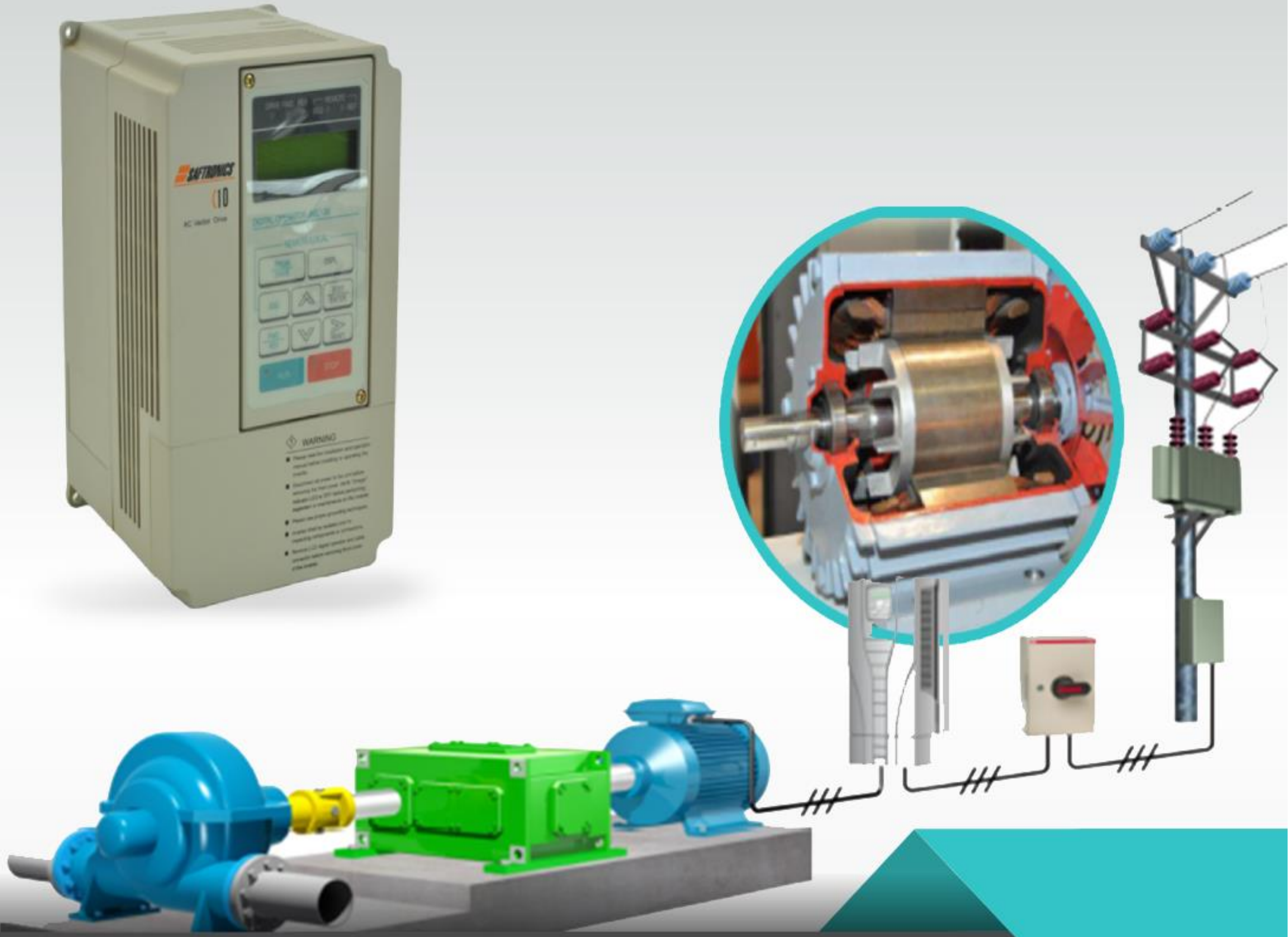

Variable frequency drive For Speed Control Of Induction Motor

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CHAPTER ONE
INTRODUCTION

CHAPTER ONE
INTRODUCTION

THE INDUCTION SPEED CONTROL BACKROUND
The history of classical motor speed control system

Today’s industries are increasingly demanding process automation in all sectors. Automation results into better quality, increased production reduced costs. The variable speed drives, which can control the speed of A.C/D.C motors, are indispensable controlling elements in automation systems. Depending on the applications, some of them are fixed speed and some of the variable speed drives.

The variable speed drives, till a couple of decades back, had various limitations, such as poor efficiencies, larger space, lower speeds, etc., However, the advent power electronic devices such as power MOSFET, IGBT , Integrated circuits, and also with the introduction of micro -controllers with many features on the same silicon wafer, transformed the scene completely and today there have variable speed drive systems which are not only in the smaller in size but also very efficient, highly reliable and meeting all the stringent demands of various industries of modern era.

Control over a wide speed range, both below and above the rated speed can be very easily achieved. The methods of speed control are simpler and less expensive than those of alternating current motors.

The phase control method is widely adopted, but has certain limitations mainly it generates harmonics on the power line and it also has got (p .f) when operated lower speeds. The second method is (PWM) technique, which has got better advantages over the phase control.

1.1 MOTOR GENERAL CLASSIFICATION

An electric motor is a device that converts electrical energy into kinetic energy (i.e. motion).

Most motors described in this guide spin on an axis, but there are also specialty motors that move linearly. All motors are either alternating current (AC) or direct current (DC).

The following lists the most common motors in use today. Each motor type has unique characteristics that make it suitable to particular applications [1].

