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Reliability and Performance Analysis of Standby Generator Systems for Enhancing Electrical Resilience at Sentani International Airport

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ABSTRACT

The reliability of a standby power system is essential for maintaining airport operations during disruptions to the primary electricity supply. Generator sets (gensets) serve as emergency power sources for critical facilities, including the Airfield Lighting System (AFL), Air Traffic Control (ATC), communication systems, and air navigation equipment. This study analyzes the reliability of the standby generator system at Sentani International Airport, evaluates its maintenance management, identifies factors affecting reliability, and examines its contribution to airport power resilience. A qualitative case study approach was employed using in-depth interviews, direct observations of standby generator units and supporting systems, and document analysis of maintenance records and operational procedures. Data were analyzed using the Miles, Huberman, and Saldaña interactive model, while credibility was ensured through triangulation and member checking. The findings indicate that the standby power system provides reliable backup support through redundant generator units, an Uninterruptible Power Supply (UPS), and structured preventive maintenance. Nevertheless, several operational and managerial factors continue to influence system reliability, including the characteristics of the power transfer mechanism, dependence on operational verification, utility power disturbances, fuel monitoring practices, and resource availability. The study proposes an integrated framework combining technical, maintenance, power transfer, and organizational aspects to strengthen the resilience of airport electrical infrastructure.

ABSTRAK

Keandalan sistem tenaga listrik siaga sangat penting untuk menjaga keberlangsungan operasional bandar udara ketika terjadi gangguan pada pasokan listrik utama. Generator set (genset) berfungsi sebagai sumber tenaga listrik darurat bagi fasilitas-fasilitas kritis, termasuk Sistem Penerangan Landasan (Airfield Lighting System/AFL), Pengendalian Lalu Lintas Udara (Air Traffic Control/ATC), sistem komunikasi, dan peralatan navigasi penerbangan. Penelitian ini menganalisis keandalan sistem generator siaga di Bandar Udara Internasional Sentani,

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mengevaluasi manajemen pemeliharaannya, mengidentifikasi faktor-faktor yang memengaruhi keandalan, serta mengkaji kontribusinya terhadap ketahanan sistem kelistrikan bandar udara. Penelitian ini menggunakan pendekatan studi kasus kualitatif melalui wawancara mendalam, observasi langsung terhadap unit generator siaga dan sistem pendukungnya, serta analisis dokumen pemeliharaan dan prosedur operasional. Data dianalisis menggunakan model interaktif Miles, Huberman, dan Saldaña, sedangkan kredibilitas data dijamin melalui triangulasi dan *member checking*. Hasil penelitian menunjukkan bahwa sistem tenaga listrik siaga mampu memberikan dukungan pasokan listrik cadangan yang andal melalui penerapan unit generator redundan, *Uninterruptible Power Supply* (UPS), dan pemeliharaan preventif yang terstruktur. Meskipun demikian, terdapat beberapa faktor operasional dan manajerial yang masih memengaruhi keandalan sistem, antara lain karakteristik mekanisme perpindahan sumber daya listrik, ketergantungan pada verifikasi operasional, gangguan pada pasokan listrik utama, praktik pemantauan bahan bakar, serta ketersediaan sumber daya. Penelitian ini mengusulkan kerangka kerja terpadu yang menggabungkan aspek teknis, pemeliharaan, perpindahan daya, dan organisasi untuk memperkuat ketahanan infrastruktur kelistrikan bandar udara.

INTRODUCTION

The reliability of airport electrical infrastructure plays a fundamental role in ensuring aviation safety and operational continuity. Electrical power supports various critical airport facilities, including the Airfield Lighting System (AFL), communication equipment, air navigation systems, security infrastructure, terminal buildings, and other operational services. Interruptions to the electrical supply may degrade airport service performance and, under certain operational conditions, compromise aviation safety due to the failure of safety-critical systems. Consequently, maintaining an uninterrupted electrical supply has become one of the essential requirements for airport operations.

The importance of emergency electrical power systems has been emphasized in international aviation regulations. ICAO Annex 14 Volume I stipulates that aerodromes shall be equipped with a secondary power supply capable of maintaining the operation of essential facilities whenever the primary electrical source becomes unavailable (ICAO, 2022). Likewise, NFPA 110 establishes that emergency and standby power systems must be designed, operated, tested, and maintained to ensure operational readiness under emergency conditions (NFPA, 2022). These international standards indicate that the reliability of standby power systems is not solely determined by generator capacity but also by maintenance quality, transfer switching performance, personnel competency, and the management of supporting assets.

