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Speed Control Analysis of Frequency Changes in Three Phase Synchronous Motor with Variable Speed Drive (VSD)

Lasmana, Muhammad Aziz Musyaffa, Taryo*
Département Electrical Engineering, Swadaya Gunung Jati University, Cirebon, Indonesia

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ABSTRACT

This study investigates the impact of frequency adjustment using a Variable Speed Drive (VSD) on the performance of a three-phase AC synchronous motor under both no-load and load conditions. Energy inefficiency in industrial systems often results from mismatches between motor speed and load demands. The motor was tested at frequencies ranging from 20 Hz to 50 Hz to evaluate changes in speed, input power, torque, and efficiency. Unlike previous studies that focused solely on motor speed, this research provides a more comprehensive performance analysis. The results show that increasing frequency leads to higher motor speed and power consumption, but a decrease in torque. Under no-load conditions, speed increased from 607 RPM at 20 Hz to 1506 RPM at 50 Hz, while torque dropped from 1.57 Nm to 0.63 Nm. Under load, speed increased from 88 RPM to 683 RPM, and torque declined from 10.9 Nm to 1.39 Nm. Although motor efficiency decreases at higher frequencies due to increased magnetizing current caused by the constant V/f ratio, it must be emphasized that VSDs can significantly enhance energy efficiency by allowing the motor to operate at an optimal speed according to the load, instead of continuously running at full speed. Therefore, dynamic frequency control based on load variation is essential to optimize motor performance. VSDs thus play a vital role in intelligent control strategies aimed at improving energy efficiency in industrial applications.

Corresponding Author:
Taryo,
Department of Electrical Engineering, Swadaya of Gunung Jati University Cirebon,
32 Pemuda Raya Street, Sunyaragi, Kesambi District, Cirebon City, West Java 45132, Indonesia.
Email: *taryo@ugj.ac.id

1. INTRODUCTION

The development of electric motors is currently progressing rapidly, and their use has expanded across all sectors including industry, transportation, agriculture, commerce, and households. In fact, in the industrial sector, electric motors dominate power consumption. This significant utilization of electric motors has encouraged many researchers to develop more efficient motors [1].

Three-phase synchronous motors have long been applied in industrial settings that require constant-speed operation [2]. A synchronous motor is a type of electric motor that uses AC input current, operates at a constant speed, and has low energy losses, making it highly efficient. Despite these advantages, synchronous motors have the drawback of producing no starting torque. In principle, they operate at a constant speed [3]. A sudden and significant change in load can cause the synchronous motor to lose synchronism [4]. Furthermore, the inability to manage load speed effectively can pose major challenges in machine maintenance and energy usage [5].

Since the behavior of these drives is nonlinear, unpredictable, and influenced by varying load torques over time [6], the motor speed must be regulated to address these issues and to save power [7]. Scalar control (V/F control) is one method of regulating the speed of a synchronous motor by adjusting voltage and frequency [8]. Speed control can be achieved by modifying the frequency variable during motor operation, which is done using an inverter commonly referred to as a Variable Frequency Drive (VFD) or Variable Speed Drive (VSD) [9].

The control of inverter voltage and frequency is based on scalar control using the V/F (voltage-to-frequency) ratio, which is essential for automatic control, controlled start-up, acceleration and deceleration, as well as maintaining constant motor flux [10]. One of the primary functions of modern Variable Frequency Drives

(VFDs) is to maintain controlled coordinate values at signal levels despite various disturbances [11]. Variable frequency generates pulse-width modulated (PWM) current that is adjusted according to the power and frequency supplied to the motor, resulting in reduced stress and energy consumption. It uses a fixed-frequency AC source and converts it into a variable-frequency AC output, regulating power usage and mechanical output so the motor can operate at the most efficient speed [12].

In addition to providing stable speed response [13], Variable Frequency Drives (VFDs) allow for smooth motor startup by reducing inrush current and improving the power factor, which consequently decreases overall power consumption [14]. The electrical current produced during the operation of a synchronous motor plays a significant role in determining its reliability and long-term performance under load conditions [15]. In industrial environments, efficient energy utilization is essential, and over the past few decades, VFDs have become critical components in both industrial and commercial applications [16]. Their ability to simplify traditionally complex control systems[17], and deliver high efficiency in power conversion applications has made them an integral part of modern electrical systems [18] .

This study was conducted to analyze the performance of a three-phase synchronous motor controlled using a Variable Speed Drive (VSD), focusing on its effects on speed, voltage, power consumption, and efficiency. It builds upon previous research by Abdul Kodir et al. (2022), which only examined motor speed in a lift door system using a BG202-XM inverter, without considering aspects such as power, torque, or efficiency. By incorporating an analysis of power quality, this study provides a more comprehensive assessment of motor performance. The main contribution of this research is to offer a deeper understanding of the efficiency and operational characteristics of a synchronous motor controlled by a VSD, serving as a reference for designing more energy-efficient and effective motor control systems.

1.1 Novel Contributions

This study presents several novel contributions to the field of electric motor control and energy efficiency, particularly in the context of three-phase synchronous motors:

1. Comprehensive Performance Analysis

Unlike prior studies that primarily focused on motor speed control, this research conducts a holistic performance analysis encompassing speed, voltage, power consumption, torque, and overall efficiency. This broader perspective enables a more accurate evaluation of motor behavior under Variable Speed Drive (VSD) control.

