EFFICACY AND ENACTMENT OF VARIABLE SPEED DRIVE IN VARIOUS ELECTRICAL INDUCTION MOTOR APPLICATION

THANABAL NAVAMANI

UNIVERSITY TUNKU ABDUL RAHMAN

EFFICACY AND ENACTMENT OF VARIABLE SPEED DRIVE IN VARIOUS ELECTRICAL INDUCTION MOTOR APPLICATION

THANABAL A/L NAVAMANI

A project report submitted in partial fulfilment of the
requirements for the award of Master of Engineering Electrical

Lee Kong Chian Faculty of Engineering and Science
UniversitiTunku Abdul Rahman

March 2023

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature :

Name : THANABAL A/L NAVAMANI

ID No. : 21UEM02861

Date : 14 APRIL 2023

APPROVAL FOR SUBMISSION

I certify that this project report entitled **EFFICACY AND ENACTMENT OF VARIABLE SPEED DRIVE IN VARIOUS ELECTRICAL INDUCTION MOTOR APPLICATION** was prepared by **THANABAL A/L NAVAMANI** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Engineering Electrical (Hons.) XXXXXXX at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________________
Supervisor : Assoc. Prof. Ts. Dr. K. W. Chew
Date : 18 Apr 2023

Signature : ____________________________
Co-Supervisor :
Date : ____________________________

The copyright of this report belongs to the author under the terms of the copyright Act 1987 as qualified by Intellectual Property Policy of Universiti Tunku Abdul Rahman. Due acknowledgement shall always be made of the use of any material contained in, or derived from, this report.

© Year, Name of candidate. All right reserved.

ACKNOWLEDGEMENTS

I would like to thank everyone who contributed to the successful completion of this project. I would like to express my gratitude to my research supervisor, Assoc. Prof. Ts. Dr. K. W. Chew for his invaluable advice, guidance, and his enormous patience throughout the development of the research.

In addition, I would also like to express my gratitude to my loving family and manager who helped and given me encouragement to complete this research and reports.

ABSTRACT

A single or three-phase induction motor is a common driven mechanical machine in many industrial applications. This electrical drive machine is one of the highest energy consuming machines among others electrical machinery. The induction motor only delivers rated full speed when it is connected directly to the oldest AC motor drivers. However, most applications in current industries need speed control of induction motor to accomplish desire output for the system and reduce the energy waste. Variable speed drive is the most simple and cost-efficient device to control speed of induction motor. Although many research and studies presented on variable speed drive performance and efficiency, in this paper experimental results of electrical unit such as voltage, current and speed on different frequencies with different AC controller which show motor speed varying according to frequency and large of energy saving to accomplish. The simulation of induction motor with conventional motor starter and with variable speed/frequency drive was enacted to determine the performance and efficiency of electronic drive. The biggest challenge to drive this experiment, to comprehend the MATLAB/SIMULINK simulation design and characteristic of each function block in Toolbox.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
CO2	Carbon Dioxide
CSI	Current Source Inverters
DC	Direct Current
FOC	Field Oriented Control
GDP	Gross Domestic Product
IGBT	Insulated-gate Bipolar Transistor
MOSFET	Metal-oxide-Semiconductor field-effect transistor
PWM	Pulse Width Modulation
SCR	Silicon Controlled Rectifier
SVM	Space Vector Modulation
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
VSI	Voltage Source Inverter

CHAPTER 1

INTRODUCTION

1.1 Background

World energy production is increasing year to year in relevant to increase the energy demand daily usage. Among the industry sector is the largest electrical energy consumer in world. A statical record of 2020 Malaysia Energy Statistics Handbook provided by the Malaysian Energy Commission show that the industry sector is second largest electricity consumer at 29.5 % of the total electricity in the country. (Energy Commission, 2020). The revolution in industrial sector caused the energy demand increasing due to increasing the electrical drive machine usage. This electrical driven machine is a workhorse in many industries for various application (Dr.M.Sundarrajan, 2020). As significant electrical load the utilization extended to application such as HVACs, compressors, fans, pumps, mining, mills, elevators, vehicles, and transportation (Dr.Hla Aye Thar, 2020). This induction motor also well known as squirrel cage motor categories as asynchronous motor.

Earliest days the DC-motor is mechanical drive machine in many industries. Since the DC-motor required higher maintenance service and increasing cost demand, an induction motor become alternative solution to many applications in industries. The primary benefit of this type of induction motor is that the stator and rotating components of the motor do not require an electrical link. Since they don't need automated commutators or brushes, induction motors are referred to as maintenance-free motors. Compared to DC-motor, the induction motor is simple construction and cost effective. Besides, induction motor has characteristic like robustness, strong makeup, and elevated efficiency up to 85%. (Ahmed Ali, Ergun Ercelebi, 2018) (Taylor L.Short, 2020). Since this motor not equipped with brushes like DC-motor, it able to work in hot headed environments because the spark will not form.

However, the advantage of DC-motor is very easy to control motor speed compared to induction motor which normally run at one speed refer to the main supply voltage frequency and construction of number of poles in the motor because the DC-motor current and torque non-linear relationship. (Hafeezul Haq, 2015). The necessity of induction motor in industrial applications expend as essential machinery to advance the system and protection design and fault tolerant control. The induction motor has ability to monitoring and find the faults in an initial stage when the speed, vibration, voltage, current and temperature exceeds the limits. (Usha Sengamalai, Subramani Chinnamuthu, 2017).

As industries grow and need change, they need advanced motor controllable systems to get the desired output. The oldest days they imposed many methods to control the speed of motors, such as changing the stator number of poles, controlling supply voltage, addition series reactor or resistances. But the advance development in power electronic and semiconductor, which drive to biggest changes in speed application such as replacement use DC-machine to AC-machine, replacement of AC-drive to DC-drive and now days it become common use in manufacturing and home applications. The huge energy saving is optimized because low energy use indirectly reduces CO2 production.

A long with the development of the variable speed drive, many research and studies was conducted to analysis the enactment and efficacy of the variable The most signification changes are variable speed drive to AC-machine in all industrial application because the variable speed drive perfection in achieve optimized method by reducing the energy consumption and operation cost. speed drive in many applications. The simulation analytical method is used to measure with operating electrical unit such as voltage, current and speed at different frequency value. Even though the variable speed drive performance refers to frequency provided, the selection of variable speed driver controller is another component that defines the performance of the unit. There are many types of controllers available, but in this paper, the analysis was made on close loop and open loop controller.

1.2 Problem Statements

There is expectation increasing world power energy will increase up to 50% between year 2018 to 2050 and the industrial sector is higher contributor (Alper Gonen, 2021). Figure 1.1, presenting the energy consumption from year 1990 until year 2018 for various industries. The industries sector is the second major energy user. Every year, each industrial allocated most of amount of operational expenses mainly for electricity bills.

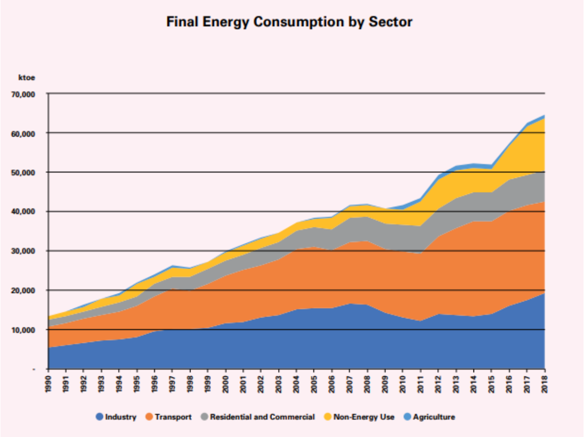


Figure 1.1: Final Energy Consumption by Sector (Energy Commission, 2019).

According to Malaysia Energy Statistics Handbook 2020 by Energy Commission Malaysia, the primary energy supply in Malaysia is mainly from the processing of fossil fuel such coal which contributes to the carbon dioxide (CO2) emission. As shown in Figure 1.2, the energy source used to produce the electricity coal become demand source. So, it is obvious that almost 40 % of the nation’s carbon emission are wrapped up in most of the activities from industries.

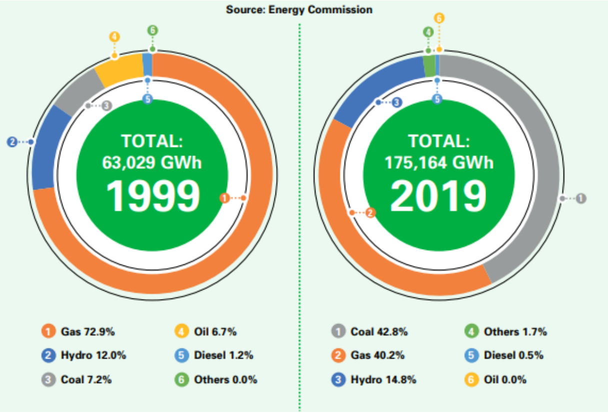


Figure 1.2: Source of Energy to Produce Electricity (Energy Commission, 2019).

Thus, increasing the electricity generation and consumption due to the high demand, not only increasing the CO2 emission excessively to the environment but it's also increasing the gross domestic product (GDP) cost in every sector in Malaysia especially. Even though alternative energy source such as renewable energy and green technology are imposed world wider but the 100% accomplishment still questionable because it has pros and cons both technologies.

1.3 Research Objectives and Aims

The aim of this research is to identify the real energy saving possibilities by replacing the variable speed drive to the existing application of induction motor. This includes the proposal of a variable speed drive system for new projects. Besides, this research also recognizes the performance of variable speed drive during operation of different parameters. Primarily, the objectives of this research are to:

I. To identify the performance of variable speed drives in terms of frequency, voltage, current and speed.
II. To evaluate the best, optimize controller to variable speed drive for higher efficiency.

III. To identify potential energy saving to achieve by optimizing variable speed drive.

To accomplish this research the induction motor theoretical aspect and knowledge are required to design the induction motor and the control system using MATLAB. The basic induction motor operation and the operating parameter is essential knowledge required to verify the calculation related to motor output value. The important part in the research is to design the various speed control algorithms and obtain the right results output.

CHAPTER 2

LITERATURE REVIEW

2.1 Alternating Current Induction Motor.

The first poly-phase induction motor prototype was introduced by Nikola Tesla at the Frankfurt exhibition in 1891. (Oinam Manganleiba Meetei. 2017). The usage of induction motor widely increases to multiple consumers like residential, commercial, industrial, and utility applications. These induction motor usages are become demand in various applications like big fans, centrifugal pumps, conveyor belts and electric vehicles. The advantages of induction motor like robustness, optimal performance, multiple speed operations, higher efficiency and low manufacturing and maintenance cost make this motor utilization expend faster. (Oinam Manganleiba Meetei. 2017). AC motors are classified into various types based on principle of operation, type of current, speed of operation and structural features. Figure 2.1 is the flowchart of the common alternating current motor classification.

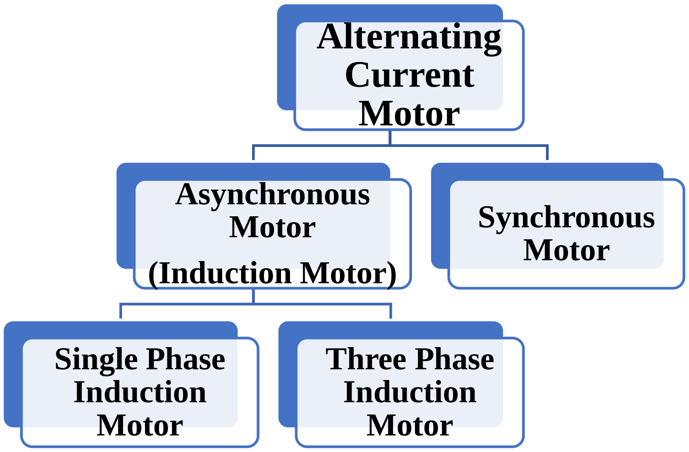


Figure 2.1: Alternating Current Motor Classification

The synchronous motor rotational speed of stator current and the rotational speed of the rotor are same because the motor operates with zero slip respect to stator current. In other words, the shaft of the rotor and the frequency of the supply current are synchronized. (Tahir, & Zarma, Tahir & Galadima, Ahmadu & Maruf, Aminu, 2019). However, the asynchronous motor is in contrast with synchronous motor. The rotational speed of the stator current is not synchronized with rotational speed of the rotor. This motor is also known as induction motor because the rotating magnetic field produces from sinusoidal alternating current after exciting the stator will be induced current in the rotor apparently produce magnetic field in the rotor. A little different frequency of magnetic field in the rotor and stator caused this motor to run with slip and torque was generated in fact. (Tahir, & Zarma, Tahir & Galadima, Ahmadu & Maruf, Aminu, 2019).

