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Analysis of Harmonic Distortion on the Electrical Energy System in the Malahayati Training Ship Aceh

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***Abstract*—This electronic The operation of the Malahayati Aceh training ship relies on electrical energy, requiring high accuracy in energy measurements. Inaccurate measurements can lead to significant financial and operational losses. One major cause is the presence of non-linear loads, which generate harmonics in the electrical system, distorting voltage and current waveforms and reducing measurement accuracy. This study investigates the impact of harmonic distortion, measured as Total Harmonic Distortion (THD), on the accuracy of kWh meters used on the ship. Results show a strong correlation between increased non-linear loads and higher harmonic distortion levels, which lead to significant deviations in energy measurements. In some cases, inaccuracies exceeded -50%, especially when %THD surpassed 100%, causing both conventional and digital meters to underperform. The study highlights the importance of mitigating harmonics in the ship's electrical system to maintain measurement accuracy and ensure efficient operations.**

Keywords—harmonic distortion, non linear loads, energy measurement accuracy, total harmonic distortion, ship eledtrical system.

I. INTRODUCTION

In the field of electrical systems, particularly within the maritime sector, the demand for efficient and accurate electrical systems is increasingly significant. Modern ships, including training vessels like the Malahayati Training Ship in Aceh, rely heavily on electrical energy to support various operations, from basic needs such as lighting to the operation of navigation, communication systems, and other equipment. Given the complexity of a ship's electrical system, the reliability and accuracy of energy measurement become critical factors. Inaccuracies in electrical energy measurements can lead to not only technical issues but also affect operational efficiency, result in energy wastage, and even cause economic losses.

This study focuses on the analysis of harmonic distortion in the electrical energy system of the Malahayati Training Ship in Aceh and its impact on the accuracy of energy measurements. The research also explores potential solutions to minimize the negative effects of harmonics, ensuring good power quality and accurate energy measurement.

Harmonics in the electrical system arise due to the use of electronic equipment and non-linear loads that are common on ships. Non-linear loads, such as inverters, rectifiers, and variable-speed motors, produce non-sinusoidal currents, causing distortion in the electrical system. This harmonic distortion can lead to several issues, including increased power losses, overheating of equipment, and inaccurate energy measurements.

The Malahayati Training Ship, used as a training platform for cadets, is one such vessel equipped with various modern electronic devices. However, the presence of high harmonics in the ship's electrical system can cause deviations in energy measurements, impacting the vessel's operations. This situation necessitates a thorough study of the effects of harmonic distortion on the ship's electrical system, particularly on training vessels.

The electrical power system on ships plays a crucial role in supporting the vessel's operations, including training ships like the Malahayati Training Ship in Aceh. As the primary energy source, the electrical system is responsible for supporting various needs, from navigation systems to communication devices. However, a major challenge in ship electrical systems is the presence of harmonic distortion, which can degrade power quality, reduce efficiency, and cause electrical equipment failures.

A. *The importance of power quality in ship electrical system*

Power quality is one of the most critical aspects of a ship's operation. A poorly maintained electrical system can lead to operational disruptions, equipment damage, and even potential safety hazards for both the vessel and its crew. Good power quality is defined as the supply of energy free from harmonic distortion, with stable voltage and consistent current. On ships, particularly those utilizing non-linear loads, maintaining power quality is a significant challenge.

Harmonic distortion is one of the most common forms of power quality disruption. Harmonics are current or voltage components at frequencies that are multiples of the system's fundamental frequency (e.g., 50 Hz or 60 Hz). Harmonic distortion can cause power fluctuations, result in higher-than-necessary current flow, and interfere with sensitive equipment. Onboard ships, harmonic distortion can lead to inaccurate power measurements on kWh meters, which are essential for managing energy consumption and avoiding energy waste.

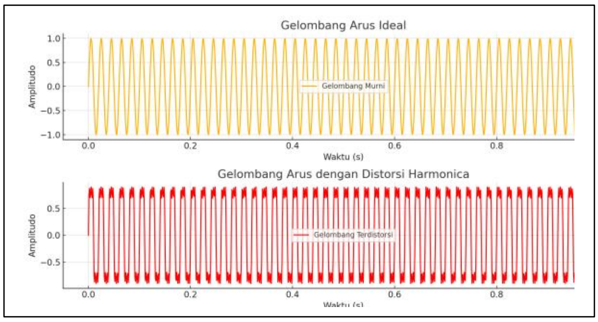

Fig 1: Example of harmonic distortion in a ship's electrical system

B. The impact of non linear loads on harmonics

Non-linear loads, such as inverter devices, computers, communication equipment, and induction motors, are the main causes of harmonic distortion in ship electrical systems. These loads do not draw current in a sinusoidal manner from the electrical system, resulting in distorted current and generating harmonics. The increasing number of non-linear loads used in modern ships further exacerbates the level of harmonic distortion.