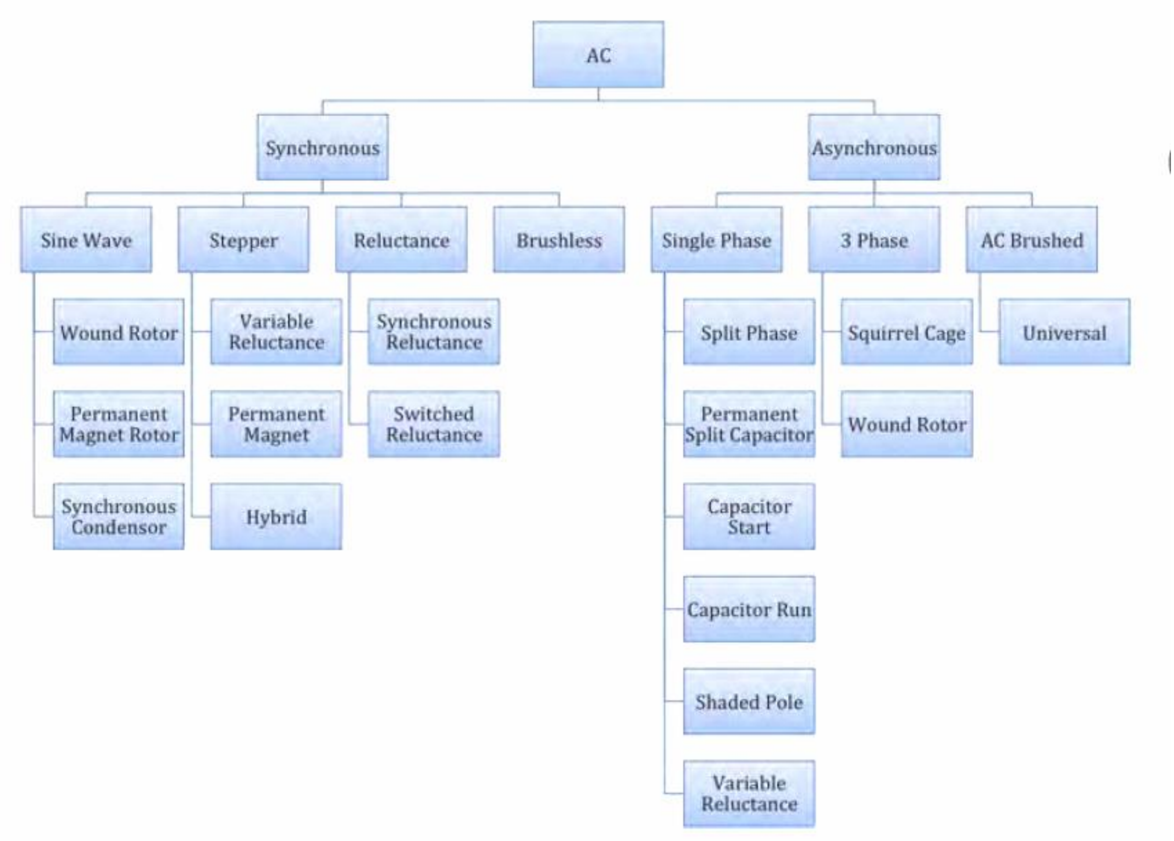


Figure (1-1) AC Motor Family Tree

1.2 THREE-PHASE AC INDUCTION MOTOR

For industrial and mining applications, 3-phase AC induction motors are the prime movers for the vast majority of machines, These motors can be operated either directly from the mains or from adjustable frequency drives.

In modern industrialized countries, more than half the total electrical energy used in those countries is converted to mechanical energy through AC induction motors.

The applications for these motors almost every stage of manufacturing and processing. Applications also extend to commercial buildings and the domestic environment. They are used to drive pumps, fans, compressors, mixers, agitators, mills, conveyors, crushers, machine tools, cranes, etc. It is not surprising to find that this type of electric motor is so popular, when one considers its simplicity, reliability and low cost.

In the last decade, it has become increasingly common practice to use 3-phase squirrel cage AC induction motors with *variable voltage variable frequency converters* for variable speed drive (VSD) applications. To clearly understand how the VSD system works, it is necessary to understand the principles of operation of this type of motor.

Although the basic design of induction motors has not changed very much in the last 50 years, modern insulation materials, computer based design optimization techniques and auto mated manufacturing methods have resulted in motors of smaller lower cost per kW.

International standardization of physical dimensions and frame sizes means that motors from most manufacturers are physically interchangeable and they have similar performance characteristics.

1.3 BASIC CONSTRUCTION

The AC induction motor comprises 2 electromagnetic parts:

1-Stationary part called the stator

2- Rotating part called the rotor, supported at each end on bearings The stator and the rotor are each made up of:

1- A magnetic circuit usually made from laminated steel, to carry magnetic flux.

2- An electric circuit usually made of insulated copper or aluminum, to carry current.

1.3.1 The Stator

The stator is the outer stationary part of the motor, which consists of:

. The outer cylindrical frame of the motor, which is made either of welded sheets steel, cast iron or cast aluminum alloy. This may include feet or a flange for mounting.

. The magnetic path, which comprises a set of slotted steel laminations pressed into the cylindrical space inside the outer frame. The magnetic path is laminated to reduce eddy currents, lower losses and lower heating.

. A set of insulated electrical winding, which are placed inside the slots of the laminated magnetic path. The cross-sectional area of these windings must be large enough for the power rating of the motor. For a 3-phase motor, 3 sets of windings are required, one for each phase stator and rotor Laminations.

1.3.2 The Rotor

This is the rotating part of the motor. As with the stator above, the rotor consists of a set of slotted steel laminations pressed together in the form of a cylindrical magnetic path and the electrical circuit**.**

. The electrical circuit of the rotor can be either:

- **Wound Rotor Type**, which comprises 3 sets of insulated windings with connections brought out to 3 slip rings mounted on the shaft. The external connections to the rotating part are made via brushes onto the slip rings. Consequently, this type of motor is often referred to as a slip ring motor.

- **Squirrel Cage Rotor Type**, which comprises a set of copper or aluminum bars installed into the slots, which are connected to an end-ring at each end of the rotor. The construction of these rotor windings resembles a '*squirrel cage*'.

Aluminum rotor bars are usually die-cast into the rotor slots, which results in a very rugged construction. Even though the aluminum rotor bars are in direct contact with the steel laminations, practically all the rotor current flows through the aluminum bars and not in the laminations [2].

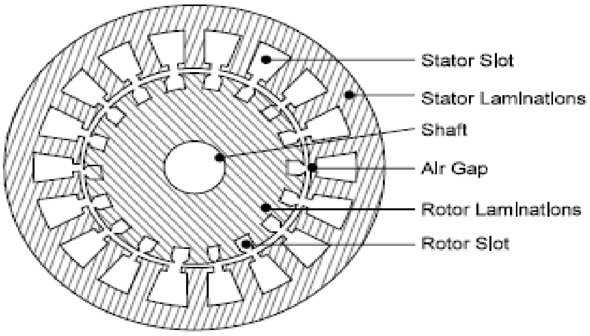


Figure (1-2) stator and rotor laminations

1.4 VFD TECHNOLOGY OVERVEW

A Variable-Frequency Drive (VFD) is a device that controls the voltage and frequency that is being supplied to a motor and therefore controls the speed of the motor and the system it is driving. By meeting the required process demands, the system efficiency is improved.

A VFD is capable of adjusting both the speed and torque of an induction motor. Therefore, it provides continuous range process speed control (as compared to the discrete speed control that gearboxes or multi-speed motors provide). Fixed speed motors (or AC induction motors) serve the majority of applications.

In these applications or systems, control elements such as dampers and valves are used to regulate flow and pressure. These devices usually result in inefficient operation and energy loss because of their throttling action.

It is often desirable to have a motor operate at two or more discrete speeds, or to have fully variable speed operation. The conventional control elements can often be replaced by incorporating variable speed operation using a VFD.

Substantial energy savings can be achieved in many of these applications by varying the speed of the motors and the driven. Load using a commercially available VFD. Savings include capital costs and maintenance costs associated with these control elements [1].

1.5 BAISC CONSTRUCTION OF A VARIABLE- FREQUENCY DRIVE

Most variable -frequency drives operate by first changing the AC voltage into DC and then changing it back to AC at the desired frequency method. There are several methods used to change the DC voltages back into AC.

The method employed DC voltage back into AC. The method employed is determined by the manufacture, age of the equipment and the size motor that the drive must control. Variable-frequency drives intended to control the speed of motors up to 500 HP generally employ transistors.

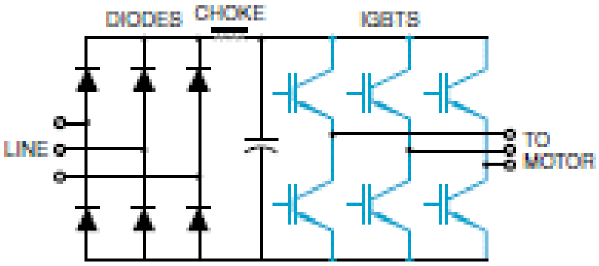


Figure (1-3) Variable-frequency drives using IGBT and diodes in the rectifier

Many transistor-controlled variable drives now employ a special type of transistor called an insulated gate bipolar transistor (IGBT).IGBT have an insulated gate very similar to some types of field effect transistors (FET) Because the gate is insulated, it has a very high impedance.

The IGBT is a voltage-controlled device, not a current-controlled device. This gives it the ability to turn off very quickly. IGBT can be driven into saturation to provide very low voltage drop between the emitter and collector, but they do not suffer from the slow recovery time of common junction transistors. [3].

1.6 VFD SELECTION CONSIDERATIONS

When investigating VFD technology, the following implications should be considered

- Harmonic
- Motor
- Physical and environmental issues

1.6.1 Harmonic Considerations Harmonic distortion of voltage and current is produced in electrical systems by non-linear loads such as VFD, welders, rectifiers, etc. Harmonics cause electrical waveform distortion that can propagate through the entire power system and even outside of the plant.

