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Analysis of Damage to Starter Generator Set Dynamo at Jayapura Aviation Polytechnic

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ABSTRACT

This study examines the reliability of backup power supply systems at Politeknik Penerbangan Jayapura, focusing on a 1,000 kVA diesel generator used to support critical loads such as server rooms, emergency lighting, and laboratory facilities. In early 2025, several failures occurred when the generator could not operate due to damage in the starter system, particularly the starter motor, leading to temporary power outages. The research aims to identify the causes of these failures, assess their impact on system reliability, and propose preventive technical measures. A field study with a descriptive comparative approach was conducted through direct observation, technical measurements (battery voltage, starting current, and engine speed), documentation, and interviews with technicians. The findings reveal that the main cause of failure is mechanical damage to the pinion gear due to excessive wear, preventing proper engagement with the flywheel. This issue is worsened by declining battery performance and insufficient preventive maintenance. As a result, the starter motor cannot generate enough torque to start the engine. The study recommends scheduled maintenance, routine inspections, and timely component replacement.

1. Introduction

The Jayapura Aviation Polytechnic is a technical implementation unit under the Ministry of Transportation's Human Resources Development Agency (BPSDMP), which focuses on vocational education in aviation to produce professional workers, particularly in eastern Indonesia. Supported by facilities such as laboratories, simulation rooms, and a competency-based learning system, this campus requires reliable technical infrastructure to support academic and administrative activities. In the context of modern vocational education, the reliability of supporting infrastructure, particularly electrical systems, has become a critical enabler for ensuring uninterrupted learning processes, digital services, and safety-critical operations. However, the electricity system in Jayapura City still faces various obstacles such as sudden blackouts, network disruptions, and voltage fluctuations due to limited PLN distribution capacity, transmission distance, and geographical conditions [1]. These challenges reflect broader issues in power system reliability in remote and developing regions, where infrastructure limitations directly impact institutional performance and service continuity. These disruptions have the potential to hamper critical operations, especially those systems that require a continuous power supply. As shown in Figure 1, scheduled maintenance activities by PLN frequently occur and have the potential to interrupt electricity supply for several hours. This condition further strengthens the necessity of a reliable backup power system, particularly in critical institutions such as aviation polytechnics.

In response to these conditions, the Jayapura Aviation Polytechnic is equipped with a generator set (genset) system, which serves as a backup power source to ensure continuous power supply in the event of disruptions to the PLN grid. The generator set used on campus is a Cummins brand stationary diesel generator with a KTA38-G5 engine with a 12-cylinder V-line configuration and a nominal capacity of 1,000 kVA (kilowatt-amperes). It is equipped with a Stamford brushless alternator and a Deepsea Digital control system. This generator set is designed to provide long-term power and is capable of handling the peak loads required by key campus facilities [2]. From a system engineering perspective, the generator set functions as a critical component within a backup power architecture, where its reliability directly determines the resilience of the overall electrical system.

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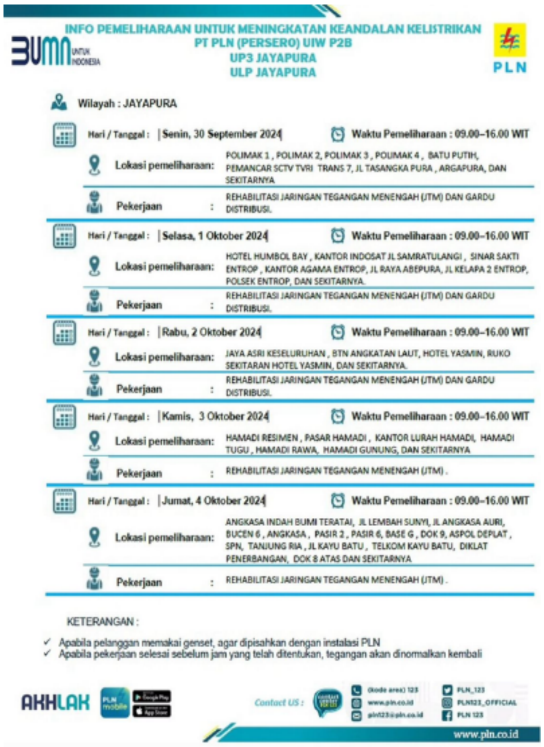

Figure 1 Electrical Maintenance Notice from PLN in Jayapura City

The generator set plays a vital role in campus operations, supplying power to priority loads such as server rooms, emergency lighting, laboratories, and communication and information systems that must be uninterrupted. Without a reliable generator set, campus activities can cease rapidly, disrupting the educational process, risking the loss of important data, and potentially endangering the safety of the academic community [3]. Therefore, generator reliability is crucial in ensuring the continuity of aviation vocational education. Previous studies on backup power systems emphasize that failure in auxiliary subsystems, particularly starting systems, often becomes the dominant cause of generator unavailability rather than the main engine failure itself. To objectively understand its performance, an analysis of generator usage data was conducted based on daily logs from February to November 2024, which included starting frequency, operating duration, and fuel consumption as a basis for operational evaluation [4].

Based on a recapitulation of data from February to November 2024, the generator set at the Jayapura Aviation Polytechnic experienced 26 starts, with a total operating duration of approximately 69.29 hours and fuel consumption of approximately 13,857 liters, with an average of 200 liters per hour, which is within the technical specifications for a 1,000 kVA generator set [5]. Therefore, the main engine's performance can be considered normal and not the primary cause of the disruption. This indicates that the reliability issue is not associated with energy conversion performance but rather with supporting subsystems involved in the starting mechanism. However, when viewed from operational patterns, the relatively high start-up frequency especially from March to July with relatively short operating durations (2–3 hours) indicates that the generator set's workload is dominated by repeated start cycles rather than continuous operation. This condition leads to an increased load on the starter system, particularly the starter dynamo and its mechanical components, which must work more intensively without optimal preventive maintenance support, potentially becoming a major source of generator set operational disruptions [6]. Such cyclic operational stress is widely recognized in mechanical systems as a key contributor to accelerated wear and fatigue failure.

