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Article

Root Cause Analysis of Alternator Mechanical Degradation and Cascading Electrical Voltage Instability in Shipboard Auxiliary Engines: A Case Study of MV. Hanglima

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ABSTRACT

This study investigates the factors contributing to electrical voltage instability in Auxiliary Engine No. 2 aboard MV. Hanglima. The research was motivated by operational disruptions where the voltage output dropped significantly from the standard 445V to 280V, leading to blackouts when the generator operated independently. Employing a qualitative research method utilizing the Fishbone (Ishikawa) diagram for root cause analysis, data was collected through onboard observation, documentation, and interviews with the engineering crew. The analysis revealed that the instability was primarily caused by mechanical failure in the alternator bearings, which had approached their operational limit. This mechanical imbalance caused friction between the rotor and stator, resulting in insulation leakage (short circuits) within the windings. Corrective measures implemented included a comprehensive overhaul, re-insulating the rotor and stator windings using insulating varnish, and replacing the worn bearings. These actions successfully restored the voltage output to a stable 445V, ensuring the safety and efficiency of the vessel's electrical system.

1. Introduction

Seafaring is a profession that is full of

challenges, the need for the profession of seafarers in the world is increasing in direct

proportion to the rate of increase in the world economy (Muhammad Zainuddin, 2021). In the availability of reliable electrical energy is a fundamental determinant in supporting the advancement of industrial and maritime sectors in developing countries like Indonesia. The ship's electrical system, powered by the auxiliary engine, plays a vital role in ensuring the continuous operation of navigation, communication, and propulsion equipment. The reliability of this system is strictly paramount for the safety and efficiency of shipping, as voltage disturbances can precipitate serious operational risks (Syamsir, 2010). Therefore, maintaining voltage stability is a crucial aspect of preventing economic losses and ensuring crew safety, underlining the importance of electrical system reliability as discussed in naval electrical engineering studies (Rukmini, 2021; Van Cutsem & Vournas, 2014).

The availability of reliable electrical energy is a fundamental determinant in supporting the continuous operation of navigation, communication, and propulsion equipment aboard modern vessels. The ship's electrical system, powered by the auxiliary engine, plays a vital role in maintaining this stability. The reliability of this system is strictly paramount for the safety and efficiency of shipping, as voltage disturbances can precipitate serious operational risks, including the failure of navigation equipment, communication systems, lighting, cooling pumps, and emergency control systems, ultimately jeopardizing ship maneuvering safety.

Specific issues regarding voltage instability were observed aboard the MV. Hanglima, particularly involving Auxiliary Engine No. 2. The incident occurred while the vessel was docking at Jurong Port, Singapore, where disconnecting the parallel connection resulted in a drastic voltage drop from 445V to 280V, causing a blackout. This phenomenon requires in-depth investigation, as the voltage levels only remained stable when the system was paralleled.

This study aims to identify the root causes of voltage instability in Auxiliary Engine No. 2 onboard MV. Hanglima and to formulate corrective and preventive maintenance actions based on onboard observations, documentation, interviews, and Fishbone analysis. The findings are expected to make a tangible contribution to enhancing safety standards, the reliability of electrical system design, and overall ship operational efficiency in the future.

2. Literature Riview

2.1. Review of Previous Studies

The literature review serves as a foundational basis for identifying research novelty. Previous studies by Bintoro (2019) focused on mechanical bearing damage in shaft generators due to lubrication issues, while Rachman (2023) examined general voltage instability caused by Automatic Voltage Regulator (AVR) and governor failures. This research addresses the existing gap by focusing specifically on the interaction between mechanical wear limits (bearing degradation) and cascading electrical insulation breakdown within the auxiliary engine's alternator.

2.2. Theoretical Framework

The ship electrical grid requires high reliability under extreme conditions. The alternator converts mechanical energy from the diesel engine into electricity through electromagnetic induction in the rotor and stator. The excitation system and AVR play critical roles in maintaining generator terminal voltage under load changes by adjusting the magnetic flux. A stable air gap between the rotor and stator is essential; mechanical imbalances, such as those caused by bearing failure, can disrupt this gap, leading to physical contact, insulation damage, and subsequent voltage instability.

2.3. Ship Electrical Distribution System

The ship's power distribution is centralized at the Main Switch Board (MSB), which manages the supply from generators to various panels. During parallel operation, multiple generators share the electrical load. Parallel release transfers the full load to a single generator. Voltage instability becomes highly critical during independent operation because the single auxiliary engine lacks the supplementary support of a paralleled unit to compensate for electrical faults or excitation drops.