The source of harmonic distortion in VFD is the solid-state power switching devices used to generate the varying supply frequencies. These effects, known as “line harmonic currents”, are multiples of the fundamental 60 Hz supply current. For example, a frequency of 180 Hz is called the third harmonic. These currents generate harmonic voltage distortions that often exceed acceptable levels.

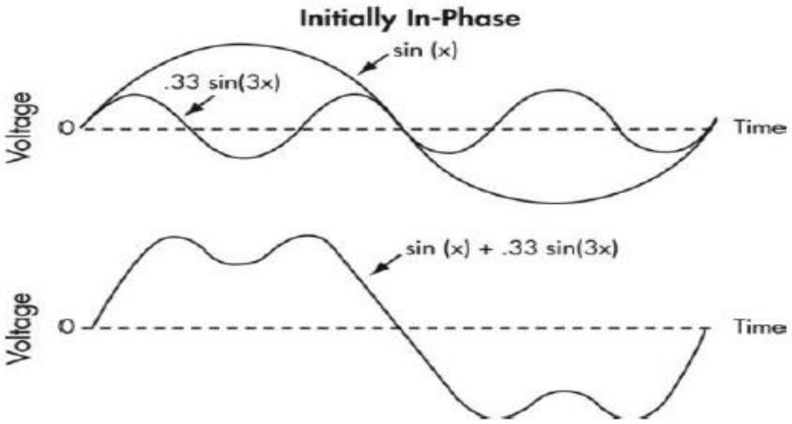


Figure (1-4).Harmonic Amplitudes

1.6.2 Motor Considerations

Application of a PWM VFD can cause voltage transients well above the rated voltage of the motor that can lead to failure of the insulation system in a very short period of time. To understand this, consider the way in which a PWM inverter approximates a sinusoidal current waveform. The following figures show typical voltage and current waveforms for Pulse Width Modulation inverters.

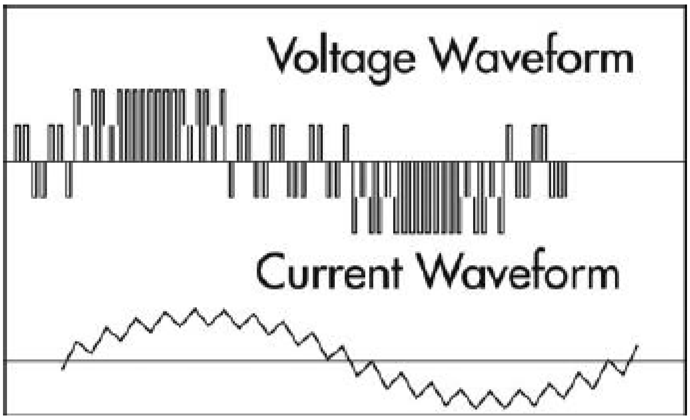


Figure (1-5) Voltage and Current Waveforms

The voltage waveform is made up of a series of pulses controlled by the inverter's output devices. The width or duration of these pulses is controlled to approximate a sinusoidal current waveform.

1.6.3 Physical and Environmental Issues

VFD must be selected to ensure that they have adequate protection from their environmental conditions.

VFD is usually mounted into an electrical enclosure with other electrical devices, or as a standalone unit in its own enclosure [1].

CHAPTER TWO
LITERATURE REVIEW

CHAPTER TWO
LITERATURE REVIEW

2.1 SPEED CONTROL OF 3-PHASE INDUCTION MOTOR

Induction motors are of two types - Squirrel-cage motor and Wound-rotor motor. There are various types of speed control methods of induction motor. These are –

(*i*) Pole Changing

(*ii*) Stator Voltage Control

(*iii*) Supply Frequency Control

(*iv*) Eddy-current Coupling

(*v*) Rotor Resistance Control

(*vi*)Slip Power Recovery

(*i*) is applicable for squirrel-cage motor, (*ii*) to (*iv*) is applicable for both wound-rotor and squirrel-cage motor and (*v*) and (*vi*) is applicable for wound-rotor.

For squirrel-cage type motor, here **pole changing, stator voltage control and supply frequency control** methods are discussed.

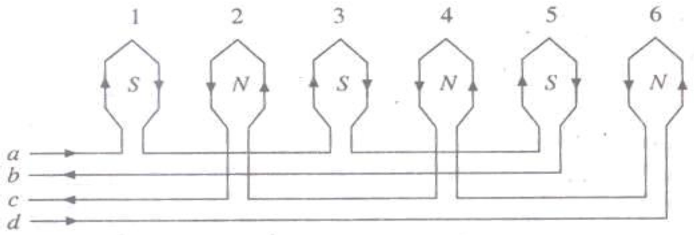
2.1.1 Pole Changing:

For a given frequency speed is inversely proportional to number of poles. Synchronous speed, and therefore, motor speed can be changed by changing the number of poles. Provision for changing of number of poles has to be incorporated at the manufacturing stage and such a machine is called "pole changing motor" or "multi-speed motor" .In squirrel cage motor the number of poles are same as the Stator winding.

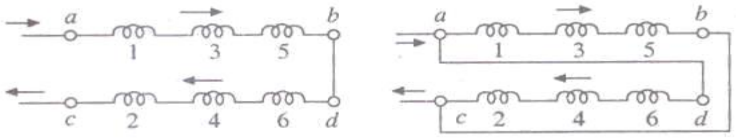
So there is no provision for changing the number of poles. But for wound rotor arrangement for changing the number of poles in rotor is required, which complicates the machine. So it is only used for Squirrel cage induction motor.

A simple but expensive arrangement for changing number of stator poles is to use two separate winding which are wound for two different pole numbers. An economical and common alternative is to use single stator winding divided into few coil groups .Changing the connections of these coil groups change number of poles.

Theoretically by dividing winding into a number of coil group and bringing out terminals of these group a number of arrangements of different pole numbers is obtained.



(a) Connection for 6 poles



(b) Series connection

(c) Parallel connection

Figure (2-1) Stator phase connection for 6-poles

Figure (2-10)(a) above shows a phase winding consisting of six coils divided into two groups – a-b consisting of odd number coils (1, 3,5) connected in series and c-d consisting even numbered coils (2,4,6) connected in series.

2.1.2 Stator Voltage Control:

This is a slip control method with constant frequency variable voltage being supplied to the motor stator. Obviously the voltage should only be reduced below the rated value. For a motor operating at full load slip, if the slip is to be doubled for constant load torque then the voltage must be reduced by a factor of $\frac{1}{\sqrt{2}}$ and the corresponding current rises to $\sqrt{2}$ of the full load value. The motor, therefore, tends to get overheated. The method therefore is not suitable for speed control. It has a limited use for motor driving fan type load whose torque requirement is proportional to the square of speed. It is a commonly used method for ceiling fans driven by single-phase induction motors that have large standstill impedance limiting the current drawn by the stator.

2.1.3 Supply Frequency Control:

Synchronous speed $N_s = 120\frac{f}{P}$ (2-1)

And, motor speed $n = (n_s - slip)$ rev/min (2-2)

The slip between the synchronous rotating field and the rotor depends on a number of factors, being the stator voltage, the rotor current and the mechanical load on the shaft. Consequently, the speed of an AC induction motor can also be adjusted by controlling the slip of the rotor relative to the stator field.