2. Integration of Power Quality Metrics

The study integrates power quality analysis, offering a deeper understanding of how VSD affects electrical parameters during motor operation. This inclusion provides valuable insights for enhancing system reliability and energy optimization in industrial applications.

3. Focus on Synchronous Motors in VSD Applications

While many existing studies focus on asynchronous motors, this research specifically addresses three-phase synchronous motors, which have distinct operational characteristics and challenges. The study highlights the effects of VSD on synchronization stability and torque control—areas that are often underexplored.

4. Application-Oriented Contribution for Industrial Systems

The findings are tailored to industrial environments where precise speed control, energy savings, and system efficiency are critical. The insights derived can inform practical improvements in motor drive systems, particularly in industries that rely heavily on synchronous motors.

5. Advancement of Scalar (V/F) Control Understanding

By implementing and evaluating scalar control (V/F) through VSD, the study advances understanding of its impact on synchronous motor performance, contributing to improved strategies for maintaining constant flux, reducing power losses, and extending motor life.

6. Benchmarking Against Existing Studies

This research builds upon and expands the work of Abdul Kodir et al. (2022) by going beyond speed analysis and offering a comparative benchmark that includes efficiency and torque parameters, thus enhancing the existing knowledge base.

1.2 Literature Review

Abdul Kodir et al. (2022), [4] This study examines the effect of frequency variation on the rotational speed of a 100-watt three-phase synchronous motor using the BG202-XM inverter as a frequency controller, specifically in elevator door drive systems. A synchronous motor operates at a speed determined by the number of poles and the supply frequency, and it lacks starting torque, requiring direct current (DC) excitation to initiate operation. In this experiment, the frequency was adjusted from 5 Hz to 50 Hz, with motor speed measured using a digital tachometer and door opening time recorded with a stopwatch. The results showed that motor speed increased proportionally with frequency; for instance, at 5 Hz the motor reached 101.2 rpm in 15.49 seconds, while at 50 Hz it reached 1000.2 rpm in 2.05 seconds. The measurement data aligned well with theoretical expectations, confirming that frequency regulation via the inverter effectively controls motor speed. Therefore, this system is suitable for applications requiring precise speed control, such as the automatic opening and closing mechanism of elevator doors.

Paolo Mercorelli et al. (2023), [6] This study is a literature review that explores various control methods for Permanent Magnet Synchronous Motors (PMSMs) used in traction drive systems such as electric vehicles, robotics, and industrial equipment. PMSMs are favored due to their high efficiency, high power density, good dynamic performance, and low power ripple. The article evaluates several control techniques, including conventional PID control, Model Predictive Current Control (MPCC), Sliding Mode Control, and artificial intelligence-based methods such as fuzzy logic and neural networks. It also discusses sensorless control approaches, fault diagnosis methods like short circuits in motor windings, and efficiency optimization strategies using modern control techniques such as MPDTC and FCS-MPC. Additionally, the review addresses current challenges and future development directions, including energy saving, rotor position estimation without sensors, and the integration of adaptive control using machine learning. Overall, the study concludes that the advancement of more efficient and intelligent control methods is essential to support the implementation of PMSMs in future industrial systems.

1.3 Research Gaps

The study conducted by Abdul Kodir et al. (2022) is limited to observing the rotational speed of a synchronous motor without considering other important aspects such as energy efficiency or the impact of load conditions. Meanwhile, the review article by Paolo Mercorelli et al. (2023) provides a broad discussion on advanced and adaptive control strategies, including PID, Model Predictive Control, and artificial intelligence-based methods; however, the discussion remains theoretical and lacks experimental validation. In contrast, this study demonstrates a clear advantage by not only evaluating the relationship between frequency and motor speed but also conducting a comprehensive analysis of performance parameters such as torque, power, and efficiency under both load and no-load conditions. This approach offers a more complete and practical understanding of the impact of frequency variation on motor performance in real-world scenarios. Therefore, this research is considered superior as it combines practical field methods with in-depth technical evaluation, providing more relevant and valuable contributions to the development of synchronous motor control systems in modern industrial applications.

Variable Speed Drive (VSD) offers several advantages over permanent control in permanent magnet motors (PMM), particularly in terms of energy efficiency, operational flexibility, and adaptability to changing load conditions. Permanent control systems typically operate motors at a constant speed without the ability to adjust performance based on actual demand. In contrast, VSDs allow simultaneous adjustment of frequency and voltage, enabling precise control of motor speed according to operational needs [19]. This not only improves energy efficiency but also reduces mechanical wear, as the motor does not run continuously at full capacity. VSDs also support soft-start functions that minimize current surges during motor startup and can be integrated with sensors and automated control systems for more responsive operation. In the context of permanent magnet motors, VSDs are also capable of supporting sensorless control techniques to estimate rotor position efficiently. Therefore, VSDs are a more effective solution for industrial applications that require precise, efficient, and adaptable motor control [20].

1.4 Problem Statement

The speed control of three-phase synchronous motors is critical in industrial applications requiring high precision. While Variable Speed Drives (VSDs) offer flexible frequency and voltage adjustment, most existing studies focus only on motor speed, neglecting key performance indicators such as torque, power, and efficiency, especially under load conditions. Furthermore, although advanced control strategies like Model Predictive Control and AI-based methods have been proposed, many remain theoretical and lack experimental validation.

