ISA Journal of Engineering and Technology (ISAJET)

Homepage: https://isapublisher.com/isajet/

Volume 3, Issue 4, July-August, 2026 ISSN: 3049-1843

A Reliability-Centered Assessment of the Operational Availability of a 500KVA Stand-alone Power Generator Supplying a Growing Polytechnic Campus

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Received: *10.06.2026* | ***Accepted:*** *20.07.2026* | ***Published:*** *22.07.2026*

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DOI: *10.5281/zenodo.21498143*

Abstract **Original Research Article**

This research will present an empirical assessment of the operational availability of a 500KVA stand-alone power generation system installed in a rapidly expanding polytechnic institution. As educational institutions grow in infrastructure and student population, the demand for reliable and uninterrupted power supply becomes critical. The research will focus on evaluating the system's performance, availability, and reliability using real-time operational data collected over a specified period. Key parameters to be assessed include total uptime, downtime, mean time between failures (MTBF), and mean time to repair (MTTR). The analysis will provide insights into the system's ability to meet increasing power demands, highlight operational bottlenecks, and identify areas requiring improvement. It is anticipated that findings will reveal whether the system performs adequately under current conditions, as well as its operational availability under different maintenance conditions including delays and fuel supply inconsistencies. Recommendations for optimizing generator performance will be proposed in order to provide more sustainable and reliable power solution for the institution's growing energy needs.

Keywords: Operational availability, Power generation system, Reliability assessment, Mean Time Between Failures, Mean Time To Repair.

Introduction

The continuous and reliable supply of electrical power is a critical requirement for the effective functioning of academic institutions, particularly in developing regions like Nigeria where grid electricity is often unreliable or unavailable. In rapidly expanding polytechnic institutions, the growing infrastructure and increasing population of students and staff result in higher energy demands, necessitating dependable power solutions to support teaching, learning, administration, and research activities.

Delta State Polytechnic, Ogwashi-Uku, is a rapidly growing institution, comprising approximately 30 academic departments and offering over 50 programs. With numerous laboratories, workshops, and extensive research and teaching activities, the institution's power demand is understandably immense—requiring a system that ensures both high reliability and availability.

To address this challenge, the Institution adopted stand-alone power generation systems, primarily diesel-powered generator, as alternative or supplementary sources of electricity. A 500KVA generator is deployed for this purpose due to its capacity to support medium to large-scale facilities. However, the efficiency and dependability of such a system is often subject to operational and environmental factors including mechanical wear, maintenance practices, fuel supply logistics, and usage patterns.

This research aims to empirically assess the operational availability of the 500KVA stand-alone generator system within this rapidly growing polytechnic. Operational availability, a key performance metric, represents the proportion of time a system is in a functioning condition and capable of delivering its intended service. By collecting and analyzing historical operational data—such as run hours, downtimes, failure frequencies, and repair intervals—this study seeks to evaluate how effectively the power system meets the institutional energy needs.

Furthermore, the research provides insights into reliability trends and operational challenges, which can guide decision-making on maintenance planning, equipment upgrades, and power infrastructure development. Ultimately, the findings are intended to inform strategic improvements in power system management to ensure sustained, reliable energy access in educational environments.

Problem Statement/ Justification

The primary objective of this study is to evaluate *availability* of the 500KVA stand-alone power supply system of Delta State Polytechnic, Ogwashi-Uku which is characterized by huge and reliable power demand , in order to identify existing gaps, analyze energy consumption patterns, and propose sustainable solutions to enhance power reliability and availability for academic, research, and administrative operations

Objectives of the Study

Delta State Polytechnic, Ogwashi-Uku, is experiencing rapid expansion, with a total of seven (7) Schools (faculties), 38 academic departments, 36 National Diploma and 37 Higher National Diploma programmes, totaling 73 programmes in all, currently in operation. This growth has led to a significant increase in the institution's power consumption due to the proliferation of laboratories, workshops, ICT infrastructures, and research facilities. However, the existing power supply system has proven to be inadequate, unreliable, and inconsistent—often disrupting academic and administrative activities.