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Sentani International Airport serves as the primary aviation gateway in Papua Province and performs a strategic role in connecting eastern Indonesia through passenger, cargo, and pioneer flight services. According to the 2025 Sentani International Airport Air Transportation Statistics, the airport handled 40,808 aircraft movements, 1,806,228 passengers, 15,106,779 kg of baggage, and 103,191,505 kg of cargo. The magnitude of these operational activities reflects the airport's high dependence on a reliable electrical infrastructure to sustain uninterrupted services. Any failure of the emergency power system has the potential to affect airport operational performance, particularly during disruptions to the utility power supply.

To maintain operational continuity, Sentani International Airport employs generator sets (gensets) as the primary emergency power source during failures of the public electricity grid. In airport electrical systems, gensets are expected to operate automatically through an Automatic Transfer Switch (ATS) while ensuring uninterrupted power delivery to essential facilities, supported by an Uninterruptible Power Supply (UPS) where required. Therefore, the operational reliability of the standby power system is influenced by multiple interconnected factors, including equipment condition, preventive maintenance practices, transfer switching performance, spare-part availability, fuel management, and the competency of operational personnel.

From an infrastructure management perspective, emergency power systems represent critical assets requiring systematic lifecycle management. ISO 55001:2022 emphasizes that infrastructure assets should be managed through integrated planning, operation, maintenance, performance evaluation, and continuous improvement to maximize asset value and operational performance. Accordingly, evaluating generator reliability should extend beyond technical performance and include operational management practices that contribute to long-term asset sustainability.

Previous studies have demonstrated that maintenance strategies significantly influence generator reliability. Widdana and Lukmandono (2023) reported that the implementation of Reliability Centered Maintenance (RCM) improves maintenance effectiveness by identifying critical components and optimizing maintenance scheduling. Similarly, Wijaya et al. (2025) found that consistent preventive maintenance extends equipment service life while reducing the probability of unexpected failures. Other studies have predominantly focused on generator engine performance, electrical protection systems, maintenance optimization, and industrial power system reliability.

Despite these advances, limited attention has been devoted to evaluating generator reliability within airport electrical infrastructures using a comprehensive operational perspective. Existing studies generally examine technical or maintenance aspects independently, whereas the reliability of airport standby power systems is simultaneously influenced by technical condition, maintenance management, transfer switching performance, spare-part logistics, personnel readiness, and organizational operational procedures.

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Furthermore, empirical investigations involving airports in eastern Indonesia remain scarce despite their strategic importance and unique operational characteristics. This limitation indicates a significant research gap in the current body of knowledge.

Unlike previous studies, this research adopts a holistic reliability assessment by integrating technical, operational, maintenance, and organizational dimensions of generator system performance within an airport environment. This integrated approach is expected to provide a more comprehensive understanding of factors affecting emergency electrical system reliability and to contribute practical recommendations for improving airport electrical resilience.

Therefore, this study aims to evaluate the reliability of the generator set system as the emergency power supply at Sentani International Airport by analyzing equipment operational conditions, maintenance implementation, power transfer mechanisms, spare-part management, personnel readiness, and other factors influencing system reliability. The findings are expected to enrich the literature on airport electrical infrastructure management while providing practical recommendations for enhancing the reliability and resilience of emergency power systems in airport operations..

RESEARCH METHOD

This study employed a qualitative descriptive approach using a case study design to evaluate the reliability of the generator set (genset) system as the emergency power supply at Sentani International Airport. A qualitative approach was selected because the reliability of the standby power system is influenced not only by the technical condition of the equipment but also by maintenance management, operational procedures, spare-part availability, Automatic Transfer Switch (ATS) performance, Uninterruptible Power Supply (UPS) readiness, and personnel competency. Therefore, an in-depth investigation was required to obtain a comprehensive understanding of the factors affecting the reliability of the airport emergency electrical system.

The research was conducted at Sentani International Airport, Jayapura Regency, Papua Province, Indonesia. The airport operates continuously and utilizes standby generator units as an emergency power source to support critical airport facilities. Data were collected through semi-structured interviews with the Technical Coordinator and Field Technician responsible for operating and maintaining the standby power system. Direct observations were conducted to examine the operational condition of the generators, Automatic Transfer Switch (ATS), Uninterruptible Power Supply (UPS), fuel storage facilities, and other supporting electrical infrastructure. Documentary evidence, including maintenance schedules, operational logbooks, technical specifications, airport operational statistics, and maintenance records, was also analyzed to complement and validate the primary data.