This creates a research gap in understanding the practical impact of frequency variation on synchronous motor performance. A comprehensive experimental study is therefore needed to evaluate not only the relationship between frequency and speed, but also the effects on motor efficiency and performance under real operating conditions.

2. RESEARCH METHODS

2.1 Definition of Methods

A quantitative method with a direct experimental approach was applied in this study. The process began with a literature review to explore fundamental concepts related to three-phase AC synchronous motors, using sources such as reference books and scholarly journals. The review covered motor characteristics, operating mechanisms, and the function of Variable Speed Drives (VSD). The experiment involved testing the motor under two conditions—unloaded and loaded. Each test was repeated five times, and the average values were calculated to ensure representative data. The main parameters measured included motor speed in RPM at various frequency settings, torque and rotational behavior, as well as current, voltage, power consumption, and system efficiency.

The experimental setup for the three-phase synchronous motor control using a Variable Speed Drive (VSD) is illustrated in Figure 1.

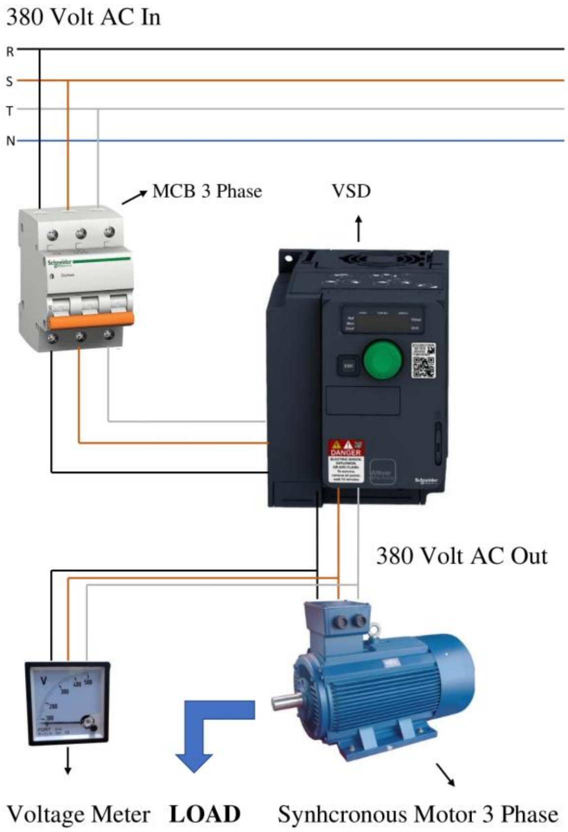

Figure 1. Single line diagram

The object of this research is a three-phase synchronous motor with the following specifications: 100 W, 415 VAC, 4 poles, 1400 RPM, 50 Hz, and a rated current of 0.6 A. The motor's rotational speed was measured using an NJK-5002C NPN Hall proximity sensor, with the output displayed on a digital tachometer having the following specifications: Power supply: DC 8–24V, Measurement range: 3.8 ~ 99,999 RPM, and an error margin of 0.5–1.5 RPM. Voltage was measured using a 42L6-V AC analog panel voltmeter with an accuracy of approximately ±2.5%, while current was measured using the ANENG ST210 digital clamp meter with an accuracy of ±(2.5% + 5 digits). To reduce experimental uncertainty, each measurement was performed five times, and the average value was used in the analysis. This approach aims to minimize the influence of random fluctuations and noise from the testing system. Although there is a margin of error associated with each instrument, the combination of using standard-compliant tools and measurement replication techniques helps ensure the reliability of the obtained data.

This study aims to analyze the motor's performance under various supply frequency conditions, controlled through a Schneider Variable Speed Drive (VSD) model ATV 320U04N4C. The test frequencies applied in this experiment were 20 Hz, 25 Hz, 30 Hz, 35 Hz, 40 Hz, 45 Hz, and 50 Hz.

2.2 Data Collection

The experimental setup is illustrated in Figure 4. In this configuration, the synchronous motor acts as the driving motor, with its speed and voltage controlled by the VSD. A second motor, a single-phase synchronous motor with specifications of 250 W, 240 VAC, 1725 RPM, 50 Hz, and 2.2 A, serves as a mechanical load. Both motors are directly coupled via their shafts to ensure efficient mechanical power transmission and to simulate realistic loading conditions.

Measurements are conducted using instruments integrated into the GOTT trainer, including a tachometer for rotational speed, a voltmeter for monitoring the supplied voltage, and ammeters for measuring the current in each phase. This setup enables a comprehensive performance evaluation of the synchronous motor under both no-load and load conditions. By adjusting the frequency through the VSD, the experiment allows detailed observation of the motor's behavior in terms of speed, current, voltage, and torque, making it highly valuable for performance analysis and control optimization in industrial applications.