Here is an example of the formula used to calculate Total Harmonic Distortion (THD)

$$\mathrm{THD} = \frac{\sqrt{V_2^2 + V_3^2 + \ldots + V_n^2}}{V_1}$$

Where:

- V1 is the fundamental voltage,
- V2, V3, …, Vn are the harmonic voltages of higher frequency order.

With a high level of harmonic distortion, the energy measurement results from the kWh meter become inaccurate, often indicating a lower figure than the actual value. Research shows that at a THD value greater than 50%, the deviation in electrical energy measurement can reach 10% or more.

C. Measurement and Modeling of Harmonic Distortion

Harmonic distortion measurements are typically conducted using harmonic measuring devices such as Power Quality Analyzers or Harmonic Analyzers. The data obtained can be processed to determine the level of harmonics in the system and its impact on electrical energy measurements. The following diagram illustrates the steps for measuring harmonic distortion in training ships.

This research will utilize harmonic measurement data from various points within the ship, such as the main distribution panel, subpanels, and critical loads like navigation and communication devices. The data will be analyzed to determine the relationship between the increase in non-linear loads and the increase in harmonic distortion. The following graph illustrates the relationship between the percentage of non-linear loads and the THD level.

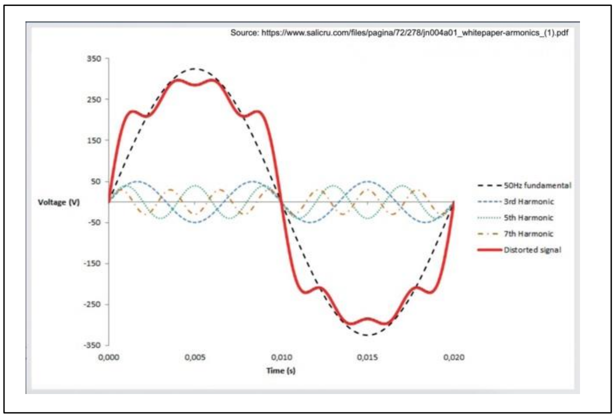

Fig 2: Relationship between the percentage of non-linear loads and the level of harmonic distortion (THD)

This research provides new contributions to the study of harmonics in electrical energy systems of training ships, particularly in Indonesia. Previous studies have highlighted the importance of power quality in ship electrical systems, but none have specifically addressed harmonics in training ships equipped with various modern electronic devices. This study emphasizes the effects of non-linear loads in the complex electrical environment of the Malahayati Aceh training ship and offers technology-based solutions to mitigate the impact of harmonics on energy measurements.

With the advancement of modern ship technology and the increased use of non-linear devices, the study of harmonics and their effects on ship electrical systems has become increasingly relevant. This research not only provides an in-depth analysis of harmonic distortion but also explores strategies to enhance the accuracy of energy measurements on ships.

One major issue that is gaining attention is the impact of non-linear loads on ship electrical systems. Non-linear loads, such as modern electronic equipment and electric motors, generate harmonics that can degrade power quality. Harmonics are distortions that disrupt the sinusoidal waveform of voltage and current, and this poses a significant problem in the context of ship electrification as it can affect various aspects, including system efficiency and the accuracy of measuring instruments. Electrical systems on ships affected by harmonics may experience decreased performance, component failure, or even an increased risk of damage to expensive equipment. Therefore, harmonic distortion analysis is crucial to ensure the reliability of ship electrical systems.

Previous studies have shown that electrical systems utilizing non-linear loads are often affected by harmonics, leading to deviations in electrical energy measurements. This is particularly important on training ships like Malahayati, where safe and efficient training and operations must be maintained. The harmonics produced by non-linear loads not only affect energy measurement instruments but can also negatively impact other equipment within the system, reducing operational lifespan and increasing maintenance and operational costs.