Table 1
Generator Operation and Diesel Generator Usage

Solar Input	Usage	Balance	Rounding (Minutes)	Usage (Hours)	Start	Stop
0	0	0	0	0	–	–
2695	0	2695	0	0	–	–
0	500	2195	150	2,5	07.00	09.30
0	600	1595	180	3	09.15	12.15
0	550	1045	165	2,75	13.05	15.50
2480	0	3525	0	0	–	–
0	650	2875	195	3,25	16.20	19.35
0	395	2480	119	1,98	06.15	07.14
0	480	2000	144	2,4	14.05	16.29
2697	0	4697	0	0	–	–
0	300	4397	90	1,5	12.05	13.35
0	600	3797	180	3	16.00	19.00
0	650	3147	195	3,25	08.10	13.25
0	450	2697	135	2,25	17.10	19.25
0	800	1897	240	4	18.18	22.18
0	897	1000	269	4,48	07.18	11.47
0	600	400	180	3	14.33	17.33
2685	0	3085	0	0	–	–
0	400	2685	120	2	18.40	20.40
0	100	2585	30	0,5	11.30	12.00
0	600	1985	180	3	08.13	11.13
0	650	1335	195	3,25	17.40	20.55
0	600	735	180	3	15.10	18.10
0	735	0	221	3,68	17.40	21.21
2690	0	2690	0	0	–	–
0	600	2090	180	3	07.13	10.13
0	600	1490	180	3	16.11	19.11
0	300	1190	90	1,5	08.14	09.44
0	600	590	180	3	16.40	19.40
3370	0	3960	0	0	–	–
0	590	3370	177	2,95	09.00	11.57
0	10	3360	3	0,05	16.10	16.13
0	600	2760	180	3	09.20	12.20

Meanwhile, on January 10, 2025, a generator set operation trial was conducted at the Jayapura Aviation Polytechnic. On the first attempt, the generator wouldn't start because the starter motor couldn't fully turn the engine. Initial inspection revealed that the pinion gear was worn and unable to engage with the flywheel[7]. This phenomenon indicates a failure in the mechanical power transmission during the cranking phase, which is essential for initiating the combustion cycle in diesel engines.

Two weeks after the initial incident, on January 23, 2025, the generator failed again during a PLN power outage because the starter motor was unable to turn the diesel engine. Observations revealed a mechanical fault with the pinion gear, which was unable to properly engage the flywheel, resulting in the backup electrical system malfunctioning and causing a power outage lasting approximately 25 minutes. A technical inspection revealed wear on the pinion gear and shaft shifting due to repeated friction, which hampered the transmission of rotational energy from the starter motor to the diesel engine[8]. Although the motor continued to rotate, the engine did not respond, indicating a problem with the power transmission mechanism. These findings confirm that the starter motor is a crucial component in the generator's starting process, where even minor damage can significantly impact operational failure. This situation underscores the importance of generator reliability as the primary emergency power source at the Jayapura Aviation Polytechnic, making starter system maintenance a vital aspect of ensuring campus operational continuity [9].

Figure 2 Checking the Generator Set Starter Dynamo

Considering the chronology of the incident and its impact, damage to the starter motor, particularly the pinion gear component, is a key issue requiring in-depth investigation [10]. Despite its importance, studies focusing on micro-level failure mechanisms of starter systems in large-scale diesel generator applications, particularly in educational infrastructure contexts, remain limited. A comprehensive analysis is needed to identify the causative factors of the failure and assess its impact on the reliability of the backup electrical system. Furthermore, this study is crucial for determining appropriate corrective and preventive measures to prevent similar incidents from recurring [11]. This research not only contributes to practical maintenance strategies but also enriches the body of knowledge in reliability engineering and maintenance management of backup power systems. The urgency of this research lies in the importance of continuous power supply in vocational education facilities, which play a strategic role in supporting the safety and continuity of campus operations.

This study addresses a critical practical issue in applied engineering, namely the reliability of backup power systems in aviation education infrastructure, where uninterrupted power supply is essential for safety, learning continuity, and operational stability. By focusing on the failure of the starter dynamo in a 1,000 kVA generator system, this research provides real-world insights into the operational challenges and risks associated with backup power systems. Therefore, the study not only contributes to academic knowledge but also offers practical value for engineers, technicians, and infrastructure managers in maintaining reliable power systems in critical environments.

In addition, this study contributes theoretically to the fields of Industrial Engineering and System Engineering, particularly in the areas of reliability engineering and maintenance management. It provides a structured analysis of starter dynamo failure by integrating electrical, mechanical, and maintenance management perspectives within a unified system framework. Furthermore, this research extends existing studies by emphasizing micro-level failure mechanisms in generator starting systems and linking them to broader system reliability performance. This contribution enriches the understanding of failure dynamics in backup power systems, especially in critical infrastructure contexts such as aviation education facilities.

2. Research methods

This study adopts a structured methodological framework consisting of five main stages: (1) research design selection, (2) determination of population and sample, (3) data collection, (4) data processing, and (5) data analysis and interpretation. This systematic approach ensures that the research process is transparent, reproducible, and aligned with the research objectives in identifying the causes of starter dynamo failure and its impact on generator reliability.