The collected data were analyzed using the interactive qualitative analysis model

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proposed by Miles, Huberman, and Saldaña (2020), consisting of data reduction, data display, and conclusion drawing with continuous verification. Interview transcripts, observation records, and documentary evidence were systematically coded and categorized according to the research indicators, including equipment operational condition, preventive maintenance, ATS performance, spare-part management, personnel competency, and operational constraints. Subsequently, thematic analysis was employed to identify recurring patterns and relationships among these indicators, allowing the interpretation of factors influencing the reliability of the generator system.

To ensure the trustworthiness of the findings, methodological triangulation was applied by comparing information obtained from interviews, direct observations, and documentary evidence. Source triangulation was also performed by cross-checking information provided by different informants with maintenance records and operational documents. This validation process enhanced the credibility, consistency, and reliability of the research findings regarding the emergency electrical power system at Sentani International Airport.

RESULTS AND DISCUSSION

Existing Condition of the Emergency Power System at Sentani International Airport

The reliability of an airport electrical system is one of the fundamental requirements for maintaining operational continuity and aviation safety. Critical airport facilities—including the Airfield Lighting System (AFL), Communication, Navigation, and Surveillance (CNS) equipment, security systems, terminal operations, and information technology infrastructure—require an uninterrupted power supply to ensure continuous operation. Consequently, the availability of an emergency power supply system becomes an essential component in maintaining airport resilience against disturbances originating from the primary electrical network.

Sentani International Airport, located in Jayapura Regency, Papua Province, Indonesia, functions as the primary aviation gateway connecting eastern Indonesia with major domestic destinations. As an airport operating continuously for 24 hours, the reliability of its electrical infrastructure directly influences operational performance and service continuity. In accordance with ICAO Annex 14 (2022), airports are required to provide a secondary power supply capable of maintaining critical operational facilities during interruptions of the primary electrical source. This requirement highlights that emergency electrical systems are not merely supporting facilities but constitute an integral component of aviation safety management.

The primary electrical supply at Sentani International Airport is obtained from the national utility network. To mitigate operational risks associated with interruptions to the utility network, the airport is equipped with an Emergency Power Supply System (EPSS) consisting of standby diesel generator units. The generator units operate as standby power sources to support critical electrical loads whenever disturbances occur within the primary

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distribution network.

From a reliability engineering perspective, the installation of two independent generator units represents a redundant configuration designed to improve system availability and operational resilience. Redundancy is widely recognized as one of the most effective strategies for reducing the probability of total system failure because electrical loads can continue to be supplied even when one standby generator becomes unavailable due to maintenance activities or unexpected equipment failure. Such redundancy is particularly important in airport electrical systems, where interruptions of critical loads may directly affect flight safety and airport operations.

The emergency electrical infrastructure is further supported by an Automatic Transfer Switch (ATS) responsible for transferring electrical loads from the utility network to the standby generators during outages and restoring the load to the utility supply once normal conditions have resumed. In addition, an Uninterruptible Power Supply (UPS) is installed to maintain uninterrupted electrical service for critical equipment during the transition period before the generators reach stable operating conditions. The integration of generator redundancy, ATS, and UPS establishes a layered protection strategy that enhances the resilience of the airport electrical system against power interruptions.

Field observations indicated that both generator units were installed within a dedicated generator room equipped with adequate ventilation, fuel storage facilities, control panels, cooling systems, batteries, and supporting electrical accessories. The physical condition of the generator room demonstrated good housekeeping practices that facilitate inspection, maintenance activities, and emergency operation while minimizing environmental factors that could potentially reduce equipment reliability.

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Figure 1. The standby generator units installed at sentani international airport.

The observational assessment further revealed that no visible structural deterioration, coolant leakage, fuel leakage, or abnormal mechanical conditions were identified during the inspection. The batteries, radiator system, fuel storage facilities, and control panels remained in operational condition. Meanwhile, the ATS was found to operate using a semi-automatic switching mechanism, whereas the UPS continuously supplied electrical power to safety-critical equipment during temporary interruptions.