Now, it is evident that varying synchronous speed, which can vary by varying the supply frequency, can vary the motor speed. Voltage induced in stator is proportional to the product of supply frequency f_s and air-gap flux φ_m.

$$E = 4.44 k_w \varphi_m f_s T_{ps} \tag{2-3}$$

If stator drop is neglected, then *E* is equal to *V*. Then the supply voltage will become proportional to f_s and φ_m.

$$V = 4.44 k_w \varphi_m f_s T_{ps} \tag{2-4}$$

Any reduction in the supply frequency f_s keeping the supply voltage constant causes the increase of air-gap flux φ_m.
Induction motors designed to operate at the knee point of the magnetization characteristic to make a full use of magnetic material. Therefore, the increase in flux will saturate the motor.

This will increase the magnetizing current and distort the line current and voltage, increase in core loss and stator I^2R loss and produce a high-pitch acoustic noise. Also, a decrease in flux is also avoided to retain the torque capability of motor. Therefore, variable frequency control below rated frequency is generally carried out at rated air gap flux by varying supply voltage with frequency so as to maintain $\frac{V}{f}$ ratio constant at the rated value.

2.2 VARIBLE FREQUENCY DRIVE OPERATION

Electronic VFD can vary the voltage and frequency to an induction motor using a technique called Pulse Width Modulation (PWM).VFD have become the preferred way to achieve variable speed operation, as they are relatively inexpensive and very reliable.

VFD use power semiconductor devices called insulated-gate bipolar transistors (IGBT). Using PWM, the speed of the motor and torque characteristics can be adjusted to match the load requirements.

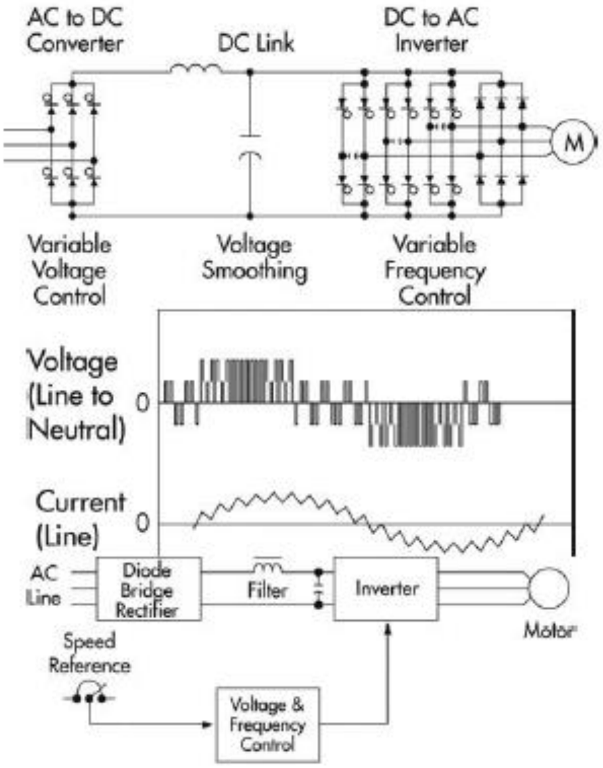


Figure (2-2) typical PWM VFD

In the simplest drives or applications, the speed reference is simply a set-point; however, in more complex applications, the speed reference comes from a process controller such as a Programmable Logic Controller (PLC) or a tachometer.

Older drive technologies, such as Current Source Inverters and Variable Voltage Controllers, used SCR or thirstier as control devices. These technologies have now been replaced by the PWM VFD, which can regulate the speed of an induction motor between 10% to 200% Wider speed ranges are possible depending on the model and options selected.

The first step in the PWM process is to convert the AC supply voltage into DC by the use of a rectifier. DC power contains voltage ripples that are smoothed using filter capacitors. This section of the VFD is often referred to as the DC link.

This DC voltage is then converted back into AC. The conversion is typically achieved through the use of power electronic devices such as IGBT power transistors using a technique called Pulse Width Modulation (PWM).

The output voltage is turned on and off at a high frequency, with the duration of on-time, or width of the pulse, controlled to approximate a sinusoidal waveform.

The speed accuracy is affected by the slip of the motor, resulting in slightly slower operation than the synchronous speed for a given frequency. The accuracy can be increased greatly by using tachometer feedback. Extremely precise speed and position control of the motor shaft can be achieved by using a VFD with Vector Control [1].

2.3 THE NEED OF VARIBLE FREQUENCY DRIVE

There are many and diverse reasons for using variable speed drives. Some applications, such as paper making machines, cannot run without them while others, such as centrifugal pumps, can benefit from energy savings.

In general, variable speed drives are used to:

- **Match the speed of a drive to the process requirements**
- **Match the torque of a drive to the process requirements**
- **Save energy and improve efficiency**

The needs for speed and torque control are usually fairly obvious. Modern electrical VFD can be used to accurately maintain the speed of a driven machine to within ±0.1%, independent of load, compared to the speed regulation possible with a conventional fixed speed squirrel cage induction motor, where the speed can vary by as much as 3% from no load to full load.

The benefits of energy savings are not always fully appreciated by many users. These savings are particularly apparent with centrifugal pumps and fans, where load torque increases as the square of the speed and power consumption as the cube of the speed.

Substantial cost savings can be achieved in some applications .An everyday example, which illustrates the benefits of variable speed control, is the motorcar. It has become such an integral part of our lives that we seldom think about the technology that it represents or that it is simply a variable speed platform.

It is used here to illustrate how variable speed drives are used to improve the speed, torque and energy performance of a machine. It is intuitively obvious that the speed of a motorcar must continuously be controlled by the driver (the operator) to match the traffic conditions on the road (the process). [2]

2.4 FUNDAMENTAL PRINCIPLES OF VFD

The following is a review of some of the fundamental principles associated with variable speed drive applications.

2.4.1 Forward Direction

Forward direction refers to motion in one particular direction, which is chosen by the user or designer as being the forward direction. The Forward direction is designated as being positive (+ve). For example, the forward direction for a motorcar is intuitively obvious from the design of the vehicle.

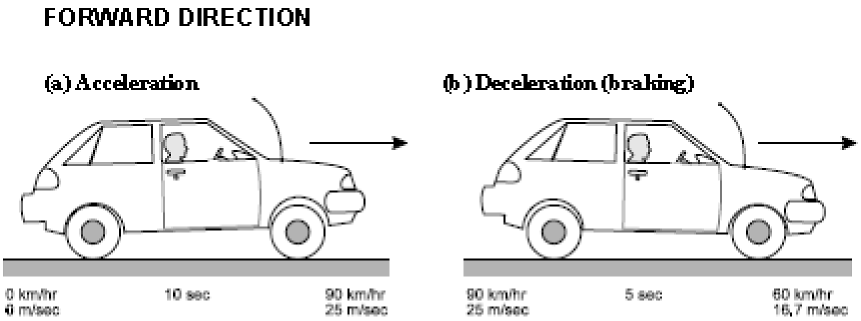


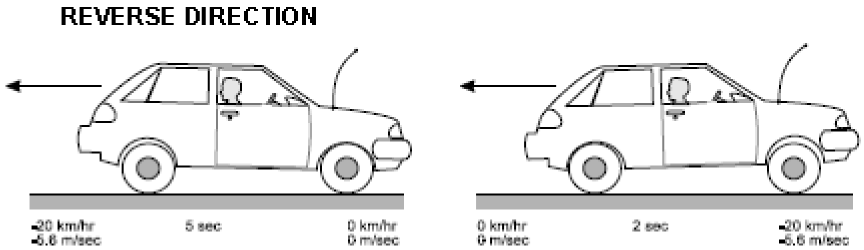
Figure (2-3) Acceleration and deceleration (braking) in the forward direction

In the example in Figure 2.3, a motorcar sets off from standstill and accelerates in the forward direction up to a velocity of 90 km/hr (25 m/sec) in a period of 10 sec. In variable speed drive applications, this acceleration time is often called the *ramp-up time*.