2.1.1 Basic Construction and Operating Principles.

The alternating current induction motor is constructed with two major sections respectively stator and rotor. Whereas, the stator is constructed with three major sections respectively outer frame, stator core and stator winding. Figure 2.2 shows the AC induction motor stator construction. The motor housing body is an outer frame and functions as stator core support and as well mechanical guard for motor inner parts. The second section of AC motor stator is stator core is built with thin, soft iron laminations and function to reduce the hysteresis and eddy current losses. The final section is stator winding, consisting of 3 winding with six terminals connected motor terminal block. (Mansour, Fady, 2020). Thus, the motor winding can be terminated either star or delta connection. (Sahdev, S. K., 2018).

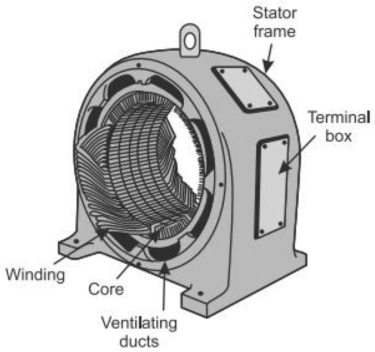


Figure 2.2: The AC Induction Motor Stator Construction

The second major section in ac induction motor is rotor which equipped with two bearing at both end shaft to smooth rotation. Figure 2.3 shows the ac induction motor rotor constructions. The motor non drives end or rotor side installed cooling fan and enclosed by fan cover. (Mansour, Fady, 2020). AC induction motors are classified depending on rotor construction, there are squirrel cage motor and phase wound motor. Among these two types, the squirrel cage is the most popular type because it is simple and robust. This rotor is built with laminated cylindrical core and copper or aluminum bar conductors. Since both end rotor shorted with similar material example copper ring or aluminum ring, this rotor winding considers perpetually short-circuited. The intentionally angle installation of copper or aluminum conductors bar into laminated cylindrical core is to achieved smooth motor operation and sufficient torque to start and reduces the magnetic locking of the stator and rotor. (Sahdev, S. K., 2018).

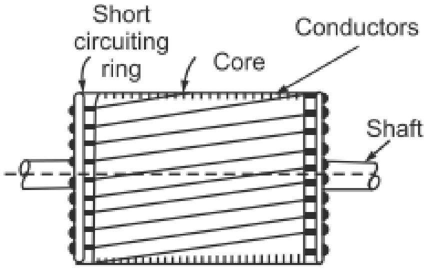


Figure 2.3: AC Induction Motor Rotor Constructions.

The operation principle of AC induction motor is referring to principle of magnetism. When the three-phase winding receives currents from power supply, will produce rotating magnetic field which induced current at rotor and produce another magnetic field at rotor. Faraday's law stated that any magnetic field changes produce emf in the rotor will cause current increase. The force creates a rotor and makes the rotor rotate in the identical direction with magnetic field. According to Lenz's law, the current going into rotor winding be against to direction of the rotor magnetic field. The rotating magnetic field is produced due to the induced current in the rotor winding. The difference frequency of magnetic field currents caused the rotor turns as stator magnetic field direction. The rotor speed increases gradually until the induced current at rotor and torque balances at load.

2.1.2 Single Phase AC Induction Motor.

Usage of single-phase AC induction motor are more often compared to other classes of motor. The advantage of this motor is low maintenance cost and cheap. Single-phase AC motor construct with single stator winding as a primary winding while the receiving supply to operate motor also single-phase power supply. This motor cannot self-start and requires additional force to kick start to operate. When the single-phase power supply is delivered to the stator winding, the current at stator winding will induce and create an alternating magnetic field to rotate the rotor with starting mechanism support. Figure 2.4 shows the single-phase motor design.

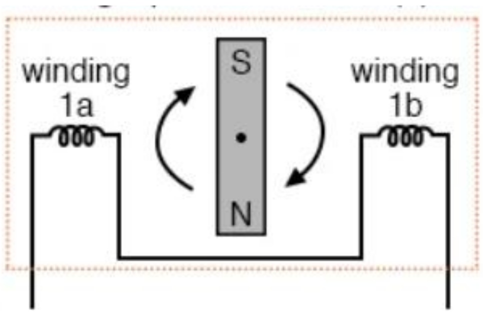


Figure 2.4: Single-Phase Motor Design

2.1.3 Three Phase AC Induction Motor.

The three-phase AC induction motor is a widely used motor for many industrial and many applications. The advantage of this motor is that it can provide higher torque operation in all speeds and is able to variable the speed. Since this motor has multiple stators winding and the three-phase current supply to winding creates rotating magnetic field in the stator its classified as self-starting motor. Mostly the squirrel cage rotor motor becomes the first choice for industrial applications due to high load performance and the least expensive. However, a wound rotor motor is a good selection when required to run very great inertia loads. Therefore, the motor needs to create pull-out torque from zero speed and achieve full speed with minimal current draw at short duration time. Figure 2.5 shows the typical stator winding arrangement for a three-phase AC induction motor.

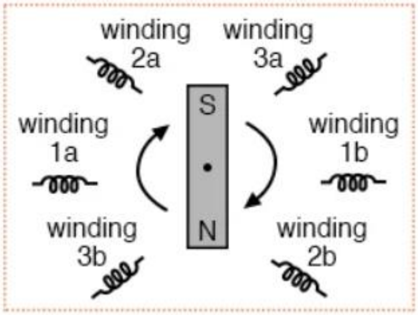


Figure 2.5: Three-Phase AC Induction Motor Design

2.2 Speed Control Drive

Past two decades the innovation in semiconductor field like power electronic devices and integrated circuit devices able to be producing high performance electrical component and make the application become easier to execute and accessible (Hemish R.Choksi, 2015). Variable speed drive is AC drive which is part of this semiconductor development. The AC drive is renowned by numerous names such as variable speed drive, an inverter and frequency converter (Ahmed Ali, Ergun Ercelebi, 2018). There are AC drives or devices that control speed namely into two terms which are variable frequency drive (VFD) and variable speed drive (VSD) with have divergent meanings (P.P.Rawale, 2018).

2.2.1 Variable Speed Drive

Variable speed drive is a driver used to control and regulate the induction motor speed by adjusting the frequency of power input supplied to the electric motor (Siswandi Siswandi, 2021). In Figure 2.6, the connection of variable speed drive between source and load (induction motor) is schematically described (Alper Gonen, 2021).

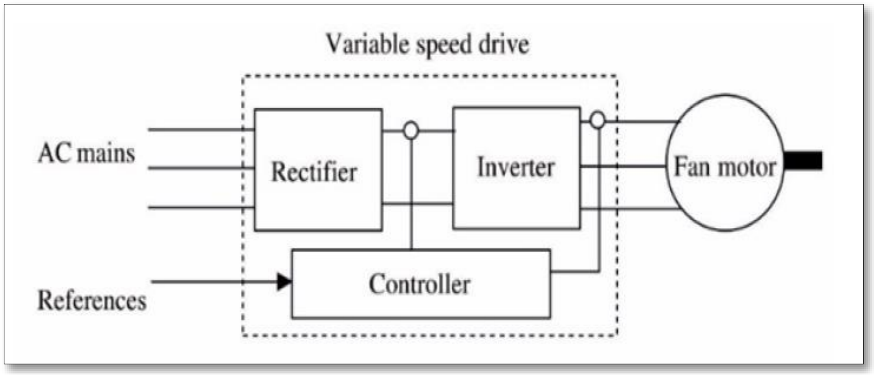


Figure 2.6: Variable Speed Drive Block Diagram

A rectifier circuit is a diode bridge rectifier consisting of 6 power diodes connected to three-phase power supply to convert AC to DC supply. This rectifier is also known as six-pulse uncontrolled rectifier and categories as non-liner load. The disadvantage of this rectifier will cause the non-sinusoidal current flow from main line (Ahmed Ali, 2018). In this filter circuit, the ripple DC supply output from rectifier circuit will be smoothening the output by filtering the ripple voltage and increasing the DC voltage. The first element of this filter circuit is capacitor which is connected in parallel with output of rectifier circuit. This capacitor is defined as smoothing capacitor or reservoir capacitor (P.P.Rawale, 2018). Inverter Circuit basically, the conversion of DC to AC supply will perform by inverters which connected parallel with DC link. This inverter is built with transistor to supply AC voltage back to the electrical driven machine. Moreover, “Insulated Gate Bipolar Transistor’ is a common type of transistor used in variable speed drive (Hemish R.Choksi, 2015). There are many types of inverters present in the market which refer to the category of power supply source and interrelated power circuit topology such as voltage source inverter (VSIs) and current source inverters (CSIs)(Shagufta,2020). Among them, the pulse with modulation (PWM) inverter or technique are common use in variable speed drive. The signification value of this inverter can produce correct output voltage as per required by load by modulating the width of the switching frequency. However, the hormonic voltage of fifth and seventh are drawback for this inverter (Shagufta, 2020).

2.2.2 Variable Frequency Drive

The variable frequency drive (VFD) is a common AC motor driver which has many characteristics to control motor speed. Unlike other standard motor drivers, variable speed drives have special operation capabilities and unique functionality with provide safe operating protection such as phase unbalance, over voltage and current and under voltage. (Ahmad, Israr, 2021). The desired speed or output able to obtain with software and interfacing option at VFD. (Ashwini.D.Gaikwad, 2015). Precision speed control and smooth or soft start/stop abilities are the main advantage of this VFD. Figure 2.7 shows the basic construction for variable frequency drive. These VFD build with four main components which is rectifier, DC link, inverter and lastly the controlling circuit. The rectifier works as a converter to convert AC supply to DC supply and fed to DC link. Even though many electronic switching devices available, but silicon-controlled rectifier is widely used as rectifier because the DC output can regulate by gate control. (Ahmad, Israr, 2021). DC-link section built with capacitor acts as storage capacity and inductors act as filter to remove the ripples. Main purpose of DC link is to receive rectified AC supply to

DC supply and store the DC supply at capacitor and deliver back to DC supply to inverter. (Ahmad, Israr, 2021).

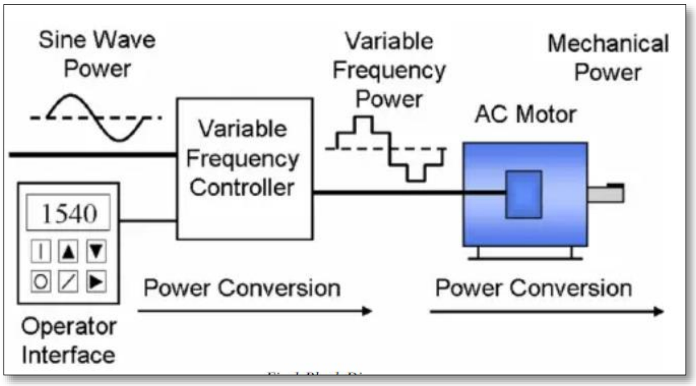


Figure 2.7: The Basic VFD Bloc Diagram.

Basically, the variable speed drive (VSD) and variable frequency drive aim are same to control the speed, optimal energy consumption and increasing the energy efficiency of the AC induction motor. However, the different working principles are the main difference between these two drives. Another difference between VSD and VFD is the compatibility, where VSD is used for AC and DC motor. Thus, VFD is only compatible with AC motor. The designation of drive is another difference between VSD and VFD. Compared with VFD, VSD is the best selection for motor operation which requires fast speed acceleration and slow declaration. In this case, VFD is good idea for persistent working process requirements.

2.2.3 Pulse Width Modulation

In three-phase inverters, pulse width modulation (PWM) is used to regulate and shape the magnitude and frequency of the three-phase output voltages while maintaining a constant input voltage. There are two different PWM techniques.: one is an on-line generation technique and the other is an off-line generation technique. The on-line generation technique is divided into two types, namely carrier-based PWM and space vector-based (SV0-based PMW. Square waves travel through the network of circuit barriers in carrier based PWM, while sine waves travel through the motor. The two intersecting spots serve as the switching points for the power electronics in the inverter. Figure 2.8 shows the PMW signal wave. However, because of the significant harmonic distortion in the power supply caused by the PWM switching traits, it is unlikely that this technique will fully utilize the inverter's supply voltage. The switching sequences must be optimized and a specific sequence of harmonics has to be eliminated for off-line generation technological advances.

