Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6, 7922-7932
2024
Publisher: Learning Gate
DOI: 10.55214/25768484.v8i6.3729

Analysis of ship electrical load management to reduce exhaust gas emissions in landing platform dock (LPD) vessel class

Abdul Rahman[1*], Antariksa[2], Bambang Semedi[3], Slamet Wahyudi[4]
[1,2,3,4]University of Brawijaya, Malang Indonesia; abdulrahmanalri36@gmail.com (A.R.).

Abstract: This paper investigates the impact of electrical load management on reducing exhaust gas emissions in Landing Platform Dock (LPD) class vessels. The study focuses on the implementation of Integrated Fully Electric Propulsion (IFEP) systems and Variable Speed Drives (VSD) to enhance energy efficiency and minimize environmental impact. The conventional Diesel Engine Propulsion system in LPD vessels often results in high fuel consumption and significant emissions, particularly under non-optimal operating conditions. By transitioning to an IFEP system and optimizing electrical load management using VSD, the study demonstrates a substantial reduction in carbon dioxide (CO_2), nitrogen oxides (NO_x), and sulfur oxides (SO_x) emissions. The results indicate a potential emission reduction of up to 40%, alongside a 20% improvement in overall energy efficiency. Additionally, the operational benefits of these technologies include increased flexibility, reduced maintenance costs, and extended equipment lifespan. The findings underscore the importance of adopting advanced propulsion and load management technologies in naval vessels to meet stricter environmental regulations and support sustainable maritime operations. This study provides a framework for future research and practical applications in expanding these technologies across different ship types and operational scenarios.

Keywords: *Exhaust gas emissions, Landing platform dock (LPD), Ship electrical load management.*

1. Introduction

The maritime industry plays a crucial role in global trade, with approximately 80% of international goods being transported by sea. However, this industry significantly contributes to environmental degradation, particularly through the emission of greenhouse gases (GHG) such as carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulate matter. These emissions are primarily due to the reliance on fossil fuels for both main propulsion engines and auxiliary power generation on ships. In recent years, global awareness and regulatory frameworks have increasingly focused on reducing these emissions to mitigate climate change. The International Maritime Organization (IMO) has set stringent limits on the sulfur content in marine fuels and introduced the Energy Efficiency Design Index (EEDI) to encourage the development of more energy-efficient ships. In response to these regulations, the maritime industry has been exploring various technological innovations, such as Integrated Fully Electric Propulsion (IFEP) systems and advanced electrical load management technologies like Variable Speed Drives (VSD), which promise to reduce fuel consumption and emission.

This study focuses on analyzing the potential of these technologies, particularly how the implementation of effective electrical load management strategies on ships can contribute to reducing exhaust gas emissions. The conventional propulsion systems on many naval ships, including those in the Indonesian Navy, rely heavily on diesel engines. These systems are often inefficient, particularly when ships operate at non-optimal loads, leading to excessive fuel consumption and higher emissions. Furthermore, the electrical load management systems on these ships are typically outdated, lacking the efficiency that modern technologies like VSD can offer. This study seeks to design a propulsion system for LPD-type ships that transitions from Diesel Engine Propulsion to Integrated Fully Electric

* Correspondence: abdulrahmanalri36@gmail.com

Propulsion (IFEP), to develop an optimized electrical load management system using Variable Speed Drives (VSD) for LPD-type ships and to compare the exhaust gas emission levels between ships using Diesel Engine Propulsion and those equipped with an IFEP system.

This study is focused on the analysis of LPD-type ships within the Indonesian Navy, specifically the *Navy Ships BSN*. The scope includes the design and analysis of the propulsion system conversion from Diesel Engine Propulsion to IFEP and the implementation of VSD in the ship's electrical load management system. The research does not cover other types of ships or naval vessels outside of the LPD category. The author does hope This research introduces several novel contributions to the field of maritime technology. Firstly, it provides a comprehensive design framework for converting LPD-type ships from Diesel Engine Propulsion to IFEP, a transition that has not been extensively explored in previous studies. Secondly, the study presents an innovative approach to electrical load management using VSD, which is tailored to the unique operational needs of naval vessels. Finally, the comparative analysis of exhaust gas emissions between conventional and IFEP systems offers new insights into the environmental benefits of electric propulsion in the maritime sector. These contributions are expected to fill existing research gaps and provide a foundation for future studies in this area.

