Sudan University of Science & Technology

College of Engineering

School of Electrical & Nuclear Engineering

Speed Control of Three Phase Induction Motor using Variable Frequency Drive

The Research submitted in partial fulfilment for requirement of B.Sc. degree in electrical engineering

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استهلالية

قَالَ تَعَالَىٰ:

﴿ بِسْمِ اللَّهِ الرَّحْمَٰنِ الرَّحِيمِ ﴿١﴾ الْحَمْدُ لِلَّهِ رَبِّ الْعَالَمِينَ ﴿٢﴾ الرَّحْمَٰنِ الرَّحِيمِ ﴿٣﴾
مَالِكِ يَوْمِ الدِّينِ ﴿٤﴾ إِيَّاكَ نَعْبُدُ وَإِيَّاكَ نَسْتَعِينُ ﴿٥﴾ اهْدِنَا الصِّرَاطَ الْمُسْتَقِيمَ ﴿٦﴾
صِرَاطَ الَّذِينَ أَنْعَمْتَ عَلَيْهِمْ غَيْرِ الْمَغْضُوبِ عَلَيْهِمْ وَلَا الضَّالِّينَ ﴿٧﴾ ﴾

صدق الله العظيم ،،،

سورة الفاتحة الآيات (1–7)

Thanks and appreciation

Thanks and respecting to the Staff of School of Electrical and Nuclear Engineering who illuminated our knowledge path and supported for reaching this stage, especially our esteemed advisor Mst. **Jaafar Babiker**, who was patent and preserved with us. Finally, we ask God for all of you to magnify your reward, enhance your fortune, raise your rank, and let you an extended term which the frequently of generations will benefit.

Abstract

Induction motors do not run at synchronous speed; they are generally fixed speed motors. In industries mechanical loads should not only be driven but should also be driven at desired speed. Therefore, the need of speed control methods for induction motor arises. There are various methods of speed control for an induction motor. In this project reviews on different speed control methods and their performance based on SPWM inverter, harmonics reduction and speed-torque characteristics so as to analyse the most effective techniques among them considering the presence of harmonics.

Thus due to the importance of speed control using VFD drive, that used scalar V/F as most common technique, this method was studied and investigated both in simulation and on the field of the industry (Green Food Processing Industry).

المستخلص

المحركات الحثية عموماً ذات سرعة ثابتة، ولا ينبغي إدارة الاحمال الميكانيكية فحسب بل يجب أيضاً إدارتها بالصورة المطلوبة. لذلك تنشأ الحاجة الى طرق التحكم في السرعة للمحرك الحثي.

في هذا البحث نستعرض طرق التحكم في السرعة وأدائها بناءً على تقنية العاكس SPWM، وخصائص تقليل التدفقات وخصائص سرعة عزم الدوران لتحليل التقنيات الأكثر فعالية. مع الأخذ في الاعتبار وجود التدفقات وبالتالي لأهمية التحكم في سرعة المحركات فقد تم دراسة التقنية Scalar V/F (PI Controller) باعتبارها التقنية الأكثر استخداماً في الــ VFD من خلال برنامج المحاكاة Matlab/ Simulink.

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CHAPTER 1
INTRODUCTION

1-1 Overview

The three phase induction motors are very important units used in industries due to components, rigid, solid, long live duration. Therefore, controlling the speed of the induction motors is required in most industrial processes to operate in sequence production lines. The Variable Frequency Drive method is a drive used to control voltage and frequency to control the motor speed.

1-2 Research problem

Due to the electrical and mechanical faults that occurred damage in the operating system, that cause the industries more losses in financial accounts.

Also delays that occurs in induction motor operation can create additional fault to the system operation.

1-3 Research objectives

The Variable Frequency Drive is very important tool used to solve these operation problems by controls the motor speed, acceleration and torque

1-4 Research methodology

- The application Variable Frequency Drive unit is used in GREEN FOOD PROCESSING INDUSTRIES to control the speed of Induced Draft fan to obtain good operation results.
- Assimilation tool is a software tool used to analyses performance of the system.

1-5 Research structure

The research is compromised from fan abstract and five chapter her

- chapter 1represent an introduction, consists of overview, research problem, research objectives, methodology and structure.
- Chapter 2
- Chapter3 after representing the introduction, this chapter also gives general information about Green Food Plant and represented the method of speed control of induced draft fan motor using VFD.
- Chapter 4 represented the first scalar V/F control method, required equations for illustrate the simulation results.
- chapter5 represented the conclusion and recommendations for the VFD applications and V/F control methods.