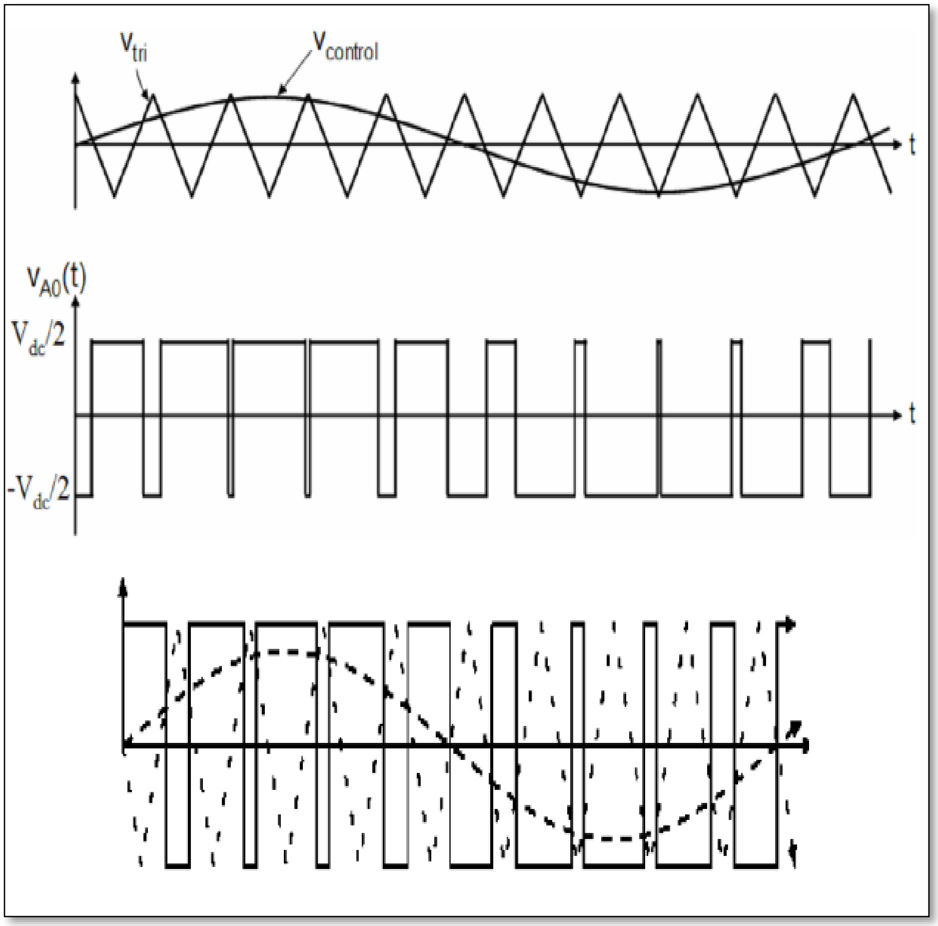


Figure 2.8: Pulse Width Modulation Signal Wave

2. 3 Drive's Effect on Motor Speed

Pulse Width Modulation Drives are used to alter a motor's speed because they supply the output frequency and voltage required to do so. The required waveform is created by combining pulses of various widths produced by a pulse width modulation (PWM) inverter. Some translators use a diode bridge to cut down on harmonics. PWM generates a current pattern that more closely resembles that of a line source, reducing unwanted heating. PWM drives have a power factor that is nearly consistent and close to unity at all speeds. PWM devices can control numerous motors with a single drive. (Tamal Aditya, 2013).

Figure 2.9 are components of the drive output waveform. As a result, the carrier frequency is determined by how quickly a power source switches on and off. Additionally known as swap frequency. Therefore, the resolution for PWM (Pulse Width Modulation) includes higher the carrier frequency. As opposed to the older SCR-based carrier frequency, which varies from 250 to 500 times per second, the typical carrier frequency ranges from 3KHz to 4KHz, or 3000 to 4000 times per second. Thus, it is evident that the precision of the output waveform will increase with the carrier frequency. It should be observed that the carrier frequency lowers the drive's efficiency because it causes the drive circuit to become hotter.

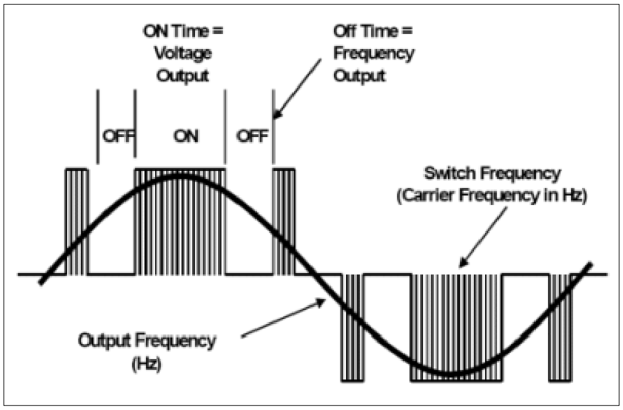


Figure 2.9: Components of the Drive Output Waveform

2.3.1 Bridge Inverter in A Three Phase 180 Degree Mode

The desired circuit must first be drawn to be divided into its three segments, namely segments one, two, and three. Switching pair S1&S2 make up segment 1, switching pair S3&S4 make up segment 2, and switching pair S5 & S6 make up segment 3. The identical segment should never have both switches closed at once because doing so causes battery short circuits, which would cause the complete setup to malfunction. Figure 2.10 shows the IGBT segment arrangement in inverter.

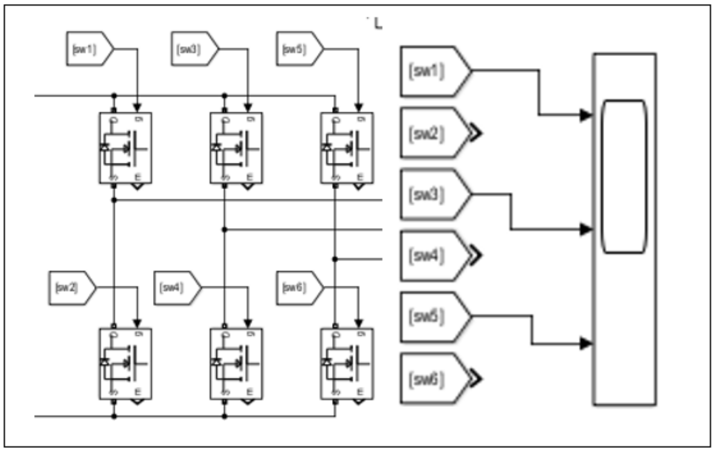


Figure 2.10: Inverter Switching Segment

Let's now begin the switching process by shutting off the switch S1 in the first section of the ideal circuit, and let's designate the start as 0 degrees. because the chosen period of 180° of transmission from 0 degrees to 180 degrees, the switch S1 will be blocked. However, as can be seen in the three-phase voltage curve, after 120 degrees of the first segment, the second segment will also have a positive cycle, so switch S3 will be closed after S1. Also, the S3 will remain blocked for another 180 degrees. S3 will therefore be closed between 120 degrees and 300 degrees and accessible only after 300 degrees. (Reshma K.Kadu, 2020).

Like the second segment, the third segment also has a positive cycle 120 degrees after the positive cycle of the second segment, as shown in the graph at the beginning of the piece. So, after the switch S3 closes at 120 degrees, or 240 degrees, the switch S5 will be shut off. The switch will remain closed for 180 degrees after being closed, closing the S5 from 240 degrees to 60 degrees.

Up until this point, all we had done was presume that once the top layer switches were closed, the conduction was finished, but that current flow from the circuit still needed to be finished. Additionally, keep in mind that no two switches within a section should ever be in the closed position at the same time; as a result, if one switch is closed, another must be open.(Reshma K.Kadu, 2020)

For fulfilling those two requirements, we will close S2, S4, and S6 in the specified sequence. We won't need to shut S2 until after S1 has been opened. Like how S3 opens at 300 degrees, S4 closes afterward, and S6 closes after S5 completes the conduction cycle. Figure 2.11 below shows this pattern of switching between switches on the same segment. Here, S2 comes after S1, S4 after S3, and S6 after S5.

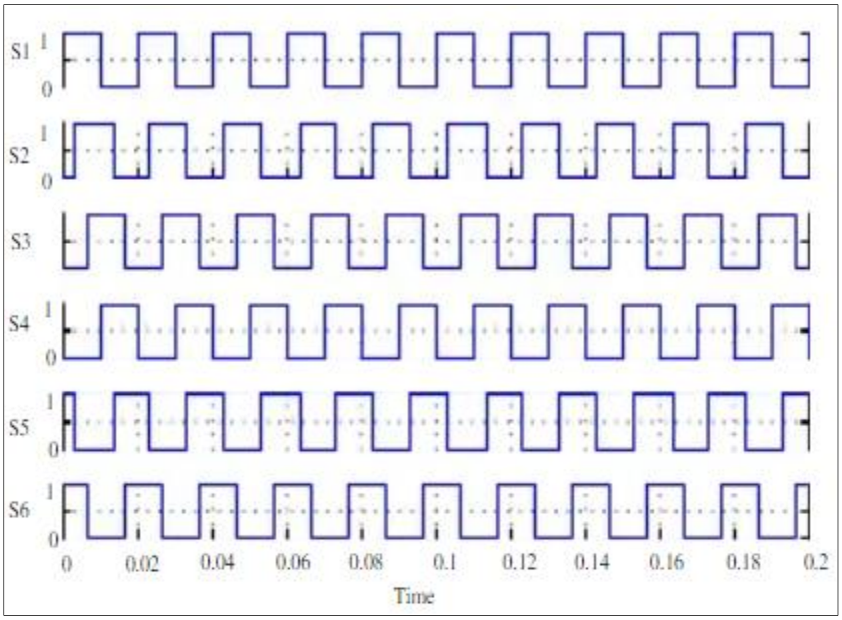


Figure 2.11: Pattern of Switching Between Switches on The Same Segment.

2.4 The Deployment of Speed Control in Various Applications.

Today industrial sector power consumption is very significant usage up to 37% out of 100% global energy consumption (Shafishuhaza Shalan, 2017). There is expectation increasing world power energy will increase up to 50% between year 2018 to 2050 and the industrial sector is higher contributor (Alper Gonen, 2021). Moreover, electricity generation was raised nearly 4 times in the past 40 years (Malli, 2019). Figure 2.12, illustration of gross output by sector and energy consumption by industrial subsector.

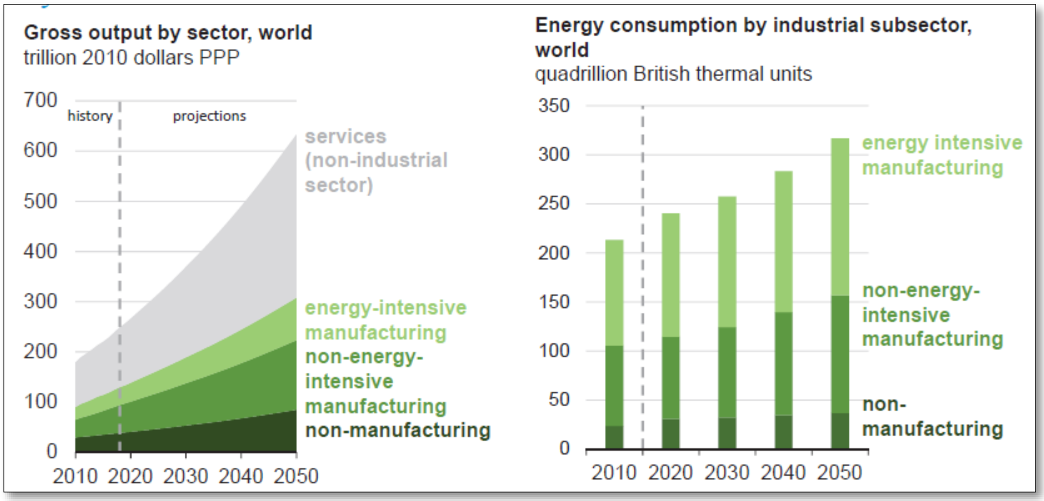


Figure 2.12: World Sector Energy Consumption

To overcome the higher energy consumption many methods were implemented in electrical systems. Speed control is one of the methods impose on electrical driven machines which commonly operate at constant speed or nearest to synchronous speed. Moreover, many applications require certain rotating speed to ensure the achieved desired output (Siswandi Siswandi, 2021). There are many methods of speed control of electric driver motor.