2. Material and Method

2.1. Previous Research Studies

The shift towards more sustainable maritime operations has led to numerous studies focused on reducing fuel consumption and emissions from ships. Mrzljak and Mrakovčić (2019) compared diesel-electric propulsion systems with Combined Gas Turbine Electric and Steam (COGES) systems, concluding that diesel-electric systems, despite their lower investment costs, offer superior efficiency at low loads, thus reducing fuel consumption and emissions. Yang et al. (2017) explored the history and recent advancements in electric propulsion systems, highlighting the increasing electrification of both propulsion and auxiliary systems in marine vessels. Their findings emphasized the significant environmental benefits of integrated electric power systems in reducing emissions.

Boulougoris et al. (2011) introduced the Energy Efficiency Design Index (EEDI) as a critical tool for optimizing ship design with a focus on reducing maritime greenhouse gas emissions. They developed a Parametric Design Software Tool for holistic ship design optimization, which considers various energy efficiency measures, including propulsion system designs.

Research by Lindstad and Ingebrigtsen (2013) emphasized the potential of hybrid power setups and hull designs to meet future EEDI requirements, indicating that innovative propulsion systems are crucial for the maritime industry's compliance with international regulations. Additionally, studies by Sequeira and Alakoon (2019) focused on Variable Speed Drives (VSD) in maritime applications, demonstrating their effectiveness in controlling motor speed and reducing energy consumption in various ship systems.

These studies collectively underscore the importance of innovative propulsion and load management systems in reducing emissions and improving energy efficiency in the maritime sector. However, they also reveal a gap in the literature concerning the integration of these technologies into a comprehensive system for naval vessels, particularly in the context of LPD-type ships

2.2. Theoretical Framework

The theoretical framework for this study is grounded in the principles of energy efficiency, propulsion system design, and load management within marine vessels. The concept of energy efficiency in maritime operations is primarily guided by the Energy Efficiency Design Index (EEDI), which serves as a regulatory framework to reduce greenhouse gas emissions from ships. The implementation of electric propulsion systems, including Integrated Fully Electric Propulsion (IFEP), represents a significant shift towards achieving these regulatory targets.

Furthermore, Variable Speed Drives (VSD) offer a modern approach to managing electrical loads on ships, optimizing energy use based on real-time demand. The integration of these technologies into a cohesive system is essential for reducing fuel consumption and emissions, particularly in naval operations where operational efficiency is critical.

2.3. Electric Propulsion Systems

Electric propulsion systems have gained traction in the maritime industry as a viable alternative to conventional diesel engines. These systems use electric motors to drive the ship's propellers, powered by generators that can run on various energy sources, including diesel, gas, or renewable energy. The primary advantage of electric propulsion is its ability to operate efficiently across a wide range of speeds, which is particularly beneficial for naval vessels that often operate under varying conditions.

Integrated Fully Electric Propulsion (IFEP) represents an advanced form of electric propulsion where all power on the ship, including propulsion and auxiliary systems, is supplied by a centralized electric power system. This configuration allows for greater flexibility and efficiency, as the electric power can be distributed according to the ship's needs, reducing fuel consumption and emissions.

Figure 1.
Propulsion electric motor.

The transition from conventional diesel engines to IFEP in LPD-type ships is expected to yield significant environmental benefits by reducing the reliance on fossil fuels and lowering the emission of harmful pollutants. Additionally, IFEP systems enhance operational flexibility, allowing ships to perform a variety of missions with optimal energy efficiency.

2.4. Energy Efficiency Design Index (EEDI)

The Energy Efficiency Design Index (EEDI) is a key regulatory measure introduced by the International Maritime Organization (IMO) to improve the energy efficiency of ships. EEDI sets minimum energy efficiency levels per capacity mile for different ship types and sizes, effectively serving as a benchmark for new ship designs. Ships that meet or exceed the EEDI requirements are considered more energy-efficient, translating to lower fuel consumption and reduced emissions.

EEDI encourages the adoption of energy-efficient technologies, including advanced hull designs, optimized propulsion systems, and alternative energy sources. For LPD-type ships, achieving EEDI compliance necessitates the integration of electric propulsion systems and the use of technologies like VSD to manage electrical loads more effectively. By optimizing the design and operation of these ships, it is possible to meet or even exceed the EEDI standards, thereby contributing to global efforts to mitigate climate change.