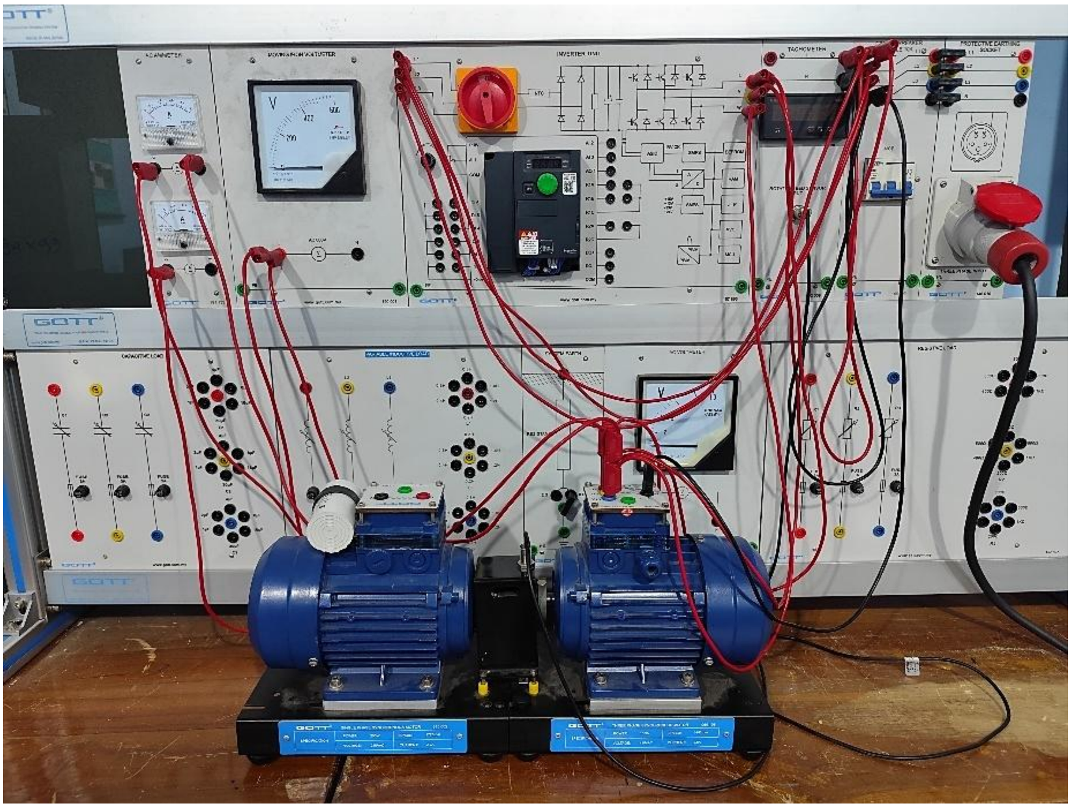

Figure 2. Motor control experiment using VSD

2.3 Research Flowchart

Figure 3 illustrates the experimental workflow carried out in this study, which aims to analyze the effect of frequency variation on the speed and efficiency of a three-phase synchronous motor. The process begins with the design and setup of experimental equipment, consisting of a Variable Speed Drive (VSD), tachometer, and voltmeter as the primary instruments for testing.

The next step involves applying various frequency values to the motor, specifically 20 Hz, 25 Hz, 30 Hz, 35 Hz, 40 Hz, 45 Hz, and 50 Hz. These frequency variations directly influence the motor's rotational speed (RPM), which is then observed and measured using a pre-installed speed sensor, namely the NJK-5002C sensor, connected to a digital tachometer for display.

If the experiment proceeds successfully and yields valid data, the collected measurements are then used to calculate the synchronous speed and power efficiency of the motor. The subsequent stage is the Result and Discussion, which evaluates the motor’s performance based on the observed parameters.

The experiment concludes with the formulation of conclusions, summarizing the key findings of the test and providing recommendations regarding optimal frequency settings for the operation of synchronous motors in industrial applications.

