Nigerian maintenance procedures continue to fall well short. In Nigeria, maintenance is typically seen as an unpleasant expense-generating job rather than one that boosts productivity, profitability, and reliability.

Because maintenance is still much too frequently neglected in most industry, the associated expenditures as a percentage of overall operating costs continue to rise. The lack of an efficient and successful maintenance procedure is the most noticeable issue. The first stage should be to audit the current maintenance system in order to find and quantify its deficiencies. After that, a medium-term plan for system improvement should be developed.

3. Methodology

3.1 Reliability and Maintainability Metrics

An artefact's reliability is the probability that it will perform the function for which it is designed under specified conditions for a predecided period of time. Dependability relates to the frequencies of outages. The fundamental reliability and maintainability metrics used in this study are defined by the following equations:

Reliability, $R(t)\ exp(\frac{t}{MTBF})=exp\,(-\lambda t)$ (1)

where t = period of failure

MTBF = 1/λ = total operating time/number of failures.

MTTR = τ = total outage time/number of failures = 1/μ

When these two factors are known for any given system or component, then the availability (A) is expressed as:

$$A=\frac{MTBF}{MTBF+MTTR}=\frac{1}{1+\lambda t}=\frac{UPTIME}{UPTIME-DOWNTIME} \quad (2)$$

Maintainability $(Mt)\ exp\,(\frac{t}{MTTR})=exp\,(-xt)$ (3)

$$\text{Utilization efficiency}=\frac{\text{Actual work hours}}{\text{Maximum potential hours of operation}+\text{delay hours}} \quad (4)$$

3.2 Study Site and Data Collection

This study was conducted at the Kwale Gas Recycling Plant Power Units TG1 and TG2. Due to the abundant natural resource deposits in the Niger Delta, this is one of the first significant gas-turbine plants for self servicing in the company's day to day operations. Nuovo-pignone constructed and installed the two power units and its auxiliary equipment. Kwale gas recycling power plant was built in 2023 and commissioned and put into service in 2024. Each of the two generating units that made up this system have an installed capacity of 27.3 megawatts.

The two 27.3 MW gas turbines, referred to as TG1 and TG2, were put into service despite significant technical issues with the individual producing units and the auxiliaries. This rapid increase has occurred, resulting in emergency or forced outages, extended or postponed outages, expensive power generation, and unpredictable power supplies. In this power location, maintenance costs account for 30% of overall production costs, which is gravely significant for operational costs (Eti et al., 2004).

Due to the need for liberalization of electricity usage and the growing and pressing need for self-generated electric power, there is a greater requirement for independent power production to support or maintain operational activity in the industries. This automatically requires raising equipment "Reliability", prioritizing maintenance activity, and reduction of maintenance costs for operational success.

According to evaluation, the power plant performance is lower than that of top-tier operations. It is necessary to establish a defined maintenance strategy and policy. Inadequate maintenance execution, training, and resource allocation should be in a buffer status. The methods, intervals between maintenance, and preventive maintenance are not well specified or adhered to. Along with employee empowerment, a maintenance culture and dedication should be established through team-based awards and recognition.

4. Results and Analysis

Self-auditing should be the initial step in order to identify opportunities, weaknesses, and strengths. The system/component availability must be defined in terms of Mean-Time Between-Failures (MTBF) and Mean-Time-To-Repair (MTTR), where MTBF is the reciprocal of the frequency of failures and MTTR is related to the length of outages, in order to apply Reliability and Maintainability principles in the Power Plant. Availability (A) is by definition correlated with outage duration and frequency. Generating units are prone to failure due to mechanical, electrical, thermal stress and adverse working environmental conditions.

Operations and Maintenance (O & M) are responsible for a large chunk or proportion of energy production cost. Reducing the maintenance cost is the key to keep the power industry competitive. This is aimed at maximizing power output, minimizing outage time and optimizing maintenance activities in the electric power industry. In mathematical maintenance analysis it may be necessary to find solutions to a set of linear differential equations, particularly, when applying the Markov method. Even though there are various methods for solving differential equations, the Laplace transform approach is probably the most effective technique for solving a set of linear differential equations. This piece of example demonstrates application of Laplace transform to solve Linear Differential Equation. Assume that the following two differential equations describe a repairable system as expressed (Bestmann, et al., 2021).

Therefore, if the two parameters, MTBF and MTTR, are known for any particular system or component, the availability goal can be translated into reliability and maintainability criteria in terms of acceptable failure rates and outage hours for each component as explicit design objectives. Equation (2) can then be used to express the system's or component's availability. For example:

For example: Total outage hrs/yr =600hrs

No. of failures / yr =17 therefore: MTTR = 60hrs; MTBF $=\frac{7860}{17}=462.4$

$$A = A\frac{MTBF}{MTBF+MTTF}=\frac{462.4}{462.4+60}=0.885$$

Hence: Unavailability = 1-A = 1-0.885 =0.115

Annual power generation in 2025 = 10.4 x 8760 MW/h

Total Installed capacity = 27.3 x 8760 MW/h.

