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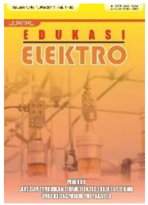

Implementation of Variable Speed Drive as Starting Control of Three Phase Induction Motor

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Abstract— The three-phase induction motor is a prevalent electrical machine utilized across various industrial applications. Notably, the surge current of the induction motor can range from five to seven times the nominal current. This research aims to address this issue by identifying an appropriate three-phase induction motor. One effective method for operating three-phase induction motors is through the implementation of a Variable Speed Drive (VSD). This study develops an induction motor starting system utilizing VSD technology to mitigate the surge current associated with three-phase induction motors. Frequency and duty cycle variations were tested to evaluate their impact. Adjusting the frequency from 25 to 75 Hz at a VSD output voltage of 220 V resulted in a current reduction of 0.74 A. Conversely, modifying the duty cycle from 10% to 100% at a frequency of 50 Hz led to an increase in current of 1.136 A.

Keywords: microcontroller, starting control, induction motor, variable speed drive.

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1 Introduction

In industrial applications, electric machines are extensively employed to replace labor-intensive tasks, thereby reducing production times and enhancing efficiency. To improve effectiveness and ensure high production quality, the utilization of electric motors is essential [1]. Electric motors offer several advantages, including cost-effectiveness, simple construction, and ease of application. However, they also exhibit significant drawbacks, particularly the high starting current, which can reach five to seven times the nominal current when directly activated under full load using the Direct On Line (DOL) method [2]. This substantial starting current poses a risk during the initial operation of the motor and can potentially lead to damage. Consequently, employing a Variable Speed Drive (VSD) starting method is necessary to mitigate the impact of these high current surges, thereby protecting the electric motor from potential harm [3].

The Variable Speed Drive (VSD) serves as a crucial device for controlling the speed of an alternating current (AC) electric motor by regulating the frequency and voltage applied to the motor. A typical VSD comprises components such as rectifiers, inverters, and microcontrollers [4]. Within the inverter or VSD module, a controller can be integrated to facilitate adjustable control values, allowing the motor to operate based on the soft starting principle. Pulse Width Modulation (PWM) is a technique employed to manage transistor switching in inverters; it involves comparing two signals to establish a transistor switching pattern [5]. This research aims to develop an application for starting current control using VSD technology, ensuring a smooth current profile in a three-phase induction motor.

This research focuses on implementing the soft starting method by gradually adjusting the voltage and current supplied from the power source to the motor. The voltage and current entering the motor are regulated through delay signals and timing for the primary components involved in soft starting, particularly the Triode Alternating Current (TRIAC) [6]. Additionally, previous studies have explored the control of variable speed drives on three-phase inverters, utilizing Power Simulation Software integrated with an AT89S52 microcontroller to generate a three-phase sinusoidal reference signal for controlling three-phase induction motors via the Sinusoidal Pulse Width Modulation (SPWM) method [7]. Despite various studies on starting current, there remains a lack of comprehensive analysis regarding the application of variable speed drives as a starting current controller, specifically through simultaneous control of frequency and voltage to optimally influence the starting current in three-phase induction motors.

The proposed research explores the application of Variable Speed Drives (VSD) for starting a three-phase induction motor. Data were collected through testing variations in frequency and voltage, allowing for adjustments to both parameters. The primary focus of the study is the current flowing through the induction motor during operation, with frequency and voltage variations serving as references to determine the measured current values. Subsequent analysis of the measured current parameters aims to demonstrate that surges are effectively minimized. In this research, the VSD method is implemented as a control device utilizing an Arduino Uno, which has been pre-programmed and connected to a 120° generation inverter circuit to serve as a control signal. The results from simulations and practical applications indicate a significant reduction in surge current compared to the Direct on Line (DOL) starting method.

2 Research Methods

This research was conducted at the Electric Power Conversion Laboratory, Department of Electrical Engineering, Faculty of Engineering, Borneo University of Tarakan. The study involved the design of tools and data collection, following a systematic approach. Key steps included:

a. Literature review, analyzing the application of Variable Speed Drives (VSD) for starting control of three-phase induction motors.
b. System design, developing a system based on insights from the literature review with a focus on VSD configuration and programming Pulse Width Modulation (PWM) on the microcontroller.
c. Program development, creating frequency and duty cycle programs utilizing the PWM control method.
d. Testing, evaluating the programs with an oscilloscope to verify the output control signals capable of managing the VSD device.
e. System configuration, conducting tests involving PWM and VSD as methods for starting control of the three-phase induction motor.
f. Current testing, performing frequency and duty cycle tests to assess motor starting current values.
g. Data analysis, analyzing the starting current measurements to align with the research objectives.

