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OPTIMIZING GENERATOR SET MAINTENANCE FOR EMERGENCY BACKUP POWER SUPPLY AT BAROMBONG POLYTECHNIC OF MARITIME STUDIES

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Abstract

Electrical power is essential for supporting educational, administrative, and operational activities at Barombong Polytechnic of Maritime Studies. Frequent interruptions in the electricity supply from the national utility company (PLN) may disrupt campus operations, making generator sets (gensets) indispensable as emergency backup power sources. This study aimed to optimize the generator maintenance system to improve its reliability, operational efficiency, and long-term performance. A descriptive qualitative approach was employed using observations, interviews, and documentation involving generator operators and maintenance technicians. The collected data were analyzed using the Failure Mode and Effects Analysis (FMEA) method to identify potential failure modes, evaluate associated risks, and establish maintenance priorities through Risk Priority Number (RPN) analysis. The results revealed that the most critical failures involved the Under Voltage Release (UVR) of the MCCB on the Automatic Transfer Switch (ATS) panel, radiator leakage, and fuel filter leakage. These failures were primarily attributed to inadequate preventive maintenance, limited spare-part availability, and insufficient technical competence among operators. The study concludes that integrating Risk-Based Maintenance (RbM), strengthening preventive maintenance practices, and enhancing technicians' competencies can significantly improve generator reliability, operational efficiency, and the continuity of emergency power supply in maritime higher education institutions.

Keywords: Generator set, preventive maintenance, maintenance optimization, Failure Mode and Effects Analysis (FMEA), Risk-Based Maintenance, emergency backup power.

INTRODUCTION

Barombong Polytechnic of Maritime Studies is a public higher education institution under the Ministry of Transportation of the Republic of Indonesia and operates under the supervision of the Transportation Human Resources Development Agency (BPSDM). The institution is responsible for providing vocational education, conducting research, and delivering community service in the maritime sector. As one of Indonesia's leading maritime education institutions, Barombong Polytechnic of Maritime Studies is committed to producing competent, professional, and ethical maritime officers capable of supporting safe and sustainable maritime transportation. This commitment requires reliable educational infrastructure, including dependable electrical systems that support teaching, training, laboratory activities, and campus administration (Abdullah, 2021; Kadir, 2021; Daryanto, 2020).

Electrical power has become an indispensable component of modern educational institutions because it supports classroom instruction, laboratory experiments, administrative services, communication systems, and digital learning technologies. Interruptions in electrical power may significantly disrupt educational activities, reduce institutional productivity, and compromise operational efficiency. Consequently, higher education institutions require reliable backup power systems capable of maintaining essential operations during unexpected power outages (Nasir & Pratama, 2020; Supriyadi, 2021; Pinciroli et al., 2023) Generator sets (gensets) are widely used as emergency backup power sources due to their ability to provide electricity immediately when the primary power supply fails. However, generator reliability is highly dependent on effective maintenance management. Inadequate maintenance may lead to unexpected equipment failures, increased repair costs, reduced equipment lifespan, and prolonged operational downtime. Recent developments in maintenance engineering emphasize the integration of preventive, predictive, and risk-based maintenance strategies to improve equipment reliability and operational efficiency (Zonta et al., 2020; Meissner et al., 2021; Carvalho et al., 2020; Pinciroli et al., 2023).

Maintenance includes inspection, servicing, cleaning, adjustment, testing, repair, and replacement of equipment components to ensure operational readiness and equipment reliability. Preventive maintenance plays a crucial role in minimizing unexpected failures by identifying potential problems before they develop into serious operational disruptions. Previous studies have shown that systematic maintenance significantly improves equipment availability, reduces maintenance costs, and enhances operational safety (Huda, 2018; Mulyadi & Rahman, 2022; Ahmad et al., 2021). At Barombong Polytechnic of Maritime Studies, uninterrupted electrical power is essential for supporting lectures, laboratory activities, simulators, workshops, internet connectivity, and administrative operations. During natural disasters or failures of the public electricity network, the availability of a reliable standby generator becomes critical for maintaining educational continuity. Therefore, optimizing generator maintenance through systematic inspection and preventive maintenance procedures is essential for ensuring operational reliability and reducing the risk of unexpected failures (Supriyadi, 2021; Nasir & Pratama, 2020).