This study adopts a descriptive qualitative research design, complemented by quantitative technical measurements, to analyze the condition of the generator starter dynamo and its impact on the reliability of the backup power system. The qualitative approach is employed to explore failure mechanisms, maintenance practices, and operational conditions in depth, while quantitative measurements, such as voltage, current, and rotational speed (RPM) are used to objectively validate the technical findings. The research was conducted at the Jayapura Aviation Polytechnic over the period from July 2025 to February 2026. The population consisted of 4 generator units, with the sample focused on the 1000 kVA generator starter dynamo that experienced damage using purposive sampling, and involving technicians as respondents [12]. Data were collected through observation, technical measurements, documentation, and interviews, then processed through reduction, presentation, and descriptive-comparative analysis by comparing field conditions to technical standards. The analysis was also supported by a correlation approach, interviews, and evaluation of maintenance patterns to identify the causes of damage and formulate recommendations for improving generator reliability [13].

2.1 Research Population and Sample

Heading The population and sample in this study were determined to determine the scope of analysis of the generator system at the Jayapura Aviation Polytechnic. The population includes all generator units that function as backup power sources, namely 4 units (3 in damaged condition and 1 active). From this population, the sample was focused on generators experiencing problems with the starter dynamo, especially on the pinion gear component, using a purposive sampling method so that the data obtained is relevant to the research objectives. In addition, technicians and maintenance staff were also involved as respondents through interviews to obtain supporting information regarding maintenance patterns and generator damage history [14].

2.2 Data Collection Techniques

Table Data collection in this study is categorized into primary and secondary data to ensure comprehensive and triangulated information. Primary data were obtained through direct field observations, technical measurements, and interviews, while secondary data were collected from maintenance records, documentation, and historical operational data. The instruments used in this study include a multimeter to measure battery voltage, a clamp meter to measure starting current, and a tachometer to measure engine rotational speed (RPM). In addition, an observation checklist was employed to assess the physical condition of starter dynamo components, and semi-structured interview guidelines were used to obtain in-depth information from technicians regarding maintenance practices, operational conditions, and failure history. Meanwhile, secondary data were obtained through documentation in the form of component damage photos, generator maintenance records, and documented blackout event data [15].

The use of multiple data sources, including technical measurements, operational logs, visual inspections, and technician interviews, enables a comprehensive field-based investigation. This multi-method approach enhances the practical validity of the findings by ensuring that the analysis is supported by both empirical technical data and contextual operational insights. As a result, the conclusions drawn reflect actual field conditions and provide reliable guidance for real-world applications.

2.3 Data Processing Techniques

The Data obtained from the field was processed through several stages to facilitate analysis and draw conclusions: data reduction, data presentation, and data analysis. In the reduction stage, data from observations, interviews, and measurements were selected based on the research focus, namely starter dynamo damage, so that only relevant data was used. The data was then presented in tables, graphs, and documentation for ease of understanding, and compared with technical standards such as Bosch, IEC, and generator manufacturer manuals[16].

Data analysis was conducted using a descriptive-comparative approach supported by correlational and qualitative analysis, comparing field conditions to international standards such as IEC 60364, NFPA 110, and Cummins specifications. Additionally, technical descriptive analysis, comparative analysis, correlation analysis, interviews, and maintenance pattern evaluation were used to identify causal relationships among starter dynamo damage. Quantitative and qualitative data were combined through triangulation to enhance the validity of the results, resulting in a comprehensive picture of the causes of damage and a basis for developing repair recommendations[17].

Overall, this methodological structure ensures a logical flow from problem identification to recommendation development, strengthening the validity and reliability of the research findings.

3. Results and Discussion

Jayapura Aviation Polytechnic has a 1,000 kVA Cummins diesel generator set that serves as a backup power source for priority loads such as the server room, emergency lighting, laboratories, and communication systems. Under normal conditions, the electricity supply comes from PLN (State Electricity Company), while the generator set is operated during testing or when blackouts occur. However, ignition failures on January 10 and 23, 2025, which caused a 25-minute blackout, demonstrated that the starter system, specifically the starter dynamo and battery, are critical components that determine the success of the generator set's operation. The research data included operational data (diesel consumption and operating duration), technical data (battery voltage and RPM), documentation of component conditions, and technician interviews. All of this data was used to analyze the causes of the disruptions and formulate corrective measures to increase the reliability of the generator set system as a backup power source.

3.1 Results

The results of this study indicate that the generator's performance is generally good, but the reliability of the starter system is a major factor in operational disruptions. These results are expected to provide a basis for evaluation and maintenance improvements to enhance the reliability of the backup power system.

3.1.1. Generator Operational Data and Diesel Fuel Consumption

Diesel generator usage was recorded consistently daily from February to November 2024, with complete operational data. While administratively sound, technical monitoring was lacking, so the data was summarized monthly to facilitate analysis of operational patterns.

Table 2.
Recap of Generator Operation and Diesel Generator Usage

Parameter	Value	Description
Total Ignitions	26 times	10-month coverage
Total Operating Duration	69.29 hours	≈ 4,158 minutes
Total Diesel Consumption	~13,857 liters	Average 200 L/hour
Average per Ignition	533 liters / 2.67 hours	Medium duration
Highest Frequency	July 2024 (6x)	Intensive period
Longest Duration	4.48 hours	May 2024
Shortest Duration	0.05 hours (3 minutes)	Brief test

The generator operating pattern from February to November 2024 showed normal engine performance, with fuel consumption within specifications and no significant interruptions. However, the high frequency of medium-duration starts placed repeated loads on the starter system, potentially accelerating component wear and triggering operational disruptions.