2.4.1 AC Induction Motor Speed Control from Stator Side

2.4.1.1 By Changing the Applied Voltage.

$$T = \frac{k_1 s E_2^{\,2} R_2}{\sqrt{(R_2^{\,2} + (s X_2)^2)}} = \frac{3}{2\pi N_S} \frac{s E_2^{\,2} R_2}{\sqrt{(R_2^{\,2} + (s X_2)^2)}}$$

Refer to torque equation for induction motor, the slip (s) can be neglected if the slip is small then $(sX_2)^2$. Thus, the torque directly proportional to (sE_2). So, the E_2 is emf of rotor induced. Therefore, the E_2 directly proportional to voltage. (Aina Parasher, 2022). Hence, torque directly proportional sV^2. So, if delivered voltage increased, the develop torque increase and vice versa when the value decrease. In other words, to maintain the constant load torque, the motor slip will increase while the voltage and speed decrease. (Kiran Daware, 2014). Even though this method is very easy and economical but has a few drawbacks which caused this method to be rarely applied. There are:

1. for small change in speed but required large change in supply voltage which mean limited speed adjustment. (Siswandi Siswandi, 2021).
2. the motor magnetic conditions will interrupt when large change in flux density due to large change in supply voltage.

2.4.1.2 Frequency Control Method

The supply frequency is inversely proportional to the flux density of the stator core. The maximum flux density (B_m) needs to deliver continuously in order minimize the core losses and optimal operation of the motor.

$$B_m \,\alpha\, V/f$$

Therefore, the voltage and frequency need to be changed to continuously deliver the maximum flux density. However, this method is not likely to be applied if the frequencies are more significant than the rated frequency since the voltage needs enhance which is not possible due to the insulation restrictions. (Aina Parasher, 2022). Thus, the varying voltage and frequency converter are required which this method will cost expensive. Hence, this method can control various range speed without impacting the motor efficiency.

2.4.1.3 Change the Number of Poles.

This can be done by changing the arrangement of stator winding in motor. Refer to equation below, the speed can define that any change in the numbers of pole (p) and frequency (f) will affect the motor speed (Siswandi Siswandi, 2021)

$$\mathbf{Ns = 120(f) / p}$$

This method not applicable to wound rotor induction motor since the number of poles in the rotor are fixed. However, in squirrel cage motor the number of poles can be adjusted. (Kiran Daware, 2014). There are two techniques to change the number of the poles in AC induction motor which is multiple winding sets and consequent pole changing. The first technique, the motor stator required designed with multiple winding sets for several sets of poles. During the operation, the set of stator winding connected as per speed required while other set of stators keep in open conditions. The motor speed will be reduced as the number of poles increased. Hence, this technique has drawback which the speed only can change by step and involving the higher cost. While consequent pole changing technique able provide 2 set of poles if the coils reversing made and limited to two set of speed only. (Aina Parasher, 2022).

2.4.1.4 Stator Resistance Method

This method is the same as the voltage control method. Whereas the variable resistor or rheostats need to be connected in series with stator winding to control the voltage in order to achieved desire speed. The speed varies when the stator voltage varies (Rajesh Kumar Dubey.2018). There will be power losses as the variable resistor or rheostats connect in series and this method recommend use during starting for low-rating motor at short duration instead of speed control. (Aina Parasher, 2022).

2.4.2 AC Induction Motor Speed Control from Rotor Side

2.4.2.1 Rotor Resistance Control Method

The squirrel cage induction motor is not suitable for this speed control method due to the slip ring not available and cannot access to the rotor. Therefore, the wound rotor induction motor is the only motor applicable to this method. (Kiran Daware, 2014). To apply this method external resistance needs to be connected to rotor through the slip rings and brushed during the motor operation. Hence, this method will impact the torque reduction for motor.

$$\mathbf{T = [3\times 60/2\pi N_s] \times sE_2^2R_2/R_2^2 + (sX_2)^2}$$

When the stator voltage supply with current, the induced emf at the rotor with E_2 is constant. Since the slip (s) very small during running, the $(sX_2)^2$ can be neglected.

$$\mathbf{\Rightarrow T \, \alpha \, s/R_2}$$

In this method, to achieve constant load torque, the speed of the rotor inversely proportional to slip. When slip increase the speed will decrease which is this method not efficient and not suitable for all applications. (Aina Parasher, 2022). Although this method has advantage increasing starting torque with external resistance, but has more disadvantage such as:

- To travel at higher speed than normal speed is not doable.
- Large resistance resistor required for large speed, but this will lead to copper losses and efficiencies drop.

2.4.2.2 Cascade Operation

Figure 2.13 shows the cascade operation circuit connection. At this method, two motor shaft connected in series or on same shaft and both motor run at ideal speed. Both type AC induction motor slip ring induction motor and squirrel cage induction motor required. (Kiran Daware, 2014). As usual one of the motor three-phase power supply directly connected to the stator winding. (Aina Parasher, 2022). However, another motor, the power supply sourced via slip ring from the induced emf in motor which directly fed three-phase supply.

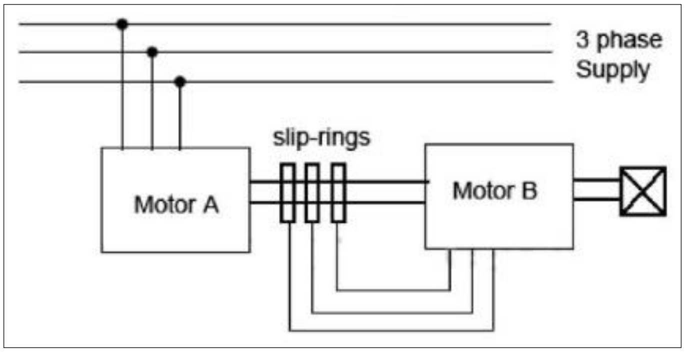


Figure 2.13: Cascade Operation Circuit Diagram

The speed of the first motor (slip-ring induction) is: $\mathbf{N_{s1}=120\ f/P_1}$

The speed of the second motor (Squirrel cage) is: $\mathbf{N_{s2}=120s_1f/P_2}$

There are four different speeds can produce through this method and there are:

a. **$120\ f/P_1+P_2$** in cumulative cascading
b. **$120\ f/P_1-P_2$** in differential cascading
c. **$120\ f/P_1$** (When motor-1 only operating)
d. **$120\ f/P_2$** (When motor-2 only operating)

2.4.2.3 Slip Power Recovery Method

In this method, to achieve constant torque the separate voltage needs to supply to motor rotor through slip ring and brushes. There are two ways to accomplished. The first technique is by increasing the rotor voltage which will increase the speed as well because the torque directly proportional to voltage. (Kiran Daware, 2014). Therefore, if increase the rotor voltage will lead to increase the torque and speed but the slip will decrease. The second technique are exactly reverse step decrease the voltage supply to rotor. When voltage decrease, torque and slip will decrease but speed will increase. The Kramer system and Scherbuis system is good example of slip power recovery method. (Aina Parasher, 2022).

2.4.3 Motor Speed Control Advanced Control Scheme

There are many conventional methods to control motor speed but none of these methods can provide economical and efficient speed control. To achieve accurate control, economical and efficiency an advanced control scheme is required. The current power electronic development can provide various range speed control.

2.4.3.1 Scalar Control (V/F)

Mainly the scalar control method also known as open loop control system where the system did not require the feedback system. Since the supply frequency can control synchronous speed by varying the frequency. However, the air-gap flux is directly proportional to voltage induced. Therefore, the stator voltage can be neglected and the unchanged supply voltage after reducing the frequency will cause the air-gap flux to increase. So, to sustain the V/F ratio steady state, the frequency and voltage will diverse subsequently. By sustaining constant V/F ratio will help sustain the maximum torque during speed vary. (Oinam Manganleiba Meetei, 2017). Figure 2.14 shows the open loop V/F control of induction motor.

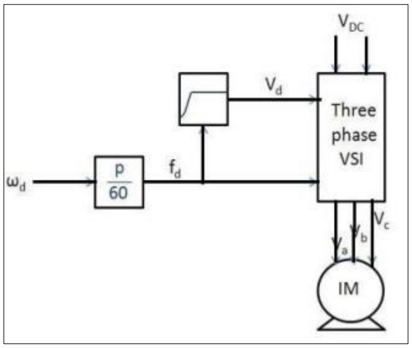


Figure 2.14: Open Loop V/F Control of Induction Motor

2.4.3.2 Vector Control

Field-oriented control is another name for vector control. A high degree of dynamic response is provided by field-oriented control, and the system's stability over the long term is guaranteed by the closed-loop motor drive. It is also known as "indirect torque control" or "flow-oriented control." Magnetic flux-oriented control, stator flux-oriented control, and rotor flux-oriented control are the three different categories of control systems. Many demanding industrial processing and manufacturing uses that call for great performance utilize induction motors. Despite parameter changes, unbalanced loads, and model uncertainties, the motor speed must maintain a specific reference curve in order to accomplish these high performances. The accompanying figures illustrate the fundamental schematics of the indirect and direct vector control methods. The unit vector derived from the stator flux is referred to as the direct vector control technique. The voltage and current impulses of the stator are used to compute or make assumptions about these vector signals. The stator quantities are used to determine the stator flux's component elements. In this method, the rotor speed is not necessary to determine the rotor field angle. Flux measurement is a labor-intensive process that requires extra equipment, and the results are inaccurate. This makes the vector control method less than ideal for speed management. In comparison to the direct vector control method, the indirect vector control method is the most widely used and reliable technique. By adding the slip frequency and rotor speed, this technique calculates the unit vectors and field angles of the rotor indirectly.

2.5 Efficacy and Enactment of Variable Speed Drive.

The variable speed drive has become common device and method of controlling speed of motor. There is numerous research conducted in various applications and different industries to justify the variable speed drive effectiveness and performance. The mining industries can achieve 53% of electricity consumption for fan application by regulation of the fan rotating speed using the variable speed drive. Furthermore, indirectly the reducing the CO2 emissions (Alper Gonen, 2021). By varying the frequency of variable frequency drive in between 45 to 70 Hz, for air handling unit fan motor speed able to control and lower the energy consumption (Mr.Manoj Minse, 2019). A significant energy saving result was obtained for black tea processing machinery when applied with high-efficiency motor and variable speed drive (G.Abhiram, 2020). The Fiber line 1 & 2 can achieve energy saving by using the variable speed drive and comparison conducted between direct online starter and VSD (Tegar Arieyyasha Fikri, 2021). Titi water treatment plant able to achieve significant reduction in energy consumption up to 26.6% and 24.6% after VSD able to adjust the motor speed (Shafishuhaza Sahlan, 2017). The AC induction motor driven by variable speed drive has a relation with output torque. Basically, the stator magnetic flux produced by the stator is directly proportional to the stator voltage. Another way can say that torque is directly proportional to voltage as well as speed (Muhammad Ahsan Niazi, 2020). By adjusting the frequency and voltage, the desired speed and torque can be achieved as same time can reduce the starting current (Ahmed M.T Ibraheem AL-Naib, 2017). The induction motor driven by variable speed drive has a relation with output torque. Basically, the stator magnetic flux produced by stator directly proportional to the stator voltage. Another way can say that torque is directly proportional to voltage as well as speed (Muhammad Ahsan Niazi, 2020). By adjusting the frequency and voltage, the desired speed and torque can be achieved as same time can reduce the starting current (Ahmed M.T Ibraheem AL-Naib, 2017).

Even though VFD/VSD usage benefited electrical system, it is having drawback of produce harmonic back to grid system due to converting the static frequency supply to adjustable frequency through VSD components (Sourabh Bodke, 2020). But this disadvantage can be overcome by installing the harmonic filter in the system to prevent voltage fluctuations in electrical system (Ahmed Ali, 2018). Another drawback of variable speed drive was described in mechanical train system. Where the system faces torsional vibration problem which could produce excessive damages to mechanical train components such as shaft or coupling failure (Vrajesh Bhandari, 2019). However, the reduction noise and vibration level become another advantage of variable speed drive (Amit Kale, 22017).

Nevertheless, the variable speed drive controller is the main key player of performance of AC drive. There are several types of control used in AC drives. Scalar control is the common type of control in most industrial applications which is simple and open loop controller with constant voltage of frequency ratio. (Ahmed Ali, 2018). This is known as cost effective controller because this scheme not required additional microprocessors and electrical transducers such as sensor or encoder to feedback signal to

VSD (Taylor L.Short, 2021). The working principle of the controller is directly proportional between the induction motor voltage and variable of motor reference speed. Even though the scalar controller is cost effective, it has the disadvantage in poor accuracy of speed and torque responses due to both torque and stator flux control not directly. However, the accuracy of speed is still acceptable within 2% with identified parameters and not accept if too low speed (Ahmed Ali,2018). The next controller known as direct torque controller which structured simple and torque responses are impressive and super-fast. Moreover, this controller delivered the indirect control both stator current and voltage (Muhammad Ahsan Niazi, 2020). This controller has become a highly significant method to deliver very efficient performance in electric motor. The torque response time is one of the factors in the selection of this controller because it worked with minimum response time. Another benefit of this controller is because it does not require voltage modulator block and controllers like PI and PID.