Table 1. Observation Results of the Emergency Electrical System

No	Component	Observation Result
1	Generator Set 1	No physical damage observed; ready for operation
2	Generator Set 2	No physical damage observed; ready for operation
3	Radiator	No indication of coolant leakage
4	Battery System	Installed and functioning normally
5	Automatic Transfer Switch (ATS)	Operated using a semi-automatic mechanism
6	Uninterruptible Power Supply (UPS)	Installed for critical loads
7	Fuel Storage Tank	Ready for operation

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No	Component	Observation Result
8	Generator Room	Clean, organized, and suitable for maintenance activities

Source: Field observation (2026).

The observational findings indicate that the emergency electrical infrastructure at Sentani International Airport satisfies the basic technical requirements for supporting operational continuity during utility power failures. The availability of dual standby generators, supported by ATS and UPS, demonstrates the implementation of multiple layers of electrical protection consistent with the principles of infrastructure resilience. However, the presence of a semi-automatic transfer mechanism suggests that system reliability remains partially dependent on operator intervention during emergency conditions. This finding indicates that although equipment availability is considered satisfactory, operational reliability may still be influenced by human factors, particularly during emergency switching procedures.

The operational significance of the emergency electrical system becomes increasingly evident when considering the airport's traffic volume. According to the 2025 Air Transportation Statistics, Sentani International Airport handled 40,808 aircraft movements, 1,806,228 passengers, 15,106,779 kg of baggage, and 103,191,505 kg of cargo, confirming its strategic role as one of the busiest airports in eastern Indonesia.

Table 2. Operational Statistics of Sentani International Airport in 2025

No	Uraian	Jumlah
1	Aircraft Movements	40,808
2	Passengers	1,806,228
3	Baggage	15,106,779 kg
4	Cargo	103,191,505 kg
5	Mail	1,294 kg

Source: Sentani Airport Statistics (2025).

The high operational intensity reinforces the necessity of maintaining a highly reliable emergency electrical infrastructure. Any interruption of electrical service, even for a relatively short duration, may disrupt communication systems, navigation aids, terminal operations, airfield lighting, baggage handling, and security facilities. Therefore, the standby power system performs not merely as a backup utility but as a critical component supporting airport operational resilience.

Overall, the findings demonstrate that the emergency electrical system at Sentani

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International Airport possesses several characteristics associated with a reliable standby power infrastructure, including redundant generator configuration, preventive operational readiness, dedicated supporting facilities, and integration with ATS and UPS. Nevertheless, the observed dependence of the transfer process on semi-automatic switching indicates an opportunity for future modernization through fully automated power transfer technology. Such improvement would further reduce operational risks associated with human intervention and enhance the resilience of airport electrical operations, particularly during emergency conditions.

Reliability Assessment of the Generator Set System

The reliability of an emergency power system is determined not only by the operational condition of the generator units but also by the effectiveness of maintenance management, spare-part availability, organizational support, and operational preparedness. Based on interviews with the Technical Coordinator and Field Technician, combined with field observations and maintenance documentation, the standby generator system at Sentani International Airport has implemented several preventive strategies to ensure operational readiness during utility power failures.

One of the major findings concerns the management of spare parts. The Technical Coordinator explained that procurement planning is conducted approximately three months before the scheduled replacement of critical components. This strategy was developed to anticipate the relatively long logistics distribution time to Papua, which is considerably longer than distribution to western Indonesia. Consequently, replacement components are generally available before maintenance activities are performed, minimizing the possibility of maintenance delays caused by supply shortages.

From the perspective of asset management, this procurement strategy represents an important preventive approach for maintaining system availability. Unlike corrective inventory practices that respond only after component failures occur, advance procurement reduces maintenance downtime and improves equipment readiness. The finding supports the principles of ISO 55001, which emphasize that asset performance is strongly influenced by systematic planning throughout the asset life cycle. Similar observations were reported by Widdana and Lukmandono (2023), who concluded that proactive spare-part management contributes significantly to improving generator reliability by reducing the probability of extended equipment outages.

In addition to inventory management, organizational commitment was reflected in the maintenance budgeting system. Interview results indicated that generator maintenance activities are financed through the company's annual work and budget plan (RKAP). Furthermore, budget allocation remains flexible whenever urgent maintenance requirements arise. According to the Technical Coordinator, maintenance activities associated with the electrical division may temporarily utilize available funds from the mechanical division before

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administrative adjustments are completed through the headquarters.