3.1.2. Technical Data of Starter System and Field Measurement

Technical inspections of the starter system were conducted to assess the generator's operating condition by measuring engine speed (RPM) and battery voltage, key factors in starting success. Data was obtained from the DSE control panel and a multimeter and compared against manufacturer standards to evaluate system performance.

a. Engine Speed (RPM) During Normal Operation

Figure 3 Engine speed (RPM) indicator on the generator control panel during normal operation

Figure 3 shows the engine speed at approximately 1,506 rpm, close to the nominal 1,500 rpm, indicating optimal operation of the speed control system. This indicates normal engine operation when stable, so potential problems are more likely to occur during the initial start-up phase.

b. Battery Voltage When the Engine is Running

Figure 4 Battery voltage indicator on the generator control panel when the engine is running

A battery voltage of around 27.5 V during operation indicates the charging system is operating normally without fluctuations. This indicates a secure power supply, suggesting that starting problems are more likely due to the battery's inability to handle the high starting load, rather than a charging system failure.

c. Measuring Battery Voltage During Starting

Figure 5 Measuring generator battery voltage using a digital multimeter

Measurements showed the battery voltage was 13.81 V under normal conditions, but dropped below 11 V during starting. This indicates the battery is still good without a load, but is unable to meet the high current demands during cranking.

Table 3
Battery Voltage Measurement Results at No-Load and Starting Conditions

Condition	Voltage	Status
Static measurement (no load)	13.81 V	Normal
Measurement during starting (under load)	< 11 V	Drops 20–25%

3.1.3. Physical Condition of Old and New Starter Dynamos

The physical condition of the starter motor was analyzed through visual documentation to compare the old and new units. This observation helped link operational failures to physical evidence, ensuring the analysis was not only based on measurement data but also supported by visual findings.

Figure 6 The old starter dynamo of the 1,000 kVA Cummins generator is damaged

Figure 6 shows an old starter motor that is dull, dusty, and has light corrosion, indicating long-term use without optimal maintenance. This condition indicates declining performance and nearing the end of its useful life.

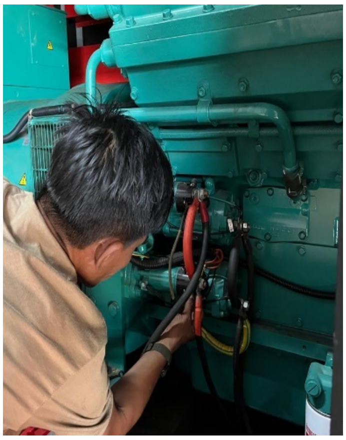

Figure 7 The old starter dynamo was still installed on the generator engine during the inspection.

Figure 7 shows an initial check of the starter motor, which found the cables and terminals to be in good condition with no external damage. This indicates the problem is internal, requiring disassembly for further inspection.

Figure 8 New starter dynamo as a replacement for the old starter dynamo

Figure 8 shows a new starter motor in good condition and ready to be installed as a replacement for the old unit. This replacement aims to restore cranking torque to specifications and reduce the risk of repeat failure.

Figure 9 The process of installing a new starter dynamo on a generator engine

Figure 9 shows the installation of a new starter motor, ensuring proper mechanical alignment and electrical connections. This process is performed according to established procedures to prevent interference and ensure optimal starter system performance.

Figure 10 The old starter dynamo after being dismantled into several components

Figure 10 shows an old starter motor that has been disassembled, showing signs of wear on various components. This confirms the widespread damage, making a complete replacement the right step to maintain operational reliability.

Damage to the starter motor isn't limited to a single component. The combination of worn pinion teeth, thinning brushes, and a dirty commutator creates a condition.

Table 4
Condition of Damage and Findings of Generator Set Starter

Aspect	Old Condition	Finding
External Surface	Dull, with oil stains, dust, and light corrosion	Indication of long-term degradation
Cables & Terminals	Still properly connected	Fault not on external connections
Pinion Gear	Worn, teeth chipped, not engaging properly	Power transmission failure
Solenoid Mechanism	Does not return to original position after start	Indication of weak spring
Brush	Thinned to critical length	Reduced current transfer
Commutator	Dirty due to brush dust	Increased electrical contact resistance

Table 4 shows that starter dynamo damage is comprehensive and not limited to a single component. Wear on the pinion gear causes mechanical power transmission failure, while brushes that have reached critical limits and a dirty commutator result in increased electrical resistance (Saputra et al., 2021). Furthermore, a solenoid mechanism that does not return to its original position indicates a weakness in the prime mover system, which also affects the starting process. This combination of mechanical and electrical disturbances directly impacts the resulting torque reduction and impedes the flow of electrical current. As a result, the generator set's initial rotation is suboptimal and has the potential to cause repeated starting failures.

3.1.4. Battery and Battery Charger Replacement

In addition to focusing on the condition of the starter dynamo, this study also examines the initial source of electrical energy, namely the battery and its charging system. This aspect is important because the performance of the starter dynamo is highly dependent on the availability of a strong and stable electric current from the battery. Therefore, the battery is evaluated through voltage measurements and observations of its physical condition. Meanwhile, the performance of the charging system is assessed based on indicator readings on the control panel and the presence and installation of a battery charger. With this approach, it can be identified whether weaknesses in the initial ignition circuit originate from the battery, the charging system, or a combination of both.

Figure 11 Battery replacement and generator battery charger installation

Figure 11 shows the replacement of an old battery with a new one and the installation of a battery charger to maintain optimal charging. This step was taken due to the voltage drop during starting, and is expected to effectively increase the initial power supply. Installing a new battery and battery charger improves the reliability of the starting system by maintaining a stable voltage during starting. Supported by a new starter motor, this repair optimizes the entire system, bringing performance closer to manufacturer specifications and significantly improving the generator's reliability.