However, this controller also has the drawback which is the estimator required for torque and flux (Ahmed Ali, 2018). Vector control is also main player of VSD controller. Filed Oriented Control (FOC) is alternate name of vector control and it’s also known as decoupling and orthogonal. In these controllers, the torque and the flux controlling as control loop (Ahmed Ali, 2018). The Park transform is one of the vector transforms used in this FOC controller, and it can obtain the speed accuracy up to 0.5% and torque up to 2%. However, FOC also has a drawback like others controller which is the controller requires giant computational capability. Furthermore, the motor parameter is mandatory and shall have good identification. (Ahmed Ali, 2018).

The configuration and controller method for variable speed and the output in terms of energy efficiency and performance is described in the next chapter. The MATLAB and Simulink model will be used to obtain results and detailed discussion will present in chapter result.

CHAPTER 3

RESEARCH METHODOLOGY AND WORK PLAN

3.1 Research Process Identification

This research will be divided into four phases. Figure 3.1 shows the process flow of the four phases.

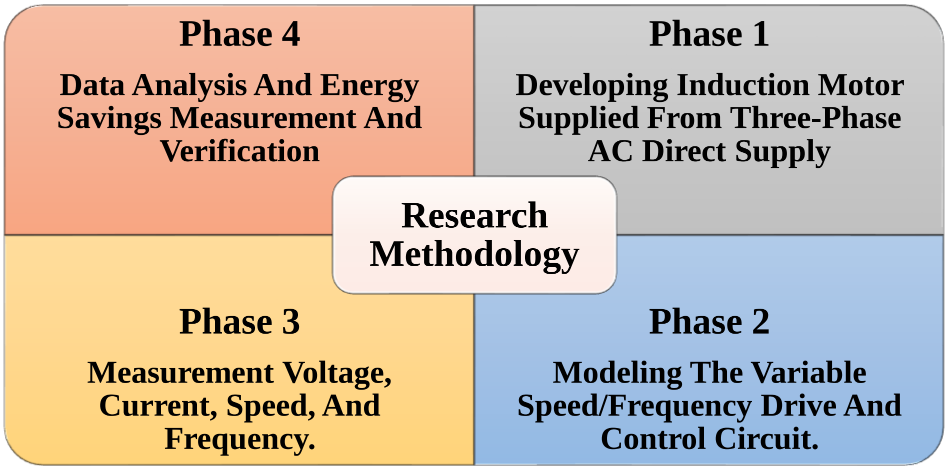


Figure 3.1: Research Methodology Process Flow

The first phase developing the induction motor supplied from 3-phase AC direct supply. The performance of voltage, current, speed and frequency characteristics are explained with respect to time. The creation of an appropriate simulation model using MATLAB is the focus of the second part. The varying frequency measurement of induction motors can be computed using the MATLAB design for a variety of applications. Software for engineering model and simulation that works well is MATLAB. It offers modelling and simulation tools for all engineering systems, including electrical and electronic, mechanical, aerodynamic, and hydraulic systems. The main highlight of this software is this different specific area or system can be shared and simulated together in Simulink environment in MATLAB. Thus, the simulation model of induction motor by variable speed drive with electrical and mechanical system can be designed. The third phase is measurement voltage, speed, and frequency for building designed circuit of different controller type for variable speed drive. In this research the two-controller open loop and close loop will emphasize variable speed drive to evaluate the performance and efficacy. The final phase is data analysis and energy savings measurement and verification. The comparison between simulation induction motor without variable speed drive and with variable speed drive for different AC controller evaluate to identify the high energy saving efficiency method.

3.1.1 Phase 1 - Induction Motor from Direct 3-Phase AC Supply.

The 1st step of the research builds the circuit of induction motor connected directly to AC supply using MATLAB. The unit of speed, voltage, current and frequency measured and the graph plot.

3.1.2 Phase 2 – Modeling the Control Circuit.

The primary element of the control system is the PWM Generator. PWM signals are created by comparing a sine wave with a pulse train and modulating the pulse width accordingly. As can be seen, the merged pulse train is compared to the sinusoidal signal. The technical description of the voltage measurement techniques and tools is one of the most interesting topics in VSD. Depending on the power electronics components used in the VSD, readings of both the AC and DC voltages may be necessary. The two primary components of a digital instrument for measuring AC voltage are a voltage conditioner and a low voltage metering system.

3.1.3 Phase 3 - Measurement Voltage, Current, Speed, And Frequency.

The right instruments and constraints must be used when conducting assessments. Higher voltage amplitudes can be utilized in high power VSD, but choosing the right voltage conditioner depends first on the nominal voltage's root mean square (RMS) value, which is usually 115/230 V for single-phase configurations and 200/400 V for three-phase configurations. A voltage modulation stage is required to provide the proper signal amplitude to the electrical measuring instrument. Insulation is frequently required. To correctly detect AC voltage, the voltage conditioner, and the digital instrument both need to have a large enough bandwidth. It must be at least twice as large as the sine wave's primary frequency.

A larger bandwidth is still favored for a more precise measurement even though a signal with a frequency closest to this frequency will be reduced by 3 dB according to the standard definition of bandwidth. Several VSD applications are unable to consider the voltage nominal frequency, which is usually 50–60 Hz, because of the implementation of both voltage waveforms and pulse width modulation. (PWM). The AC electricity from the mains is received by the rectifier, which transforms it into DC before supplying it to the PWM Inverter.

The PWM Inverter alters the delivering supplies frequency to keep the ratio constant, which causes the voltage to alter as a result. The electromagnetic force is determined by the stator flux, which is in turn directly proportional to the relationship between the terminal voltage and supply frequency. Therefore, by varying the magnitudes of V and f while keeping a constant V/f ratio, the flux and, as a result, the torque, can be kept constant throughout the speed range. The user had to input different frequencies into a MATLAB programmed before the voltage could be changed to keep the V/f ratio constant.

The current and voltage properties were plotted to illustrate the different synchronous speeds that correlate to the different frequency ranges as the rotor speed was raised from zero to synchronous speed in each instance.

3.1.4 Phase 4 - Data Analysis and Energy Savings Measurement and Verification

Basically, the final step is to analysis the measurement gains from simulation for design without variable speed and design with variable speed drive for both open loop and close loop AC controller. The energy savings can be quantified by comparing the energy generated from both design and the total energy consumption performance.

3.2 Work Schedule and Framework

Table 3.1: Research Work Scope and Timeline

Research Work Schedule							
Year	2022			2023			
Month	10	11	12	1	2	3	4
Literature Review & Conceptual Research Model	🟨	🟨					
Construction Simulation Model for Induction Motor			🟨				
Simulating and Testing the Design Circuit			🟨				
Data & Result Analysis					🟨		
Data Measurement & Verification					🟨		
Final Reporting						🟨	🟨

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Simulation Outcomes

The outcomes and result for this research are expected as per literature review other studies on enactment and efficacy of variable speed drive. From the comparative analysis of induction motor with variable speed drive and induction motor without variable speed, it observes that the significant amount of electrical energy. From the proposed simulation model for three-phase induction motor is implemented successfully manner, the performance parameter of induction motor with the help of variable speed drive control huge energy can save. Indirectly the consumption of electricity is reduced means the demand is reduced so directly generation is reduced. Hence, required input to generating plant is reduced. primary fuel and secondary fuels also reduce the harmful effect on atmosphere from generating power plant.

4.1.1 Conventional Three-Phase Induction Motor Control

Figure 4.1 shows the MATLAB Simulink simulation model build for conventional three-phase AC induction motor control without VSD. In this model the motor drive by standard driver like direct online starter. Three-phase supply magnitude 400 line to line voltage supplied to this model to drive three-phase motor.

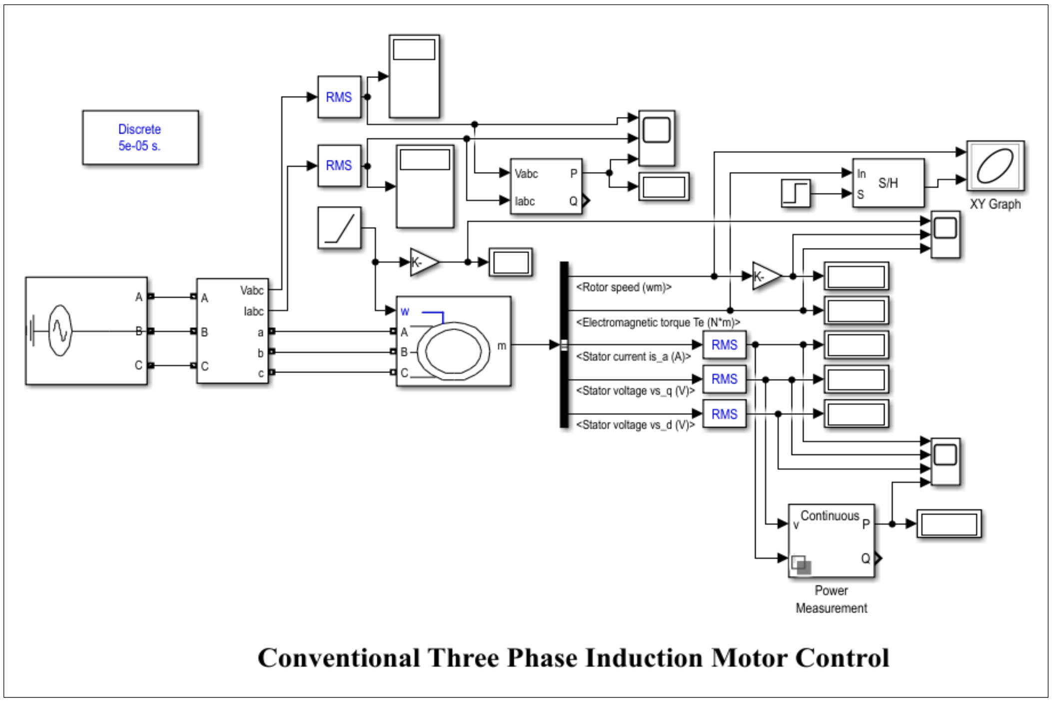


Figure 4.1: MATLAB Simulation Model Conventional Three-Phase Induction Motor Control Without VSD

Table 4.1 shows the motor specification which use in this simulation model. Squirrel cage three-phase induction motor capacity of 10HP or 7.5kW, 400 V, 50 HZ and 1440 rpm selected for MATLAB simulation.

Table 4.1: AC Induction Motor Specification

Description	Value
Type	Squirrel Cage
Power	10 HP/ 7.5 kW
Phase	3
Voltage	400 V
Frequency	50 Hz
Speed	1440 RPM
Pole	4

Basically, from this MATLAB simulation model various parameter like phase current, phase voltage, consumption energy, speed and torque were gathered through the display. At same time the graph was plotted from the data gathered. Table 4.2 shows the parameter was obtained from the simulation.

Table 4.2: Simulation Conventional Three-Phase Induction Motor Control Output Results

Time	***Input RMS Phase Voltage (Vph)***	***Input RMS Phase Current (Aph)***	***Reference Speed (RPM)***	***Input Energy (kW)***	***Output RMS Phase Voltage (Vph_d)***	***Output RMS Phase Current (Aph)***	***Output Speed (RPM)***	***Torque (N.m)***	***Output Energy (kW)***
1s	*250*	*105*	*180*	*3.25 x* 10^4	*250*	*105*	*180*	*140*	*2.25 x* 10^4
3s	*250*	*90*	*420*	*3.10 x* 10^4	*250*	*95*	*420*	*150*	*2.10 x* 10^4
5s	*250*	*50*	*750*	*2.90 x* 10^4	*250*	*90*	*750*	*180*	*1.90 x* 10^4
10s	*250*	*15*	*1432*	*0.50 x* 10^4	*250*	*15*	*1432*	*60*	*0.40 x* 10^4

Refer to the simulation output Table 4.2, the measure rms input phase voltage and rms output phase voltage are same. Similar to current measure at input and output. However, the voltage supplied to motor are constant at 250 Vp-p from starting at zero rpm until motor reached reference speed 1432 rpm. In this case current are not maintain at constant value. The starting current is 105 A and gradually reduce 15 A when the motor reach to reference speed. In this case, the power generate are like current. During motor starting the power draw are high at 2.25 x 10^4 kW and gradually drop to 0.40 x 10^4 kW when the motor reached to reference speed. Basically, the motor speed slowly accelerates as per ramp setting. Thus, the reference speed and motor output speed capture same rpm. Hence, the input energy and output energy have different value. This different assume as the internal losses like core and copper losses. Figure 4.2 shows the plotted graph for voltage, current and power at input of motor. Figure 4.3 shows the plotted graph for voltage, current and power at output of motor.