Although numerous studies have investigated generator maintenance, most previous research has focused on industrial facilities, hospitals, manufacturing systems, and maritime vessels (Ardhi Dharmawan, 2020; Alief Yuliyanto, 2023; Daffa Rizky Aulia, 2023). Studies specifically examining the application of **Failure Mode and Effects Analysis (FMEA)** to optimize standby generator maintenance in maritime higher education institutions remain limited. Furthermore, few studies have combined field observations with risk prioritization to develop maintenance recommendations for educational facilities. Therefore, this study applies the FMEA approach to identify critical failure modes and propose maintenance strategies that improve the reliability of emergency backup power systems at Barombong Polytechnic of Maritime Studies. Furthermore, the importance of an effective emergency power system becomes even more significant during natural disasters or extreme weather conditions that may interrupt the main electricity supply. Under such circumstances, a well-maintained generator system ensures the continuity of teaching, learning, and administrative services. Maintenance optimization therefore involves not only routine inspections but also systematic preventive maintenance, proper operational procedures, timely component replacement, and adequate technical training for operators and maintenance personnel. This study aims to evaluate the existing generator maintenance practices at Barombong Polytechnic of Maritime Studies and to develop strategies to optimize maintenance performance, thereby improving generator reliability and operational efficiency as an emergency backup power source. The findings are expected to contribute to more effective maintenance management and support sustainable electrical infrastructure within the institution.

Based on the background described above, this study addresses the following research questions:

1. How effective is the current generator maintenance system implemented at Barombong Polytechnic of Maritime Studies?
2. What factors influence the reliability and operational efficiency of the generator system?
3. What maintenance strategies can be implemented to improve the reliability and efficiency of generator sets as emergency backup power sources at Barombong Polytechnic of Maritime Studies?

LITERATURE REVIEW

Maintenance Optimization

Maintenance optimization is a systematic approach to maximizing equipment availability, reliability, and operational efficiency while minimizing maintenance costs and unexpected failures (Abdullah, 2021; Pinciroli et al., 2023). In industrial facilities, maintenance optimization has evolved from traditional corrective maintenance toward predictive and risk-based maintenance strategies supported by Industry 4.0 technologies (Zonta et al., 2020; Meissner et al., 2021). These approaches emphasize data-driven decision-making to improve equipment reliability and reduce operational downtime. For critical electrical infrastructure, standby generator systems must remain operational whenever the primary power supply fails. Although public electricity networks generally provide reliable service, interruptions caused by natural disasters, equipment failures, or grid disturbances may still occur. Consequently, organizations that depend on continuous electrical power should implement systematic maintenance programs to ensure generator readiness (Kadir, 2021; Daryanto, 2020).

Preventive Maintenance

Preventive maintenance is widely recognized as one of the most effective maintenance strategies for improving equipment reliability and extending service life (Supriyadi, 2021). This maintenance strategy consists of scheduled inspections, cleaning, lubrication, replacement of worn components, and routine operational testing before

failures occur (Huda, 2018). According to Ahmad et al. (2021), preventive maintenance significantly reduces unexpected equipment failures and minimizes maintenance costs when implemented systematically.
For diesel generator systems, preventive maintenance generally includes inspections of the lubrication system, cooling system, fuel system, starting battery, electrical control system, and periodic generator exercise (Nasir & Pratama, 2020). Environmental conditions such as high temperature, humidity, dust, and salt exposure may accelerate component deterioration and therefore require shorter maintenance intervals (Daryanto, 2020).

Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) is a systematic risk assessment tool used to identify potential equipment failures, determine their causes, evaluate their consequences, and prioritize corrective actions (McDermott et al., 2009). The method evaluates each failure mode using three parameters: Severity, Occurrence, and Detection, which are multiplied to calculate the **Risk Priority Number (RPN)** (Wang et al., 2009). Recent studies have demonstrated that FMEA remains one of the most effective methods for maintenance planning because it enables maintenance managers to prioritize resources toward the most critical equipment failures (Liu et al., 2022; Yadav et al., 2023). In electrical power systems, FMEA has been successfully applied to identify failure risks in generator systems, transformers, switchgear, and industrial electrical equipment (Hidayat & Nugroho, 2023).

Maintenance Optimization in Generator Systems

Generator reliability depends not only on component quality but also on systematic maintenance management. Common causes of generator failures include battery deterioration, contaminated fuel, cooling system failures, lubrication problems, and electrical control malfunctions (Supriyadi, 2021). Previous maritime studies also reported that inadequate maintenance of cooling systems and emergency generators significantly increases the risk of blackout conditions aboard ships (Alief Yuliyanto, 2023; Daffa Rizky Aulia, 2023). Recent developments in maintenance engineering encourage organizations to integrate traditional preventive maintenance with Risk-Based Maintenance (RbM) and predictive maintenance supported by digital technologies (Pinciroli et al., 2023). These approaches enable maintenance decisions to be based on equipment condition and failure risk rather than fixed maintenance schedules, thereby improving equipment availability and reducing maintenance costs (Carvalho et al., 2020; Lee et al., 2021).