After traveling at 90 km/hr for a while, the brakes are applied and the car decelerates down to a velocity of 60 km/hr (16.7 m/sec) in 5 sec.

2.4.2 Reverse Direction

Reverse direction refers to motion in the opposite direction. The Reverse direction is designated as being negative (–ve). For example, the reverse direction for a motor car is occasionally used for special situations such as parking or un-parking the vehicle.



(a) Acceleration **(b) Deceleration (braking)**

Figure (2-4) Acceleration and deceleration (braking) in the reverse direction

From the example outlined in Figure 2-4 the acceleration time (ramp-up time) to 20 km/hr in the reverse direction is 5 sec. The braking period (ramp-down time) back to standstill is 2 sec.

There are some additional terms and formulae that are commonly used in association with variable speed drives and rotational motion.

2.4.3 Power

Power is the rate at which work is being done by a machine. In SI units, it is measured in watts. In practice, power is measured in (kW) or (MW) because watts are such a small unit of measurement.

In rotating machines, power can be calculated as the product of torque and speed. Consequently, when a rotating machine such as a motor car is at standstill, the output power is zero. This does not mean that input power is zero! Even at standstill with the engine running, there are a number of power losses that manifest themselves as heat energy.

Using SI units, power and torque are related by the following very useful formula, which is used extensively in VSD applications:

$$\mathit{Power}\ (\mathrm{kW}) = \frac{\mathit{Torque}\ (\mathrm{Nm}) \times \mathit{Speed}\ (\mathrm{rev/min})}{9550} \qquad (2\text{-}5)$$

Alternatively,

$$\mathit{Torque}\ (\mathrm{Nm}) = \frac{9550 \times \mathit{Power}\ (\mathrm{kW})}{\mathit{Speed}\ (\mathrm{rev\ /min})} \qquad (2\text{-}6)$$

2.4.4 Energy

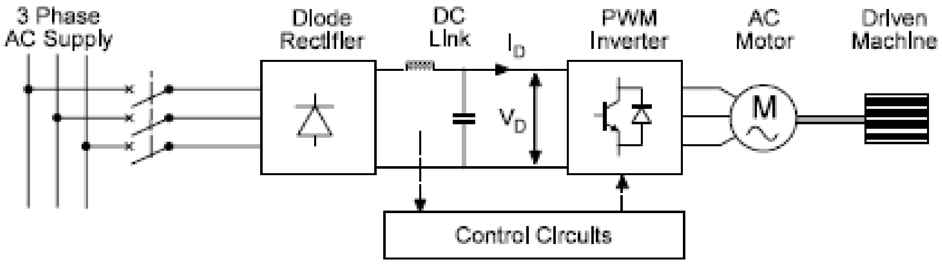
Is the product of power and time and represents the rate at which work Is done over a period of time. In SI units it is usually measured as kilo Watt hours (kWh). In the example of the motorcar, the fuel consumed over a period of time represents the energy consumed.

$$\mathit{Energy}\ (\mathrm{kWh}) = \mathit{Power}\ (\mathrm{kW}) \times \mathit{Time}\ (\mathrm{h}) \qquad (2\text{-}7)$$

2.5 THE BASIC COMPONENTS OF AC VFD

The mains AC supply voltage is converted into a DC voltage and current through a rectifier. The DC voltage and current are filtered to smooth out the peaks before being fed into an inverter, where they are converted into a variable AC voltage and frequency.

The output voltage is controlled so that the ratio between voltage and frequency remains constant to avoid over-fluxing the motor. The AC motor is able to provide its rated torque over the speed range up to 50 Hz without a significant increase in losses.



(2.5) *Main components of a typical PWM-type AC drive*

Ac/DC converter, usually comprising a diode rectifier, for converting the 3-phase AC voltage to a DC voltage of constant amplitude. In some cases a phase-controlled thirstier bridge is used for DC bus charging. Once full DC voltage is achieved, the thirstier bridge is controlled to behave as a diode bridge.

The DC link, usually comprising a DC choke and DC capacitor and a DC bus, for maintaining a smooth fixed DC voltage for the inverter stage.

The DC/AC inverter, comprising a semiconductor bridge, for converting the DC voltage to a variable frequency variable voltage AC output. [2]

2.6 APPLICATION VFD CONSIDERATION AND SAVINGS ESTIMATION

The following section will discuss:

- Driven load characteristics
- Cost considerations
- Energy and operational savings

2.6.1 Driven load Characteristics

The characteristics of the driven load are important in motor selection and were discussed in Section 0. The behavior of torque with respect to speed partially determines the requirements of the motor-drive system. We can categorize drive applications by their operational torque requirements:

- **Constant Torque Loads**

A constant torque load is characterized as one in which the torque is constant, regardless of speed. Some of the advantages VFD s offer in constant torque applications include precise speed control and starting and stopping with controlled acceleration/deceleration.

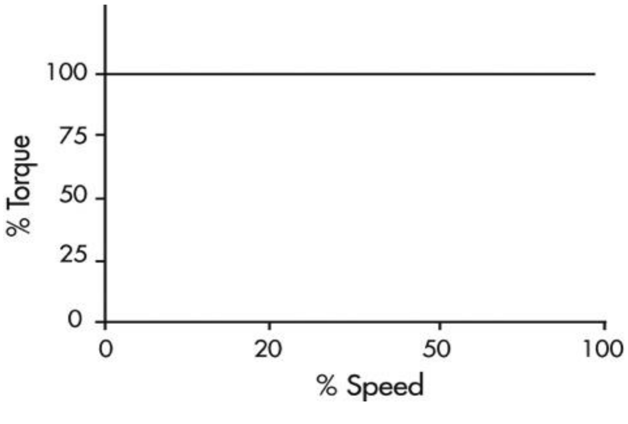


Figure (2.6) Constant Torque Load

- **Variable Torque Loads**

Variable torque load Examples include centrifugal fans, blowers and pumps. The use of a VFD with a variable torque load may return significant energy savings.

In these applications:

1. Torque varies directly with speed squared
2. Power varies directly with speed cubed

This means that at half speed, the horsepower required is approximately one eighth of rated maximum.

Throttling a system by using a valve or damper is an inefficient method of control because the throttling device dissipates energy that has been imparted to the fluid. A variable frequency drive simply reduces the total energy into the system when it is not needed.

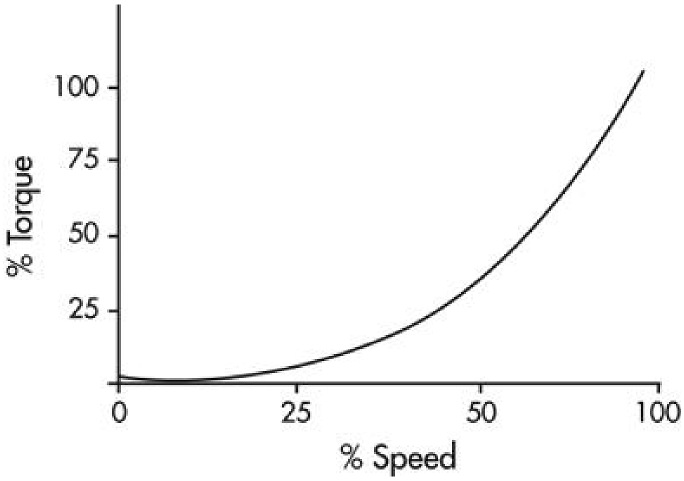


Figure (2.7) Variable Torque Load

2.6.2 Cost Considerations

The cost of VFD s can vary greatly, depending on the options required. The cost should include:

- **New Motor Purchase**

The cost of an inverter duty motor should be considered for a new system; however, if the system is being considered for an upgrade to a VFD then the existing motor should be reviewed for size, capacity and efficiency. Usually only high efficiency motors should be considered.