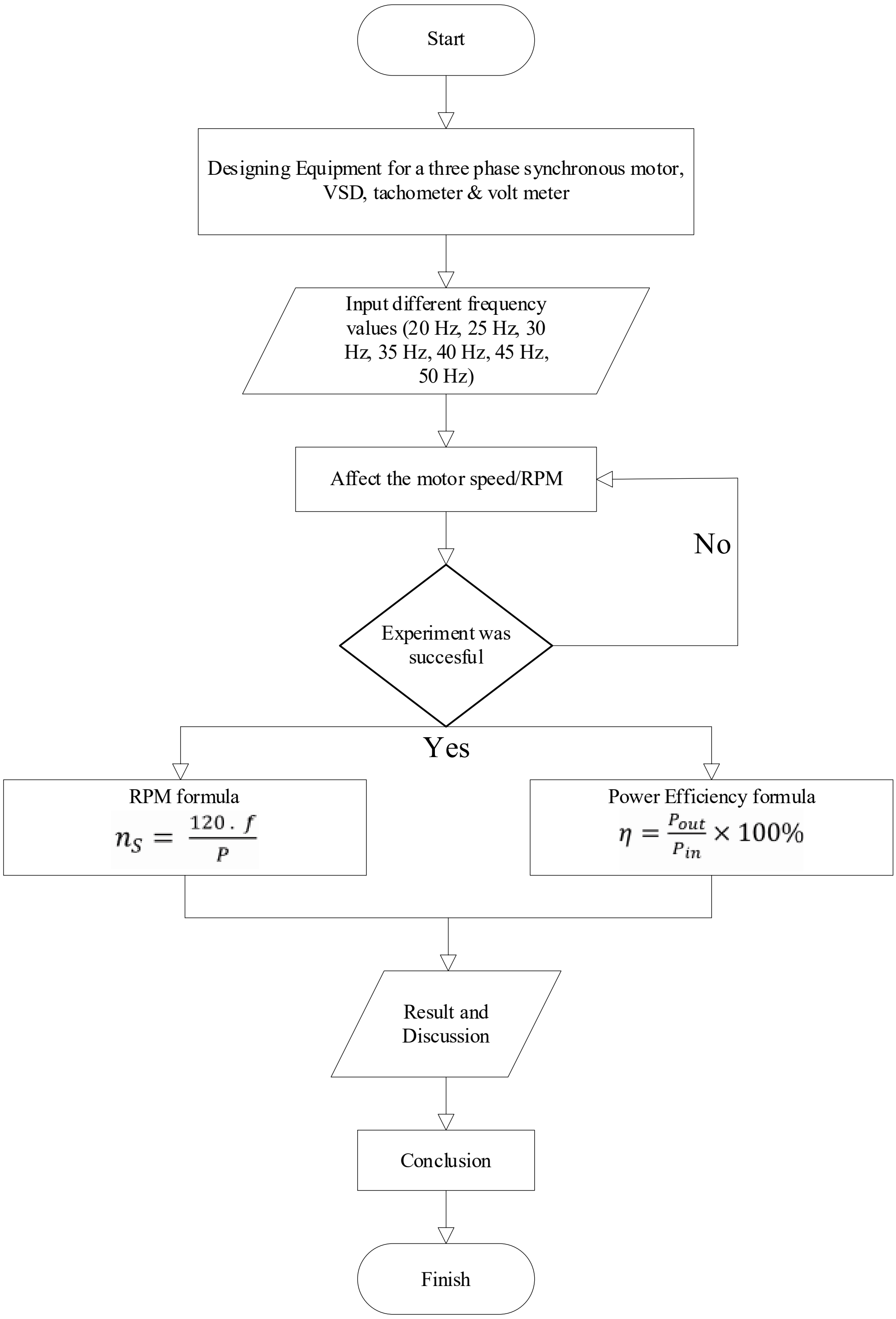

Figure 3. Research schematic.

3. RESULTS AND DISCUSSION

3.1 Research Results Without no-Load

The no-load testing was carried out to observe the basic characteristics of a three-phase synchronous motor operating without any mechanical load attached to its shaft. This experiment aimed to analyze the effect of frequency variation on key performance parameters such as voltage, current, rotational speed (RPM), electric power (Watt), and torque output. The motor was tested at seven different frequency levels: 20 Hz, 25 Hz, 30 Hz, 35 Hz, 40 Hz, 45 Hz, and 50 Hz. Each frequency point was tested five times to obtain accurate and representative average values. The measured data were recorded and presented in tabular form for easier analysis. Table 1 presents the average values of voltage, current for phases R, S, and T, rotational speed, and electric power consumption. Meanwhile, Table 2 shows the average torque produced by the motor at each frequency level.

Table 1. Average voltage, ampere, speed and watt

Frequency	Voltage	Average of ampere			Average of speed	Average of watt
		R	S	T		
20 Hz	140.6	0.554	0.540	0.542	607.4	100.590
25 Hz	185.4	0.530	0.530	0.564	755.8	137.704
30 Hz	225.0	0.544	0.550	0.608	907.0	181.100
35 Hz	261.0	0.492	0.574	0.616	1057.4	202.518
40 Hz	301.0	0.522	0.550	0.594	1205.4	230.874
45 Hz	341.2	0.532	0.554	0.580	1336.4	260.976
50 Hz	381.2	0.556	0.582	0.662	1506.0	314.822

Table 2. Results of no-load torque calculations

Frequency	Average of torque
20 Hz	1. 57 Nm
25 Hz	1.25 Nm
30 Hz	1.05 Nm
35 Hz	0.90 Nm
40 Hz	0.79 Nm
45 Hz	0.70 Nm
50 Hz	0.63 Nm

3.1.1 Effect of Frequency on Voltage and Power Consumption

The variation in frequency from 20 Hz to 50 Hz has been proven to affect both voltage levels and power consumption [21] [22]. Based on five measurements. the lowest voltage was recorded at 140.6 V at 20 Hz. while the highest reached 381.2 V at 50 Hz. This condition also impacted power consumption. with the lowest recorded at 100.59 watts and the highest at 314.82 watts. These findings indicate that frequency regulation through a Variable Speed Drive (VSD) can be utilized as a strategy to improve energy efficiency. This is in line with the findings of R. N. Rachmadita et al. (2024)**.** whose research showed that the application of VSD can reduce power consumption. The average no-load voltage values are presented in Figure 4. while the no-load power results are shown in Figure 5.