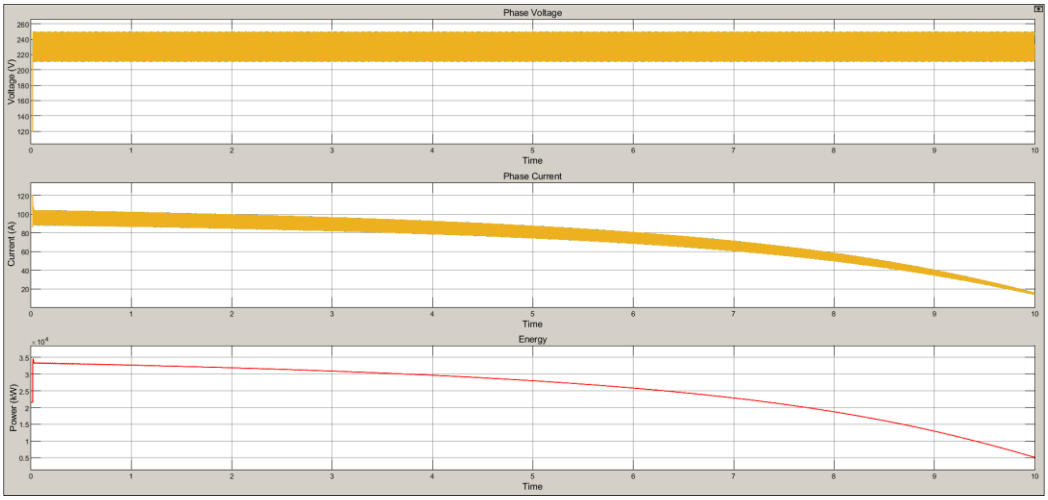


Figure 4.2: Graph Plotted for Voltage, Current and Power at Input of Motor.

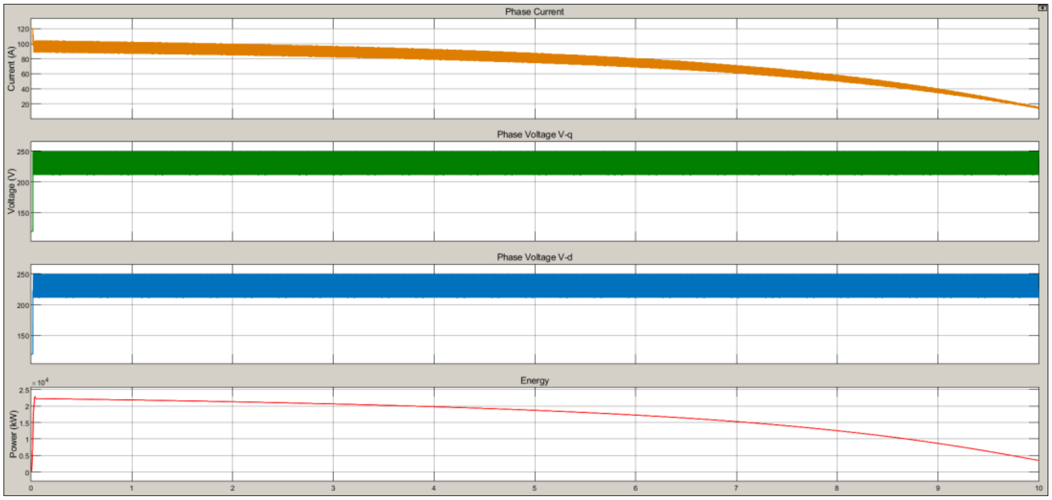


Figure 4.3: Graph Plotted for Voltage, Current and Power at Output of Motor.

Observed that the energy directly proportional to current. Since the voltage are constant the current increase and the energy increase respectively and vice versa. Refer to figure 4.4 shows graph for output of speed, the speed increasing linearly as per ramp setting or reference setting. However, the torque during motor starting is not stable and required high torque. But the torque started to decrease when the motor reached to maximum speed or reference speed.

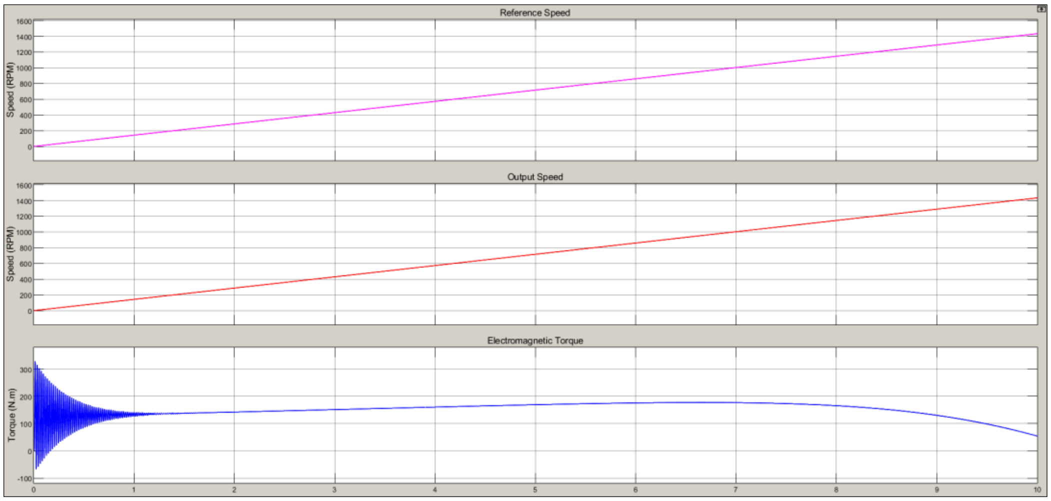


Figure 4.4: Graph Plotted for Reference Speed, Output Speed and Electromagnetic Torque.

The X-Y graph in figure 4.5 represents the torque speed characteristics curve for squirrel cage induction motor obtained from the simulation. From observation of this X-Y graph, the curve is almost linear until reached to pullout speed. Breakdown torque is maximum torque of the machine and its 2 or 3 of motor full load torque.

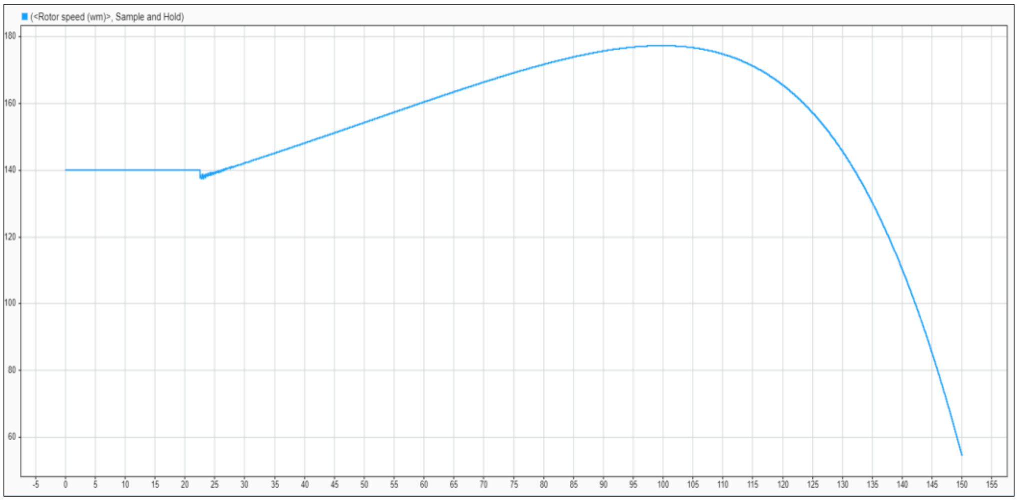


Figure 4.5: Graph Plotted for Speed Vs Torque

4.1.2 Simulink Model Open Loop Three-Phase Induction Motor using Pulse Width Modulation (Scalar Control)

The Figure 4.6 shows the MATLAB/Simulink model for open loop AC three-phase induction motor with PWM Scalar Control. In this model, the same specification motor as of first simulation model without inverter are used. The purpose uses the same specification motor is to identify the identical different between motor driven by conventional starter and power electronics components starter.

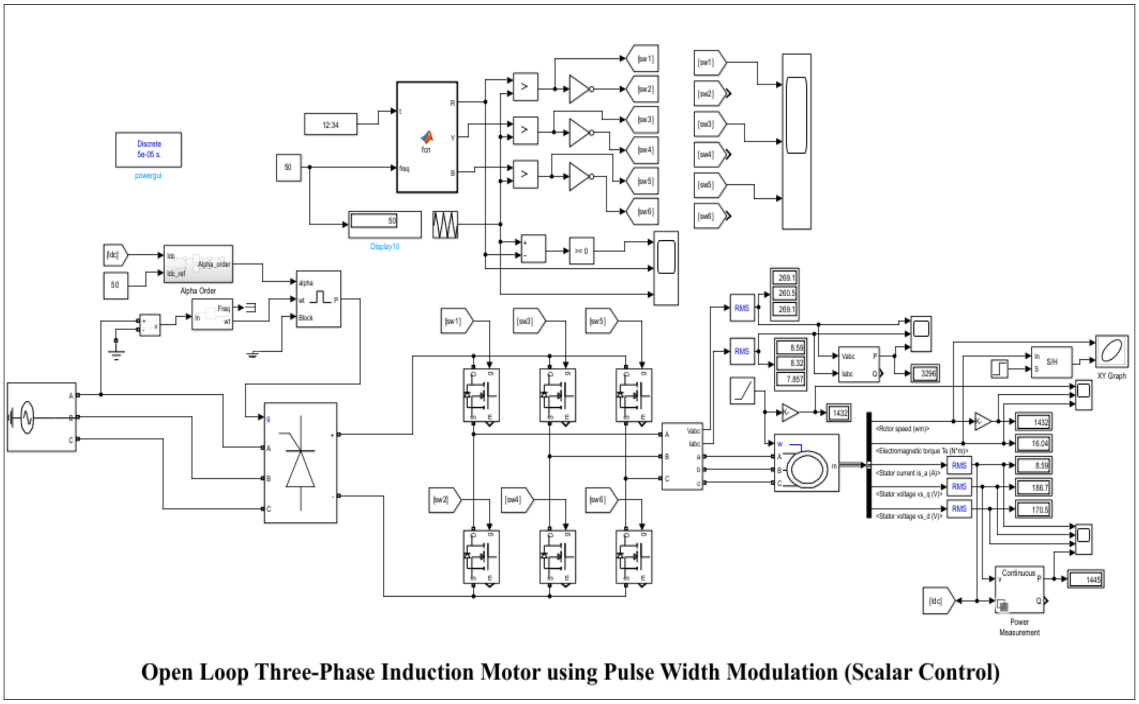
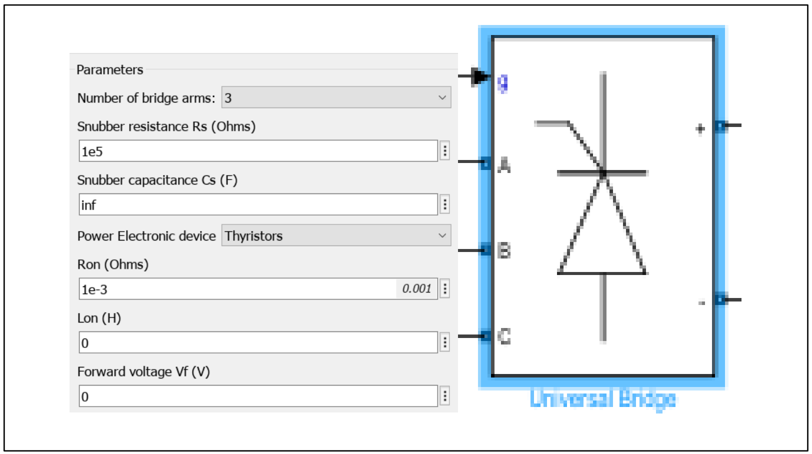


Figure 4.6: MATLAB/Simulink Model for Open Loop Three-Phase Induction Motor with PWM Scalar Control

This variable speed control model builds with universal thyristor as rectifier to rectified AC to DC supply and the gate control by feedback current for motor stator. Then, the MOSFET are used as inverter to be inverting the DC supply to AC supply which the gate control by PWM signal. The thyristor and MOSFET selection detail shows in the Figure 4.7 for the universal thyristor and Figure 4.8 for MOSFET.