2.5. Variable Speed Drives (VSD)

Variable Speed Drives (VSD) are devices that control the speed and torque of electric motors by adjusting the power supply frequency and voltage. In marine applications, VSDs are used to optimize the performance of various systems, such as propulsion motors, pumps, fans, and compressors. By matching the motor speed to the actual demand, VSDs can significantly reduce energy consumption and extend the lifespan of mechanical components.

The application of VSDs in the electrical load management of ships, particularly in the context of electric propulsion systems, offers substantial benefits. For instance, by controlling the speed of propulsion motors, VSDs can help maintain optimal efficiency across different operational conditions, reducing fuel consumption and emissions. Additionally, VSDs can improve the efficiency of auxiliary systems, such as ventilation and cooling, which are critical for maintaining the operational readiness of naval vessels.

The integration of VSDs into the electrical load management system of LPD-type ships is expected to enhance the overall energy efficiency of these vessels, contributing to reduced operational costs and lower environmental impact.

3. Methodology

3.1. Research Approach

This study employs a mixed-method research approach, combining both qualitative and quantitative methods to thoroughly analyze the management of electrical loads on naval vessels with the aim of reducing exhaust gas emissions. The qualitative component involves a detailed review of existing literature, regulations, and technological advancements related to electric propulsion systems and Variable Speed Drives (VSD). The quantitative component includes the design and simulation of the Integrated Fully Electric Propulsion (IFEP) system and electrical load management using VSD for LPD-type ships.

The research is structured in several phases: initial data collection, system design and modeling, simulation, and comparative analysis. The focus is on developing a comprehensive understanding of how these technologies can be applied to LPD-type ships to enhance energy efficiency and reduce emissions.

3.2. Object and Location of Study

The object of this study is the *Navy Ships BSN*, a Landing Platform Dock (LPD)-type ship operated by the Indonesian Navy. This vessel was chosen due to its size, operational profile, and the availability of data, which make it an ideal candidate for the implementation of IFEP and VSD technologies.The study is conducted at the naval facilities where the *Navy Ships BSN* is based, with additional data collection and analysis carried out at the research laboratories of the naval engineering department. The location was selected due to its proximity to the ship and the availability of necessary resources and expertise for conducting the research.

3.3. Data Collection Techniques

Data collection for this study is conducted through several methods:

1. **Literature Review:** A comprehensive review of existing literature on electric propulsion systems, VSD, and energy efficiency in maritime operations is conducted to establish the theoretical framework for the study.
2. **Technical Data Analysis:** Technical data on the propulsion system, electrical load management, and fuel consumption of the *Navy Ships BSN* is collected. This includes operational logs, engine performance data, fuel consumption records, and emission levels.
3. **Interviews and Expert Consultation:** Interviews with naval engineers, ship operators, and industry experts are conducted to gather insights on the practical challenges and considerations in implementing IFEP and VSD systems on naval vessels.
4. **Simulation Data:** The proposed designs for the IFEP system and the VSD-managed electrical load are modeled and simulated using specialized maritime engineering software. The simulation provides data on energy efficiency, fuel consumption, and emission levels under different operational scenarios.

3.4. Analytical Techniques

The data collected is analyzed using a combination of qualitative and quantitative analytical techniques:

1. **Descriptive Analysis:** The technical data and literature review are analyzed descriptively to identify patterns, trends, and key considerations in the design and implementation of IFEP and VSD systems.
2. **Comparative Analysis:** The performance of the existing Diesel Engine Propulsion system is compared with the proposed IFEP system using simulation results. Key metrics such as fuel consumption, emission levels, and energy efficiency are used for comparison.
3. **Scenario Analysis:** Different operational scenarios are simulated to assess the impact of various factors (e.g., ship speed, load conditions) on the performance of the IFEP system and the effectiveness of VSD in managing electrical loads.
4. **Cost-Benefit Analysis:** A cost-benefit analysis is conducted to evaluate the economic feasibility of implementing the IFEP system and VSD technology on LPD-type ships, considering both initial investment and long-term operational savings.

The combination of these analytical techniques allows for a comprehensive evaluation of the potential benefits and challenges associated with the transition to electric propulsion and advanced load management systems in naval vessels.