This research is therefore necessary to assess the power demands of the Polytechnic, evaluate the current energy supply infrastructure, and propose a more reliable, sustainable, and efficient power solution. The findings will not only enhance energy planning and resource allocation but also support the institution's long-term development goals and improve the learning and research environment

Literature Review

By instinct, system availability denotes the system is operational when you have work to do with it. This implies that the system is not inoperative by reason of problems or other unforeseen disruptions (Yuo-Tern et al.,2004; Yuo-Tern et al.,2001 and Ebeling, 2008). Numerically speaking, system availability means that the system is on hand for use as a percentage of scheduled uptime. The chief constituents of this explanation consist of:

- **(i)** The rate of recurrence of system outages within the period under consideration.
- **(ii)** (ii) The time span of outages.
- **(iii)** (iii) Scheduled uptime

Kan (2001) Observed that the frequency of outages is a direct reliability statement; and that the time span of outages may be a true reflection of the gravity of the outages. Li et al, (2020) noted that *availability* is not only a function of reliability, but also a function of maintainability and supportability. Ebeling(2008) suggested that the asymptotic is dependent on the system's Mean Time

To Failure (MTTF) and Mean Time to Repair (MTTR), in addition to maintenance and supply delay time, Where MTTF is the key indicator of system reliability, and MTTR, the key determinant of system maintainability. Gao et al (2005) investigated the operational availability and advanced delay probability into the statement of availability. Vargas (2000), accounting on reliability versus availability, opined that reliability provides a metric of how frequently a device fails, whereas availability take into account the consequences of downtime occasioned by any failures.

There is no doubt therefore that *availability* A(t) is the degree of realized mostly for repairable systems. In contrast with non-repairable system however, it equates to reliability R(t). In repairable systems, *availability* is equal or greater than *reliability.*

This paper seeks to empirically appraise the *availability* of the 500kva stand-alone power supply generating unit in the aforementioned institution, which is characterized by huge and reliable power demand, this will be done, using data collected over a period of eleven months for the evaluation. The scheduled uptime statement i.e. the institution's business requirements of the system availability are averagely 5x8 (5 days a week, 8 hours a day).

I. The Concept of Availability

Availability is defined as the probability that the system will appropriately perform its function when it is called upon. That is, it is the probability that a system has neither failed nor going through a repair activity. It therefore connotes that *availability* is a function of both reliability and maintainability (Hajeeh, M.A, 2012). The correlativity of these tripartite factors is that if the reliability is kept constant, albeit at a high value, that does not precisely purport a high availability. If the time to repair is increased, the availability dwindles. In contrast, an improvement in maintainability denotes a decline in the time taken to effect maintenance. It is informative therefore to know that a system with low reliability could have a lofty availability if it's time to repair is short Reliability Hotwire, 2003)

Availability is basically the function of time the system is in a functional status. It only counts on the operating time and downtime and disregards (discounts) idle time. It is governed by this relation:

$$\boldsymbol{Availability(A)} = \frac{\boldsymbol{Operating\ Time}}{\boldsymbol{Operating\ Time+Downtime}}$$
(i)

There is yet another extremity of *availability* referred to as *Intrinsic Availability* (A_I). This limb of availability disregards all free time such as storage time, administrative time, and logistic time. In other words, just as the name implies, intrinsic availability talks about the in-built capacity of the system to function satisfactorily within stipulated condition (Reliability blog, 2011). Intrinsic Availability (A_I) of a system is therefore expressed as the probability that it is a functioning satisfactorily at any point in time when used under stipulated conditions, where only operating time and active repair time are only considered.

$$\boldsymbol{A_I} = \frac{\boldsymbol{Operating\ Time}}{\boldsymbol{Operating\ Time+Active\ repair\ time}} \qquad \text{(ii)}$$

For a more practical purpose, equation (i) is a veritable measure of the system operational characteristics. Frequently, it is required to evaluate the interval availability, which is expressed as:

$$\boldsymbol{A\,(T)} = \frac{\boldsymbol{1}}{\boldsymbol{T}}\int_{\boldsymbol{0}}^{\boldsymbol{T}} \boldsymbol{A(t)dt} \qquad \text{(iii)}$$

This relationship denotes the measure of the *Point availability* averaged over some time interval T. The T may signify the design life of the system or the time required to perform some mission.