Parameters

Number of bridge arms: 3

Snubber resistance Rs (Ohms)

1e5

Snubber capacitance Cs (F)

inf

Power Electronic device Thyristors

Ron (Ohms)

1e-3 0.001

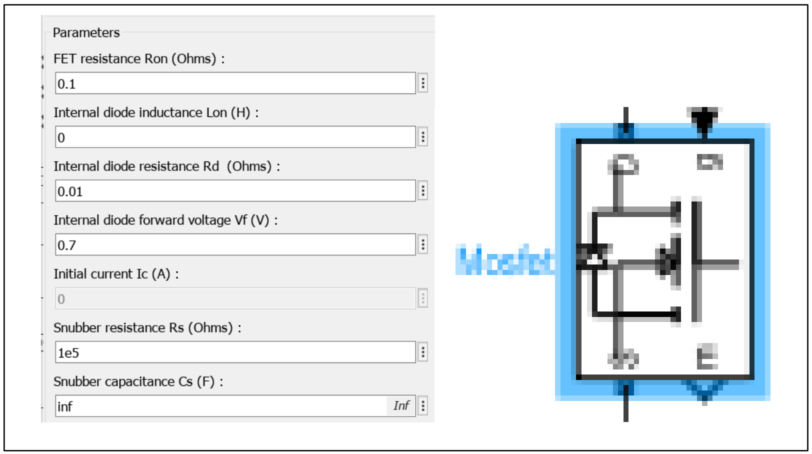
Lon (H)

0

Forward voltage Vf (V)

0

Figure 4.7: Universal Thyristor Specification



Parameters

FET resistance Ron (Ohms) :

0.1

Internal diode inductance Lon (H) :

0

Internal diode resistance Rd (Ohms) :

0.01

Internal diode forward voltage Vf (V) :

0.7

Initial current Ic (A) :

0

Snubber resistance Rs (Ohms) :

1e5

Snubber capacitance Cs (F) :

inf Inf

Figure 4.8: MOSFET Specification.

Basically, from this MATLAB simulation model various parameter like phase current, phase voltage, consumption on energy, speed and torque were gathered through the display. At same time the graph was plotted from the data gathered. Table 4.3 show the parameter was obtained from the simulation.

Table 4.3: Simulation Open Loop Three-Phase Induction Motor using Pulse Width Modulation Output Parameter Results.

Time	*Input RMS Phase Voltage (Vph)*	*Input RMS Phase Current (Aph)*	*Reference Speed (RPM)*	*Input Energy (kW)*	*Output RMS Phase Voltage (Vph_d)*	*Output RMS Phase Current (Aph)*	*Output Speed (RPM)*	*Torque (N.m)*	*Output Energy (kW)*
1s	*260*	*55*	*180*	*1.90 x 10^4*	*180*	*55*	*180*	*40*	*0.85 x 10^4*
3s	*260*	*45*	*420*	*1.80 x 10^4*	*180*	*45*	*420*	*43*	*0.80 x 10^4*
5s	*260*	*40*	*750*	*1.65 x 10^4*	*180*	*40*	*750*	*48*	*0.75 x 10^4*
10s	*260*	*10*	*1432*	*0.35 x 10^4*	*180*	*10*	*1432*	*15*	*0.18 x 10^4*

Refer to the simulation output Table 4.3, the measure rms input phase voltage and rms output phase voltage are not same. However, the current measure at input and output are same. The input voltage supplied to motor are constant at 260 Vp-p from starting at zero rpm until motor reached reference speed 1432 rpm. Even though, the measured output voltage is different from input voltage, but the voltage is constant at 150 Vp-p. In this case current are not maintain a constant value. The starting current is 55 A and gradually reduce 10 A when the motor reach to reference speed. In this case, the power generate are like current. During motor starting the power draw are high at 0.18 x 10^4 kW and gradually drop to 0.18 x 10^4 kW when the motor reached to reference speed. Basically, the motor speed slowly accelerates as per ramp setting. Thus, the reference speed and motor output speed capture same rpm. Hence, the input energy and output energy have different value. This different assume as the internal losses like core and copper losses. Figure 4.9 shows the plotted graph for voltage, current and power at input of motor. Figure 4.10 shows the plotted graph for voltage, current and power at output of motor. Result obtained have clear understanding between the input and output value. Unlikely the first simulation for conventional induction motor starter simulation results between the input and output value. Observed that the energy directly proportional to current. Since the voltage are constant the current increase and the energy increase respectively and vice versa.

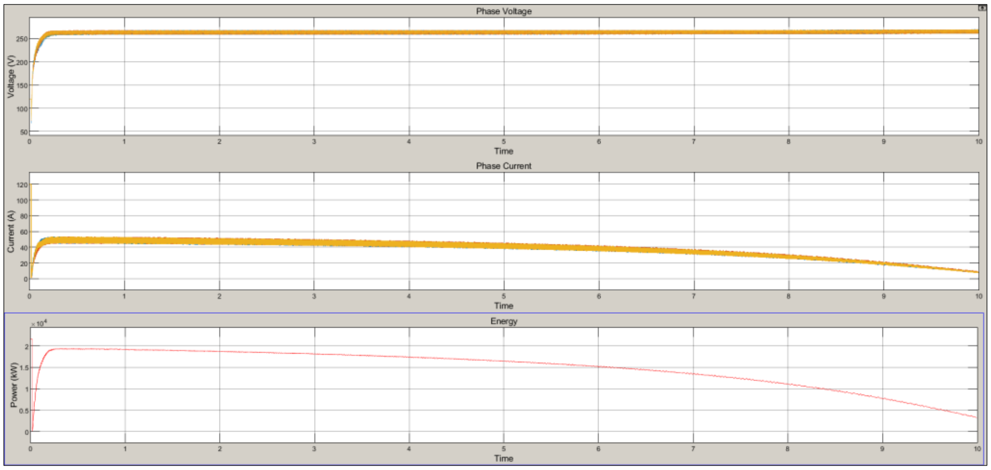


Figure 4.9: Graph Plotted for Voltage, Current and Power at Input of Motor Drive VSD

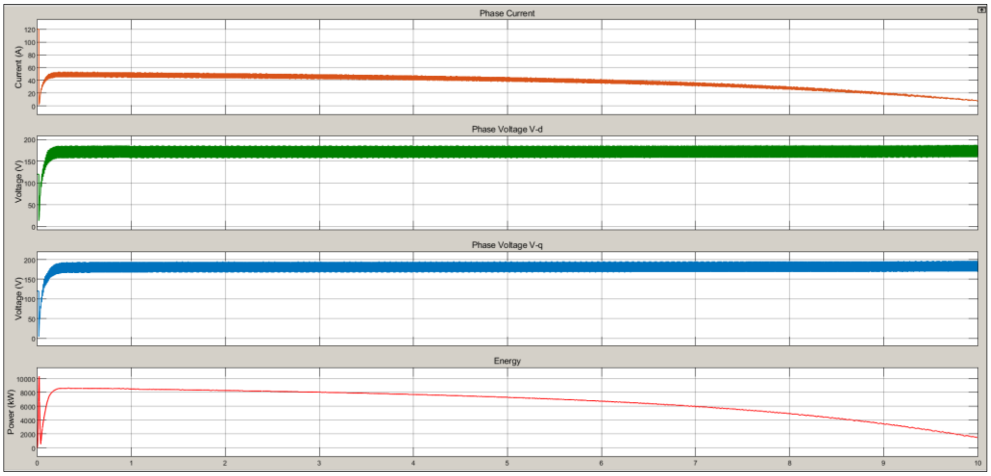


Figure 4.10: Graph Plotted for Voltage, Current and Power at Output of Motor Drive Inverter.

Refer to Figure 4.11 graph for output of speed, the speed increasing linearly as per ramp setting or reference setting. Unlike conventional induction motor simulation, the inverter model simulation shows the torque during motor starting is stable and require less torque compare with without inverter model. However, the torque started to decrease when the motor reached to maximum speed or reference speed.

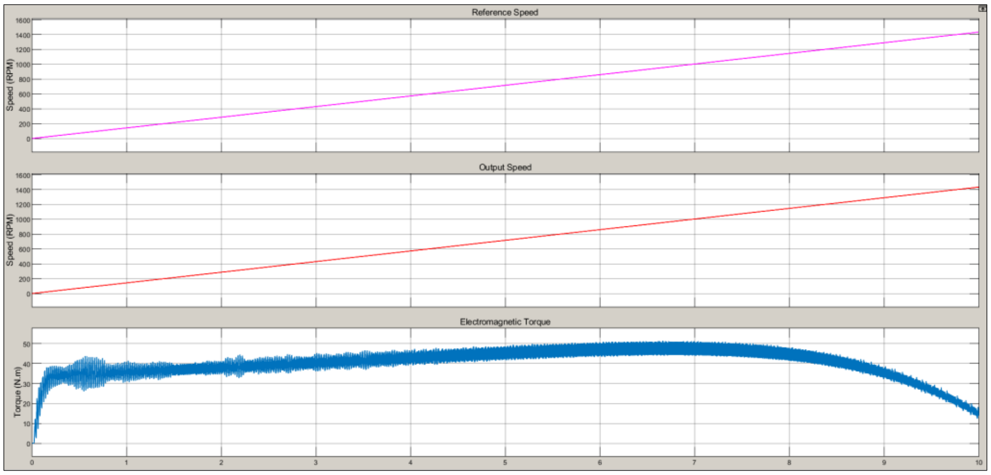


Figure 4.11: Graph Plotted for Reference Speed, Motor Output Speed and Electromagnetic Torque.

Figure 4.12 shows the pulse width modulating (PWM) signal generated to control the inverter gate. This signal reduces the mean power supply or voltage supplied from the electrical signal by changing the signal into discrete parts. This PWM presenting the duty cycle of MOSFET. The give time determine the PWM signal “ON” and “OFF” where defined the duty cycle either 25% or 50% or 100%.

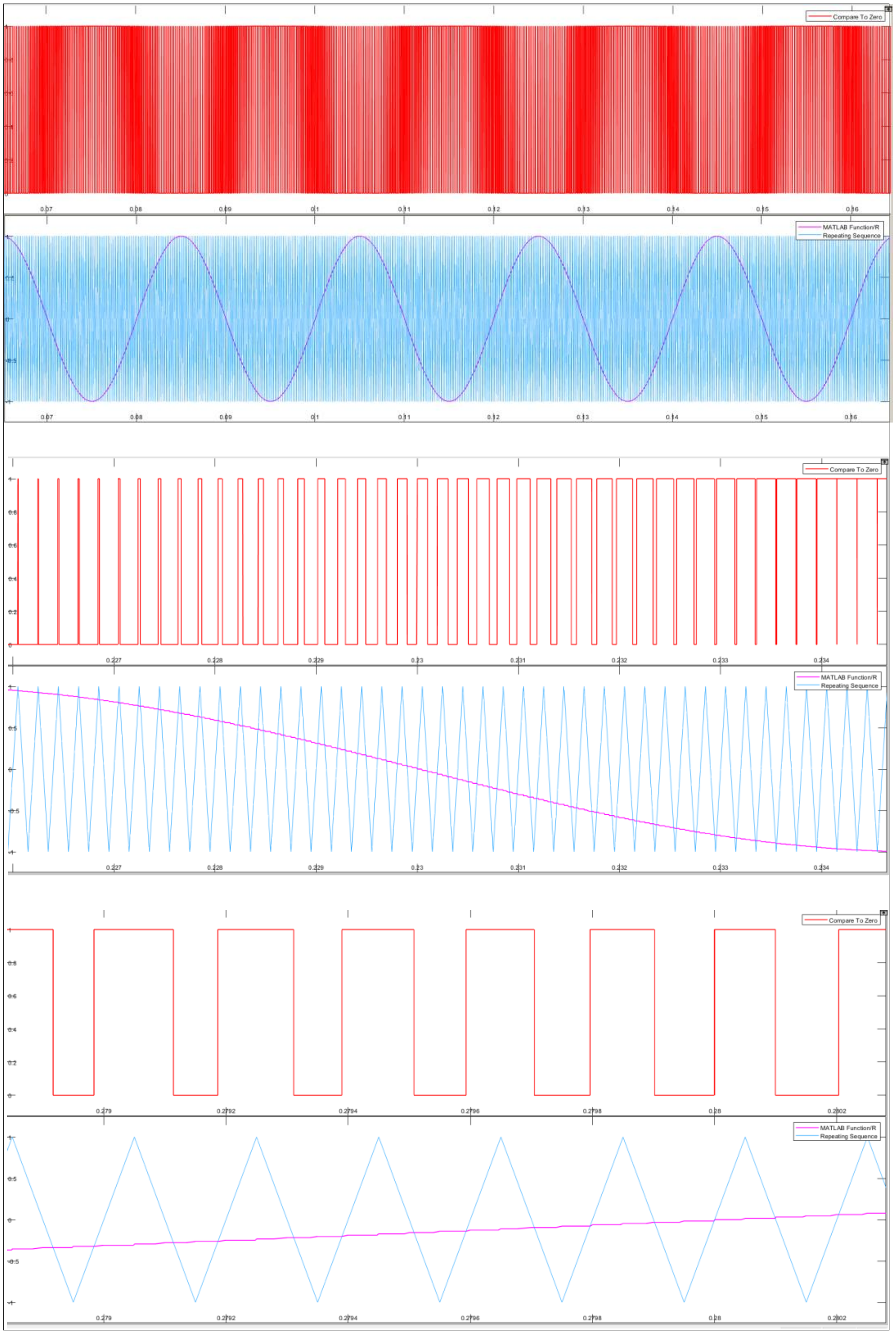


Figure 4.12: Pulse Width Modulate Signal for Inverter Gate

4.1.3 Comparison of Simulation AC Induction Motor without and with VSD

Table 4 shows the comparison measured parameter between the AC induction motor driven by conventional starter and power electronic device called VSD.