4. Results and Discussions

4.1. Design of Integrated Fully Electric Propulsion (IFEP) System

The design of the Integrated Fully Electric Propulsion (IFEP) system for the *Navy Ships BSN* involved reconfiguring the ship's propulsion architecture from a conventional Diesel Engine Propulsion system to an electric propulsion system. The key components of the IFEP system include electric motors, power converters, and an integrated power management system that coordinates the distribution of electrical energy across the ship's propulsion and auxiliary systems.

The design process began with a detailed assessment of the ship's power requirements under various operational conditions, such as cruising, maneuvering, and docking. Based on this assessment, electric motors with appropriate power ratings were selected to replace the existing diesel engines. These motors are powered by diesel generators that supply electricity to the entire ship, including propulsion and auxiliary systems.

A central feature of the IFEP system is the ability to operate at optimal efficiency across a wide range of speeds, thanks to the flexibility of electric motors. This flexibility allows the ship to maintain high efficiency even at lower speeds, where conventional diesel engines typically become less efficient. Additionally, the IFEP system integrates with the ship's existing power distribution network, allowing for seamless control of power flow and ensuring that the ship's operational demands are met efficiently.

4.2. Design of Electrical Load Management Using VSD

The Electrical Load Management system using Variable Speed Drives (VSD) was designed to optimize the energy consumption of the ship's auxiliary systems, such as ventilation fans, pumps, and compressors. VSDs were selected for their ability to adjust the speed of electric motors in response to varying load demands, thereby reducing unnecessary energy consumption.

In the design phase, each auxiliary system on the ship was analyzed to determine its typical load profile and operating conditions. Based on this analysis, VSDs were installed on critical systems where significant energy savings could be achieved by varying the motor speed according to real-time demand. For example, ventilation systems that typically run at constant speeds regardless of actual air demand were retrofitted with VSDs to allow for speed adjustment based on the need for ventilation, resulting in reduced energy consumption during periods of low demand.

The implementation of VSDs also included the integration of a central control system that monitors the load on each motor and adjusts the speed accordingly. This system not only optimizes energy use but

ISSN: 2576-8484
Vol. 8, No. 6: 7922-7932, 2024
DOI: 10.55214/25768484.v8i6.3729

also extends the lifespan of the equipment by reducing mechanical stress on motors and other components.

4.3. Comparison of Emission Values between Diesel Engine Propulsion and IFEP Systems

A comparative analysis of emission values between the conventional Diesel Engine Propulsion system and the IFEP system was conducted using data from simulations and real-world operational scenarios. The results indicated a significant reduction in exhaust gas emissions with the IFEP system.

- **Carbon Dioxide (CO_2):** The IFEP system showed a reduction in CO_2 emissions by approximately 25% compared to the diesel engine system. This reduction is attributed to the higher efficiency of electric propulsion, especially at lower speeds where diesel engines are less efficient.
- **Nitrogen Oxides (NO_x):** The emission of NO_x, which is a major pollutant contributing to smog and acid rain, was reduced by 30% with the IFEP system. Electric propulsion reduces the reliance on diesel combustion, which is the primary source of NO_x emissions in conventional systems.
- **Sulfur Oxides (SO_x):** The reduction in SO_x emissions was even more pronounced, with a decrease of approximately 40%. This is due to the lower sulfur content in the fuel used for generating electricity compared to marine diesel fuel.

The analysis confirmed that transitioning to an IFEP system offers significant environmental benefits, particularly in reducing harmful emissions that contribute to air pollution and climate change.

4.4. Impact on Emission Reduction

The implementation of the IFEP system and VSDs resulted in a substantial reduction in overall emissions from the ship. The combined effect of improved propulsion efficiency and optimized electrical load management led to a reduction in total greenhouse gas emissions by approximately 30% compared to the conventional diesel engine setup.

This reduction is particularly important in the context of global efforts to combat climate change and meet international maritime emission standards. The findings suggest that adopting such technologies on a wider scale could make a significant contribution to reducing the environmental footprint of the maritime industry.

4.5. Energy Efficiency Improvements

The energy efficiency improvements achieved through the IFEP system and VSD implementation were significant. The simulations showed an increase in overall energy efficiency of the ship by approximately 20%. This improvement was mainly due to the following factors:

- **Optimal Propulsion Efficiency:** The IFEP system allows for more precise control of power delivery to the propulsion system, enabling the ship to operate efficiently across a wide range of speeds.
- **Reduced Auxiliary Power Consumption:** The use of VSDs in managing the ship's auxiliary systems resulted in lower energy consumption during periods of reduced demand, leading to overall energy savings.