CHAPTER2

THREE PHASE INDUCTION MOTOR

2.1 Introduction

The three phase induction motor is the most widely used in the industrial requirement it runs at essentially constant speed from no load to full load. There are three important parts of controlling induction motor

- Controlling the starting current (starting methods)
- Controlling the speed during normal operation (speed control methods).[1]

2.2 Starting Method of three phase Induction Motors

When the motor is being started and before it has begun to turn, however, there is no emf to limit the current, so initially there is a high starting, or locked-rotor, current. This high current will cause the motor to burn out quickly. Therefore, to avoid this there are famous methods of starting the induction motor. [1]

2.2.1 Direct on Line Starting Method of Induction Motor

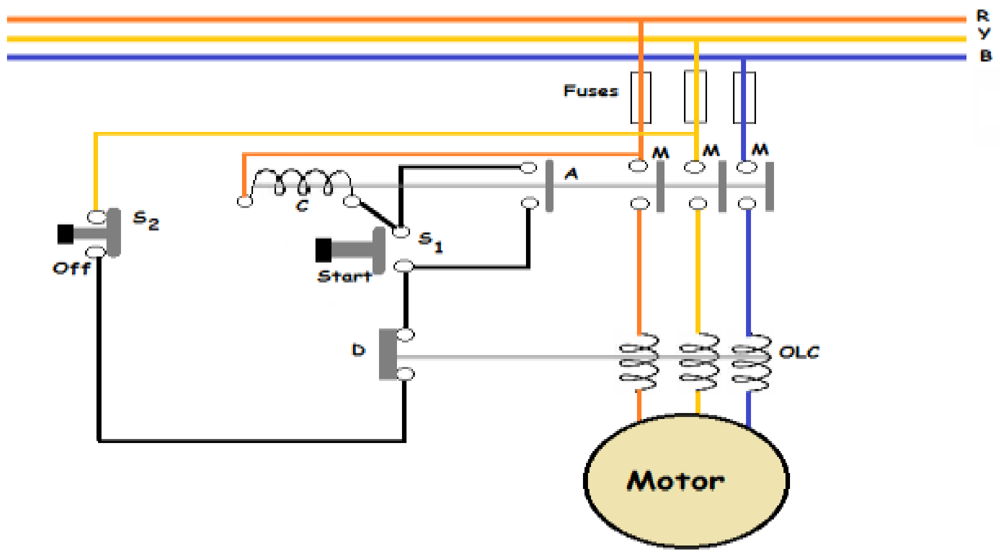

Fig 2.1 Direct on Line Starting Method of Induction Motor

In this starting method of induction motor, the motor is switched on direct to the supply mains by switching contactor. This operation results in a heavy rush of motor current. This high current rapidly decreases as motor picks up speed but it is at very low power factor thus it tends to disturb the voltage of the supply in the distribution lines.

The principle operation if the current is more than normal more heat is generated a thermal element through which the motor current passes. When the motor current reaches a predetermined value the heat generated deflects strip thereby opening the control circuit and the motor does not get the supply. Overload protection is achieved by thermal overload relays. the main features of this method of starting as follow

- Is normally limited to small induction motors (up to 5 H.P).
- The starting torque obtained by this method is higher than that of the auto transformer or star-delta starter.

2.2.2 Star Delta Starting Methods

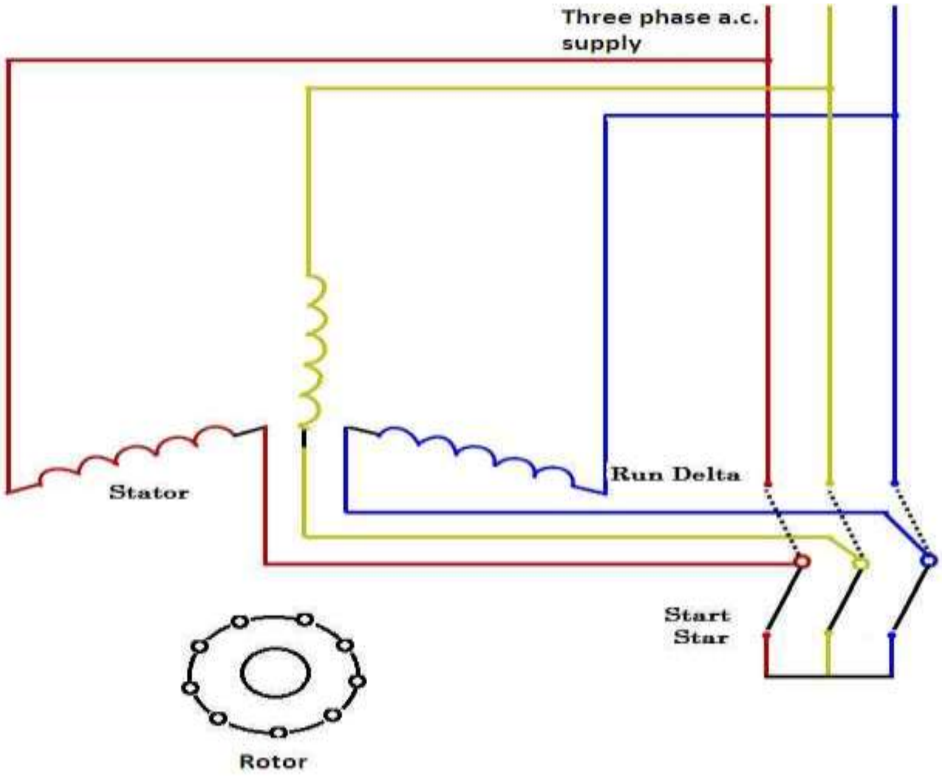

Fig. 2-2Star Delta Starting Methods of Induction Motor

This method is based on the principle that in star connections, the voltage across each winding is phase voltage i.e. 1/√3 times the line voltage whereas the same winding, when connected in delta, will have full line voltage across it.