Capacity factor = 10.4/27.3 =0.38

Annual generation reduction (on 10.4MW) = 10.4 x 27.3

If the cost of power replacement is N0.9/kWh.

Then annual outage cost due to turbine failures = N27.3 x 10.4 x 0.38 x 1000 x 0.9 =N97,100.64.

An overall plant operating cost can be calculated by adding this expense to the installation and maintenance expenditures.

5. Discussion

There do not seem to be any criteria or benchmarks based on the generating power units TG1 and TG2 at Kwale Recycling plant existing records; instead, the estimations of likely job time are variable and untrustworthy. There is no process in place for reporting productivity and performance, maintenance expenses, PM initiatives, malfunctions, etc. Graphs and charts do not display any control data. For the power units to increase productivity and maintenance management systems, more precise goals are required. A new maintenance paradigm that enhances PM and maintenance control should serve as the foundation for this. While some may be used for benchmarking or assessment, performance metrics are an essential tool for monitoring development (Al-Muhaisen and Santarisi, 2012).

Power plant operators must gather, retrieve, and analyze data in order to make informed decisions, develop strategies, and track success against plans. System availability, dependability, maintainability, and other operating system details are provided by reliability models utilizing real data and repair timeframes, which enable cost and trade-off estimates (Barringer, 2000). Finding methods to improve equipment dependability and prolong its life through economical maintenance should be the goal in order to minimize downtime and attain high production capabilities. The system must switch from the conventional reactive maintenance mode to proactive maintenance and management philosophy in order to accomplish these goals.

Total Quality Maintenance and Total Productive Maintenance operating modes should be completely addressed by maintenance procedures. A Total Planned Quality Maintenance (TPQM) approach, a maintenance and management philosophy that promotes planning all maintenance (i.e., preventive, predictive, and corrective) as well as the control of quality in maintenance activities, is necessary for such a transition. It will be necessary for plants, divisions, and businesses to have failure databases created from global data. Maintaining local data in Weibull databases should give end users information for life-cycle pricing so they can make better grade decisions of acquired equipment and how malfunctions impact ongoing operating expenses (Barringer, 1996). Using failure data, reliability optimization begins at the beginning of the design process and continues through life-cycle costs. Optimizing the cost of unreliability begins after plants are constructed and successfully lowers systemic issues by taking trade-offs into account when taking corrective measures. Therefore, gathering age-to-failure data, exchanging failure data, and the costs related to the failures are the first steps in the reliability optimization process.

6. Conclusion

This study concludes that integrating advanced reliability models and continuous maintenance improvement frameworks can significantly improve operational efficiency, safety, and long-term economic performance of gas turbine power plants. The findings indicate that over time, the cost associated with lost power generation due to equipment failure significantly exceeds the initial capital investment of the generating units. This underscores the importance of adopting proactive and data-driven maintenance strategies to enhance dependability and optimize lifecycle costs. A strategic shift from reactive to proactive maintenance, supported by robust data collection and analysis systems like CMMS and Weibull databases, is essential for improving the dependability of the TG1 and TG2 units at the Kwale Gas Recycling Plant.

References

Abernethy, R.B. (2000), *The New Weibull Handbook*, 3rd edition.

Al-Muhaisen, M. and Santarisi, N. (2012), Journal of Quality in Maintenance Engineering, Vol. 8 N0.1, pp. 62-76.

Barringer, H.P. (2009), Monte-Carlo Simulations. LCC Subset, http://www.barringer1.com/lcc.htm, 4th edition.

Barringer, H.P. (2000), Weibull Database, http://www.barringer1.com/wdbase.htm

Barringer, H.P., (2001) Reliability Engineering Principles. http://www.barringer1.com/read/htm

Barringer, H.P., and Roberts, W.T.J. (2002), Process Reliability: Do you have it? Barringer & Associates, Humble Inc, Texas.

Barringer, H.P. (1996), An Overview of Reliability, Engineering Principles, Energy Week, Penn Well Publishing Co, Tulfa, Oklahoma.

Dunn, S. (2022), The Reliability Revolution. Webmaster, Plant Maintenance Resource Centre, info@maintenanceresources.com, 6th edition.

Fabrycky, W.J., and Blanchard, B.S., (1991), *Life-Cycle Cost and Economic Analysis*, Prentice Hall, Englewood Cliffs, New Jersey.

Fulton, Wes (2010) WinSmith Weibull Probability plotting software, http://www.Weibullnews.com, 3rd edition.

Moubray, J., (2000), Maintenance Management- A New paradigm, info@maintenanceresources.com pp.1-18

M. C. Eti, S. O. T. Ogaji and S. D. Probert, Reliability of the Afam electric power generating station, Nigeria, Applied Energy, Volume 77, Issue 3, March 2004, Pages 309-315. http://hdl.handle.net/1826/760.

T.D. Bestmann, A. O. Odukwe, J. C. Agwunwamba and k. Orima: Minimizing equipment downtime by adopting basic math model to improve electric power production in Nigeria, International Journal of Advances in Engineering and Management (IJAEM), Volume 3, Issue 11 Nov 2021, pp: 702-714 www.ijaem.net ISSN: 2395-5252