These improvements not only contribute to lower fuel consumption and emissions but also result in operational cost savings, making the ship's operations more economically viable.

4.6. Operational Benefits

In addition to the environmental and energy efficiency benefits, the adoption of the IFEP system and VSDs offered several operational advantages:

- **Increased Operational Flexibility:** The IFEP system allows the ship to operate efficiently at various speeds, providing greater flexibility in mission profiles without compromising fuel efficiency.

Edelweiss Applied Science and Technology
ISSN: 2576-8484
Vol. 8, No. 6: 7922-7932, 2024
DOI: 10.55214/25768484.v8i6.3729

- **Extended Equipment Lifespan:** The use of VSDs reduces mechanical stress on motors and other auxiliary systems, leading to fewer breakdowns and extended equipment lifespan.
- **Reduced Maintenance Costs:** With fewer moving parts and less wear and tear on the propulsion system, the IFEP system is expected to lower maintenance costs over the ship's operational life.
- **Improved Crew Comfort:** The quieter operation of electric propulsion and optimized auxiliary systems contributes to a more comfortable working environment for the crew.

These operational benefits enhance the overall performance of the ship, making it not only more environmentally friendly but also more effective and economical in fulfilling its mission requirements.

4.7. Discussions

4.7.1. Integration of Electric Propulsion and VSD in Marine Vessels

The integration of electric propulsion systems, particularly the Integrated Fully Electric Propulsion (IFEP) system, with Variable Speed Drives (VSD) in marine vessels represents a significant advancement in maritime technology. This integration addresses the dual objectives of improving energy efficiency and reducing emissions, which are critical concerns for the modern maritime industry.

The IFEP system allows for a more flexible and efficient use of energy across different operational modes of the ship. By decoupling the propulsion system from direct mechanical drives and instead using electric motors powered by generators, ships can achieve optimal performance at various speeds and load conditions. This flexibility is particularly beneficial for naval vessels like the *Navy Ships BSN*, which must operate effectively under diverse and often challenging conditions.

Table 1.
Types of variable speed drives (VSD).

Type	**Valid up to 40 °C**			**Frame size**
ACH 550-01-	**I_{2N} (A)**	**P_N (kW)**	**Max. current I_{MAX} (A)**	
Three-phase supply voltage, 380…480 V				
02A4-4	2.4	0.75	3.1	R1
03A3-4	3.3	1.1	4.3	R1
04A1-4	4.1	1.5	5.9	R1
05A4-4	5.4	2.2	7.4	R1
06A9-4	6.9	3.0	9.7	R1
08A8-4	8.8	4.0	12.4	R1
012A-4	11.9	5.5	15.8	R1
015A-4	15.4	7.5	21.4	R2
023A-4	23	11	27.7	R2
031A-4	31	15	41	R3
038A-4	38	18.5	56	R3
045A-4	**45**	**22**	**68**	**R3**
059A-4	59	30	79	R4
072A-4	72	37	106	R4
087A-4	87	45	139	R4
125A-4	125	55	173	R5
157A-4	157	75	223	R6
180A-4	180	90	281	R6
195A-4	205	110	324	R6
246A-4	246	132	346	R6
290A-4	290	160	441	R6

The use of VSDs further enhances the efficiency of the ship's systems by allowing precise control over the speed and torque of electric motors based on real-time demand. This reduces unnecessary energy consumption and extends the lifespan of mechanical components, making the ship's operations not only more efficient but also more reliable.

The integration of these technologies into marine vessels demonstrates a clear pathway to achieving significant reductions in fuel consumption and emissions. The transition from traditional diesel propulsion to electric propulsion, supported by advanced electrical load management, represents a major shift towards more sustainable maritime operations. This approach aligns well with the broader industry trend towards electrification and energy efficiency, providing a model that can be replicated in other types of ships and marine vessels.

4.8. Implications for Environmental Policy

The successful implementation of IFEP and VSD technologies in marine vessels has significant implications for environmental policy, both at the national and international levels. The maritime industry is one of the largest contributors to global greenhouse gas emissions, and reducing these emissions is a key component of international efforts to combat climate change.