Methodology

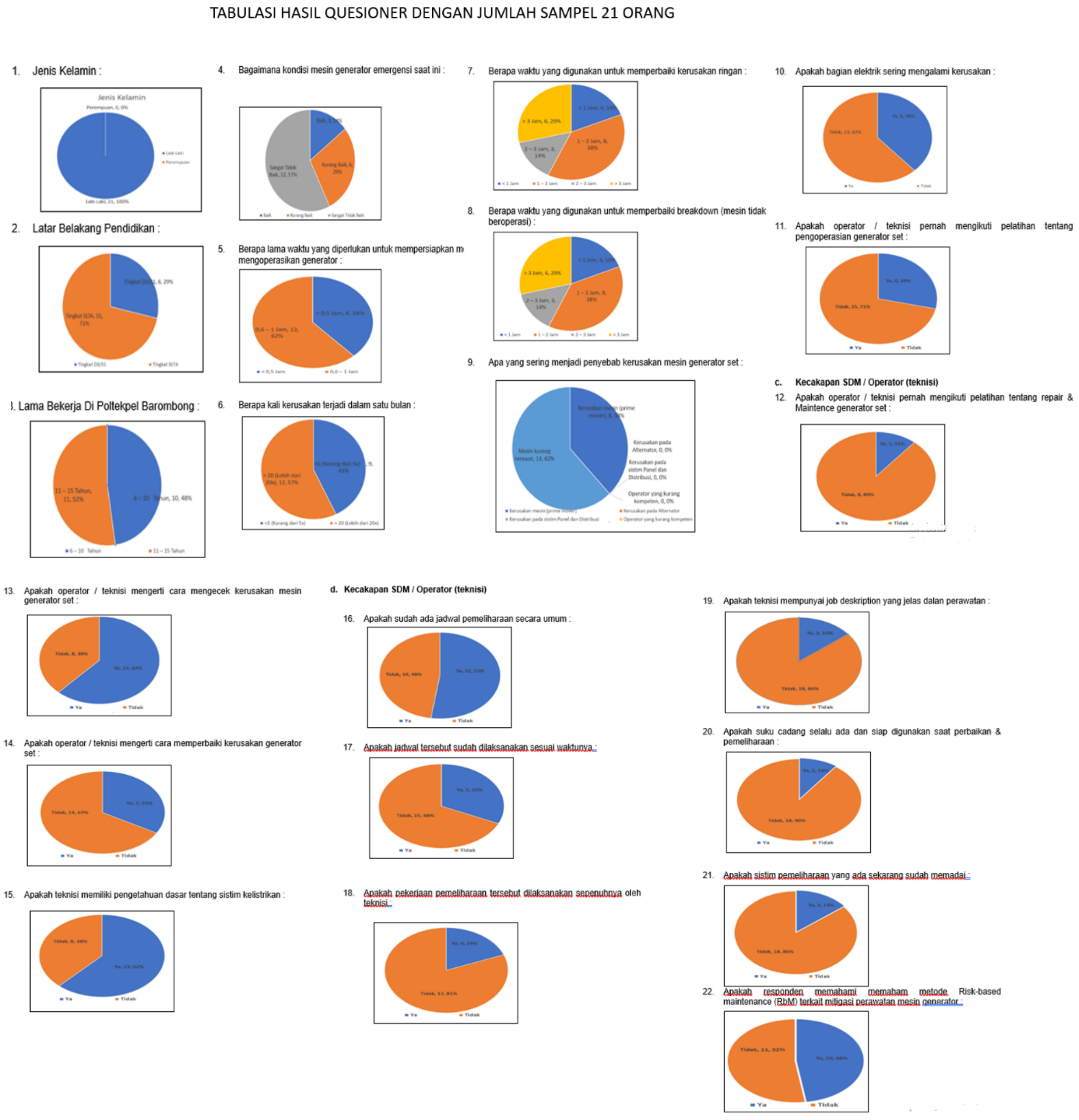
This study employed a **mixed-method descriptive research design**, combining qualitative and quantitative approaches (Sugiyono, 2015). The qualitative phase involved field observations, semi-structured interviews with generator operators and maintenance technicians, and documentation of maintenance records at Barombong Polytechnic of Maritime Studies. These methods were used to obtain comprehensive information regarding existing maintenance practices and operational problems. The quantitative phase consisted of questionnaire analysis and **Failure Mode and Effects Analysis (FMEA)** to evaluate maintenance risks systematically. FMEA is a widely accepted reliability engineering technique for identifying potential failure modes, determining their causes and consequences, and prioritizing corrective actions based on risk (McDermott et al., 2009; Wang et al., 2009). Recent studies have further confirmed the effectiveness of FMEA for maintenance optimization and industrial risk management (Liu et al., 2022; Yadav et al., 2023). Each identified failure mode was evaluated using three standard FMEA criteria: **Severity (S)**, representing the impact of failure; **Occurrence (O)**, representing the likelihood of failure; and **Detection (D)**, representing the capability of the maintenance system to detect failures before they occur. The **Risk Priority Number (RPN)** was calculated using the following equation:

$$\textbf{RPN} = \textbf{Severity} \times \textbf{Occurrence} \times \textbf{Detection}$$

Failure modes with higher RPN values were considered more critical and therefore received higher priority for corrective actions and maintenance improvement. The application of FMEA enabled the researchers to identify the most vulnerable components within the generator system, determine the root causes of equipment failures, and propose appropriate maintenance strategies to improve generator reliability and operational efficiency as an emergency backup power source at Barombong Polytechnic of Maritime Studies.