Conclusion drawing, formulating conclusions based on the evaluation of the research results. If the evaluation aligns with the objectives, the conclusions confirm that the proposed approach effectively addresses the identified problem and meets the research goals.

2.1 Induction Motor

Induction motors are commonly classified into two types three phase induction motors and single-phase induction motors. Three-phase induction motors operate within a three-phase power system and are widely utilized across various industrial sectors. In contrast, single phase induction motors function on a single phase power system and are predominantly used in household appliances, including fans, refrigerators, water pumps, and washing machines, due to their lower output power [9].

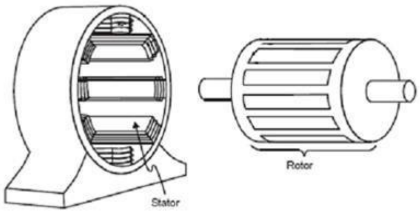

Fig. 1. Cross-section of the stator and rotor of a three-phase induction motor [10]

The construction of a three-phase induction motor is similar to that of other electric motor types. This motor comprises two main components: the stator, which is the stationary part, and the rotor, which is the rotating part, as illustrated in Figure 1. The stator and rotor are separated by a narrow air gap, typically ranging from 0.4 mm to 4 mm [10].

2.2 Working Principle of Induction Motor

In the stator, a rotating magnetic field interacts with the conductors of the rotor, inducing a voltage (induced electromotive force, or EMF) across the rotor coils. Since the rotor coils form a closed circuit, a current (I) flow through them. The conductors (rotor windings) situated within the magnetic field experience a force (F). If the force generated on the rotor is sufficient to overcome the load torque, the rotor will rotate in the direction of the stator's rotating field. The induced voltage arises from the interaction between the rotor conductors and the stator's rotating magnetic field, indicating that a relative difference between the stator's rotating field speed (ns) and the rotor's rotating speed (nr) is necessary for voltage induction [2], [11].

2.3 Star and Delta Connection in 3 Phase Induction Motors

The PLN low-voltage distribution network typically operates at voltages of 220/380 V or 127/220 V. In the future, only the 220/380 V system will be utilized for local distribution. Motors must be connected either in a star or delta configuration, depending on the network voltage. The required voltage for motor connection is usually specified on the nameplate, e.g., 220/380 V [12].

For a 220/380 V grid voltage system, Equation (1) provides the current flowing through the motor coils.

$$I_n = \frac{6600}{380 \times \sqrt{3}} = 10 \text{ A} \quad (1)$$

In the case of a 127/220 V grid voltage system, Equation (2) indicates that the current flowing through the motor coils remains at 10 A.

$$I_n = \frac{6600}{220 \times \sqrt{3}} = 10 \times \sqrt{3} = 17{,}3 \text{ A} \quad (2)$$

When this motor is directly connected to the grid, its starting current is six times the nominal current. The current in a three-phase induction motor can be calculated using Equation (3).

$$I_L = \frac{\text{P}}{\sqrt{3} \times \text{V} \times \text{Cos } \varphi} \quad (3)$$

2.4 Variable Speed Drive (VSD)

A variable speed drive is an essential control device for three-phase induction motors, functioning by regulating the voltage and frequency supplied to the motor. By simultaneously adjusting voltage and frequency, the speed can be altered while maintaining a constant torque [7].

2.5 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a technique used for regulating square wave pulse widths in circuits, such as inverters, soft starters, converters, and Switch Mode Power Supplies (SMPS). These circuits incorporate electronic switches, including power electronics components such as MOSFETs, transistors, and TRIACs. The control of these switches relies on PWM [13]. PWM signals typically possess a fixed amplitude and base frequency, while the pulse width varies. The width of the PWM pulse is directly proportional to the amplitude of the original unmodulated signal, resulting in a fixed wave frequency with a duty cycle that varies between 0% and 100% [14]. The duty cycle represents the ratio of high pulses to low pulses within the waveform. In a stable medium-voltage circuit, if the output frequency is 2 kHz with a 70% duty cycle, the waveform will reflect this 70% high period [15]. The switching pattern can be achieved by combining the ON and OFF time sequences of each sector's switching. These patterns are generated through PWM pulses based on the duty cycle, with the determination of the PWM pulse period and the magnitude of the duty cycle dependent on the period (T) [16].