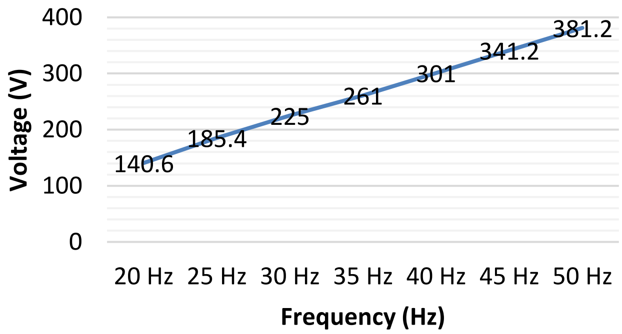

Figure 4. Graph of no-load voltage measurement results

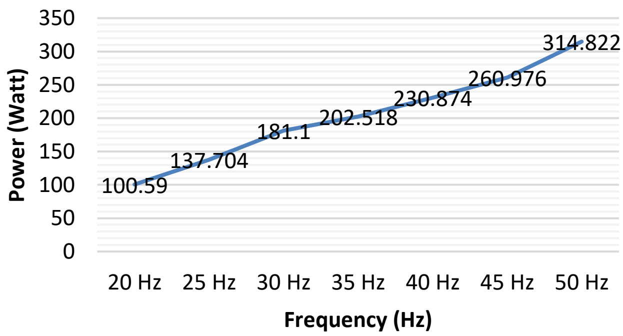

Figure 5. Graph of no-load electrical power measurement results

3.1.2 3.1.2 Effect of Frequency on Speed

After conducting observations and collecting data five times. it was found that the average motor speed changed with the increase in frequency from 20 Hz to 50 Hz. The lowest speed was recorded at 607.4 RPM at 20 Hz. while the highest speed reached 1506 RPM at 50 Hz. This indicates that frequency is directly proportional to motor speed. which is in agreement with the findings of R. Gafar et al. (2022**).** The results are shown in Figure 6.

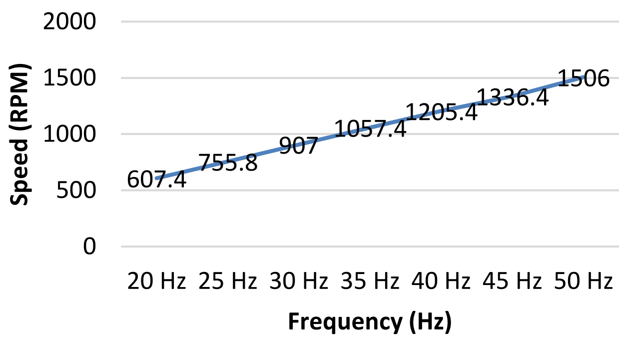

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Figure 6. Graph of no-load speed measurement results

3.1.3 Effect of Frequency on Torque

Adjusting the frequency affects the motor's speed. which in turn impacts its torque output [23]. Based on the data obtained. the highest torque of 1.57 N·m occurred at the lowest speed (20 Hz). while the lowest torque of 0.63 N·m was recorded at the highest speed (50 Hz). This supports the general principle of electric motors. where an increase in speed tends to result in a decrease in torque. and a decrease in speed generally leads to an increase in torque. This principle is consistent with the findings of Fitzgerald et al. (2003). who stated that in both induction and synchronous motors. there is an inverse relationship between speed and torque. especially during no-load or light-load operation. as shown in Figure 7.

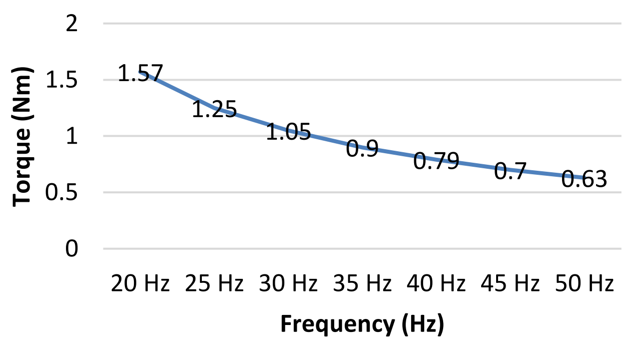

Figure 7. Graph of torque measurement results without load

3.2 Research Result with Load

Table 3 shows the effect of frequency changes on several electrical parameters. namely voltage. current in three phases (R. S. and T). speed. and output power. It can be observed that as the frequency increases from 20 Hz to 50 Hz. there is a significant rise in voltage. from 142.4 Volts to 382 Volts. Similarly. speed increases drastically from 88 rpm to 683.6 rpm. indicating a linear relationship between frequency and motor speed. The current in each phase shows a pattern that is not entirely linear. For example. the current in phase R decreases from 0.61 A (at 20 Hz) to 0.49 A (at 35 Hz). then increases again to 0.544 A at 50 Hz. A similar trend is observed in phases S and T. which fluctuate but generally remain within the range of 0.42–0.64 A.As for output power (watt). there is a fairly consistent increase with rising frequency. The power increases from 123.914 watts (20 Hz) to 290.358 watts (50 Hz). This indicates that the electrical load receives more energy as the frequency. voltage. and motor speed increase. Overall. this data shows that increasing the frequency in this system directly contributes to an increase in voltage. speed. and power. which is essential for managing the performance of electric motors in variable speed control systems.

Table 3. Results of voltage. current (R. S. T). speed. and power measurements at various frequencies

Frequency	Voltage	Average of ampere			Average of speed	Average of watt
		R	S	T		
20 Hz	142.4	0.610	0.640	0.636	88.0	123.914
25 Hz	185.4	0.544	0.538	0.420	145.0	127.414
30 Hz	223.2	0.644	0.422	0.540	221.0	164.526
35 Hz	283.0	0.490	0.570	0.546	266.6	207.826
40 Hz	313.8	0.544	0.548	0.600	297.2	243.492
45 Hz	341.0	0.524	0.550	0.572	315.4	255.150
50 Hz	382.0	0.544	0.540	0.570	683.6	290.358

The measurement results of torque. output power. and efficiency of a three-phase synchronous motor at various frequency levels (20 Hz to 50 Hz) under load conditions are presented. It can be seen that the highest torque of 10.852 Nm was achieved at the lowest frequency of 20 Hz. while the lowest torque of 1.39 Nm was recorded at 50 Hz. Although the output power remained relatively stable at around 99 watts. the motor's efficiency showed a decreasing trend as the frequency increased. The highest efficiency was recorded at 0.80% at 20 Hz. and the lowest at 0.34% at 50 Hz. These results indicate an inverse relationship between frequency increase and both torque and efficiency under load conditions. as shown in Table 4.