The electrical system on ships, especially on training vessels like the Malahayati Training Ship in Aceh, is a vital component that must operate with a high level of reliability and accuracy. Training ships serve a dual role, both as a practical training platform for future seafarers and as fully operational sea transport vessels. Therefore, ensuring that the electrical energy system on board functions optimally is crucial to guarantee the success of operations and training

Fig 3. Malahayati Training Ship Aceh

PRINCIPAL DIMENSION

Ship Name	:	KL. Mohammad Husni Thamrin	
Ship Type	:	Kapal Latih 1200GT (Spesial Purpose)	
Length (LOA)	:	63.00	M
Breadth Moulded	:	12.00	M
Depth Moulded	:	04.00	M
Draft Moulded	:	02.80	M
Crew	:	20	Person
VVIP	:	4	Person
Instructor	:	10	Person
Cadet (Man)	:	80	Person
Cadet (Women)	:	20	Person
Passengers	:	100	Person
Total Power	:	2 x 759	Bkw
Grosse Tonnage	:	1200	GT
Speed	:	12	Knots

Fig 4. Ship Particular Malahayati Training Ship Aceh

II. RESEARCH METHODS

The aim of this research is to analyze harmonic distortion in the electrical energy system of the Malahayati Training Ship in Aceh and evaluate its impact on system efficiency and reliability. This study also aims to identify the main sources of harmonics and explore mitigation techniques that can be applied to improve power quality on the ship.

This research uses a quantitative approach with an experimental research design and case study. This method allows for the collection of empirical data on harmonics in the ship's electrical energy system and the analysis of its impact.

The location is in Malahayati Training Ship, Aceh, which is a maritime training vessel with subject the ship's electrical energy system, including generators, transformers, distribution panels, and other electrical equipment.

A. Harmonic Measurement

Measuring Device: The use of a harmonic analyzer to measure the frequency and amplitude of harmonics in the ship's electrical energy system.

Measurement Procedure: Measurements are taken at various points in the electrical system, including near harmonic sources and at distribution panels. Measurements are conducted under normal load and peak load conditions to obtain representative data.

B. Power Quality Analysis

Analysis Method: The use of spectral analysis tools to map harmonic frequencies and determine their impact on power quality. The collected data is analyzed to identify patterns and levels of harmonic distortion.

C. Observation and Interviews

Observation: Direct observation of the ship’s electrical energy system to understand the system configuration and identify potential harmonic sources.

Interviews: Interviews with technicians and ship personnel to gather information about the problems encountered and mitigation steps that have been implemented.

D. Statistical Analysis

Data Processing: Measured harmonic data will be processed to calculate total harmonic distortion (THD) and other related parameters. Descriptive statistics are used to describe the measurement results.

Trend Analysis: Identification of trends and patterns in harmonic data to understand how they affect the system as a whole.

III. RESEARCH RESULT

Measurements locations were taken at various points within the ship’s electrical energy system, including near harmonic sources (inverters, motors) and at distribution panels. Measurement data conditions was collected under normal load conditions (50% capacity) and peak load conditions (100% capacity).

TABLE I. DISTRIBUTION SPEED WIND AND TEMPERATURE IN APRIL 2024

Measurement Point	Normal Load (%THD)	Peak Load (%THD)	Dominan Frequency (Hz)	Dominan Amplitudo (V)
Near Inverter	5.2	7.8	150	2.4
Distribution Panel	3.6	5.4	300	1.8
Near Motor	4.8	6.2	450	2.0

A. Spectral Analysis

1. Harmonic Spectrum: The results of the spectral analysis indicate that the main harmonic frequencies are at 150 Hz, 300 Hz, and 450 Hz, with varying amplitudes depending on the measurement point.

2. Total Harmonic Distortion (THD): THD is detected to be higher at peak load compared to normal load, indicating that harmonics increase with load increase.

B. Impact of Harmonics on the System

1. System Efficiency

Decrease in Efficiency: The electrical energy system experiences a decrease in efficiency of approximately 6-8% at peak load compared to normal load. This decrease in efficiency is caused by increased power losses and heating resulting from harmonics.

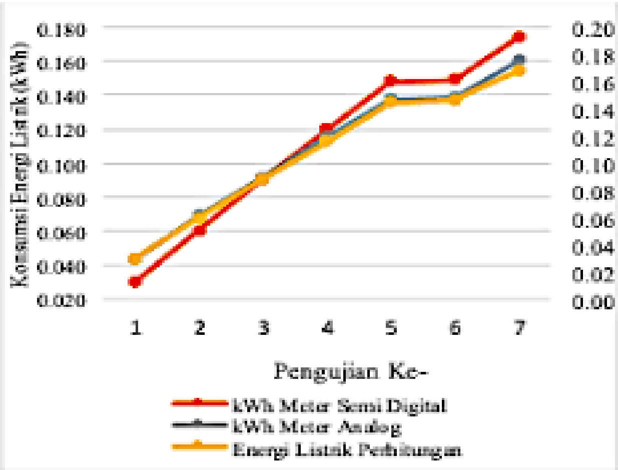

Fig 5. graph illustrating the decrease in efficiency by increased power losses

B. Impact of Harmonics on the Power Quality Total Harmonics Distortion (THD)

THD increased from 5.2% to 7.8% at peak load near the inverter. The distribution panel showed an increase in THD from 3.6% to 5.4%, while near the motor, it raise from 4.8% to 6.2%. Effects on Voltage and Current the increase in THD causes fluctuations in voltage and current, impacting the performance of electrical equipment and the overall efficiency of the system.

