Mar. Sci. Tech. Bull. (2023) 12(3): 252-258
e–ISSN: 2147–9666
info@masteb.com

dergipark.org.tr/en/pub/masteb
www.masteb.com
DOI: 10.33714/masteb.1299692

Marine Science and Technology Bulletin

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RESEARCH ARTICLE

A case study on the variable frequency drive for ship engine room ventilation

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ARTICLE INFO

Article History:
Received: 25.05.2023
Received in revised form: 29.06.2023
Accepted: 23.07.2023
Available online: 28.09.2023

Keywords:
Ship energy efficiency
Variable frequency drive
Electric motors
Engine room ventilation

ABSTRACT

Increasing ship energy efficiency is essential to reducing fuel consumption and ship-based harmful emissions. In a ship's engine room, there are a lot of electric motors, and their energy consumption is remarkable. The effective operation of these electric motors becomes significant when taking into account ship energy efficiency with regard to the effects on the environment and climate change. The electrical, mechanical, and operational efficiencies of electric motors can be improved with a variable frequency drive. In order to improve the ship's overall energy efficiency, the electric motors used for engine room ventilation are examined in this paper using variable frequency drives for two different ambient temperatures. Energy consumption of the engine room ventilation fans is calculated and the change in the efficiency depending on the air temperature is analyzed. By using data from actual crude oil tanker ships, the outcomes are compared with those of the traditional system. The results indicate an energy consumption reduction of more than 80% is achievable by using VFD electric motors for engine room fans. The result corresponds to 153.279 kWh of energy instead of 613.116 kWh annually.

Please cite this paper as follows:

Inal, O. B., & Koçak, G. (2023). A case study on the variable frequency drive for ship engine room ventilation. *Marine Science and Technology Bulletin*, *12*(3), 252-258. https://doi.org/10.33714/masteb.1299692

Introduction

Maritime transportation is a vital component of global trade, accounting for approximately 90% of its share (Deniz & Zincir 2016; Inal & Deniz, 2020). The most important component of maritime trade is ships, which are powered by marine diesel engines. Therefore, considering its environmental effects, the amount of fossil fuel consumed becomes substantial. The maritime industry is facing increasing pressure of reducing ship-sourced harmful emissions, and enhance sustainability (IMO, 2020). From this perspective, energy efficiency plays a critical role for ships, and cannot be overstated with many benefits ranging from cost savings to sustainability. The International Maritime Organization (IMO), a United Nations agency responsible for the maritime industry, has implemented a series of rules and regulations aimed at addressing shipping emissions and promoting

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increased energy efficiency in ships (IMO, 2021). For instance, the Energy Efficiency Design Index (EEDI) sets energy efficiency requirements for new ships, while the Ship Energy Efficiency Management Plan (SEEMP) encourages ship operators to implement energy-saving measures. Adhering to these regulations is essential for ships to maintain compliance and ensure access to ports worldwide. Ships are responsible for significant global greenhouse gas emissions and air pollutants (Dere & Deniz, 2019). By embracing energy-efficient practices, ships can minimize their carbon footprint, reduce harmful emissions, and contribute to the global fight against global warming and climate change. Energy-efficient practices can reduce emissions such as CO_2, SO_x, NO_x, or PM, helping meet international emission reduction targets and regulatory requirements (Inal, 2018; Inal & Deniz, 2021).

The energy efficiency of the ships can lead to many advantages, such as cost savings, environmental sustainability, fuel consumption reduction, and improved operational performance. Therefore, energy-efficient practices and technologies are essential for the maritime industry to move forward through the challenges of the future and achieve a more sustainable and efficient shipping sector. Electric motors are one the most important electricity consumers of ships, and they can play a critical role in improving the overall energy efficiency of ships (Schroer et al., 2022). Electric motors are used for propulsion purposes in almost all machinery systems on ships. On a ship, electric motors are utilized in the circulation of various fluids, including those that need to be generated, used, required, treated, or considered waste (such as centrifugal pumps, bilge separators, ballast systems, and sewage systems). They are also employed in the transfer of cargo (using centrifugal, gear, screw, or piston pumps), as well as in ventilation, heating, and cooling systems (such as air conditioning, refrigerators, and fans), and pumping systems. For instance, based on the examinations conducted on the Engine Room Simulator of Kongsberg MC-90v, the total load on the generators during the slow ahead condition of the main engine is 789.7 kW, of which 694.16 kW is attributed to electric motors. This means that electric motors account for 87.9% of the total load on the generator. Similarly, during the full ahead condition of the main engine, the total load on the generators is 802.24 kW, with electric motors constituting 674.68 kW of that load. This indicates that electric motors account for 84.1% of the generator's load. As a result, it can be understood that by achieving efficiency in electric motors, the fuel consumption of the generators can also be reduced.