2.4. Excitation System

In an effort to enhance power generation efficiency, modern rotor designs have modified conventional electromagnets by utilizing an iron claw construction enclosing the magnetic coil to create 12 magnetic poles; this closely spaced pole configuration significantly minimizes the time interval between current peaks of opposite

polarity as the rotor spins rapidly, resulting in a more efficient and stable energy output.

2.5 Ship Electrical Diagram

The ship's power distribution system is centralized at the Main Switch Board (MSB), which manages the supply from the main and emergency generators to various distribution panels, including lighting, navigation, and galley equipment, featuring a safety mechanism that allows the system to automatically switch to the Emergency Generator via a bus tie in the event of a main supply failure, to ensure the reliability of ship operations (Rukmini, 2021).

3. Research Methodology

3.1 Research Design

This research utilizes a descriptive qualitative approach suitable for onboard failure case studies. The unit of analysis is Auxiliary Engine No. 2 of the MV. Hanglima. This method focuses on understanding the sequence of

mechanical and electrical degradation through systematic field data processing.

3.2 Data Collection

Data was gathered aboard the MV. Hanglima through triangulation:

- a. **Observation:** Direct monitoring of Engine Control Room (ECR) indicators (Voltage, Frequency, Current) during parallel release and visual inspection of alternator components during the overhaul.
- b. **Documentation:** Review of the Engine Log Book, Yanmar/Taiyo Instruction Manuals, and maintenance records to verify running hours and maintenance history.
- c. **Interviews:** Structured discussions with the Chief Engineer and Second Engineer regarding procedural maintenance history, operational anomalies, and early warning signs

Table 1. Indicators Abnormal Condition Ship Electrical Panel

Parallel			
Normal Conditions		Abnormal Conditions	
F	55	F	55
V	445	V	380
A	70	A	70
Parallel Release			
Normal Conditions		Abnormal Conditions	
F	60	F	60
V	445	V	280
A	200	A	200 (blackout)

3.3 Data Analysis

The collected data were analyzed using the Fishbone diagram to systematically map the Machine, Method, Man, and Material factors

contributing to the voltage instability.

4. Results and Discussion

MV. Hanglima has the following specifications of the main engine:

Table 2. Specification of Auxiliary Engine MV Ship. Hanglima

Diesel Engine	
Maker X Model	Yanmar Diesel Engine, . Co. Ltd
Type X Quantity	Vertical, Single Acting 4 Cyle Diesel Engine
Output X Number Of Revolutions	270 Ps X 1200 Rpm
Cyl Number X Bore X Stroke	6 X 135 Mm X 160 Mm
Total Weight	2850 Kg With A.C Generator
Main Generator	
Maker X Model	Taiyo Electric Mfg, Co. Ltd
Type X Quantity	Driprprof Brushless A.C. Generator
Output X Number Of Revolutions	225 Kva X 1200 Rpm
Voltage X Phases X Frequency	Ac 445v X 3 X 60 Hz
Driving Engine	Yanmar Diesel Engine, . Co. Ltd

4.1 Incident Chronology and Measured Parameters

The incident occurred on March 2, 2024, at Jurong Port. Under normal parallel conditions with AE No. 1, AE No. 2 maintained 445V and 60Hz. However, upon disconnecting the parallel link (parallel release), AE No. 2 failed to sustain the load independently. The voltage dropped

drastically from 445V to 280V, triggering a blackout condition while the frequency remained at 60Hz. AVR failure was ruled out during initial diagnostics, redirecting the investigation toward mechanical and winding integrities.

Table 3. Bearing Running Hours vs. Manufacturer Limit

Component	Current Running Hours	Recommended Replacement	Status
Bearing AE No. 1	35,763 hours	50,000 hours	Safe
Bearing AE No. 2	45,173 hours	50,000 hours	Critical

4.2 Physical Inspection and Testing Findings

Although the bearing running hours (45,173 hours) were technically within the 50,000-hour manufacturer limit, physical inspection revealed:

- 1. Bearing Damage:** Severe wear and cracking in the ball bearings.
- 2. Rotor-Stator Contact:** Scuff marks indicating loss of concentricity and physical friction between the rotor and stator.
- 3. Insulation Failure:** Megger tests (Insulation Resistance) confirmed a short circuit in the stator windings resulting from friction abrasion.

logged or reported minor abnormal vibrations and acoustic anomalies prior to catastrophic failure.

- 4. Material (Supporting Cause):** Thermal and age-related degradation of the winding varnish reduced its mechanical resistance to abrasion once friction occurred.