2.6 Microcontroller

The microcontroller used in this study is an Arduino, which can be activated by connecting it to a computer via a USB (Universal Serial Bus) cable or by supplying it with DC voltage from a battery or an AC to DC adapter. The microcontroller is programmed to function as a USB-to-serial converter for serial communication with the computer via the USB port [16].

2.7 Software Arduino IDE

The Integrated Development Environment (IDE) is a crucial software tool for writing programs, compiling them into binary code, and uploading them to the microcontroller's memory. Processing is the programming language employed for Arduino, resembling high-level languages such as C++ and Java. Consequently, users familiar with either language will find Processing accessible. This programming language facilitates rapid and straightforward program creation, in contrast to low-level languages like Assembly, which can be more complex and challenging to convert into binary code for microcontroller upload [17], [18].

2.8 Research Framework

This subsection outlines the research framework and steps taken in this study as follows:

a. Testing the PWM Program Against Frequency

In this phase, frequency value testing is conducted by setting frequency parameters within the microcontroller's program. The output shape of the PWM wave signal is observed using an oscilloscope, following the upload of the frequency program. A circuit is then assembled to visualize the program's output, indicated by an LED light. This setup is depicted in Figure 2.

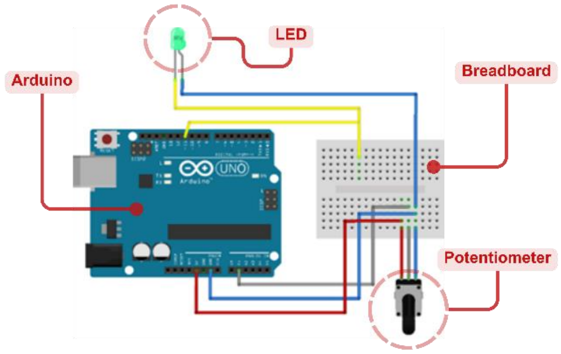

Fig. 2. Testing the PWM program against frequency

b. Testing the PWM Program Against Duty Cycle Value

This section focuses on adjusting the duty cycle based on the microcontroller program. The PWM wave signal output is again monitored on an oscilloscope after the duty cycle program has been uploaded. A circuit is assembled to observe the LED output, as shown in Figure 3.

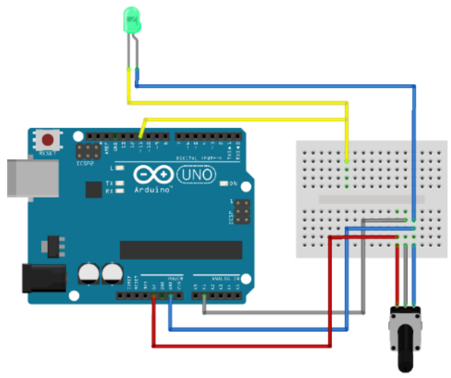

Fig. 3. Testing the PWM program against duty cycle value

c. Phase Difference Program Testing

Phase difference testing is performed between phases R and S to evaluate the ignition angle difference based on the microcontroller program. The PWM wave signal output for both phases is displayed on an oscilloscope following program upload, with an LED light output as an indicator. This setup is illustrated in Figure 4.

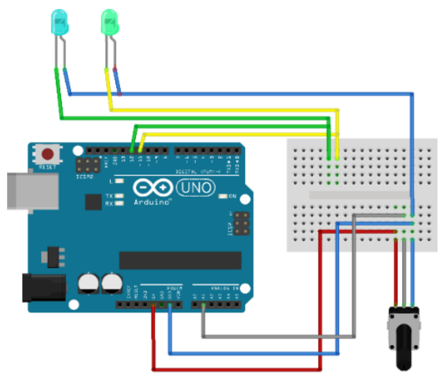

Fig. 4. Phase difference testing circuit between phase R and phase S

d. Overall VSD system testing

The variable speed drive (VSD) system undergoes comprehensive testing by configuring the system and initiating the induction motor. During startup, key parameters, particularly the electrical current, are measured and analyzed for the three-phase induction motor. The motor used in this study is a three-phase squirrel cage induction type, rated at 220 V and 1.4 A, with a power output of 0.3 kW (approximately 0.4 HP) and an operational frequency range of 50 to 60 Hz. Under different load conditions, the motor's rotational speed spans from 1420 to 1670 rpm. This testing circuit is shown in Figure 5.