- **Power Conditioning Equipment**

The cost of any power conditioning equipment, such as harmonic filters, should be included. This includes filters for incoming power to the motor as well as power conditioners for harmonic voltages and currents sent back to the power supply from the drive.

- **Space Requirement**

This includes the cost of any indoor space requirements for the drive and filters, as well as any outdoor space costs, such as those associated with transformers, filters or reactors.

- **Cooling**

Additional cooling may be required for drive installation. Water-cooling may be a much more economical alternative for large applications, although HVAC equipment is often used. [1]

CHAPTER THREE
SIMULATION

CHAPTER THREE
SIMULATION

TOOL OVERVIEW

There are tools which will be used for the effective implementation of this project they include Mat lab tool and SIMULINK tool.

1. **MATLAB**

MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. Using Mat lab you can analyze data, develop algorithms, and create models and applications. The language, tools and build-in math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages.

2. **SIMULINK**

SIMULINK developed by Math Works, is a data flow graphical programming language tool for modeling, simulating and analyzing multi-domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. SIMULINK is widely used in control theory and digital signal processing for multi-domain simulation and Model-Based Design.

3.1 THREE-PHASE SOURCE

The Three-Phase Source block implements a balanced three-phase voltage source with an internal R-L impedance. The three voltage sources are connected in Y with a neutral connection that can be internally grounded or made accessible. You can specify the source internal resistance and inductance either directly by entering R and L values or indirectly by specifying the source inductive short-circuit level and X/R ratio.

Phase-to-phase rms voltage	380
Phase angle of phase A	0
Frequency	50
3-phase short-circuit level at base voltage	100e6

Table 1: Voltage source parameters

3.1.1Phase-to-Phase rms Voltage

The internal phase-to-phase voltage in volts rms . This parameter is available only if a Specify internal voltage for each phase is not selected.

3.1.2 Phase Angle of Phase A

The phase angle of the internal voltage generated by phase A in degrees. The three voltages are generated in a positive sequence. Thus, phase B and phase C internal voltages lag phase A by 120 degrees and 240 degrees, respectively. This parameter is available only if Specify internal voltages for each phase is not selected.

3.1.3 Three-Phase Short-Circuit Level at Base Voltage

The three-phase inductive short-circuit power, in volts-amperes (VA), at specified base voltage, used to compute the internal inductance L. This parameter is available only if Internal and Specify short-circuit level parameters are selected.

The internal inductance L (in H) is computed from the inductive three-phase short-circuit power Psc (in VA), base voltage Vbase (in Vrms phase-to-phase), and source frequency f (in Hz) as Follow

$$L = \frac{V_{base}^2}{Psc} \cdot \frac{1}{2\pi f}. \qquad (3\text{-}1)$$

The X/R ratio at nominal source frequency or quality factor of the internal source impedance .This parameter is available only if Internal and Specify short-circuit level parameters are selected.

The internal resistance R (in Ω) is computed from the source reactance X (in Ω) at specified frequency, and X/R ratio as follows:

$$R = \frac{X}{(X/R)} = \frac{2\pi f L}{X/R}. \qquad (3\text{-}2)$$

3.2 UNIVERSAL BRIDGE

The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The Universal Bridge block allows simulation of converters using both naturally commutated (and line-commutated) power electronic devices (diodes or thirstier) and forced-commutated devices (GTO, IGBT, and MOSFET).

The Universal Bridge block is the basic block for building two-level voltage-sourced converters (VSC).The device numbering is different if the power electronic devices are naturally commutated or forced-commutated.

Power electronic device	Diode
Number of bridge arms	3
Rs	1e5 Ω
Cs	inf
Forward voltages	0

Table 2: Universal bridge parameters (Rectifier)

Power electronic device	IGBT/Diode
Number of bridge arms	3
Rs	1000 Ω
Cs	inf
Forward voltages	[0.8 0.8]

Table 3: Universal bridge parameters (Inverter)

3.2.1 Number of Bridge Arms

Set to 1 or 2 to get a single-phase converter (two or four switching devices). Set to 3 to get a three-phase converter connected in Graetz bridge configuration (six switching devices).

3.2.2 Snubbed Resistance Rest

The snubbed resistance in ohms (Ω) . Set the Snubbed resistance parameter to inverse to eliminate the snobbery from the model.

3.2.3 Snubbed Capacitance Cs

The snubbed capacitance, in farads (F) . Set the Snubbed capacitance Cs parameter to 0 to eliminate the snubbed, or to inverse to get a resistive snubbed.

use the following formulas to compute approximate values of Rs and Cs:

$$Rs > 2\frac{T_s}{Cs}$$

$$Cs < \frac{P_n}{1000(2\pi f)V_n^2},$$

Pn = nominal power of single or three phase converter (VA)

Vn = nominal line-to-line AC voltage (Vrms)

Ts = sample time (s)

3.2.4 Forward Voltage Vf

This parameter is available only when the selected Power electronic device is Diodes or Thrusters. Forward voltage, in volts (V), across the device when it is conducting

3.3 PULSE WIDTH MODULATION

The PWM Generator (2-Level) block generates pulses for carrier-based pulse width modulation (PWM) converters using two-level topology. The block can control switching devices (FETs, GTOs, or IGBTs) of three different converter types: single-phase half-bridge (1 arm), single-phase full-bridge (2 arms), or three-phase bridge (3 arms). The reference signal (Uref input), also called modulating signal, is compared with a symmetrical triangle carrier. When the reference signal is greater than the carrier, the pulse for the upper switching device is high (1), and the pulse for the lower device is low (0).

Generator type	Three-phase bridge (6 pulses)
Mode of operation	Unsynchronized
Carrier frequency	18*60Hz (1080 Hz)
Internal generation of modulating signals	Selected
Modulation index m	0.9
Output voltage frequency	50 Hz
Sample time	10e-6 s

Table 4: Pulse width generator parameters (initial)

3.3.1 Generator Type

Specify the number of pulses to generate. The number of pulses generated by the block is proportional to the number of bridge arms to fire. Select Single-phase half-bridge (2 pulses) to fire the self-commutated devices of a single-phase half-bridge converter. Pulse 1 fires the upper device, and pulse 2 fires the lower device.

Select Single-phase full-bridge (4 pulses) to fire the self-commutated devices of a single-phase full-bridge converter. Four pulses are then generated. Pulses used are 1 and 3and this fire the upper devices of the first and second arm. Pulses 2 and 4 fire the lower devices.

Select Three-phase-bridge (6 pulses) to fire the self-commutated devices of a three-phase bridge converter. Pulses 1, 3, and 5 fire the upper devices of the first, second, and third arms. Pulses 2, 4, and 6 fire the lower devices.

3.3.2 Mode of Operation

When set to Unsynchronized, the frequency of the unsynchronized carrier signal is determined by the Carrier frequency parameter.

3.3.3 Carrier Frequency (Hz)

Specify the frequency, in hertz, of the triangular carrier signal. This parameter is visible only if the Mode of operation parameter is set to Unsynchronized.

3.3.4 Internal Generation of Modulating Signal (s)

When selected, the reference signal is generated by the block. When not selected, the external reference signals are used for pulse generation. The parameter is visible only if the Mode of operation parameter is set to Unsynchronized.

3.3.5 Modulation Index

Specify the modulation index to control the amplitude of the fundamental component of the output voltage of the converter. The modulation index must be greater than 0 and lower than or equal to 1. The parameter is visible only when the internal generation of modulating signal (s) parameter is selected.

3.3.6 Output Voltage Frequency (Hz)

Specify the output voltage frequency used to control the frequency of the fundamental component of the output voltage of the converter. The parameter is visible only when the internal generation of modulating signal (s) parameter is selected.