3.1.5. Qualitative Findings Related to Generator Operation and Maintenance

Qualitative data from technician interviews complements technical observations by providing a chronology of failures, component conditions, and operation and maintenance patterns. This data helps identify early symptoms and understand the relationship between technical conditions and overall maintenance practices.

Table 5
Qualitative Findings with Technicians

Aspect Analyzed	Key Finding	Technical Interpretation
Initial fault condition	Genset could not start during PLN blackout due to non-functioning starter motor and no initial combustion	Failure occurred at the starting phase, not in the fuel system or main engine
Initial repair actions	Inspection of battery, cables, terminals, and disassembly of starter motor	Troubleshooting approach began from the electrical system before moving to mechanical
Starter battery condition	Battery voltage dropped below 11 V during starting process	Battery capacity degraded under high current load, resulting in suboptimal starter torque
Pinion gear condition	Pinion gear worn, teeth chipped, not engaging properly with flywheel, and not returning to original position	Mechanical wear caused torque transmission failure from starter to engine
Other internal component conditions	Brush thinned and commutator dirty	Increased electrical current flow resistance, reducing armature performance
Early symptoms before failure	Pinion gear did not disengage from flywheel after engine started	Early indication of starter mechanism damage that was not promptly addressed
Genset maintenance pattern	Maintenance was general, not specific to the starter motor	Preventive maintenance had not targeted critical components of the starter system
Genset testing pattern	Routine weekly testing was not performed and full-load testing was rarely conducted	Potential starter system faults were not detected early
Operational impact	Office power outage disrupted operations and posed safety risks	Genset failed to perform its function as a backup power source
Primary cause of damage	Pinion gear wear compounded by suboptimal battery condition and lack of maintenance	Damage was cumulative due to electrical, mechanical, and managerial factors
Technical recommendations	Periodic preventive maintenance, replacement of pinion gear and brush per service life, battery checks, and weekly genset testing	Systematic improvement in genset maintenance management is required

Based on Table 5, the main generator problems are caused by decreased starter system performance due to electrical and mechanical factors, as well as inadequate maintenance. These conditions lead to generator malfunctions, thus providing the basis for causal analysis and further prevention.

3.2 Discussion

This discussion presents a comprehensive analysis of the causes, mechanisms, and impacts of generator starter motor failure, as well as its relationship to electrical, mechanical, and maintenance management factors. Furthermore, preventive technical measures are formulated to continuously and optimally improve system reliability.

The findings of this study are consistent with previous research indicating that failures in auxiliary systems, particularly starter systems, are often the dominant cause of generator unavailability rather than failures in the main engine. Previous studies have emphasized the role of maintenance and electrical performance in ensuring system reliability. However, this study provides a more comprehensive perspective by demonstrating that starter dynamo failure is not caused by a single factor, but rather by the interaction of electrical degradation (battery voltage drop), mechanical wear (pinion gear and brush), and inadequate maintenance management.

Compared to prior studies that tend to analyze these factors separately, this research highlights the interconnected nature of failure mechanisms within the generator system. The causal relationships identified in this study strengthen the understanding that reliability problems in backup power systems are systemic rather than component-specific.

3.2.1. Identifying the Causes of Starter Dynamo Damage in Generator Sets

The generator failure on January 23, 2025, was the result of an accumulation of interrelated electrical, mechanical, and managerial factors. Therefore, a holistic analysis was conducted using a causal approach to identify the interrelationships between factors that led to the system failure.

a. Electrical Factors: Battery Capacity Limitations

A drop in battery voltage during starting from 13.81 V to below 11 V indicates degradation of the battery's internal capacity. This condition is caused by increased internal resistance and suboptimal charging cycles, preventing the battery from supplying high currents to its full capacity [18]. Consequently, the starter motor's electromagnetic performance decreases because the energy supply is below ideal.

The impact of this voltage drop is a reduced ability of the starter motor to generate initial torque to crank the diesel engine. When the voltage falls below the minimum threshold, the magnetic field weakens, resulting in suboptimal starter rotation. This prevents the crankshaft from reaching sufficient speed to initiate combustion, resulting in delayed engine start [19], [20].

This condition is influenced by several factors, such as the battery's age without replacement, the tropical environment accelerating degradation, unstable generator operating patterns, and the lack of an automatic battery charger. This combination of factors accelerates battery performance degradation and serves as an important basis for planning preventative maintenance.

b. Mechanical Factors: Wear of the Pinion Gear and Internal Components of the Starter Dynamo

Observations revealed significant wear on the starter dynamo pinion gear, characterized by scuffing and tooth wear due to repeated friction. This wear occurred gradually over 26 starting cycles over ten months, resulting in a progressive response to cyclic loading. This directly reduced the effectiveness of power transmission from the starter dynamo to the engine.

Pinion gear wear affected the quality of engagement with the flywheel ring gear. Changes in tooth geometry caused uneven contact, resulting in suboptimal torque transmission [21]. Consequently, the engine did not receive sufficient initial torque for starting, accelerating further wear due to stress concentration at certain points.

Furthermore, a fault was found in the solenoid mechanism, which was unable to return the pinion gear to neutral. The loss of spring elasticity caused the pinion to remain engaged and rotate with the flywheel. This condition created excessive mechanical stress and accelerated internal component damage, indicating a decline in overall system performance.

Furthermore, brush wear was also approaching critical limits, causing unstable electrical contact and disrupted current flow. Dust buildup on the commutator increased resistance and reduced current efficiency. As a result, the magnetic field weakens and the rotational torque decreases, thus worsening the condition of the starter dynamo until it leads to system failure.

c. Maintenance Management Factors: Preventive Maintenance System

Starter dynamo damage is also influenced by suboptimal maintenance management. The maintenance system implemented is still general and does not target critical components such as the starter dynamo and its internal elements. Furthermore, the lack of a structured preventive maintenance schedule results in reactive inspections, resulting in component wear not being monitored until it reaches a critical condition.