RESULTS AND DISCUSSION

Respondent Characteristics



FMEA analysis

The data in this study were analyzed using the Failure Mode and Effects Analysis (FMEA) method to identify and evaluate potential failures in the generator set system at Barombong Polytechnic of Maritime Studies. FMEA is a systematic, structured, and preventive analytical technique used to examine each component, process, or system function to identify the failure mode (the manner in which a component fails), the failure cause (the underlying cause of the failure), and the failure effect (the consequences resulting from the failure). Through this method, each potential failure is evaluated using three key parameters: Severity (S), which measures the seriousness of the failure consequences; Occurrence (O), which represents the likelihood or frequency of the failure occurring; and Detection (D), which indicates the ability of the existing system to detect the failure before it causes significant consequences. These three parameters are combined to calculate the Risk Priority Number (RPN), which serves as the basis for prioritizing corrective actions. A higher RPN value indicates a more critical level of risk that requires immediate attention. By applying FMEA, this study identifies the generator components most susceptible to failure, determines their root causes, and proposes appropriate corrective actions to improve the reliability and maintenance effectiveness of the generator set as an emergency backup power source. Within the FMEA framework, a failure mode is the specific manner in which a component, subsystem, or process may fail to perform its intended function. Such failures may result from defects, malfunctions, or operational errors that can adversely affect the performance of the entire system or its users. Effect analysis refers to the evaluation of the consequences associated with each potential failure. The primary objective of FMEA is to reduce or eliminate potential failures by prioritizing risks according to their severity, frequency of occurrence, and detectability. Consequently, corrective actions are first directed at failure modes with the highest risk. Beyond its application during the design stage, FMEA is also widely used as a process control tool throughout system operation to continuously monitor and improve system reliability. Therefore, FMEA can be regarded as a comprehensive risk management approach that supports product and system reliability from the conceptual design stage through the entire operational lifecycle. The implementation of FMEA in this study consisted of determining the Severity (S), Occurrence (O), and Detection (D) ratings for each identified failure mode, followed by calculating the corresponding Risk Priority Number (RPN) to establish maintenance priorities and formulate appropriate corrective actions.

Table 1. Identifikasi Faktor Kerusakan Mesin Genset

No	*Equipment*	*Failure Mode*	*Failure Cause*	*Failure Effect*
1	*Starting Error*	*Battery low*	Mesin tidak bisa starter	Aki Bermasalah, sistim pengkabelan ada bermasalah atau dinamo starter sudah rusak
2	*Low Power*	Terjadinya masuk angina	Mesin susah dinyalakan dan mesin ngadat, sering-sering mati	kualitas bahan bakar yang buruk, masalah pada sistem injeksi, filter udara yang kotor, atau tekanan udara yang tidak seimbang.
3	*Seal oil*	Seal oli bocor	Left time, tekanan oli berlebihan, dan getaran mesin yang keras.	Oli cepat habis yang menyebabkan pelumasan tidak memadai dan peningkatan gesekan yang meningkatkan potensi kerusakan pada mesin seperti aus,
4	*Fan belt*	Fan belt robek	Material fan belt sudah aus serta kelebihan tekanan dan getaran yang keras.	Gangguan pada alternator dan kipas pendingin mesin.
5	*Fuel System*	Fuel Filter bocor	Seal karet filter aus atau robek	Tekanan Bahan Bakar Turun, sehingga proses pembakaran tidak sempurna, Masuknya Udara ke saluran bahan bakar, yang dapat membuat mesin sulit hidup, mati mendadak.
6	Filter udara	Filter udara bocor	Pemasangan filter kurang tepat dan filter yang sudah aus.	Masuknya debu atau kotoran ke dalam mesin, penurunan efisiensi pembakaran, dan overheating.
7	Radiator	Radiator bocor	Tekanan berlebihan dalam sistem pendingin dan kerusakan fisik akibat benturan atau getaran berlebih serta overheat	Body mesin lepas, peningkatan getaran dan kebisingan dan kerusakan fisik akibat benturan atau getaran berlebih, dan mesin mati karena overheat

8	ATS (Automatic Transver Switch)	UVR (Under Voltage Release) MCCB panel ATS Tidak berfungsi normal	MCCB trip terus-menerus walaupun tegangan normal, Indikator panel ATS atau MCCB menunjukkan "trip undervoltage" terus-menerus	UVR coil yang rusak menyebabkan MCCB tidak mendapat sinyal untuk menutup kontak, sehingga aliran listrik ke sistem terputus, Jika UVR tidak bekerja, maka saat tegangan turun, MCCB tetap ON — ini bisa merusak motor, trafo, atau beban sensitif akibat suplai tegangan rendah.
9	Tegangan (voltase) Tidak Keluar atau Tidak Stabil	*Over Voltage*	AVR Bermasalah	Tagangan tidak stabil dapat merusak perangkat kelistrikan