VFD drives are substantial topics for more efficient air conditioning systems in the previous literature. Some of them are summarized as follows: Pérez-Lombard et al. (2011) analyzed the development of building energy codes concerning Heating, Ventilation and Air-Conditioning (HVAC) systems and concentrated on energy efficiency of HVAC systems of non- residential buildings. Awbi (2017) studied the air quality and energy efficiency of building mechanical ventilation and distribution systems and compares the traditional and some new type systems. SeppĘnen (2008) studied ventilation strategies for good air quality and energy efficiency and described several strategies such as control of air rates by air quality, efficient air distribution and local control of indoor climate. Sharapov et al. (2019) studied energy efficiency of mechanical ventilation systems based on microclimate parameter analysis. They propose to improve efficiency through heat recovery of ventilation emissions. Giama (2022) carried out a review study aiming to analyze ventilation technologies considering energy consumption and environmental issues using the life cycle approach focusing on the parameters related to the efficient technical design and sufficient maintenance of mechanical ventilation systems. Lönnberg (2007) studied energy savings in hospitals HVAC systems using variable speed drives and showed that the ventilation fan motor power factor at 40% flow of air dampers can be increased from 0.4 to 0.8. Tolvanen (2008) claim that the energy efficiency of pump and fan systems can be improved by 50% using variable speed drives and show the results of a case study for a food manufacturer which reached the annual saving of £30000 in electricity cost. Saidur et al. (2012) studied variable speed drives for increasing energy efficiency of electrical motors. They show the relation of speed reduction with potential energy saving and claim that the energy saving can be increased to 89% at 60% of speed reduction. One of the important conclusions of their study is that application of variable speed drives to HVAC systems provide excellent opportunities to reduce energy consumption.

In this paper, a case study has been conducted to examine the energy efficiency capacity that would result from operating the electric motor of fans used in ship engine room ventilation more efficiently with VFD (Variable Frequency Drive). By using data from actual two crude oil tanker ships, the outcomes are compared with those of the traditional system.

Lastly, the paper is organized as follows: the second section provides a review of VFD drivers, the third section presents the case study and discusses the results, and lastly, the final section concludes the paper by summarizing the findings and providing suggestions for future research.

VFD Drivers

Variable Frequency Drives (VFDs) play a crucial role in enhancing the performance and efficiency of electric motors

(Gritter et al., 2005; Kocak & Durmusoglu, 2017; Su et al., 2014). There are several important reasons of VFDs for electric motors:

- Energy Efficiency
- Soft Start and Smooth Operation
- Speed Control and Flexibility
- Improved Motor Protection
- Reduced Mechanical Stress and Wear
- Process Optimization and Control
- Energy Cost Savings

Energy Efficiency: By altering the frequency and voltage of the electricity supplied to the motor, VFDs provide precise control of motor speed and torque. VFDs reduce energy waste and maximize motor efficiency by adjusting motor speed to the actual load requirements. As a result, there is a significant reduction in energy consumption, operational expenses, and environmental impact.

Soft Start and Smooth Operation: VFDs give electric motors a soft start and smooth acceleration. VFDs progressively increase the voltage and frequency rather than starting at maximum speed and voltage, preventing unnecessary mechanical stress and wear on the motor and related equipment. This functionality is crucial for motors moving high loads or for situations where damage could be done by a sudden start.

Speed Control and Flexibility: With VFDs, the speed of electric motors can be easily adjusted within a wide range. This flexibility allows precise control of the motor operation to meet specific process requirements. Whether it's maintaining a constant speed, varying speeds for different tasks, or ramping up and down as needed, VFDs provide the ability to adapt motor performance to changing conditions.

Improved Motor Protection: VFDs offer advanced motor protection features. They monitor motor parameters such as current, voltage, and temperature, providing real-time feedback and allowing for quick response to any abnormalities. VFDs can detect issues like overload, phase loss, overvoltage, under voltage, and excessive heat, triggering protective actions to prevent motor damage and costly downtime.

Reduced Mechanical Stress and Wear: By controlling motor speed and torque, VFDs minimize mechanical stress on the motor and connected equipment. Belts, gears, couplings, and other mechanical components have a longer lifespan and require less maintenance because to the progressive acceleration and deceleration offered by VFDs.

Process Optimization and Control: With the help of VFDs, motor speed may be precisely controlled, allowing for process optimization and enhanced system performance. VFDs can adapt motor speed to the needed flow rate or load in applications like pumps, fans, and conveyors, maximizing system efficiency and maintaining stable performance even under changing circumstances.

Energy Cost Savings: In energy-intensive applications, VFDs can result in significant cost savings by improving motor efficiency and lowering energy usage. Energy is used effectively when motor speed can be adjusted based on demand, preventing wasteful energy use during periods of low load or idle operation.