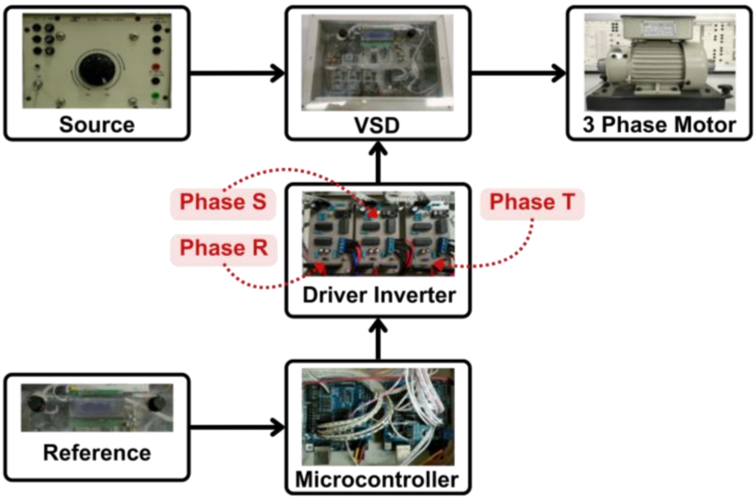

Fig. 5. Testing circuit of the VSD system as a whole

3 Result and Discussion

This chapter presents the research results derived from the methods implemented according to the established research steps, aimed at determining whether the research objectives have been met.

3.1 Testing PWM Against Frequency Values

At this section, PWM testing is carried out using an at this stage, PWM testing is conducted using an oscilloscope to measure the frequency utilized, which aligns with the specifications of the three-phase induction motor set at 50 Hz, as shown in Figure 6.

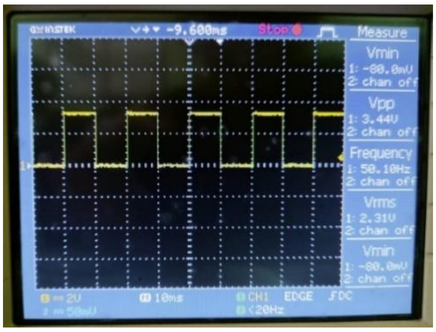

Fig. 6. 50 Hz frequency waveform

3.2 Testing PWM Against Duty Cycle Values

PWM testing is performed to assess the duty cycle value. This step ensures that the Arduino Uno programming operates in accordance with the desired duty cycle value, as depicted in Figure 7, which illustrates the 50% duty cycle waveform.

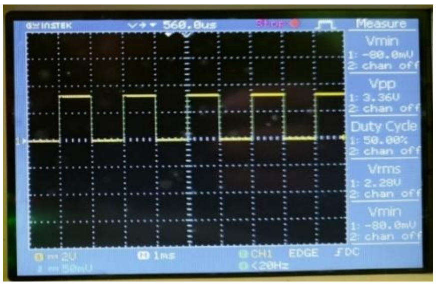

Fig. 7. 50% Duty cycle waveform

The oscilloscope readings confirm that the PWM output operates as designed, achieving the specified duty cycle. This is substantiated by the observed duty cycle value of 50%. Consequently, the VSD output voltage effectively regulates the input voltage supplied to the induction motor.

3.3 Phase Difference Testing

In this section, the PWM program is tested to observe the phase difference, as the motor in use is a three-phase induction motor. Adjustments to the ignition angle between the phases are necessary.

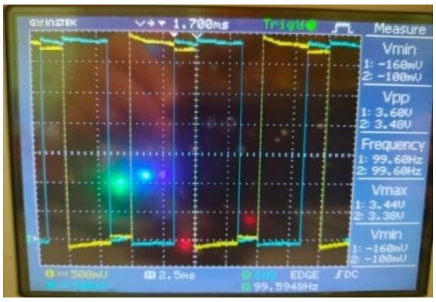

Fig. 8. Phase difference test

Figure 8, illustrates that phase R and phase S exhibit an ignition angle difference of 120°. This determination of the ignition angle is achieved by calculating the time division on the oscilloscope. For instance, 2.5 ms multiplied by 4 horizontal boxes yields 10 ms, with the difference between phase R and phase S measured at 3.34 ms. This value is then divided by the total wave duration of 10 ms and multiplied by 360° to derive the result of 120°.