II. Theoretical Concept of Availability

Assuming we have a two condition set up for the system (i.e. operational or failed), if $\boldsymbol{A(t)}$ and $\widetilde{\boldsymbol{A}}$(t) are the probabilities of system being operational or having failed at any time, t, respectively, then the initial state of play is:

$\boldsymbol{A(t) = 1}$, $\widetilde{\boldsymbol{A}}$(t) = 0 and,

$\boldsymbol{A}(\boldsymbol{t}) + \widetilde{\boldsymbol{A}}(\mathrm{t}) = 1$ (iii)

Then, we can derive the equation for availability, using differential equation. Taking into account a change in $\boldsymbol{A}(\boldsymbol{t})$between $\boldsymbol{t}$and $(\boldsymbol{t} + \Delta\boldsymbol{t})$. There are two likelihood or prospects, which are:

(i) $\boldsymbol{\lambda}\Delta\boldsymbol{t}$is the conditional probability of failure during $\Delta\boldsymbol{t}$, given that the system was available at time $\boldsymbol{t}$.

(ii) $\mu\Delta\boldsymbol{t}$is the conditional probability of repair during $\Delta\boldsymbol{t}$ given system failure.

Lemmata:

(i) P [system failure during $\Delta\boldsymbol{t}$] = $\boldsymbol{\lambda}\Delta\boldsymbol{t}$

(ii) P [repair during $\Delta\boldsymbol{t}$/ system failure] = $\mu\Delta\boldsymbol{t}$

(iii) $\mathrm{A}(\boldsymbol{t} + \Delta\boldsymbol{t}) = \boldsymbol{A}(\boldsymbol{t})[1- \boldsymbol{\lambda}\Delta\boldsymbol{t}] + [1- \boldsymbol{A}(\boldsymbol{t})]\,\mu\Delta\boldsymbol{t}$

(iv) Either the system was available in time $\boldsymbol{t}$ and did not fail in the interval $\Delta\boldsymbol{t}$ or it failed during $\Delta\boldsymbol{t}$ with probability (1- $\boldsymbol{A}(\boldsymbol{t})$) and was repaired with probability$\mu\Delta\boldsymbol{t}$.

Hence,

$$\mathrm{A}(\boldsymbol{t} + \Delta\boldsymbol{t}) = \boldsymbol{A}(\boldsymbol{t})[1- \boldsymbol{\lambda}\Delta\boldsymbol{t}] + [1- \boldsymbol{A}(\boldsymbol{t})]\,\mu\Delta\boldsymbol{t} \rightarrow$$

$$\boldsymbol{A}(\boldsymbol{t}) - \boldsymbol{\lambda}\boldsymbol{A}(\boldsymbol{t})\Delta\boldsymbol{t} + \mu\Delta\boldsymbol{t} - \mu\boldsymbol{A}(\boldsymbol{t})\Delta\boldsymbol{t} \qquad \text{(iv)}$$

Hence,

$$\frac{\mathbf{A}(\boldsymbol{t}+\Delta\boldsymbol{t}) - \boldsymbol{A}(\boldsymbol{t})}{\Delta\boldsymbol{t}} = -(\boldsymbol{\lambda} + \mu)\boldsymbol{A}(\boldsymbol{t}) + \mu \qquad \text{(v)}$$

As $\Delta\boldsymbol{t} \rightarrow 0$, we have $\frac{\boldsymbol{d}}{\boldsymbol{dt}}\boldsymbol{A}(\boldsymbol{t}) = -(\boldsymbol{\lambda} + \mu)\boldsymbol{A}(\boldsymbol{t}) + \mu$

The solution to the differential equation is given by:

$$\boldsymbol{A}(\boldsymbol{t}) = \frac{\mu}{(\mu+\boldsymbol{\lambda})} + \frac{\boldsymbol{\lambda}}{(\mu+\boldsymbol{\lambda})}\boldsymbol{e}^{-(\mu+\boldsymbol{\lambda})\boldsymbol{t}} \qquad \text{(vi)}$$

$$\boldsymbol{A}(\boldsymbol{t}) = -(\boldsymbol{\lambda} + \mu)\boldsymbol{A}(\boldsymbol{t}) + \mu \qquad \text{(vii)}$$