3.3.7 Sample Time

Specify the sample time of the block, in seconds. Set to 0 to implement a continuous block. The sampling period is equal to 1/Carrier Frequency/2 for asymmetrical sampling and to 1/Carrier Frequency for symmetrical sampling

3.4 ASYNCHRONOUS MACHINE

The Asynchronous Machine Squirrel Cage (fundamental) block models a squirrel-cage-rotor asynchronous machine with parameterization using fundamental parameters.

Nominal power, voltage (line-line), and frequency	[746*493, 380, 50]
Stator resistance and Inductance	[1.115 0.005974]
Rotor resistance and Inductance	[1.083 0.005974]
Mutual inductance	0.2037
Inertia constant, friction factor, and pole pairs	[0.02 0.005752 2]

Table 5: Asynchronous machine parameters (initial values)

Stator resistance and inductance, rotor resistance and inductance are chosen to have smallest values possible to minimize current mitigation. The number of pole pairs is chosen to be two to implement a 4 pole

Setting the nominal power to 746*493 VA and the nominal line-to-line voltage Vn to 220 Vrms implements a 3 HP, 50 Hz machine with two pairs of poles. Its nominal speed is therefore slightly lower than the synchronous speed of 1800 rpm.

The stator self-inductance Lss, stator leakage inductance Lls, and magnetizing inductance Lm are related by

$$Lss = LIs + Lm \tag{3.5}$$

The rotor self-inductance Lrrd, rotor leakage inductance Llrd, and magnetizing inductance Lm are related by