This situation is exacerbated by the lack of routine generator testing. Testing is only conducted at specific times without following standardized schedules, so early signs of damage are not detected. As a result, problems that could have been addressed early develop over several months, ultimately leading to total system failure.

Furthermore, the lack of a component replacement program based on service life further exacerbates the situation. The lack of historical usage and replacement data leaves technicians with no reference point for determining when to replace components. As a result, components continue to be used well past their intended service life, ultimately leading to sudden failure.

3.2.2. Analysis of Disturbances and Damage Mechanisms of Generator Set Starter Dynamos

Starter dynamo fault analysis cannot be performed in isolation because the generator system is an integrated whole. Electrical, mechanical, and managerial factors interact in a complex cause-and-effect relationship, so that a fault in one component can trigger the degradation of other components [22]. This interaction creates a cascading effect that magnifies the impact of the damage until it progresses to a complete system failure.

Chronologically, a decrease in battery voltage weakens the starter dynamo's ability to generate torque, while mechanical wear increases the electrical current demand [22]. These conditions exacerbate each other and are exacerbated by a lack of monitoring and routine maintenance. As a result, what initially appears to be a minor fault can develop into a systemic, difficult-to-control failure.

Table 6
Qualitative Findings with Technicians

Timeline	Dominant Factor	Main Event	Technical Impact	Further Consequence
Early operation	Electrical	Battery voltage began to drop	Starter working current increased	Thermal load on motor increased
Intermediate	Mechanical	Pinion gear and brush wear	Initial torque decreased	Engagement not optimal
Advanced	Electrical–Mechanical	Solenoid weakened and starter RPM low	Friction increased	Wear accelerated
Final	Management	No preventive inspection	Fault went undetected	Total system failure

The causal chain of starter motor failures is summarized in a table that presents the sequence of events and the interrelationships between factors during the operational period. This presentation provides a systematic overview of the damage dynamics. This approach understands the relationships between factors as interconnected, rather than separate, processes. Therefore, this table serves as an important basis for further analysis of the development of starter motor failures.

a. Causal Chain of Starter Dynamo Failure Time

Starter dynamo failure in generators develops gradually through changes in battery condition, mechanical components, and operating patterns. Therefore, identifying the failure phase is crucial to understanding the relationship between workload, wear, and system failure. Observations show that failure progression can be grouped into three main phases.

Table 7
Causal Chain of Starter Dynamo Failure

Damage Phase	Time Period	Main Technical Condition	Observed Symptoms	Operational Impact
Initiation and Early Symptom Phase	February–May 2024	Battery voltage >12 V, pinion gear and brush still serviceable, solenoid beginning to weaken	Initial pinion–ring gear friction, delayed pinion release	Minor performance degradation, operations not yet disrupted
Damage Acceleration Phase	June–October 2024	High starting frequency, battery voltage declining, magnetic field weakening	Pinion gear frequently failing to return to neutral position, wear increasing	Risk of starter failure increasing, but not yet addressed
Critical and Total Failure Phase	November 2024–23 January 2025	Battery voltage below safe threshold, brush thinned, engagement unstable	Starter spinning without being able to start the engine	Genset failed to operate during emergency conditions

In the initial phase, the system still operates normally, but increased starting frequency begins to cause friction, leading to early wear on the pinion gear and ring gear. This results in symptoms such as delayed pinion release by the solenoid, which is an early indication of decreased reliability, although it does not significantly disrupt operation.

As the acceleration phase progresses to critical, damage develops due to the combination of high mechanical loads and reduced battery voltage. The magnetic field weakens, resulting in suboptimal starter torque, accelerating component wear until the starter eventually fails to reach minimum RPM, leading to total system failure.

b. Mechanisms Causing Starter Dynamo Problems

Starter dynamo failure demonstrates a mutually reinforcing mechanism between factors. A decrease in battery voltage causes increased current demand, which leads to rising winding temperatures and accelerated insulation aging. This condition also accelerates brush and commutator wear, thus accelerating electrical degradation, accelerating mechanical failure.

Conversely, decreased mechanical performance leads to longer engagement durations, increasing friction and accelerating pinion gear wear. This increases the starter's workload and current demand, further exacerbating the battery voltage drop. Consequently, a cycle of repeated failures forms, further deteriorating the system.

Furthermore, a lack of preventive maintenance and routine testing allows early symptoms to go undetected. Without technical intervention, the negative interaction between factors continues, causing the failure to progress systematically. Therefore, understanding the causal relationship is crucial for designing an effective maintenance strategy.

c. Impact of Generator Set Failure on Facility Operational Continuity

The generator failure during the blackout on January 23, 2025, was not a minor disruption, but a critical event with a broad impact on the operation of educational facilities. In aviation educational institutions, the reliability of backup power is crucial for safety, academic continuity, and the protection of information systems. Therefore, a comprehensive impact analysis, encompassing both technical and non-technical aspects, is necessary as part of the evaluation of campus infrastructure reliability.

The analysis and interviews revealed that the generator failure impacted various interrelated operational aspects. The outage, lasting approximately 25 minutes, disrupted systems requiring continuous power supply and potentially impacted the safety and image of the institution. For ease of understanding, the impacts are categorized in a table based on dimension, type of disruption, duration, and risk level, confirming the systemic nature of the impact.