Integration factor (IF) approaches:

$$\frac{\boldsymbol{d}}{\boldsymbol{dt}}\boldsymbol{A}(\boldsymbol{t}) + (\mu + \boldsymbol{\lambda})\boldsymbol{A}(\boldsymbol{t}) = \mu, \mathrm{IF=P} = \boldsymbol{e}^{\int(\mu+\boldsymbol{\lambda})\boldsymbol{dt}} = \boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}}$$

$$\frac{\boldsymbol{d}}{\boldsymbol{dt}}\left(\boldsymbol{A}(\boldsymbol{t})\boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}}\right) = \mu\boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}} \rightarrow \boldsymbol{A}(\boldsymbol{t})\boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}} = \mu\int\boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}} + \mathrm{C}$$

$$\boldsymbol{A}(\boldsymbol{t})\boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}} = \frac{\mu}{(\mu+\boldsymbol{\lambda})} + \boldsymbol{e}^{(\mu+\boldsymbol{\lambda})\boldsymbol{t}} + \mathrm{C}, \text{ at } \boldsymbol{t} = \mathbf{0}, \boldsymbol{A}(\mathbf{0}) = \mathbf{1}$$

Hence, $\mathrm{C} = \mathbf{1} - \frac{\mu}{(\mu+\boldsymbol{\lambda})} = \frac{\boldsymbol{\lambda}}{(\mu+\boldsymbol{\lambda})}$

$$\therefore \boldsymbol{A}(\boldsymbol{t}) = \frac{\mu}{(\mu+\boldsymbol{\lambda})} + \frac{\boldsymbol{\lambda}}{(\mu+\boldsymbol{\lambda})}\boldsymbol{e}^{-(\mu+\boldsymbol{\lambda})\boldsymbol{t}} \qquad \text{(viii)}$$

As $\boldsymbol{t}$ becomes large, the availability $\boldsymbol{A}(\boldsymbol{t})$ clearly approaches a constant value. The steady state availability is given by:

$$\lim_{\boldsymbol{t}\to\infty}\boldsymbol{A}(\boldsymbol{t}) = \frac{\mu}{(\boldsymbol{\lambda}+\mu)} = \frac{\boldsymbol{Mean\ Repair\ Rate}}{\boldsymbol{Mean\ Failure\ Rate+Mean\ Repair\ Rate}} \qquad \text{(ix)}$$

Rewriting the equation $\frac{\boldsymbol{\lambda}}{(\boldsymbol{\lambda}+\mu)}$ as:

$$\frac{\frac{1}{\lambda}}{\frac{1}{\lambda}+\frac{1}{\mu}} = \frac{1}{\lambda}\left[\frac{1}{\frac{1}{\lambda}+\frac{1}{\mu}}\right] = \frac{1}{\lambda}\left[\frac{1}{\frac{\lambda+\mu}{\lambda\mu}}\right] = \frac{\lambda\mu}{\lambda}\left[\frac{1}{\lambda+\mu}\right] = \frac{\mu}{(\lambda+\mu)} \qquad \text{(x)}$$

Therefore, $A^{*}_{(\infty)} = A_{(\infty)} = \frac{\boldsymbol{Mean\ time\ to\ failure}}{\boldsymbol{Mean\ time\ to\ repair+Meantime\ to\ failure}}$

$$A_{(\infty)} = \frac{\boldsymbol{MTTF}}{\boldsymbol{MTTF+MTTR}} \qquad \text{(xi)}$$

Methodology

The hub of this research is the "power house" of the Delta State Polytechnic Ogwashi-uku. The investigations will be carried out between September 1st, 2025 when academic activities resume for the 2025/2026 academic and June 1st, 2026. This is a period of 273 days (39 weeks)

The failure of the stand-alone generating set would be observed and recorded (i.e. t_f) and the times for its restoration back to service would as well be monitored and recorded as (t_r).

The 10months availability of the generating set will then be evaluated from the MTTF and the MTTR will also be determined. Finally, the interval (steady state) availability of the system will be calculated.

V. Results

During the period under consideration, 273 days i.e. between September 1st 2025 and June 1st 2026. The number of failures recorded is as tabulated inTable 1.