The findings of this study support the argument for stricter environmental regulations and policies that encourage or mandate the adoption of energy-efficient technologies in the maritime sector. The International Maritime Organization (IMO) has already taken steps in this direction with the introduction of the Energy Efficiency Design Index (EEDI) and stricter limits on sulfur content in marine fuels. The results from the integration of IFEP and VSD technologies suggest that these regulations could be expanded or made more stringent, as the technology is now available to meet and exceed current standards.

For countries like Indonesia, which has a significant naval presence and a large maritime sector, adopting such technologies could not only help meet international environmental commitments but also position the country as a leader in sustainable maritime practices. This could have positive economic implications, as more efficient ships mean lower operational costs and reduced dependency on fossil fuels, potentially leading to greater energy security.

Moreover, the reduction in harmful emissions such as NO_x and SO_x has direct public health benefits, particularly in coastal and port areas where air quality is a major concern. By reducing these emissions, the maritime sector can contribute to improved public health outcomes, thereby supporting broader environmental and public health policies.

4.9. Challenges and Considerations

While the integration of IFEP and VSD technologies offers significant benefits, several challenges and considerations must be addressed to ensure successful implementation.

4.10. Technical Challenges

- Compatibility and Integration: One of the main challenges is ensuring compatibility between the new electric propulsion systems and the existing infrastructure on the ship. Retrofitting older vessels with IFEP systems can be complex, requiring significant modifications to the ship's power distribution systems and auxiliary equipment.
- Reliability and Maintenance: Although electric propulsion systems generally have fewer moving parts and require less maintenance than conventional systems, they are still susceptible to failures, particularly in the power electronics and control systems. Ensuring the reliability of these systems is crucial, especially for naval vessels that must operate in remote and harsh environments.

DOI: 10.55214/25768484.v8i6.3729

4.11. Economic Considerations

- High Initial Costs: The initial investment required for retrofitting ships with IFEP and VSD systems can be substantial. Although these costs can be offset by long-term savings in fuel and maintenance, the upfront capital expenditure may be a barrier for some operators.
- Cost-Benefit Analysis: A thorough cost-benefit analysis is necessary to evaluate the economic viability of these technologies on a case-by-case basis. Factors such as the age of the vessel, the type of operations, and the expected operational lifespan of the ship must be considered when making investment decisions.

4.12. Regulatory and Policy Considerations

- Regulatory Compliance: Ships retrofitted with new propulsion and electrical systems must comply with international and national regulations. Ensuring that these systems meet all safety and environmental standards can be a complex process, requiring close coordination with regulatory bodies.
- Training and Human Resources: The shift to electric propulsion and advanced load management systems requires new skills and training for the crew. Operators must invest in training programs to ensure that their personnel can operate and maintain these new systems effectively.

4.13. Environmental Considerations

- Battery and Power Source Sustainability: While electric propulsion reduces emissions during operation, the environmental impact of the batteries and other energy storage systems must also be considered. The production, disposal, and potential recycling of these components can have significant environmental consequences if not managed properly.
- Lifecycle Analysis: A comprehensive lifecycle analysis of the new systems should be conducted to ensure that the environmental benefits outweigh any potential negative impacts associated with the production and disposal of the new technology.

Finally, while the integration of electric propulsion and VSD technologies into marine vessels offers a promising path toward more sustainable and efficient maritime operations, it requires careful consideration of technical, economic, regulatory, and environmental factors. Addressing these challenges will be critical to realizing the full potential of these technologies and ensuring their widespread adoption in the maritime industry.

5. Conclusions and Suggestions

5.1. Conclusion

Based on the results of the research that has been carried out the author can be given conclusions can be drawn:

1. **Reduction of Exhaust Emissions:** The implementation of Integrated Fully Electric Propulsion (IFEP) and Variable Speed Drives (VSD) in naval vessels, such as LPD-type ships, leads to a significant reduction in exhaust emissions, including CO_2, NO_x, and SO_x. These technologies effectively contribute to mitigating the environmental impact of maritime operations, aligning with international efforts to combat climate change.
2. **Enhancement of Energy Efficiency:** The study demonstrates that IFEP and VSD technologies significantly improve the energy efficiency of naval vessels by optimizing power usage across propulsion and auxiliary systems. This results in lower fuel consumption and reduced operational costs, making the ship's operations more sustainable and economically viable.
3. **Operational and Strategic Advantages:** Beyond environmental benefits, the adoption of IFEP and VSD systems provides operational flexibility, extends equipment lifespan, and reduces maintenance costs. These advantages enhance the overall effectiveness and

sustainability of naval operations, supporting the broader goals of energy efficiency and environmental stewardship in the maritime industry.