Case Study and Analysis

As is known, ships are constantly in motion and continuously change their position. While changing their position, they also encounter different weather conditions, including different seawater temperatures and different air temperatures. However, regardless of the air temperature, the parameters of the machines on the ship always operate at the same values. Unfortunately, operators have not been able to fully utilize this situation to their advantage. If this situation is explained through a fan application, an ordinary electric motor will operate at the same speed, so the fan will operate at the same speed regardless of the temperature in the area where the ship is located. However, a fan with a VFD controlled electric motor, with a temperature sensor placed in the engine room, it will detect the ambient temperature and bring it to the temperature range determined by the manufacturer's software. If the temperature in the engine room increases due to various reasons (machines operating under heavy load, ambient temperature variation due to the sailing area, or work performed on the engines, etc.), the electric motor will start drawing more current and accelerate. When the temperature in the machinery space reaches the designated range in the software, the electric motor will start drawing less current, slow down, and attempt to maintain the environment at the same temperature. However, if the machinery space cools down due to various reasons (machines being shut down, transitioning to a port position, or sailing in a cold geography, etc.), there will be no need for the electric motor to operate at high power. Therefore, it will operate with much less current, at lower frequencies, and naturally consume much less power. In this analysis, crude oil tanker ship data is used to show the energy efficiency of the VFD drivers for engine room ventilation. Two different ambient temperatures are benchmarked for two different systems. The electric motor data is given in Table 1.

The pictures have been taken from onboard the ship which show the motor current and frequency at 35.9°C and at 30.2°C ambient temperatures are shown in Figure 1 and Figure 2, respectively. The left pictures at the figures shows the frequency of the electric motors of the ventilation that are 50 and 27 Hertz, respectively, while the right ones show the motor currents as 21.1 and 10.4 Amperes, respectively.

The case ship loads its cargo at the Hatay port within 2 days (48 hours), then takes a 2-day (48-hour) voyage in the Mediterranean Sea (Antalya Gulf) before reaching the Çanakkale Strait. After passing through the Çanakkale Strait, it continues its voyage for 12 hours and finally reaches the discharge port of Kocaeli, where it takes approximately 30 hours to discharge the cargo. Throughout this journey, the tanker is constantly in different positions for certain periods of time, either sailing or in loading/discharging status, and it is also affected by different sea water and air temperatures. The operation details according to duration are given in Table 2.

Table 1. Electric motor data for different conditions

Parameter	Value
Motor Power and Frequency	22 kW and 60 Hz
Daily Operation Time	24 hours
Motor Load without VFD at all temperature	100% Load and 22 kW
Motor Load with VFD at 35.9°C and 50 Hz	84% Load, 10.5 kW and 21.1 Amper
Motor Load with VFD at 30.2°C and 27 Hz	45% Load, 1.1 kW and 10.4 Amper

Figure 1. Electric motor frequency and current at 35.9°C ambient temperature

Figure 2. Electric motor frequency and current at 30.2°C ambient temperature

Table 2. Summary of operation profile of the case ship

Operation	Duration (hours)
Loading	48
Sailing	60
Before Çanakkale Strait Sailing	48
After Çanakkale Strait Sailing	12
Discharge	30
Total Operation	138

Table 3 resumes the results of the electric motor energy consumption with VFD and without VFD. Two columns are separated into 3 sub-columns by showing the voyage hours, motor loads, and energy consumptions. The electric motors are the same with a power of 22 kW. Energy consumption are calculated by the multiplication of operation time and power requirement.

If the values are compared, an electric motor without VFD continuously running at the same speed consumes 3036 kWh of energy throughout the journey, while an electric motor with VFD consumes only 603 kWh which means that more than 80% decrease in energy consumption, as shown in Figure 3. This indicates that if an operator decides to use VFD, they can save 2433 kWh of energy from just one electric motor in a single journey. Assuming this ship makes the same journey 63 times a year, it will save a total of 153.279 kWh of energy annually. In the mentioned case ship, there are a total of 4 fans, and all the motors read the temperature from the same sensor, so they operate at the same load. Therefore, a total savings of 613.116 kWh (153.279×4) can be achieved. Thus, it can be said that in today's technological conditions, the use of VFD in machinery space fans on ships has become not a luxury but a necessity. The fuel consumption of marine diesel generators onboard the ship is 205 g/kWh. According to the previously calculated energy deficit, approximately 125 tons less marine diesel oil will be consumed, yearly. Since the carbon factor of diesel fuel is 3.206, there is a 402 tons reduction in carbon dioxide emissions.