Table 8
Impact of Generator Failure on Facility Operational Continuity

Impact Dimension	Impact Specification	Duration / Scale	Critical Risk
Academic Data System	Risk of loss or corruption of grade, attendance, and academic transcript data	±25 minutes	Permanent data loss
Emergency Lighting	Emergency lighting system not functioning optimally	>25 minutes	Safety risk to academic community
Academic Activities	Cancellation or postponement of scheduled laboratory sessions	±25 minutes	Loss of learning opportunities
Communication & IT Systems	Data network, telephone, and email not operational	±25 minutes	Disruption to coordination and operations
Institutional Reputation	Negative perception of infrastructure reliability	Long-term	Decline in public trust
System Reliability	Backup power system failure during critical conditions	Ongoing	Recurring risk to vital systems

Based on Table 8, the impact of generator failure is cross-sectoral and goes beyond temporary technical disruptions. Risks to academic data systems have the potential to have long-term consequences, particularly if permanent data loss occurs. Furthermore, failure of emergency lighting increases safety risks, particularly during operating hours, while disruptions to academic activities and communications hamper the institution's core functions. This demonstrates that the impact of generator failure encompasses both safety and the quality of educational services.

Overall, generators are critical systems, not simply optional backup devices. Failure of the starter motor can shut down the entire backup power system, so repairs require more than just replacing damaged components; they also require a comprehensive evaluation of the system and maintenance management. These findings form the basis for developing technical and managerial recommendations.

To obtain an objective assessment, the condition of the generator starting system is compared with the manufacturer's technical standards and international practices. This comparison aims to assess the suitability of field conditions to the required parameters, as deviations from these standards can increase the risk of failure.

Table 9
Comparison of Field Conditions with Technical Standards

Technical Parameter	Reference Standard	Field Condition	Status	Technical Implication	Regulatory Standard
Minimum starting voltage	≥11.5 V	<11 V	Non-compliant	Cranking torque decreased	SAE International J537 – Storage Batteries; ISO 16750-2 – Road Vehicles Electrical Loads
Starting current	200–400 A	Not measured	Unconfirmed	Further measurement required	IEC 60034; Genset Manufacturer Technical Manual
Cranking torque	> compression resistance	Submaximal	Non-compliant	Transmission efficiency decreased	ISO 15550; Diesel Engine Technical Manual
Starter rotation	70–100 rpm	<50 rpm (estimated)	Non-compliant	Combustion not triggered	SAE Starting System Standard; Diesel Engine Literature
Maintenance interval	6 months / 200–500 hours	Unstructured	Non-compliant	Risk of undetected wear	Permenhub RI Number PM 45 Year 2021
Periodic testing	Routine	Not routine	Non-compliant	Early symptoms overlooked	Permenhub RI PM 45 Year 2021; ICAO Annex 14
Brush service life	2–3 years	Not recorded	Unconfirmed	Risk of excessive wear	Starter Motor Manufacturer Technical Manual; IEC 60034
Pinion gear service life	3–5 years	~2–3 years	Marginal	Potential to exceed service life	Manufacturer Technical Manual; ISO/IEC Mechanical Component Lifetime

Based on the comparison, the generator starting system does not meet most key technical parameters, particularly starting voltage, preventive maintenance, and periodic testing. These discrepancies directly impact the reliability and safety of the backup power system. Therefore, improvements must focus on meeting technical standards to sustainably enhance generator reliability.

a. Relationship between Maintenance Patterns and the Frequency and Level of Damage

The relationship between maintenance patterns and starter motor failure was analyzed temporally by comparing the frequency of use, type of maintenance, and component condition at each time point. The results indicate that a lack of specific maintenance accelerates failure, which occurs gradually rather than suddenly. A summary of the analysis is presented in Table 10.

Table 10
Relationship between Operational Period, Maintenance, and Damage

Period	Ignition Frequency	Maintenance Pattern	Starter Motor Condition	Damage Manifestation
Feb–May 2024	1–4 times/month	General maintenance	Initial normal condition	Early disengagement symptoms
Jun–Oct 2024	2–6 times/month	General maintenance	Accelerated wear	Pinion and solenoid wear
Nov 2024–Jan 2025	Intensive + blackout	General maintenance	Critical condition	Total failure

In the initial period, maintenance was still general without specific inspections of the starter motor. As usage frequency increased, workloads increased without adequate technical supervision, resulting in accelerated wear and tear in the middle period, characterized by decreased solenoid and pinion gear function. Entering the final period, critical battery voltage and mechanical wear caused the starter motor to fail, thus proving that the unstructured maintenance pattern significantly contributed to system failure.

3.2.3. Technical Steps and Efforts to Prevent Repeated Damage to Generator Set Starter Dynamos

a. Systemic Approach in Preventing Starter Dynamo Damage

Starter dynamo failure results from the interaction of various factors within a single system and cannot be addressed in isolation. Preventive measures must utilize a comprehensive, systemic approach, considering electrical, mechanical, and maintenance management aspects. Designed solutions must be able to break the chain of causes early on, rather than simply addressing the final impact.

A systemic approach also emphasizes shifting the focus from immediate functionality to long-term reliability. System success is measured not only by the ability to start, but also by consistent performance and minimal component degradation. Therefore, prevention focuses on maintaining a balance between workload and design capacity to avoid wear and progressive failure.

Furthermore, integration between technical and managerial aspects of maintenance is necessary. Without a planned and documented maintenance system, technical measures will be suboptimal. Failure prevention must be implemented consistently through corrective, preventive, and predictive approaches as part of improving overall system reliability.

b. Strengthening Electrical and Mechanical Dimensions as the Foundation for Starting System Reliability

Preventing starter dynamo damage must begin with the electrical aspects, particularly the battery and charging system. Optimal battery condition is crucial for starter performance because it affects the voltage and current required to generate starting torque. A voltage drop, even gradual, can accelerate component degradation, so managing battery life, charging stability, and regular monitoring are key steps to maintain performance as designed.