Table 4. Torque. power output. and efficiency results under loaded conditions

Frequency	Torque	Power out	Efficiency
20 Hz	10.852 Nm	99.890 watt	0.80%
25 Hz	6.582 Nm	99.380 watt	0.78%
30 Hz	4.320 Nm	99.790 watt	0.60%
35 Hz	3.580 Nm	99.736 watt	0.48%
40 Hz	3.208 Nm	99.832 watt	0.40%
45 Hz	3.026 Nm	99.672 watt	0.39%
50 Hz	1.390 Nm	99.464 watt	0.34%

3.2.1 Effect of Frequency on Voltage and Power Consumption

During testing under load with five sets of data. it was found that voltage varied depending on the frequency. At 20 Hz. the lowest frequency. the average voltage was recorded at 142.4 V. while at 50 Hz. the highest frequency. it reached 382.2 V. This also affected the amount of power used. which was 123.91 watts at 20 Hz and 290.36 watts at 50 Hz. These results indicate that adjusting the frequency can help save energy and improve power usage efficiency. This finding is consistent with the study by R. N. Rachmadita et al. (2024). which showed that the implementation of VSD can reduce power consumption [24]. The average voltage values under load are presented in Figure 8. while the power results under load are shown in Figure 9.

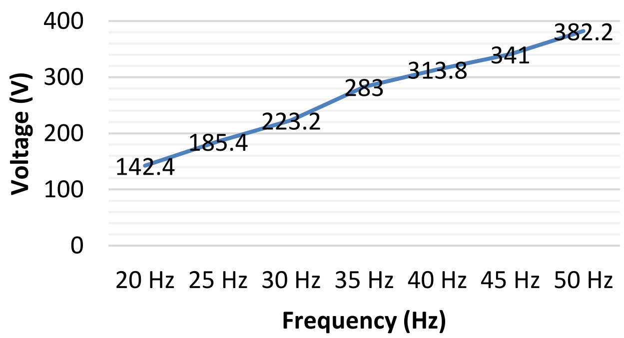

Figure 8. Measurement results of load voltage under various test conditions.

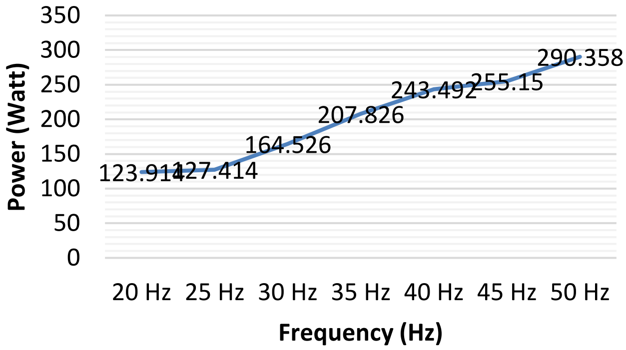

Figure 9. Load power measurement results (in watts) at different operating frequencies.

3.2.2 Effect of Frequency on Speed

Figure 10 shows that after testing the motor under load and conducting five sets of measurements. the average speed ranged from 88 RPM at 20 Hz to 688.6 RPM at 50 Hz. These speeds were significantly lower compared to when the motor was operating without a load. This decrease in speed occurs due to the motor being under load. especially when the load is too heavy [25]. This was also stated in the study by Abdul Kodir et al. (2022). which noted that significant changes in load will affect the motor's speed.

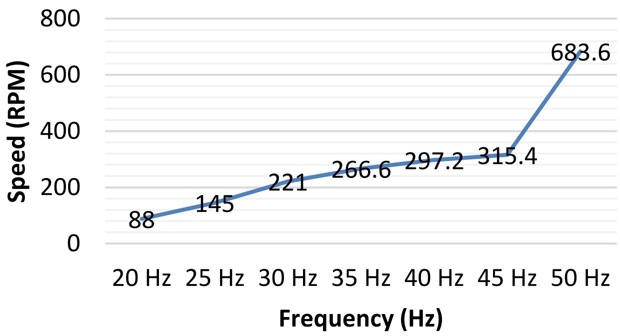

Figure 10. Motor speed measurement results (in RPM) at different operating frequencies.

3.2.3 Effect of Frequency on Torque

In Figure 11. the results show that when the motor was tested under load conditions. the torque increased significantly. At a frequency of 20 Hz. the torque reached 10.852 N·m. and at 50 Hz. it decreased to 1.59 N·m. This occurs because the load slows down the motor’s rotation. causing the torque to increase. Compared to no-load conditions. the motor produces greater torque when operating under load. This supports the general principle of electric motors. where an increase in speed tends to result in a decrease in torque. and a decrease in speed generally leads to an increase in torque. This principle is also in line with the findings of Fitzgerald et al. (2003**)**. who stated that in both induction and synchronous motors. there is an inverse relationship between speed and torque [26].