$$Lrrd = LIrd + Lm \tag{3.6}$$

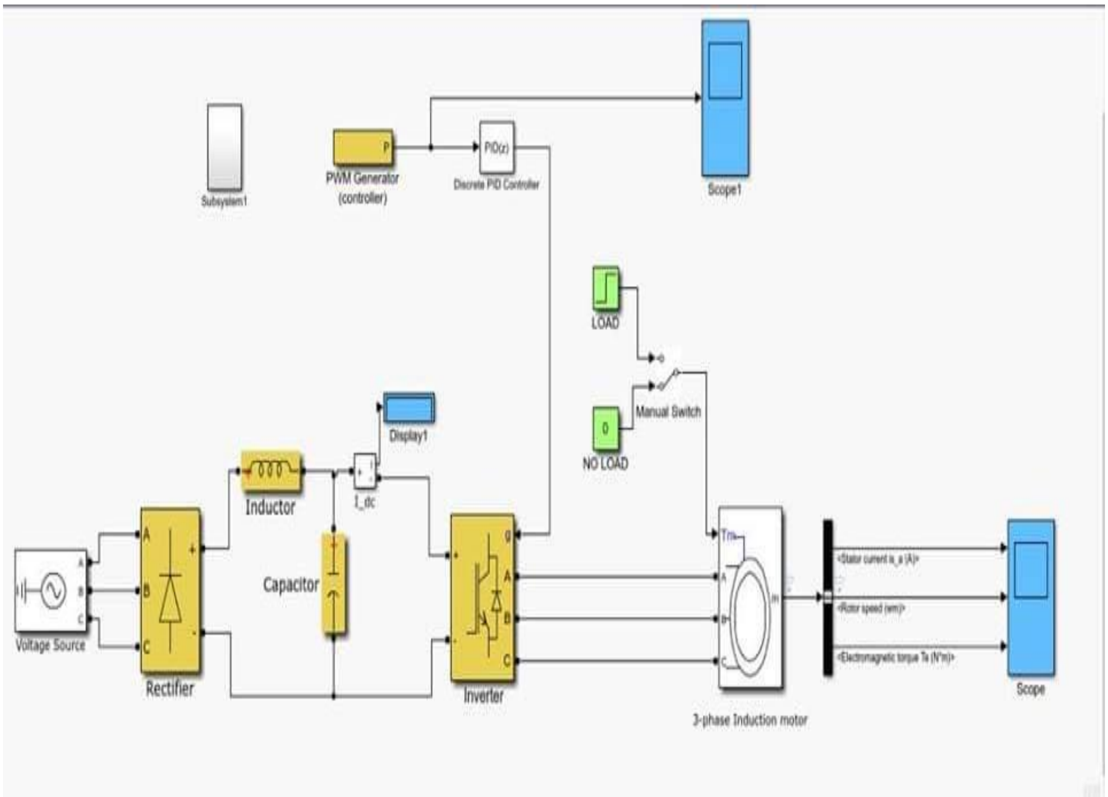


Figure (3-1) Simulation and analysis of variable speed drive circuit

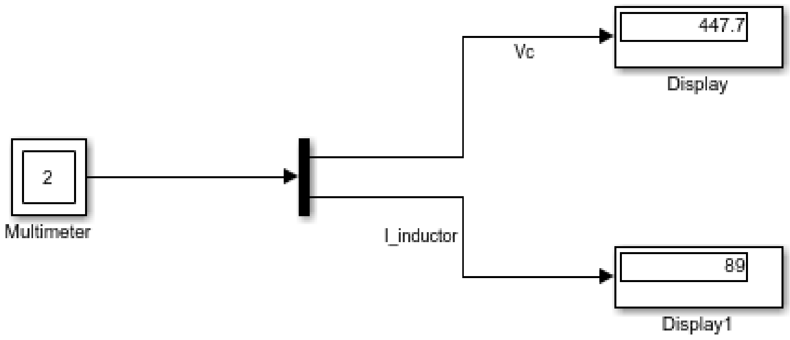


Figure (3-2) subsystem

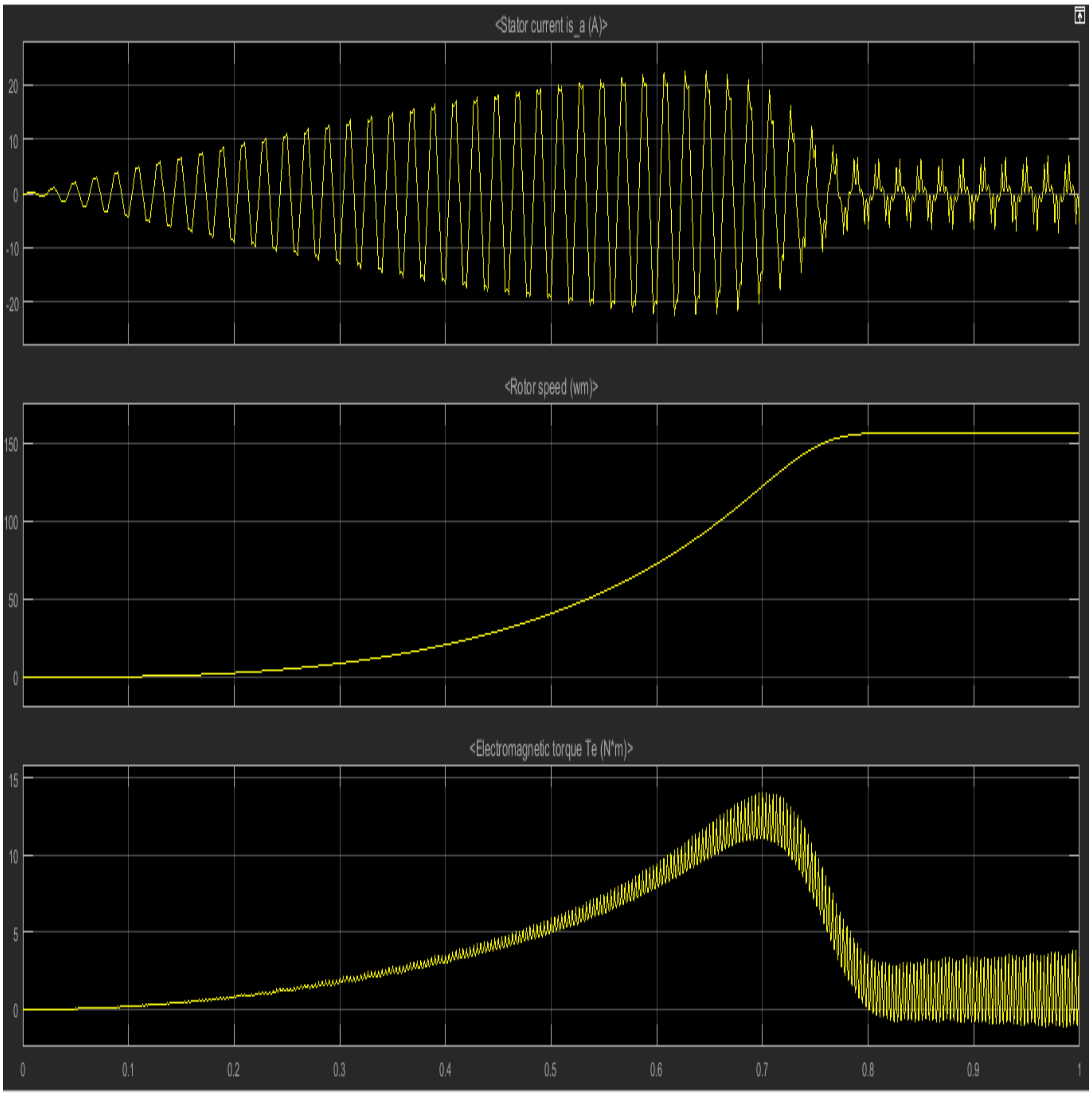


Figure (3-3) scope showing stator current and rotor speed and electromagnetic torque

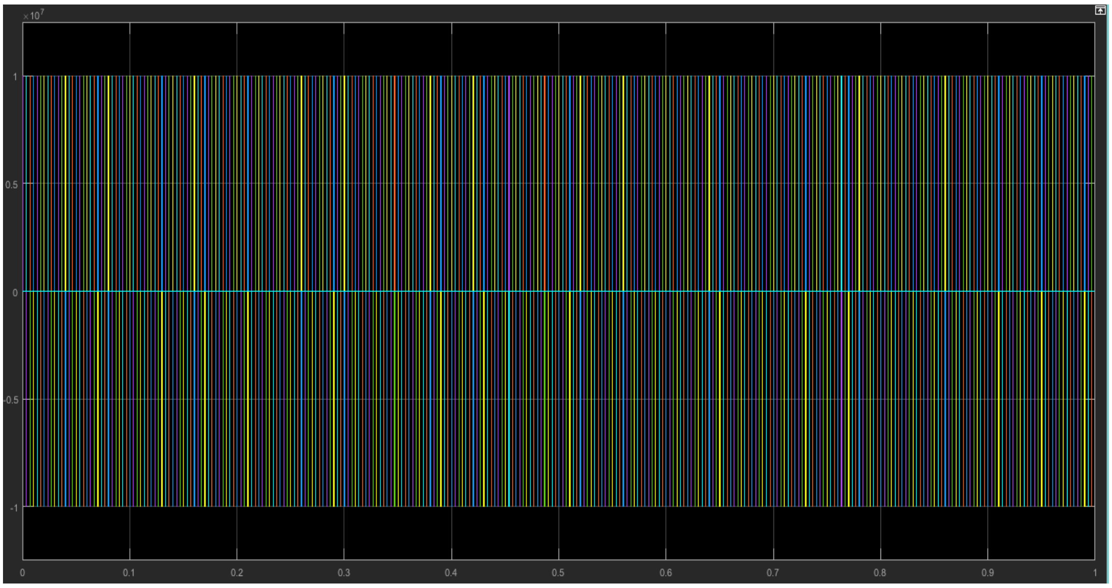


Figure (3-4) scope1 showing PWM before PI controller

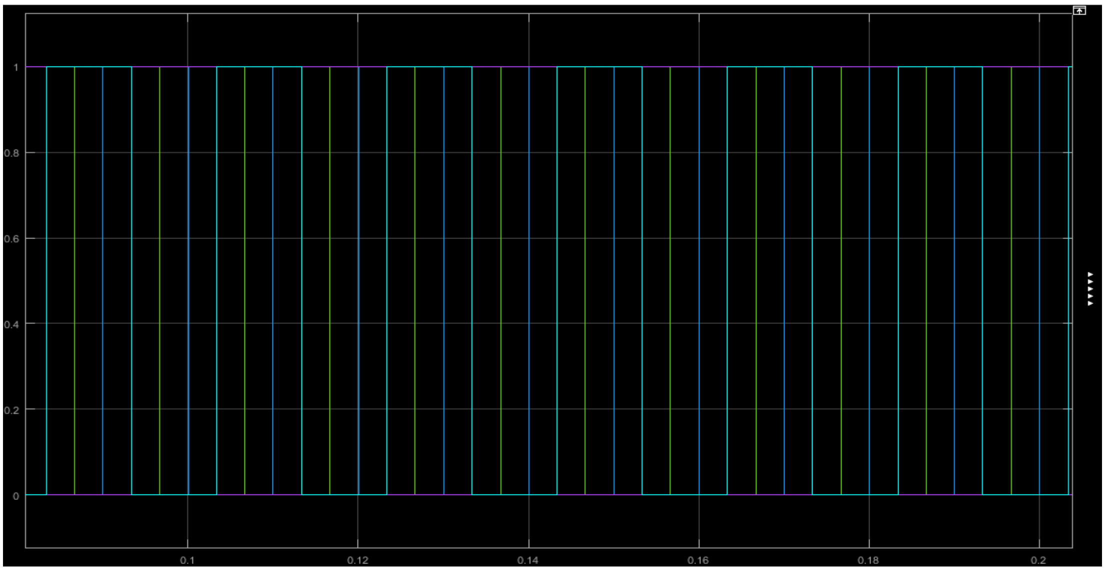


Figure (3-4) scope1 showing PWM after PI controller

3.6 RESULT OF MATLAB SIMULITION VFD

Theoretical speed formula

Ns=120*f/p (3-7)

Ns: synchronous speed
f: frequency
p: number of pole

Frequency(Hz)	Theoretical speed(rpm)	Practical(rpm)
30	900	909.26
40	1200	1023.4
50	1500	1499.52
60	1800	1795.60
70	2100	2091.69

Table 6: Result of MATLAB SIMULITION

CHAPTER FOURE
CONCLUSION AND RECOMMENDATIONS

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CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Speed control is a major issue in any industrial process. Induction motors are widely used in many processes due to their rugged nature, low cost and reliability to meet load demands. This is however limited by the fact that induction motors tend to have fixed speed. Variable speed drives, devices which employ different speed control techniques according to their circuitry, control speed through variation of frequency by employing these techniques such as PWM, SVPWM, IFOC and FOC.

A formulation of this problem is proposed in this project with the main aim being reduction in total running costs, power consumption reduction and overall efficiency improvement while still meeting load demands. Variable speed drives PWM speed control is proposed as a solution to speed control of induction motors. Results indicate that the objectives of the project are met as speed of induction is varied with a PWM variable speed drive hence

- Optimum speed control of induction motors is achieved.
- Power consumption reduction has been achieved due to power, speed and torque relations.
- Total overall cost reduction was achieved.

5.2 Recommendations

Proposed speed control technique is based on variable speed drives techniques to speed control. This works under certain conditions which if not met, the variable speed drive will not be able to work efficiently hence not achieve set objectives. A recommendation to this is being able to work into reducing the constraints rendering the variable speed drive inefficient.

Variable speed drive control circuitry and ratings with regards to motor and load ratings are have not been fully understood. This makes production and installation of variable speed drives ineffective. Hence another major recommendation being to do more research on improving the circuitry of the variable speed drive.