The identification process of failure factors revealed the various types of failures occurring in the generator set at the power plant. In addition to identifying the failure factors, this process also determined the failure mode (the specific type of failure), failure cause (the underlying cause of the failure), and failure effect (the consequences resulting from the failure). The identification of generator failure factors was carried out after analyzing the potential failure modes of each component within the generator system. The subsequent stage of the Failure Mode and Effects Analysis (FMEA) involved identifying generator failure factors, assigning Severity (S), Occurrence (O), and Detection (D) ratings, calculating the Risk Priority Number (RPN) for each identified failure mode, and proposing appropriate corrective actions. The RPN calculation was performed to establish maintenance priorities by identifying failure modes with the highest risk levels. Higher RPN values indicate more critical risks and therefore require higher priority for corrective maintenance. By identifying the failure modes with the highest RPN values, maintenance efforts can be focused on the most critical components, thereby minimizing the likelihood of recurring failures and improving the overall reliability of the generator system. The results of the FMEA analysis are presented as follows:

Risk Priority Number (RPN) Analysis

Table 2. RPN Calculating

No	*Equipment*	*Failure Mode*	*Severity Rating*	*Occurance Rating*	*Detection Rating*	RPN	*Rank*
1	Starting Error	Battery low	2	8	7	112	6
2	Low Power	Terjadinya masuk angin	10	2	3	60	8
3	Seal oil	Seal oli bocor	7	4	6	168	4
4	Fan belt	Fan belt robek	3	6	5	90	7
5	Fuel System	Fuel Filter bocor	5	7	8	280	3
6	Filter udara	Filter udara bocor	8	5	4	160	5
7	Radiator	Radiator bocor	4	10	9	360	2
8	ATS (Automatic Transver Switch)	UVR (Under Voltage Release) MCCB panel ATS Tidak berfungsi normal	6	9	10	540	1
9	Tegangan (voltase) Tidak Keluar atau Tidak Stabil	Over Voltage	9	3	2	54	9

Based on the Risk Priority Number (RPN) analysis, the failure of the Under Voltage Release (UVR) on the MCCB in the Automatic Transfer Switch (ATS) panel was identified as the most critical failure mode, with an RPN of 540. This high RPN reflects the severity of its impact on generator operation, its relatively frequent occurrence, and the effectiveness of failure detection. Other significant failure modes include radiator leakage (RPN = 360) and fuel filter leakage (RPN = 280), both of which also require immediate maintenance attention due to their potential to reduce the reliability of the generator system. As presented in Table 3, the highest RPN value of 540 falls into the high-risk category, indicating that this failure mode should receive the highest maintenance priority. The FMEA results provide valuable information for understanding potential failure mechanisms within the generator system and establishing effective maintenance priorities. Therefore, appropriate corrective actions should be implemented to prevent further equipment deterioration, maintain optimal generator performance, and minimize the risk of future operational failures.

Although the UVR failure was identified as the highest-priority issue based on the RPN analysis, field observations revealed that the most frequently encountered operational problem was fuel filter leakage, which ranked third in the RPN analysis (RPN = 280). Leakage in the fuel filter reduces the minimum fuel pressure required for normal engine operation, allowing air to enter the fuel supply system. This condition disrupts fuel delivery, leading to system failure and preventing the generator from operating properly. Therefore, in addition to addressing the highest-risk failure identified in the FMEA analysis, particular attention should be given to improving the reliability of the fuel system, given its frequent occurrence during daily generator operation. The recommended corrective actions are presented in the following table.