This flexible budgeting mechanism demonstrates that management recognizes the emergency power system as a critical operational asset. Within the framework of Reliability Centered Maintenance (RCM), organizational support through adequate financial resources is considered an essential factor for sustaining maintenance effectiveness. Maintenance activities that are delayed due to budget limitations frequently increase equipment failure risk and reduce operational availability. Therefore, the budgeting strategy implemented at Sentani International Airport contributes positively to maintaining standby power reliability.

Another important aspect influencing reliability is the implementation of preventive maintenance. Based on interview findings, maintenance activities consist of daily inspections, scheduled engine exercise, and monthly performance testing. Rather than waiting until equipment failure occurs, maintenance personnel continuously monitor the operational condition of the generator system to identify potential abnormalities before they develop into major failures.

Daily inspections include examination of lubrication oil, cooling water, batteries, fuel supply, electrical control panels, and visual inspection for leakage or abnormal operating conditions. All inspection results are documented in maintenance logbooks, allowing maintenance personnel to evaluate equipment trends and identify gradual performance degradation over time.

The implementation of routine inspections reflects the application of condition monitoring, which is widely recognized as one of the most effective preventive maintenance practices in electrical infrastructure. Continuous monitoring enables maintenance personnel to detect early indications of deterioration before failures affect operational performance. Similar findings have been reported by Maulana (2024), who demonstrated that systematic inspection activities significantly improve equipment availability by reducing unexpected failures.

The airport also performs routine engine exercise as part of its preventive maintenance program. Regular operation allows lubricating oil to circulate through internal engine components, maintains battery charging conditions, reduces the potential for moisture accumulation, and verifies the functionality of cooling and fuel systems. Maintaining these operating conditions is particularly important because standby generators may remain inactive for extended periods while being required to operate immediately during emergency situations..

Engine exercise serves several technical purposes beyond simply starting the generator. Regular operation allows lubricating oil to circulate throughout internal engine components, maintains battery charging conditions, prevents moisture accumulation within the engine, and verifies the functionality of cooling and fuel systems. Maintaining these operating conditions is particularly important because standby generators generally remain inactive for extended periods and are required to operate immediately during emergency situations.

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From a reliability engineering perspective, scheduled engine exercise contributes directly to improving starting reliability, which represents one of the most critical performance indicators for emergency generators. Failure to start during utility outages would immediately compromise airport operational continuity regardless of the physical condition of the generator itself. Therefore, routine engine exercise reduces the likelihood of latent failures caused by prolonged standby conditions. These findings are consistent with Wijaya et al. (2025), who emphasized that periodic engine operation significantly improves generator readiness while extending equipment service life.

Preventive maintenance activities are further strengthened through monthly performance checks, during which the entire generator system is operated under standard operational procedures. Unlike routine inspections, performance testing evaluates the integrated operation of the generator, electrical control system, battery starter, cooling system, distribution panels, and supporting equipment under actual operating conditions.

Performance testing represents an important verification process because it confirms that the standby power system is capable of supplying electrical loads whenever interruptions occur within the utility network. According to the Technical Coordinator, all performance testing activities are documented and subsequently evaluated to identify maintenance requirements before operational failures occur.

The implementation of periodic performance testing demonstrates that maintenance management at Sentani International Airport extends beyond equipment inspection toward functional verification of the complete emergency electrical system. Kamal et al. (2026) similarly reported that regular testing of generator starter batteries and electrical control systems significantly reduces emergency starting failures in airport standby power systems.

Overall, the findings indicate that maintenance management at Sentani International Airport has adopted the fundamental principles of preventive maintenance rather than relying primarily on corrective maintenance. This strategy is characterized by scheduled inspections, periodic engine exercise, systematic performance testing, structured maintenance documentation, and proactive spare-part procurement. The integration of these maintenance activities enhances operational readiness while reducing the probability of unexpected equipment failure.

Nevertheless, several opportunities remain for improving maintenance effectiveness. Current maintenance activities are primarily based on predetermined schedules rather than continuous equipment condition monitoring. Recent developments in industrial asset management increasingly recommend the implementation of Condition-Based Maintenance (CBM) and Predictive Maintenance (PdM), which utilize digital sensors to monitor parameters such as engine temperature, lubrication pressure, battery health, vibration levels, and fuel consumption in real time. The adoption of these technologies would enable maintenance activities to be scheduled according to actual equipment condition, thereby improving

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maintenance efficiency while further increasing the reliability of the airport emergency power system.