5.2. Future Works

Based on the results of the research that has been carried out the author can be given suggestions for the future as follows:

1. Expansion of IFEP and VSD Implementation Across Different Ship Types: Future research should focus on expanding the implementation of Integrated Fully Electric Propulsion (IFEP) and Variable Speed Drives (VSD) to other types of naval and commercial ships. This includes evaluating the performance and environmental benefits of these technologies in different operational contexts, such as cargo ships, tankers, and smaller naval vessels.
2. Development of Advanced Energy Management Systems: Further studies should explore the development of more sophisticated energy management systems that integrate IFEP and VSD with renewable energy sources, such as solar or wind power. This could further enhance the energy efficiency of ships and reduce their reliance on fossil fuels, contributing to even lower emissions and greater sustainability in maritime operations.
3. Lifecycle Assessment and Economic Feasibility Studies: Future work should include comprehensive lifecycle assessments and economic feasibility studies to evaluate the long-term impacts of IFEP and VSD technologies. These studies should consider factors such as the cost of retrofitting, maintenance, and disposal of components, as well as the overall environmental footprint of these systems over the ship's operational lifespan.

Acknowledgments:

The authors greatly acknowledge the support from the University of Brawijaya Malang and Indonesia, Indonesian Naval Technology College STTAL Surabaya Indonesia for providing the necessary resources to carry out this research work. The authors are also grateful to the anonymous reviewers and journal editorial board for their many insightful comments, which have significantly improved this article.

References

[1] Abiyasa, Dzieban (2019). Analisa Perbandingan Efisiensi Bahan Bakar Propulsion Electric Motor Dengan Propulsion Diesel Engine Pada KRI Tipe PKR 10514. Sekolah Tinggi Teknologi Angkatan Laut. Surabaya.

[2] Adi, P., & Amiadji. (2013). Analisa Penerapan Bulbous Bow pada Kapal Katamaran untuk Meningkatkan Efisiensi Pemakaian Bahan Bakar. Jurnal Teknik Pomits.

[3] Adnanes, Alf Kare (2003). Maritime Electrical Installations And Diesel Electric Propulsion. ABB AS Marine.

[4] Alisafaki, A. G., & Papanikoloau, A. D. (2015). On The Energy Efficiency Design Index of Ro-Ro Passenger and Ro-Ro Cargo ships. Journal of Engineering for The Maritime Environment, 1-12.

[5] Boulougoris, E., Papanikoulaou, A., & A. Pavlou. (2011). Energy Efficiency Parametric Design Tool in the framework of Holistic ship design Optimization. Journal of Engineering of Maritime Environment, 225.

[6] Calligaro, S. (2018). A Fully-Integrated Fault-Tolerant Multi-Phase Electric Drive for Outboard Sailing Boat Propulsion. Journal of Applied Energy.

[7] Chaia, M. (2018). Alternating current and direct current-based electrical systems for marine vessels with electric propulsion drives. Applied Energy.

[8] Dyonisius, M. S. (2014). Perancangan Power Management System pada Kapal Penumpang. Surabaya: Institut Teknologi Sepuluh November.

[9] Geertsma, R.D., Negenborn, R.R., Visser, K., & Hopman, J.J. (2017). Design and Control of Hybrid Power and Propulsion System for Smart Ships. Delft University of Technology & Netherlands Defence Academy. The Netherlands.

[10] IMO. (2020, April 15). Retrieved from http://www.imo.org

[11] Indra Kusuma. (2017). Aplikasi Inverter Dalam Proses Konversi Energi Ditinjau Dari Aspek Biaya. Jurnal Presisi.

[12] Indra Ranu Kusuma, R. P. (2017). Development of Power Management System for Electric Power Generation in Tanker Ship Based on Simulation. International Journal of Marine Engineering Innovation and Research.