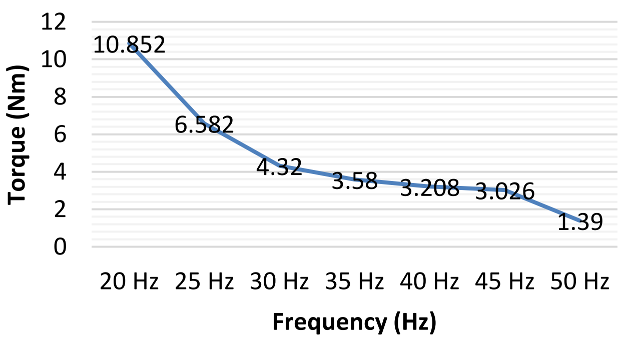

Figure 11. Torque measurement results (in N·m) at different operating frequencies.

3.2.4 Power Out

Power output refers to the mechanical power generated by the synchronous motor. Based on the measurement data. the average mechanical output power (P_out) within the frequency range of 20 Hz to 50 Hz remains relatively stable at around 99 watts. as shown in Figure 14. This P_out value is then used to calculate the motor's efficiency. The efficiency is calculated according to Equation 2.

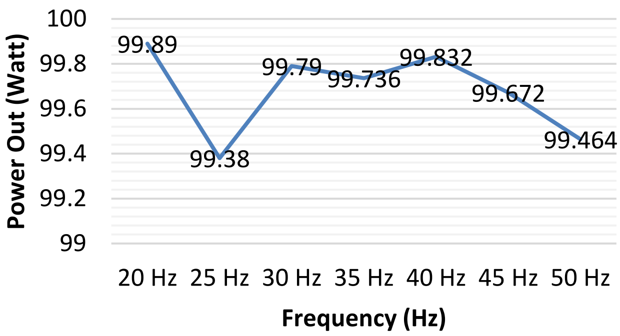

Figure 12. Power Out

3.2.5 Effect of Frequency on Efficiency

In Figure 15**.** the test results under load conditions clearly show that frequency affects the efficiency of a three-phase synchronous motor. As illustrated in the graph. the motor achieved its highest efficiency at a frequency of 20 Hz with 0.80%. and its lowest efficiency at 50 Hz with 0.34%. This indicates that by adjusting the frequency. the motor's efficiency can be improved. The low efficiency is caused by the fact that. at low speeds. the magnetizing current remains high because the V/f ratio is kept constant. This leads to an increase in core losses. This finding is in line with the study conducted by L. Latchoomun et al. (2019). which stated that one of the factors affecting motor efficiency is that. at low speeds. core losses increase. resulting in lower efficiency.

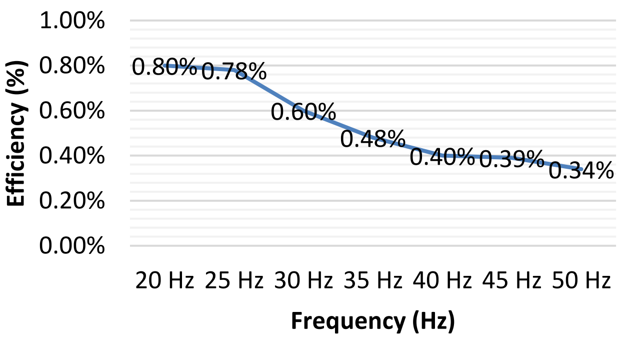

Figure 13. Efficiency of the motor at different operating frequencies under load conditions.

3.3 Implications of the Research

The implications of this study are highly relevant for industries that rely on three-phase synchronous motors in their operations. The experimental results show that the use of a Variable Speed Drive (VSD) allows flexible motor speed control through frequency variation. which directly impacts motor performance. including rotational speed. torque. power consumption. and efficiency.

However. it was found that although motor speed increases with frequency. efficiency actually decreases—especially under constant load conditions—with the highest efficiency reaching only 0.80% at a frequency of 20 Hz. This drop in efficiency is caused by an increase in magnetizing current due to the constant V/f ratio. which contributes to core losses. Therefore. these results indicate that motor frequency control must be dynamically adjusted according to load variations to achieve optimal efficiency.

Practically. these findings can serve as an important reference in designing VSD-based motor control systems. particularly for industrial applications such as pumps. fans. and conveyors. where precise and efficient speed control is essential. Implementing adaptive control based on actual load conditions can significantly improve energy efficiency. reduce power consumption. and extend the operational lifespan of the motor.

4. CONCLUSION

This study shows that frequency control using a Variable Speed Drive (VSD) has a significant impact on the performance of a three-phase synchronous motor. particularly in terms of speed. power consumption. torque. and efficiency under both loaded and unloaded conditions. The research findings reveal that although increasing the frequency results in higher motor speed. efficiency remains low. with a maximum value of only 0.80%. The low efficiency is caused by the fact that. at low speeds. the magnetizing current remains high due to the constant V/f ratio. which leads to increased core losses. In comparison. the study conducted by Abdul Kodir et al. (2022) focused solely on analyzing motor speed in an elevator door system using the BG202-XM inverter. While their study confirmed a linear relationship between frequency and motor speed. it did not include analysis of power consumption. torque. or efficiency. Therefore. although both studies observed a positive correlation between frequency and motor speed. the present study provides a more comprehensive evaluation of motor performance across various operational parameters. As such. VSD can be considered a viable solution in the industrial sector for addressing speed control issues in machines such as pumps and others. as well as for improving energy efficiency.

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