4.3 Root Cause Analysis (Fishbone)

The causal relationship mapping identifies the following factors:

- 1. Machine (Dominant Cause):** Structural failure of the alternator bearing caused rotor imbalance and an uneven air gap. This led directly to rotor-stator rubbing, stripping the insulation, and causing the voltage-collapsing short circuit.
- 2. Method (Supporting Cause):** Maintenance relied exclusively on Time-Based Maintenance (50,000 hours) without adequate Condition-Based Monitoring (CBM), such as vibration or thermal analysis, missing early degradation signals.
- 3. Man (Supporting Cause):** Procedural weaknesses in monitoring early symptoms. Operators inadequately

4.3 Corrective Actions

The engineering team executed a comprehensive Planned Maintenance System (PMS) overhaul:

- 1. Insulation Repair:** Cleaning windings with electro-cleaner and applying high-grade red insulating varnish (e.g., Dolph-Spray ER-44).
- 2. Parts Replacement:** Installation of original OEM bearings.
- 3. Post-Repair Testing:** Confirmatory Megger testing and load running tests verified a stable output of 445V/60Hz under independent load.

4.4 Discussion

1. Factors Causing the Decline in Auxiliary Engine Alternator Performance

The analysis using the Fishbone diagram identifies that the decline in alternator performance is driven by a combination of human error and mechanical failures. Operators contributed to the issue through a lack of sensitivity to early indicators of voltage instability, failing to identify the problem promptly. Mechanically, the primary failure

involved cracked alternator bearings, likely caused by engine overspeed or inadequate maintenance; this structural failure prevented the bearings from stabilizing the shaft, resulting in friction between the rotor and stator.



Figure 1. Overhaul Alternator Auxiliary Engine 2

This mechanical imbalance led to severe electrical consequences, specifically the abrasion of the copper winding insulation, which resulted in short circuits and voltage leakage that compromised the generator's output. These issues were exacerbated by methodological deficiencies, such as the absence of routine performance testing, and the utilization of non-standard or defective spare parts in an attempt to reduce costs, which collectively degraded the alternator's stability and overall efficiency.

2. Measures to Restore Auxiliary Engine Alternator Performance

The restoration process for Auxiliary Engine No. 2 necessitated a comprehensive overhaul, beginning with the dismantling of the alternator from the generator shaft to access the internal components. Diagnostic procedures included a Megger Test to evaluate insulation integrity; upon detecting leakage, the existing insulation was stripped using a chemical varnish remover, followed by the application of a new insulating varnish spray to ensure complete coverage and sealing against future leaks.

Following the re-insulation and a subsequent confirmatory Megger Test, the damaged bearings were replaced with original spare parts as specified in the manual book to ensure precise fitment and

stability. The maintenance cycle concluded with the reassembly of the alternator and a rigorous running test, during which key electrical parameters—including current, voltage, and frequency—were monitored to verify that the auxiliary engine had returned to optimal operational status.

3. The Impact of Declining Alternator Performance on Ship Machinery

The degradation of the alternator's performance significantly compromises the vessel's electrical and auxiliary systems, leading to dimmed lighting that reduces visibility and potential damage to sensitive electronic equipment, such as navigation and control units, due to voltage fluctuations. Furthermore, the lack of stable power disrupts critical auxiliary machinery, reducing the efficiency of pumps essential for cooling and fuel transfer, as well as impairing the function of air compressors and refrigeration systems required for cargo and engine maintenance.

Beyond mechanical disruptions, voltage instability poses severe safety and operational risks by compromising alarm systems, emergency equipment, and electronic navigation aids, thereby increasing the likelihood of maritime accidents. From an operational perspective, unreliable power generation escalates the risk of voyage delays or cancellations and necessitates frequent, costly repairs, ultimately resulting in significant financial losses and potential damage to the cargo.

5. Conclusion and Recommendations

The electrical voltage instability in Auxiliary Engine No. 2, characterized by a drastic drop to 280V during independent operation, was fundamentally caused by mechanical degradation. Cracked alternator bearings (at 45,173 running hours) resulted in rotor-stator friction, which subsequently caused insulation leakage and short circuits in the windings. Corrective overhaul, encompassing re-insulation and bearing replacement, successfully restored the generator's optimal output to 445V.

To prevent recurrence, it is highly recommended to shift from purely Time-Based Maintenance to Condition-Based Monitoring (CBM). Watchkeeping personnel must implement routine vibration measurements,

bearing temperature monitoring, and periodic Megger testing to detect anomalies early. Additionally, periodic AVR inspections and functional load testing after maintenance should be incorporated into the standard operating procedures to ensure electrical reliability.

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