3.4 Frequency Variation Testing

Testing processes are conducted by varying the frequency at a voltage of 220 V to evaluate the effects of frequency and voltage on the starting current of the three-phase induction motor, summarized in Table 1.

Based on measurement results, illustrated in Table 1 show the current measurements during motor startup and operation. As the source frequency varies, the speed of the induction motor gradually increases, resulting in a measured current that decreases from 1.526 A to 0.74 A as the source frequency increases. Figure 9 depicted the effect of frequency on motor current during startup and operation.

Table 1. Induction Motor Specification

Voltage (V)	Current (A)	Cos phi	Frequency (Hz)	Power (W)
221,9	1,526	0,264	25	154,65
222,8	1,370	0,253	30	133,6
223,2	1,219	0,239	35	112,5
223,6	1,138	0,227	40	99,9
224	1,019	0,230	45	90,8
225,6	0,970	0,224	50	84,8
225,9	0,914	0,213	55	76,1
223,7	0,856	0,223	60	73,8
224,6	0,808	0,225	65	70,6
225,5	0,740	0,230	70	66,4
224,6	0,744	0,236	75	68,22

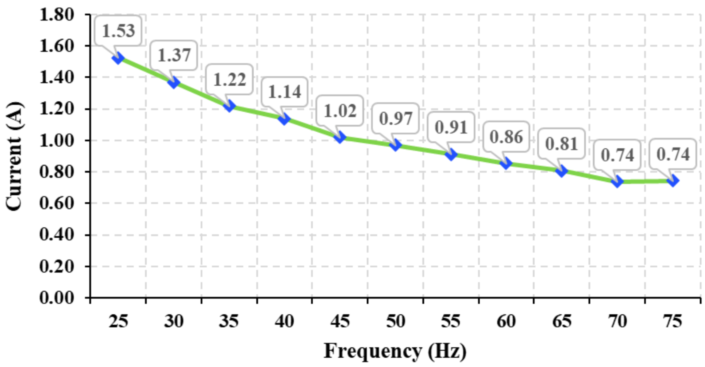

Fig. 9. Effect of frequency on motor current during startup and operation

In testing the starting current control via Variable Speed Drive (VSD), various frequency adjustments yield a measured current of 0.97 A at a duty cycle of 60% (220 V) and a frequency of 50 Hz, with a calculated power of 84.8 W. The variation data serve as a comparison for current values in the three-phase induction motor, revealing that an increase in frequency and a duty cycle of 60% result in a gradual reduction of current, falling below the motor's nominal current. This trend is represented in the graph shown in Figure 9. Based on the frequency variation test data with a constant voltage, current calculations for the three-phase induction motor are performed using Equation (3):

$$I_L = \frac{P}{\sqrt{3} \times V \times \mathrm{Cos}\ \varphi}$$

$$I_L = \frac{84{,}8}{\sqrt{3} \times 225{,}6 \times 0{,}224}$$

$$I_L = 0{,}969 \text{ A}$$

The calculated current aligns with the measured current of 0.969 A, confirming that the test results are accurate and meet the objective of achieving smooth current flow.

3.5 Testing *Duty Cycle* Variation

Testing is conducted by varying the duty cycle at a frequency of 50 Hz to assess the impact of the duty cycle on the starting current of the three-phase induction motor, as summarized in Table 2.

The results from this test, detailed in Table 2, illustrate the variations in starting and running conditions as the duty cycle shifts from 10% to 100%. As the induction motor voltage gradually increases, the corresponding current also increases due to the direct proportionality between voltage and current. The measured current ranges from 0.132 A to 1.136 A.