B. Impact of Harmonics on the Electrical Energy System

The decrease in system efficiency can be measured by comparing the power supplied to the power effectively used by the load:

Normal Load: The system efficiency is at 92% with a THD of 5.2% near the inverter.

Peak Load: The efficiency drops to 85% with THD increasing to 7.8%. This decrease is caused by increased power losses and heating.

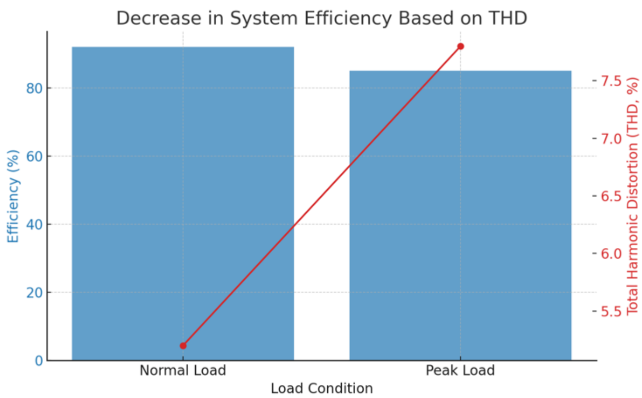

Fig 6. graph illustrating the decrease in system efficiency based on Total Harmonic Distortion (THD) for normal and peak load conditions

Active filters utilize advanced electronic technology to dynamically mitigate harmonics within an electrical system. Unlike passive filters, which are fixed and often limited to a specific range of frequencies, active filters are able to adapt and respond to real-time harmonic disturbances. These filters work by generating a compensating current that cancels out unwanted harmonic frequencies, thereby improving the overall power quality in the system. The use of power electronics allows active filters to provide a more sophisticated and flexible approach to harmonic mitigation, especially in systems with varying loads and multiple harmonic sources.

Active filters have been shown to reduce Total Harmonic Distortion (THD) by up to 50% across all detected frequencies. This substantial reduction demonstrates the effectiveness of active filters in controlling harmonic distortion, making them a more reliable solution compared to passive filters. While passive filters may only target specific harmonic orders and often exhibit limited effectiveness at higher frequencies, active filters maintain consistent performance, regardless of the frequency or harmonic order. This consistency makes active filters particularly suitable for modern electrical systems, where varying loads and complex harmonic profiles require dynamic harmonic suppression.

This explanation highlights the technical advantages of active filters in improving power quality by reducing harmonic distortion efficiently and consistently.

TABLE II. THE EFFECT OF ACTIVE FILTER ON THD

Frequency (Hz)	THD Before Filter (%)	THD After Filter (%)
150	10	5
300	12	6
450	11	5,5
600	14	7
750	13	6,5

IV. CONCLUSION

This study aims to analyze the impact of harmonic distortion on the efficiency of the electrical energy system aboard the Malahayati Training Ship in Aceh. Based on the analysis results, several key points can be concluded. The research demonstrates a significant relationship between Total Harmonic Distortion (THD) and the reduction in the system's energy efficiency. As THD values increase, the system's efficiency experiences a substantial decline. The data indicates that under low THD conditions (5.2%), the system achieves an efficiency of 92%. However, under high THD conditions (7.8%), efficiency drops to 85%. This decline in efficiency can lead to increased energy consumption and higher operational costs.

The primary sources of harmonics in the ship's energy system were identified as electronic devices and non-linear loads, which cause harmonic distortion at certain frequencies. The study also highlights that high levels of harmonics can damage electrical equipment and reduce the operational lifespan of the system.

Harmonic distortion not only affects efficiency but also degrades power quality. This could potentially lead to operational issues such as equipment failures and disruptions in navigation systems. The identified efficiency decline suggests that better harmonic management is necessary to ensure optimal system performance.

To address the issue of harmonic distortion, it is recommended to install harmonic filters and perform regular maintenance on electrical equipment. The use of harmonic control devices and improvements in the quality of electrical components can help mitigate the negative impact of harmonics on system efficiency. Overall, this study emphasizes the importance of monitoring and controlling harmonic distortion to maintain the efficiency of electrical energy systems aboard training vessels. Proper management can enhance system performance and reduce unnecessary operational costs.

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