The overall findings demonstrate that preventive maintenance constitutes one of the most influential factors supporting generator reliability at Sentani International Airport. Combined with effective inventory planning and organizational commitment, the existing maintenance strategy has established a solid foundation for maintaining the operational readiness of the airport standby power system. However, future integration of digital monitoring technologies and predictive maintenance approaches would further strengthen asset reliability and improve the resilience of critical airport electrical infrastructure.

Performance Analysis of the Power Transfer System

The effectiveness of an emergency power supply system is determined not only by the operational readiness of the standby generators but also by the capability of the power transfer system to restore electrical service rapidly and safely following disturbances in the primary utility network. In airport electrical infrastructure, the transfer process represents one of the most critical stages because delays in power restoration may interrupt the operation of communication systems, navigation equipment, airfield lighting, security systems, and other safety-critical facilities.

Field observations and interviews revealed that the emergency power system at Sentani International Airport employs an Automatic Transfer Switch (ATS) integrated with an Uninterruptible Power Supply (UPS) to maintain operational continuity during utility failures. Although the existing system has successfully supported airport operations, the study identified several operational characteristics that influence the overall reliability of the standby power system.

1. Performance of the Automatic Transfer Switch (ATS)

Interview results indicated that the Automatic Transfer Switch (ATS) operates with a semi-automatic transfer mechanism. Under normal operating conditions, the control system detects disturbances in the utility electrical network and initiates the generator starting sequence. Before electrical loads are completely transferred to the standby generators, operators are required to verify the breaker position and perform operational checks according to established procedures.

The transfer process therefore remains partially dependent on operational verification and procedural compliance. Although this configuration has supported airport operations under the conditions observed during the study, the involvement of operators introduces a human factor that may influence the consistency of emergency power restoration.

From the perspective of reliability engineering, the performance of the transfer system is an important component of emergency power system reliability because it determines the effectiveness of the transition between primary and standby power sources. Consequently,

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overall system reliability depends not only on equipment condition but also on operator readiness, decision-making, and compliance with established procedures.

The findings indicate that the standby power system demonstrates satisfactory equipment reliability, while operational reliability remains influenced by the characteristics of the transfer mechanism and human factors. Improvements in transfer automation may therefore contribute to reducing operational variability and strengthening the resilience of the emergency electrical system.

2. Contribution of the Uninterruptible Power Supply (UPS)

Although the generator transfer process requires a measurable transfer interval, interviews confirmed that electrical service to critical airport facilities remains uninterrupted because these loads are continuously supported by an Uninterruptible Power Supply (UPS).

The UPS functions as an instantaneous backup power source during the interval between utility failure and generator stabilization. Critical facilities supplied by the UPS include communication equipment, navigation systems, computer servers, network infrastructure, and operational control systems that cannot tolerate even brief interruptions.

The integration of UPS technology substantially improves the resilience of the airport electrical system because it eliminates transient power interruptions that could otherwise affect aviation safety. Consequently, the observed transfer delay associated with the semi-automatic ATS does not directly interrupt critical airport operations, since the UPS bridges the temporary loss of utility power until generator output becomes stable.

This layered protection strategy reflects the application of the defence-in-depth principle, whereby multiple backup systems collectively reduce the probability of complete electrical failure. Rather than relying solely on standby generators, the airport electrical infrastructure incorporates complementary protection through UPS technology, thereby enhancing the overall resilience of the emergency power supply system.

The present findings are consistent with IEC 62040-1 (2023), which identifies UPS systems as essential components for maintaining uninterrupted power to critical electrical loads during switching between primary and standby power sources.

3. Operational Risks Associated with Semi-Automatic Transfer

Despite its satisfactory operational performance, the existing transfer configuration presents several operational considerations that should be addressed within future reliability improvement programs. The main consideration is the dependence on operator verification and procedural compliance during the transfer of electrical loads between the primary and standby power sources.

Such dependence may introduce variability in emergency response, particularly when operational conditions require rapid decision-making. Factors such as workload,

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communication, and the complexity of emergency conditions may influence the consistency of the transfer process.

Within the framework of Human Reliability Analysis (HRA), these findings indicate that operational performance is influenced not only by equipment capability but also by human and organizational factors. Strengthening automation, procedural controls, competency development, and monitoring systems may therefore contribute to reducing operational uncertainty and improving the consistency of emergency power transfer.