Table 4.4: Comparison Simulation AC Induction Motor without and with VSD

Time	**Without VSD**					**With VSD**				
	Output RMS Phase Voltage (Vph_d)	***Output RMS Phase Current (Aph)***	***Output Speed (RPM)***	***Torque (N.m)***	***Output Energy (kW)***	***Output RMS Phase Voltage (Vph_d)***	***Output RMS Phase Current (Aph)***	***Output Speed (RPM)***	***Torque (N.m)***	***Output Energy (kW)***
1s	*250*	*105*	*180*	*140*	*2.25 x* 10^4	*180*	*55*	*180*	*40*	*0.85 x* 10^4
3s	*250*	*95*	*420*	*150*	*2.10 x* 10^4	*180*	*45*	*420*	*43*	*0.80 x* 10^4
5s	*250*	*90*	*750*	*180*	*1.90 x* 10^4	*180*	*40*	*750*	*48*	*0.75 x* 10^4
10s	*250*	*15*	*1432*	*60*	*0.40 x* 10^4	*180*	*10*	*1432*	*15*	*0.18 x* 10^4

As shown in the above table, there are obvious differences in output between the two types of simulation without and with VSD. Both simulations were supplied with same frequency 50Hz with mechanical input as asynchronous speed 1432 RPM control by ramp generator. The measured stator voltage from induction motor drive by conventional driver or without inverter driver is constant voltage 250p-p and slightly higher than the inverter driving induction motor which is constant voltage 180p-p. Compare the torque produce by induction motor with inverter are greater less than induction motor without inverter. The produce torque is directly proportional to the energy produced by induction motor. At asynchronous speed 1432 RPM, the induction motor drive without inverter produces 60 N.m torque respectively 0.40 x 10^4 kW energy. Whereas induction motor drive with inverter produces 15 N.m torque respectively 0.18 x 10^4 kW energy. The relationship between torque and stator current is same as relationship torque proportional to energy since the voltage is constant. Refer to results obtained from the simulation of induction motor with inverter presenting the performance of VSD. The VSD can drive induction motor greater efficiently and deliver better performance in terms of energy. The less power and torque required to drive the same induction motor at same speed.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Refer to results obtained from the simulation of induction motor with inverter presenting the performance of VSD. The VSD can drive induction motor greater efficiently and deliver better performance in terms of energy. The less power and torque required to drive the same induction motor at same speed. In other words, the objective of this research was accomplished as expected. All research on the induction motor's capabilities, traits, and operating techniques has been done and is known.

It can be seen from the comparison analysis of induction motors with and without variable frequency drives (VFDs) that a sizable quantity of electrical energy is consumed. The proposed simulation model for a three-phase induction motor was effectively implemented, and it allowed for 45 % energy savings in the induction motor's performance parameter.

5.2 Recommendations

It takes a lot of effort to conduct research and get a better understanding of the performance when studying dynamic performance and fine-tuning the controller design. For the author to be able to comprehend more when using the equations with MATLAB coding, a better grasp of MATLAB is crucial. The creator may have difficulty locating the code and putting it together. To determine the effectiveness of modelling for upcoming motor control algorithms, a comparison between Simulink results and real measured results is required.

The most modern sophisticated processor is the DsPIC controller. It provides better efficiency and minimal power losses while the motors are running. Numerous industry-focused programming tools offer extensive support for the dsPIC. As dsPIC requires C language, strong MATLAB coding skills are strongly advised.

REFERENCES

[1] ALI, A. and ERÇELEBİ, E., 2018. A Low-cost modelling of the variable frequency drive optimum in industrial applications. Journal of Energy Systems, pp.28-42.

[2] A. Kale, N. R.Kamdi, P. Kale, and A. A.Yeotikar, "REVIEW PAPER ON VARIABLE FREQUENCY DRIVE," *International Research Journal of Engineering and Technology (IRJET)*, vol. 4, no. 1. pp. 1281–1284, Jan-2017.

[3] A. M. T. I. A. L. Naib, "Speed control of three-phase induction motor based on V/F Technique," *Al-Kitab Journal for Pure Science*, Dec-2017. [Online]. Available: https://www.researchgate.net/publication/326225682_Speed_Control_of_Three-Phase_Induction_Motor_Based_on_VF_Technique.

[4] A. Multi and E. Febryane, "Penggunaan Variable Speed drive pada motor induksi untuk penghematan Konsumsi Energi Listrik," *Sainstech: Jurnal Penelitian dan Pengkajian Sains dan Teknologi*, vol. 22, no. 2, 2020.

[5] D. Wasnik, H. K. Naidu, and P. Ghutke, "Speed Control of Induction Motor using Variable Frequency Drives and PLC," *Volume 6, issue 6 - low processing fee journal in EEE/ECE/E&I/ECE/ETE - impact factor-7.122*. [Online]. Available: https://www.ijareeie.com/volume-6-issue-6.

[6] G. Abhiram, M. M. Manathunga, K. Raveendran, and N. S. Withanage, "Performance analysis of high-efficiency motor and variable speed drive in black tea processing machinery," *Journal of Biosystems Engineering*, vol. 45, no. 4, pp. 310–317, 2020.

[7] H. A. Thar, A. Zeya, and Okka, “Modeling and Simulation of Energy Efficiency Improvement for Water Level Control,” *INTERNATIONAL JOURNAL FOR INNOVATIVE RESEARCH IN MULTIDISCIPLINARY FIELD*, vol. 6, no. 3, pp. 90–99, Mar. 2020.

[8] H. R. Choksi and H. I. Joshi, “Experimental results of variable frequency drive for three phase induction motor using microcontroller,” *IJIREEICE*, vol. 3, no. 3, pp. 89–93, 2015.

[9] M. Nimase, M. Padwal, S. Suryawanshi, D. K.More, and B. S.Kale, *Review paper on the control system of the air handling units*, vol. 6, no. 3. pp. 3881–3892, Mar-2019.

[10] M. S. Rajan, S. Kefake, and A. Mesfin, “Variable Frequency Drive Source Based Efficiency Measurement of an Induction MotorM,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 10, pp. 349–352, Aug. 2020.

[11] Muhammad Ahsan Niazi, Qaisar Hayat, Basit Khan, and Muhammad Afaq, “Speed control of three phase induction motor using Variable Frequency Derive Control System,” *International Journal of Current Engineering and Technology*, 2020. [Online]. Available: https://inpressco.com/wp-content/uploads/2020/01/Paper25-10.pdf.

[12] P.P.Rawale, “Contrive And Enactment of Energy Frugality with Variable Frequency Drive for Induction Motor,” *International Journal of Scientific Research and Review*, vol. 7, no. 6, pp. 84–91, 2018.

[13] R. K. Dubey, “Review paper on the control system of the air handling units,” *www.jetir.org*. [Online]. Available: https://www.jetir.org/papers/JETIREP06053.pdf. [Accessed: Mar-2018].

[14] S. Bodke, D. Patil, R. Salgar, and D. N. Ghuge, “Application of VFD for three phase induction motor,” *SSRN Electronic Journal*, 2020.

[15] S. Sahlan, N. A. Norzain, Z. A. Hj Zainudin, M. S. Abdul Manaf, K. I. Rosli, M. S. Samsudin, R. Abdul Rahim, S. Z. Mohd Muji, and E. J. Mohamad, “Variable speed drives: Energy saving and SCADA systemS,” *International Journal of Integrated Engineering - Special Issue on Electrical Electronic Engineering*, 2017. [Online]. Available: https://core.ac.uk/download/pdf/268563395.pdf.

[16] S. Shagufta and S.N.Joshi, “Performance analysis of three-phase asynchronous motor with AC Direct and VFD,” *International Journal of Engineering Research and*, vol. V9, no. 08, pp. 170–173, 2020.

[17] S. Siswandi, A. Firmansyah, D. A. Pratama, Y. Marniati, M. I. Abdulah, M. I. Pratama, and I. Amzah, “Modeling of variable speed drive in the control system laboratory at the Electrical Department of State Polytechnic of Sriwijaya,” *Atlantis Highlights in Engineering*, pp. 182–187, 2022.

[18] T. A. Fikri, “ANALISIS EKONOMIS PENGGUNAAN VARIABLE SPEED DRIVE SEBAGAI PENGENDALI MOTOR INDUKSI TIGA PHASA,” *Assoc Prof Dr Azriyenni ST MEng*. [Online]. Available: https://azriyenni.com/web/supervisor/. [Accessed: 08-Mar-2022].

[19] T. L. Short, S. Wang, L. M. Tolbert, J. Wang, Y. Ma, Y. Liu, and F. Wang, "Primary frequency control using motor drives for short term grid disturbances," *IEEE Open Journal of Industry Applications*, vol. 2, pp. 1–10, Jan. 2021.

[20] Bhandari, V. (2019). *ANALYSIS AND SIMULATION OF VARIABLE FREQUENCY MEASUREMENT FOR INDUCTION MOTOR*. https://www.researchgate.net/publication/330601025_ANALYSIS_AND_SIMULATION_OF_VARIABLE_FREQUENCY_MEASUREMENT_FOR_INDUCTION_MOTOR.

[21] Haq, Hafeez Ul & Imran, Mehedi & Okumuş, Halil & Habibullah, Mohammad. (2015). Speed Control of Induction Motor using FOC Method. International Journal of Engineering Research and Applications. 5. 154-158.

[22] Sengamalai, U. and Chinnamuthu, S. (2017). An Experimental Fault Analysis and Speed Control of an Induction Motor using Motor Solver. *Journal of Electrical Engineering and Technology*, 12(2), pp.761–768. doi:https://doi.org/10.5370/jeet.2017.12.2.761.

[23] Oinam Manganleiba Meetei (2017). ADBU Journal of Electrical and Electronics Engineering (AJEEE). [online] www.tinyurl.com. Available at: http://www.tinyurl.com/ajeee-adbu.

[23] Tahir, & Zarma, Tahir & Galadima, Ahmadu & Maruf, Aminu. (2019). A Review of Motors for Electric Vehicles.

[24] Mansour, Fady. (2020). Induction Motors: Construction, Principle of Operation, Power and Torque Calculations, Characteristics and Speed Control. 10.13140/RG.2.2.15490.71360.

[25] Sahdev, S. K., 2018. Electrical Machines. Cambridge: Cambridge University Press.

[26] Ahmad, Israr. (2021). Working Principle of Variable Frequency Drive (VFD). Pakistan Forum. 1432-0487. 4.

[27] Ashwini.D.Gaikwad, ENERGY CONSERVATION USING VFD International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163 Volume 2 Issue 1 (January 2015) www.ijirae.com

[28] parasher, aina. "Speed Control of Induction Motor: Formula & Methods [GATE Notes]." Byjusexamprep.com, 2022, byjusexamprep.com/speed-control-of-induction-motor-i.

[29] Daware, Kiran. "Speed Control Methods of Induction Motor." Electricaleasy.com, 2014, www.electricaleasy.com/2014/02/speed-control-methods-of-induction-motor.html.