Table 3. Improvement Proposals

No	*Equipment*	*Failure Mode*	*Failure Cause*	*Repair Action*
1	Starting Error	Battery low	Mesin tidak bisa starter	Ganti aki baru sesuai kapasitas sesuai spesifikasi genset, Bersihkan terminal dengan amplas halus dan kencangkan baut pengikat, Periksa alternator, regulator, dan sabuk (fan belt), ganti komponen rusak, Periksa output charger panel (harus ±13.5V DC), ganti unit charger jika tidak keluar tegangan.
2	Low Power	Terjadinya masuk angin	Mesin susah dinyalakan dan mesin ngadat, sering-sering mati	Periksa seluruh sambungan pipa bahan bakar dan kencangkan dengan benar, ganti pipa atau clamp bila retak atau aus, Lakukan bleeding (pengeluaran udara) pada sistem bahan bakar sebelum menghidupkan mesin, Lakukan penggantian filter bahan bakar secara berkala sesuai jam kerja mesin
3	Seal oil	Seal oli bocor	Left time, tekanan oli berlebihan, dan getaran mesin yang keras.	Ganti dengan seal baru sesuai spesifikasi pabrikan, Periksa sistem pendingin (radiator, fan, water pump), pastikan mesin tidak panas berlebih, Lepas dan pasang ulang seal dengan alignment tool, pastikan dudukan bersih dan rata.
4	Fan belt	Fan belt robek	Material fan belt sudah aus serta kelebihan tekanan dan getaran yang keras.	Ganti fan belt baru sesuai ukuran dan tipe pabrikan, Atur kekencangan belt sesuai spesifikasi (biasanya defleksi 10–15 mm dengan tekanan jari), Luruskan posisi pulley dan periksa keausan alurnya.

5	Fuel Sistem	Fuel Filter bocor	Seal karet filter aus atau robek	Ganti filter dengan unit baru yang berkualitas baik, Lakukan bleeding bahan bakar hingga solar keluar tanpa gelembung udara, Lepas dan pasang ulang filter dengan posisi lurus dan kencang sesuai torsi yang dianjurkan.
6	Filter udara	Filter udara bocor	Pemasangan filter kurang tepat dan filter yang sudah aus.	Ganti filter udara baru sesuai tipe dan ukuran pabrikan, Ganti seal/gasket baru dan pastikan terpasang rata, ganti housing filter dengan unit baru, Pasang ulang filter dengan posisi lurus dan terkunci sempurna
7	Radiator	Radiator bocor	Tekanan berlebihan dalam sistem pendingin dan kerusakan fisik akibat benturan atau getaran berlebih.	Perbaiki dengan las timah (soldering) atau ganti core radiator jika kerusakan luas, eriksa dan tambahkan mounting karet radiator agar tidak langsung terkena getaran mesin
8	ATS (Automatic Transver Switch)	UVR (Under Voltage Release) MCCB panel ATS Tidak berfungsi normal	MCCB trip terus-menerus walaupun tegangan normal, Indikator panel ATS atau MCCB menunjukkan "trip undervoltage" terus-menerus	Cek tegangan suplai ke coil UVR; pastikan sesuai spesifikasi (mis. 220VAC), Periksa arus dan tegangan suplai, ganti dengan UVR baru jika lilitan terbakar, Cek wiring kontrol antara ATS dan MCCB UVR, perbaiki koneksi relay atau terminal.
9	Tegangan (voltase) Tidak Keluar atau Tidak Stabil	Over Voltage	AVR Bermasalah	Periksa koneksi kabel sensing dan terminal AVR, ganti AVR jika rusak, Cek supply ke AVR dan koneksi exciter coil, lakukan flashing medan jika perlu, Atur kembali potensiometer AVR (VR Adjust), jika tidak berubah ganti AVR baru.