Table 2. Induction Motor Specification

Voltage (V)	Current (A)	Cos phi	*Duty cycle* (%)	Power (W)
79,4	0,132	0,102	10	1.85
126,2	0,432	0,181	20	17.07
155,9	0,749	0,226	30	45.65
196,7	0,792	0,230	40	61.98
204,5	0,935	0,295	50	97.58
224,1	0,965	0,218	60	81.56
230,3	1,017	0,221	70	89.55
234,5	1,028	0,211	80	87.99
236.1	1,079	0,239	90	105.33
238,9	1,136	0,230	100	107.98

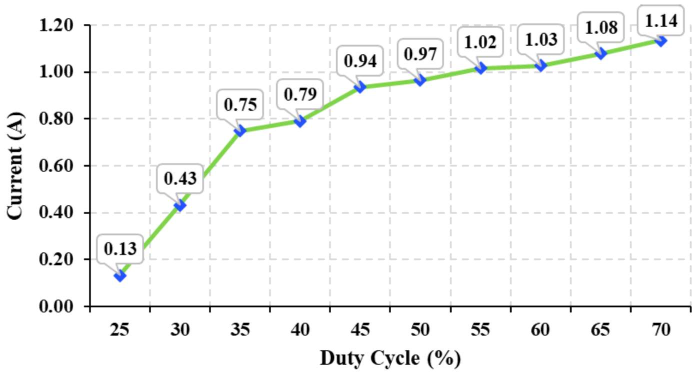

Fig. 10. Graph of *duty cycle* against 3-phase induction motor current

For the starting current control using VSD, current measurements yield 0.965 A at a duty cycle of 60% and a frequency of 50 Hz, with a calculated power of 81.56 W. The variation data provide a basis for comparing the impact of frequency and increasing duty cycle values on the induction motor's current. As illustrated in Figure 10, the results indicate that the current approaches the nominal value of the motor as the duty cycle increases.

$$I_L = \frac{P}{\sqrt{3} \times V \times \text{Cos } \varphi}$$

$$I_L = \frac{81{,}56}{\sqrt{3} \times 224{,}1 \times 0{,}218}$$

$$I_L = 0{,}964 \text{ A}$$

Based on the duty cycle variation test data at 50 Hz, the current calculation can be performed using Equation (3). The results show that the measured current is consistent with the calculated value of 0.964 A, confirming that the tests align with the objective of achieving smooth current.

3.6 Comparison of DOL and VSD System Starting Current

This research compares the starting current of the Direct-On-Line (DOL) system motor with that of the VSD system, as depicted in Figure 11.

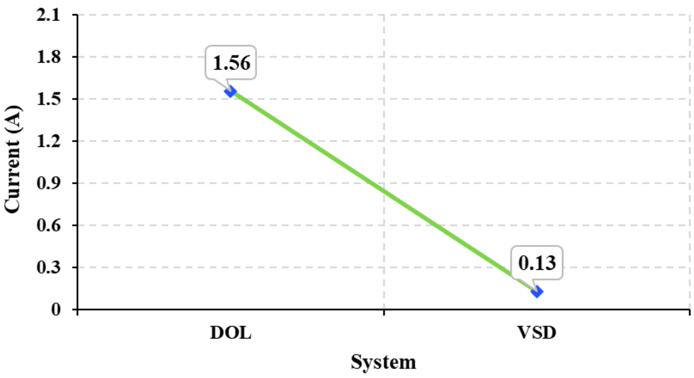

Fig. 11. Comparison chart of DOL current with VSD current

Measurements of the DOL system reveal a current of 1.56 A, whereas the VSD system records a current of 0.132 A. This comparison indicates that the starting current in the DOL system is significantly higher than that of the VSD system. Continuous operation using the DOL system may jeopardize the induction motor's integrity. Therefore, it can be concluded that the VSD system is preferable, as it allows for frequency and voltage adjustments, enabling the induction motor to operate according to user specifications. This capability effectively minimizes the surge in starting current when the motor is initiated.

4 Conclusion

In this study, the authors designed and tested the VSD tool as a means of starting control for a three-phase induction motor. The conclusions drawn from the tests indicate that using VSD for starting current control, with frequency and duty cycle variations, enables the monitoring of current, voltage, and power factor changes in three-phase induction motors. The starting current control test using VSD yielded a current of 0.97 A at a frequency setting of 50 Hz and a duty cycle of 60% (220 V), demonstrating a gradual decrease in measured current as frequency increases. Similarly, the starting current control test resulted in a measured current of 0.965 A at a duty cycle of 60% and a frequency of 50 Hz, illustrating a gradual increase in measured current with increasing duty cycle values.

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