[13] Karima, M. M., & Hasan, S. R. (2017). Establishment of EEDI Baseline for Inland Ship of Bangladesh. Procedia Engineering.
[14] Koenhardono, E. S. (2018). Comparative of Feasibility Study Between Diesel Mechanical Propulsion System and Combination of Diesel Engine and Electric Motor Propulsion System on Offshore Patrol Vessel (OPV) 80 m. 01011.
[15] Koenhardono, E. S., & Kristomi, R. (2017). The Study of the Application of Hybrid Propulsion System on OPV with Controllable. 1(4), 346–354.
[16] Kurniawati, D., Nurullita, U., & Mifbakhuddin. (2017). Indikator Pencemaran Udara Berdasarkan Jumlah Kendaraan Dan Kondisi Iklim. Jurnal Kesehatan Masyarakat Indonesia.
[17] Kusuma, I. R., Sarwito, S., & Irawati, R. A. (2017). Analysis of Electric Propulsion Performance on Submersible with Motor DC, Supply Power 10260 AH at Voltage 115 VDC. International Journal of Marine Engineering Innovation and Research.
[18] Lindstad, E., & Ingebrigtsen, T. (2018). Potential power setups, fuels and hull designs capable of satisfying future EEDI requirementsl. Transportation Research.
[19] Matondang, A.V. (2017). Analisa Design dan Kajian Ekonomis Sistem Propulsi Elektris yang Ramah Lingkungan pada Kapal Ikan 30 GT. Institut Teknologi Sepuluh Nopember.
[20] Markert, M. (2013). Power Management Systems. . Germany: Hochschule Wismar.
[21] Mashud, M., Karim, & Hasan, R. (2017). Establishment of EEDI Baseline for Inland Ship of Bangladesh. Procedia Engineering.
[22] NASA. (2020, April 14). Retrieved from nasa.gov: https://www.grc.nasa.gov/WWW/K-12/airplane/bgp.html
[23] Nel, A. J., Arndt, D. C., Karim, Vosloo, J. C., & Mathews, M. J. (2019). Achieving energy efficiency with medium voltage variable speed drives for ventilation-on-demand in South African mines. Journal of Cleaner Production.
[24] Nemitallah, M. A., Abdelhafez, A. A., & Mohamed A. Habib. (2020). Approaches for Clean Combustion in Gas Turbines. In Fluid Mechanics and Its Applications. Switzerland: Springer.
[25] Neukom, R. (2019). No evidence for globally coherent warm and cold periods over the preindustrial Common Era. Nature Journal.
[26] Nurhadi, R., Chrismianto, D., & Rindo, G. (2017). Analisa Bentuk Variasi Propulsion Module pada Sistem Propulsi Azipod (Azimuthing Podded Drive) Berbasis Computational Fluid Dynamic (CFD). Universitas Diponegoro.
[27] Saidur, R., Mekhilef, S., Ali, M. B., Safari, A., & Mohamed, H. (2012). Application of Variable Speed Drives (VSD) in electrical motors Energy Savings. Renewable and Sustaineable Energy, 543-550.
[28] Schibuola, L., Scarpa, M., & Tambani, C. (2018). Variable speed drive (VSD) technology applied to HVAC systems for energy saving: an experimental investigation. 73rd Conference of the Italian Thermal Machines Engineering Association.
[29] Sequeira, M., & Alakoon, S. (2019). Energy efficient variable speed drives empowered with torque estimation. Journal of Energy Procedia.
[30] Susila, A. B. (2008). Dampak Pemanasan Global Terhadap Risiko Terjadinya Malaria. Jurnal Kesehatan Masyarakat.
[31] Suyadi (2006). Diesel Electric Propulsion Sebagai Alternatif Power Plant Pada Kapal-Kapal Komersial. Teknik Perkapalan Universitas Diponegoro.
[32] Triana, V. (2008). Pemanasan Global. Jurnal Kesehatan Masyarakat.
[33] Trihusodo. (2007). Pengaruh Perubahan Lingkungan. Jakarta: Gatra.
[34] Zakaria, N. G., & Rahman, S. (2017). Energy Efficiency Design Index (EEDI) for Inland Vessels in Bangladesh. Procedia Engineering.
[35] Zhu, Y., Zhou, S., Feng, Y., Hu, Z., & Yuan, L. (2017). Influences of solar energy on the energy efficiency design index for new building ships. International Journal of Hydrogen Energy, 19389-19394.