DISCUSSION

The findings indicate that the reliability of the standby generator system depends not only on the physical condition of mechanical and electrical components but also on the effectiveness of maintenance management. Several high-risk failures identified in this study, including UVR malfunction, radiator leakage, and fuel filter leakage are preventable through systematic preventive maintenance, regular inspections, and timely replacement of deteriorated components. These results are consistent with Meissner et al. (2021), who emphasized that modern maintenance management should integrate preventive, predictive, and prescriptive maintenance strategies to minimize unexpected equipment failures. Similarly, Pinciroli et al. (2023) demonstrated that risk-based maintenance improves equipment availability by prioritizing maintenance activities according to failure risk rather than fixed maintenance schedules.

Another important finding concerns the role of maintenance personnel. Interviews and questionnaire responses indicated that limited technical competence and insufficient training reduced the effectiveness of preventive maintenance activities. This observation supports previous studies suggesting that maintenance performance is strongly influenced by technicians' knowledge, diagnostic capability, and adherence to standardized maintenance procedures. In addition, organizations with highly trained maintenance personnel generally achieve lower equipment downtime and higher operational reliability than those relying solely on corrective maintenance. From an engineering perspective, the results suggest that Barombong Polytechnic of Maritime Studies should gradually shift from conventional time-based maintenance toward a Risk-Based Maintenance (RbM) strategy. Such an approach enables maintenance decisions to be based on the probability and consequences of equipment failure, thereby improving maintenance efficiency while reducing operational costs. Recent advances in predictive maintenance further recommend integrating condition monitoring technologies, digital inspection records, and machine learning techniques to support maintenance decision-making in critical power systems. Overall, the present study demonstrates that combining FMEA with preventive maintenance provides a practical framework for identifying critical generator components and establishing maintenance priorities. The proposed maintenance strategy is expected to improve generator reliability, reduce emergency power failures, extend equipment service life, and enhance the continuity of electrical services at Barombong Polytechnic of Maritime Studies.

Conclusion

Based on the findings and analysis of the generator set (genset) system at Barombong Polytechnic of Maritime Studies, the following conclusions can be drawn:

1. The electrical system at Barombong Polytechnic of Maritime Studies remains highly dependent on the electricity supply provided by the Indonesian State Electricity Company (PLN). Therefore, the availability of an emergency generator set is vital as a backup power source to ensure the continuity of campus operations during power outages. The results of the maintenance assessment and field observations indicate that most generator operational failures are primarily due to inadequate implementation of preventive maintenance procedures, particularly in the fuel, cooling, and lubrication systems. Based on the Failure Mode and Effects Analysis (FMEA), the highest failure risk was identified in the radiator leakage, with a Risk Priority Number (RPN) of 540, followed by fuel filter leakage (RPN = 360) and oil seal leakage (RPN = 280). These findings indicate that the cooling and fuel systems are the most critical components requiring priority attention in the generator maintenance program. Field observations further revealed that failures within the fuel system, particularly fuel filter leakage, were the most frequently encountered operational problems. Such failures reduce fuel pressure and may lead to engine starting failure. These problems can be minimized by periodically replacing components in accordance with the manufacturer's maintenance recommendations.
2. The competency of maintenance personnel, including operators and technicians, should be further enhanced through regular technical training on generator repair and maintenance procedures. Training should also include implementing Risk-Based Maintenance (RbM) principles to ensure maintenance activities are conducted systematically and in line with risk mitigation.
3. The optimization of generator maintenance can only be achieved through the implementation of a well-planned and scheduled maintenance program supported by competent maintenance personnel and adequate availability of spare parts. Such an approach will improve the operational reliability of the generator system while minimizing the risk of equipment failure and ensuring a reliable emergency backup power supply.

Overall, this study demonstrates that integrating preventive maintenance with a risk-based maintenance approach using FMEA provides an effective framework for improving the reliability, operational efficiency, and service life of generator systems. The proposed maintenance strategy may also serve as a practical reference for the management of standby power systems in other educational institutions and public facilities with similar operational characteristics.

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