4. Discussion of Power Transfer System Reliability

Overall, the findings demonstrate that the power transfer system currently provides an acceptable level of operational reliability for supporting airport activities. The combination of redundant standby generators, UPS protection, and established operating procedures enables continuous operation of critical airport facilities during electrical disturbances.

However, the present study also indicates that system resilience may be further improved through increased automation. While equipment reliability is already satisfactory, operational reliability remains constrained by the semi-automatic transfer mechanism, which introduces dependency on operator intervention and procedural execution.

From a resilience perspective, modernization of the ATS would provide several operational advantages, including reduced transfer time, lower probability of human error, faster restoration of electrical service, and improved consistency during emergency operation. Furthermore, integration of digital monitoring technologies with the transfer control system would enable continuous supervision of breaker status, synchronization conditions, and electrical parameters, thereby supporting predictive decision-making and enhancing situational awareness for maintenance personnel.

These findings suggest that future improvements in airport emergency electrical systems should prioritize not only increasing generator capacity but also strengthening the intelligence and automation of supporting electrical infrastructure. Such developments would align with current trends in smart electrical asset management, where digital monitoring, automated control, and predictive maintenance are integrated to maximize system reliability and operational resilience.

Factors Affecting Generator Reliability and Practical Implications

The findings of this study demonstrate that the reliability of the standby power system at Sentani International Airport is influenced by multiple interrelated technical and organizational factors rather than by the operational condition of the generator units alone. Analysis of field observations, interviews, and maintenance documentation indicates that generator reliability is determined by the interaction between maintenance management, power transfer performance, spare-part availability, human resources, external electrical disturbances, and supporting

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infrastructure. These findings reinforce the concept that emergency power reliability should be evaluated from a systems perspective, where the performance of each subsystem contributes to the reliability of the overall airport electrical infrastructure.

One of the technical factors identified during the study was the occurrence of disturbances in the utility electrical supply. Such disturbances may activate the protection and standby power response mechanisms even when a complete loss of utility power does not occur. Although the response indicates that the protection system functions in accordance with its intended purpose, unnecessary activation of standby equipment may increase operating hours and maintenance requirements.

From the perspective of power system protection, periodic evaluation of protection parameters and coordination should therefore form part of routine maintenance activities. Appropriate evaluation may help minimize unnecessary generator activation while maintaining the required level of operational reliability.

Another significant factor influencing reliability is the semi-automatic configuration of the Automatic Transfer Switch (ATS). As discussed in the previous section, operator intervention remains necessary before transferring electrical loads from the utility network to the standby generators. Although the existing procedure has proven effective under current operational conditions, dependence on manual verification inevitably introduces variability into emergency response performance.

From the standpoint of Human Reliability Analysis (HRA), operational performance depends not only on equipment capability but also on the cognitive performance of operators during emergency situations. Fatigue, workload, communication delays, or procedural deviations may increase restoration time and consequently reduce operational resilience. Accordingly, modernization toward a fully automatic transfer system represents one of the most effective strategies for reducing operational risks associated with human intervention.

Fuel management also emerged as an important factor affecting long-term generator reliability. Interviews indicated that fuel level monitoring is currently supported by routine recording and inspection activities. Although this practice has supported operational requirements, the absence of continuous digital monitoring limits the availability of real-time information regarding fuel conditions.

The implementation of an appropriate digital fuel monitoring system could improve operational visibility and support more effective planning during prolonged emergency generator operation. Such technology may also contribute to condition-based maintenance by providing more consistent information for maintenance and operational decision-making.

Although manual recording has supported operational activities satisfactorily, this approach provides limited real-time information regarding available fuel capacity. In emergency situations requiring prolonged generator operation, inaccurate estimation of remaining fuel could potentially affect operational continuity. Recent developments in

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industrial asset management increasingly recommend the implementation of digital fuel monitoring systems capable of continuously measuring storage levels and transmitting operational data to maintenance personnel. Such technology supports condition-based maintenance by providing accurate information for operational planning while reducing

The study also identified organizational factors affecting standby power reliability. Interviews indicated that the electrical maintenance unit is supported by technical personnel assigned across operational shifts to provide continuous support for airport operations. The existing staffing arrangement has supported maintenance activities and emergency response under normal operating conditions.

Nevertheless, staffing capacity may become constrained when personnel participate in training, annual leave, or other assignments. Under such circumstances, the workload of available technical personnel may increase, particularly when multiple maintenance activities or unexpected electrical disturbances occur simultaneously.