Table 1: Failure and Repair times of 500kva Stand-alone generating set

S/N	t_f(days)	t_r (days)	t_{ri} - t_{ft}	t_{ft} – t_{ri} -1
1	40.6	41.0	0.4	40.6
2	80.2	81.0	0.8	39.2
3	131.4	133.4	2.0	50.4
4	150.3	150.6	0.3	17.3
5	192.7	192.8	0.1	42.1
6	230.1	231.2	1.1	37.3
7	262.4	262.9	0.5	31.2
8	274.0	275.1	1.1	11.1
9	314.1	314.6	0.5	39.0
10	330.2	330.8	0.6	15.6
11	340.2	340.6	0.4	9.4
12	342.1	342.8	0.7	1.5

Through the period under consideration, failure was recorded for twelve times.

Hence, the availability $\tilde{A}(T) = \frac{1}{T}\sum_{i-1}^{12}(t_{ri} - t_{ft})$

$\tilde{A}(T) = \frac{1}{347}[0.4 + 0.8 + 2.0 + 0.3 + 0.1 + 1.1 + 0.5 + 1.1 + 0.5 + 0.6 + 0.4 + 0.7]$

$\tilde{A}(T) = \frac{1}{347}(8.5) = 0.0244956772$

$$A(T) = 1 - 0.0244956772$$

$$A(T) = \mathbf{0.976}$$

Estimation of the MTTF and MTTR, Let t_{ro}= 0

MTTF $= \frac{1}{N}\sum_{i-1}^{12}(t_{ft} - t_{ri})$

$= \frac{1}{12}[40.6 + 39.2 + 50.4 + 17.3 + 42.1 + 37.3 + 31.2 + 11.1 + 39.0 + 15.6 + 9.4 + 1.5]$

$= \frac{1}{12}(337.7)$

MTTF= **28.14 days**

MTTR $= \frac{1}{N}\sum_{i-1}^{12}(t_{ri} - t_{ft})$

$= \frac{1}{12}[0.4 + 0.8 + 2.0 + 0.3 + 0.1 + 1.1 + 0.5 + 1.1 + 0.5 + 0.6 + 0.4 + 0.7]$

$= \frac{1}{12}(8.5)$

MTTR = **0.71 days ≈ 17.04 hours**

Evaluation of the *Steady State Availability*:

$A^*_{(\infty)} = \frac{\mu}{(\mu+\lambda)} = \frac{\mu/\mu}{\mu/\mu + \lambda/\mu} = \frac{\frac{1}{MTTR}}{MTTF}$

$= 1 + \frac{\frac{1}{0.71}}{28.14} = \frac{1}{1.02532}$

Steady State Availability= **0.9753 = 98%**

VI. Discussion of Result

The computed result of 0.976 (97.6%) availability of the generating set implies that for the period under consideration, the 500kva generator had a 97.6% satisfactory performance, putting into consideration, the operating time and downtime.

Additionally, the MTTF result shows that the system operates for 28.14day on the average before recording any failure. In the same vein, assuming that the repair rate is constant, it always takes an average time of 0.71 days (17.04 hours) to repair the system each time it fails.

Finally, the steady state or long-run or asymptotic availability as obtained from the computation is the limit of the availability function as time tends to infinity, which also applies to mean availability.

This is typically useful in three ways namely:

- **i.** When both the failure and repair processes are exponentially distributed;
- **ii.** For evaluating the overall availability since for a reasonable time period T, availability tends to be insensitive to the details of repair and failure process and
- **iii.** As an approximation even when the failure and repair distributions are not exponential.

VII. Conclusion

In this paper, an empirical appraisal of the availability of a 500kva stand-alone electric power generating set supplying a fast growing Polytechnic has been undertaken. The study evaluated the rate of recurrence of the system outages within the period under consideration, using data collected over a period of 9 months for the appraisal of the availability of the generating set as well as estimation of the MTTF and the MTTR. Furthermore, the interval (steady state) availability of the system was determined cogitating on the scheduled uptime statement.

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Acknowledgment

The author wishes to appreciate the Tertiary Education Trust Fund (TETFund) for its financial assistance in the course of this research.