Furthermore, the electrical aspects must be balanced with mechanical maintenance of the starter dynamo. Components such as brushes, commutators, pinion gears, and solenoids experience natural wear and tear, but this can be controlled through regular inspection, lubrication, and cleaning. This allows for early detection of damage and maintains optimal mechanism performance.

These two dimensions are interrelated and must be managed in an integrated manner. Low voltage can increase heat and accelerate mechanical wear, while worn mechanical components increase the electrical load. By maintaining a balance between the electrical and mechanical aspects, the risk of failure can be minimized and the starting system more stable.

c. Continuous Strengthening of Maintenance Management and System Reliability

Successful prevention of starter dynamo failures depends heavily on quality maintenance management. An effective system must shift from a reactive to a preventative approach through a structured maintenance schedule, ensuring routine and planned inspections and testing to detect potential damage early.

Periodic operational testing of the generator set is also crucial for evaluating the performance of the starting system. Parameters such as starting time, engine response, and voltage stability can be used to monitor system condition, allowing deviations to be addressed promptly before total failure occurs.

Furthermore, technician competence and a robust record-keeping system contribute to maintenance success. Adequate technical understanding and the use of digital systems help improve consistency and historical analysis. This combination allows for more reliable and sustainable management of the generator set starting system.

3.2.4. Starter Dynamo Preventive Maintenance

Preventive maintenance of a generator starter motor focuses on the condition of the battery, mechanical components, and control system. The starter motor plays a crucial role in ensuring a successful starting process, especially during emergencies, making regular monitoring of the power system, electrical system, and drive mechanism crucial. Regular inspections of the battery, cables, and contactors, as well as testing the starting function, have proven effective in reducing the risk of failure. These procedures adhere to manufacturer standards and generator maintenance practices, preventing unexpected operational disruptions.

Starter dynamo problems can be identified by several symptoms, such as no cranking due to a weak battery or faulty cables, slow cranking due to low voltage or high resistance, and the starter turning without starting the engine due to mechanical damage. Intermittent problems are generally caused by battery degradation or current leakage. For recurring cases, automatic monitoring and parallel batteries are recommended to improve reliability.

Table 11
tarter Dynamo Preventive Maintenance Protocol

Component	Main Inspection	Frequency
Starter Motor	Physical cleanliness, mounting tightness, signs of heat/burning, shaft oil leakage	Weekly
Battery & Charging System	Resting voltage (>12.6 V), terminal connections, cell condition, charger	Weekly
Contactor & Solenoid	Contact wear, discoloration, mechanical operation, response time	Monthly
DC Cables & Terminals	Corrosion, tightness, insulation condition, grounding system	Weekly
Start/Stop Control Panel	Start logic, interlock, start delay, voltage and current protection	Monthly
Auxiliary System (Capacitor)	Condition of capacitor bank or parallel circuit (if available)	Quarterly
Drive Mechanism (Bendix)	Gear engagement, tooth wear, smoothness of locking mechanism	Monthly

The maintenance schedule follows manufacturer standards, starting with daily and weekly visual and battery inspections, followed by monthly maintenance including starting function tests and component checks, and then annually with a comprehensive inspection and overhaul. Recording inspections and implementing standard operating procedures (SOPs) are essential for early detection and performance evaluation. Starter dynamo testing includes checking cranking voltage, current, temperature, and relay performance. Repairs are made based on test results, such as component replacement or cable repair, and must be followed by retesting. In certain circumstances, alternative starter systems may be used.

This study provides both practical and academic implications. From a practical perspective, the findings offer a systematic basis for improving generator maintenance strategies in industrial and institutional settings. The identification of critical factors such as battery degradation, pinion gear wear, and unstructured maintenance practices enables organizations to implement targeted preventive maintenance programs, routine inspections, and performance monitoring systems to enhance reliability and reduce operational risks. From an academic perspective, this research contributes to the development of reliability analysis by integrating qualitative and quantitative approaches in evaluating complex system failures. It also provides a reference model for analyzing similar failure mechanisms in other electromechanical systems, particularly in backup power systems and critical infrastructure.

4. Conclusion

The starter motor failure at Politeknik Penerbangan Jayapura resulted from the interaction of three compounding factors: electrical, mechanical, and maintenance management. Reduced battery capacity caused starting voltage to drop significantly, preventing the starter motor from producing optimal initial torque. This was further aggravated by progressive mechanical wear on the pinion gear, brush, and solenoid components due to high starting frequency, while the absence of a structured preventive maintenance system meant that early fault symptoms went undetected. These accumulated conditions ultimately led to total starting system failure on 23 January 2025, causing a 25-minute power outage that disrupted campus operations, disabled emergency lighting, and posed risks to data integrity and academic information systems highlighting the starter motor as a single point of failure critical to the institution's backup power reliability.

Preventing future starter motor failures requires an integrated systemic approach addressing electrical, mechanical, and maintenance management aspects simultaneously. Planned battery management, regular mechanical servicing, and consistent implementation of a preventive maintenance program are the key elements needed to improve starting system reliability. This integrated approach enables the causal chain of damage to be interrupted at an early stage before it escalates into full system failure, ensuring the genset can sustainably fulfill its role as a reliable backup power source.

In terms of scientific contribution, this study advances the understanding of failure mechanisms in generator starter systems by proposing an integrated analysis framework that combines electrical, mechanical, and maintenance management factors. Unlike conventional studies that focus on isolated components, this research demonstrates the importance of a systemic approach in reliability analysis. The findings provide a conceptual foundation for future research in predictive maintenance, reliability modeling, and system failure analysis in complex engineering systems.

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