These findings highlight the importance of human resources as a critical component of infrastructure reliability. Continuous professional development, periodic technical training, and appropriate workforce planning therefore remain important strategies for sustaining long-term operational reliability.

The present study further demonstrates that maintenance documentation contributes significantly to reliability management. Daily inspection reports, engine exercise records, monthly performance tests, and maintenance logbooks provide historical operational information that supports maintenance planning and facilitates early identification of equipment deterioration. Documentation also enhances traceability, enabling maintenance personnel to evaluate equipment performance trends throughout the operational life cycle.

Despite the generally satisfactory operational condition observed during the study, opportunities remain for improving the reliability of the emergency electrical system through digital transformation. Contemporary airport infrastructure is increasingly adopting smart maintenance technologies, including Internet of Things (IoT)-based sensors, Supervisory Control and Data Acquisition (SCADA), predictive analytics, and remote monitoring systems. Integration of these technologies would enable continuous observation of engine temperature, lubrication pressure, battery condition, vibration, fuel level, electrical loading, and transfer system status. Consequently, maintenance decisions could be based on actual equipment condition rather than predetermined maintenance intervals.

The implementation of predictive maintenance would represent a significant advancement beyond the preventive maintenance strategy currently employed at Sentani International Airport. Whereas preventive maintenance reduces failure probability through scheduled inspections, predictive maintenance further improves reliability by identifying degradation before functional failure occurs. Such an approach is fully consistent with the asset management principles established in ISO 55001, which emphasize lifecycle optimization, risk-

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based decision-making, and continual improvement of infrastructure performance.

Overall, the findings indicate that the standby generator system at Sentani International Airport currently demonstrates a satisfactory level of operational reliability. The combination of redundant generator units, preventive maintenance practices, structured spare-part management, organizational support, and UPS protection has successfully maintained electrical service continuity during disturbances affecting the primary utility network. However, this study also demonstrates that future improvements should focus on enhancing system intelligence rather than merely increasing equipment capacity.

The proposed framework illustrates that generator reliability is the result of interactions among technical performance, maintenance management, organizational capability, and supporting electrical infrastructure. Unlike previous studies that primarily focused on generator performance or maintenance scheduling, this research demonstrates that the reliability of airport standby power systems should be evaluated using an integrated systems approach. The findings therefore contribute not only to improving maintenance practices at Sentani International Airport but also provide a practical framework that may be adopted by other airports with similar operational characteristics to strengthen the resilience of emergency electrical infrastructure.

CONCLUSION

This study analyzed the reliability and operational performance of the standby generator system at Sentani International Airport by examining its technical condition, maintenance management practices, power transfer system, and organizational support. The findings indicate that the emergency power system demonstrates satisfactory operational reliability in supporting electrical service continuity during disturbances affecting the primary utility network. The implementation of redundant standby generator units, Uninterruptible Power Supply (UPS) support, preventive maintenance activities, and structured spare-part management contributes to maintaining the operational readiness of critical airport facilities.

The study further demonstrates that standby power reliability is determined by the interaction of technical, operational, maintenance, and organizational factors rather than by generator performance alone. Preventive maintenance, routine inspections, equipment testing, maintenance documentation, spare-part planning, and personnel readiness collectively support equipment availability and operational continuity.

Nevertheless, the findings indicate that further improvements are required in the areas of power transfer automation, digital condition monitoring, fuel monitoring, and human-resource capability. These improvements should be implemented as part of an integrated asset management approach that considers technical infrastructure, operational procedures, maintenance practices, and organizational readiness.

The practical contribution of this research lies in providing an integrated framework for

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evaluating standby power system reliability in airport environments. The framework incorporates technical performance, maintenance management, power transfer, supporting infrastructure, spare-part management, and human-resource readiness. Future improvements should prioritize appropriate automation of the power transfer system, implementation of digital condition monitoring and predictive maintenance technologies, and continuous enhancement of technical personnel competencies.

Future research is recommended to complement the qualitative findings with quantitative reliability analysis using approaches such as Failure Mode and Effects Analysis (FMEA), Reliability Centered Maintenance (RCM), Fault Tree Analysis (FTA), Reliability Block Diagram (RBD), or Mean Time Between Failure (MTBF) analysis. Such approaches may provide a more comprehensive assessment of standby power system reliability while supporting evidence-based improvement of airport electrical infrastructure.

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