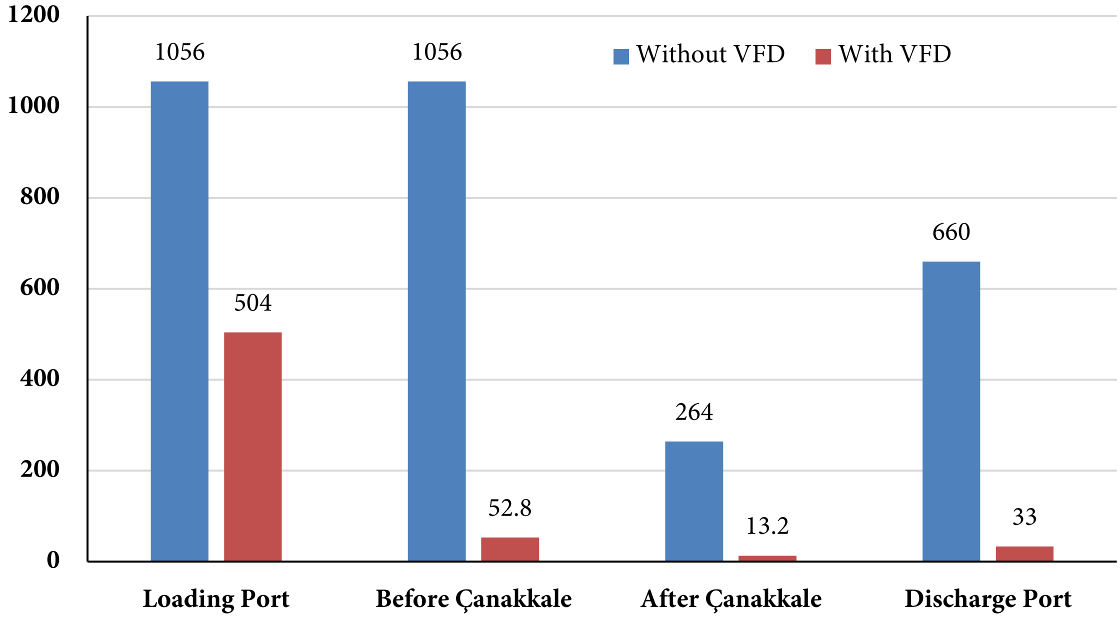

Figure 3. Ventilation fan energy consumption (kWh)

Table 3. 22 kW electric motor data with and without VFD

Ship's Position	Electric Motor without VFD			Electric Motor with VFD		
	Voyage (hours)	*Load (%)*	*Energy Consumption (kWh)*	*Voyage (hours)*	*Load (%)*	*Energy Consumption (kWh)*
At Loading Port	48	100	1056	48	84	504
Voyage through Çanakkale Strait	48	100	1056	48	45	52.8
Voyage after Çanakkale Strait	12	100	264	12	45	13.2
At Discharge Port	30	100	660	30	45	33
Total	138		3036	138		603

Conclusion

The use of Variable Frequency Drives in ships has emerged as a crucial solution to optimize energy efficiency and performance in marine operations. The continuous movement and changing environmental conditions experienced by ships necessitate the adaptation of machinery systems to varying loads and temperatures. Electric motors may vary their speed and power usage in response to the environment thanks to the sophisticated control mechanisms provided by VFDs, which result in significant energy savings.

Through the case study of a crude oil tanker, it becomes evident that the implementation of VFDs in machinery space fans yields significant energy conservation. The comparison between an electric motor without VFD and one equipped with VFD demonstrates a remarkable reduction in energy consumption during the ship's voyage. When extrapolated to a large-scale fleet, the annual energy savings achieved through VFD utilization exemplify the substantial positive impact on energy efficiency and environmental sustainability.

Moreover, the advantages of VFDs extend beyond energy efficiency. These systems provide enhanced control over engine operations, contributing to improved performance, reduced wear and tear, and increased lifespan of equipment. The ability to adjust motor speed and torque based on real-time conditions enables optimized operation, leading to enhanced reliability and operational safety. In light of these findings, it is evident that the integration of VFDs in ships' electrical systems has transitioned from being a luxury to a necessity. Ship operators and industry stakeholders should recognize the significant benefits of VFD technology and actively promote its adoption across the maritime sector. Government regulations and incentives can play a crucial role in encouraging the widespread implementation of VFDs, leading to a greener and more sustainable maritime industry.

Future studies should examine more VFD technology uses in different maritime systems and assess how they affect the overall performance of the vessel. The effectiveness and dependability of VFD-driven systems on ships can also be improved through the development of sophisticated control algorithms and preventative maintenance techniques. And last, the incorporation of VFDs into ships is a game-changing development in marine engineering, resulting in significant energy savings, enhanced functionality, and environmental sustainability. In the face of environmental difficulties and strict regulatory frameworks, embracing this technology is essential to address the growing need for efficient and environmentally friendly maritime transportation.

Acknowledgements

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance With Ethical Standards

Authors' Contributions

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, and writing of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical Approval

For this type of study, formal consent is not required.

Data Availability Statement

All data generated or analysed during this study are included in this published article.

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