So at the time of start connections of the motor are made in star fashion so that reduced voltage is applied across each winding. After motor attains speed the same windings through a changeover switch are connected in delta. The starter is provided with overload and under voltage protection devices.

In this starting method of induction motor starting, torque is reduced to 1/3 of starting torque obtained with direct switching. The star delta starters are very suitable for delta connected motors up to 25 H.P.

2.2.3 SOFT STARTING

Electronic solid-state soft starters limit motor starting current and torque by ramping (gradually increasing) the voltage applied to the motor during the selected starting time. They are commonly used in operations requiring smooth starting and stopping of motors and driven machinery.

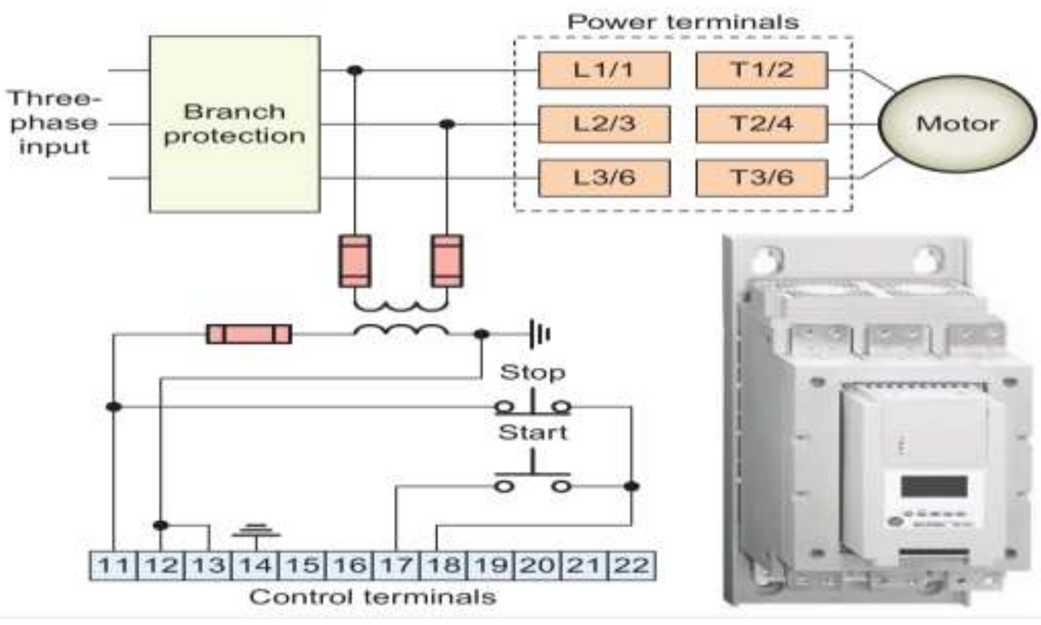

Fig.2-3 SOFT STARTING

2.3 Three- Phase Induction Motor Speed Control Methods

The speed of a three phase induction motor is given by,

$$N=N_s(1-s)\ldots\ldots\ldots\ldots\ldots(2.1)$$

$$N_s = 120f/P\ldots\ldots\ldots\ldots\ldots(2.2)$$

where N is the rotor speed, Ns is synchronous speed, f is the frequency supply(Hz), s is the slip and P is the number of poles. This shows the speed of three phase induction motor depends upon synchronous speed (N_s) and slip(s). The synchronous speed of induction motor depends upon supply frequency and the number of stator poles. So by changing the supply frequency, the number of stator poles and slip we can change the speed of 3 phase induction motor. Therefore, speed control of 3 phase induction motor can be achieved by following methods:

- Stator voltage control method
- Rotor resistance control
- By changing the number of poles of the stator
- Stator frequency control method
- Constant V/f ratio control
- Flux control (flux weakening)

2.3.1 Stator voltage control method:

The torque (and hence the running speed) of a cage motor can be controlled simply by altering the supply voltage. The torque at any slip is approximately proportional to the square of the voltage, so we can reduce the speed of the load by reducing the voltage. [2]

The disadvantages of this method:

- Limited speed control
- the reduction of the stator voltage lead to increase the rotor
- current which result in winding overheating

- very low starting torque is produced
- Low efficiency.

Therefore, this type of control is not suitable for constant torque loads. This type of control is preferred in the applications such as fans, centrifugal pumps and blowers where low star This method is only applicable for small motors and for fan type loads where the load torque increases with the speed. The motor tends to get overheated with other loads. It is a commonly used method for ceiling fans driven by single-phase induction motors which have large standstill impedance limiting the current drawn by the motor.

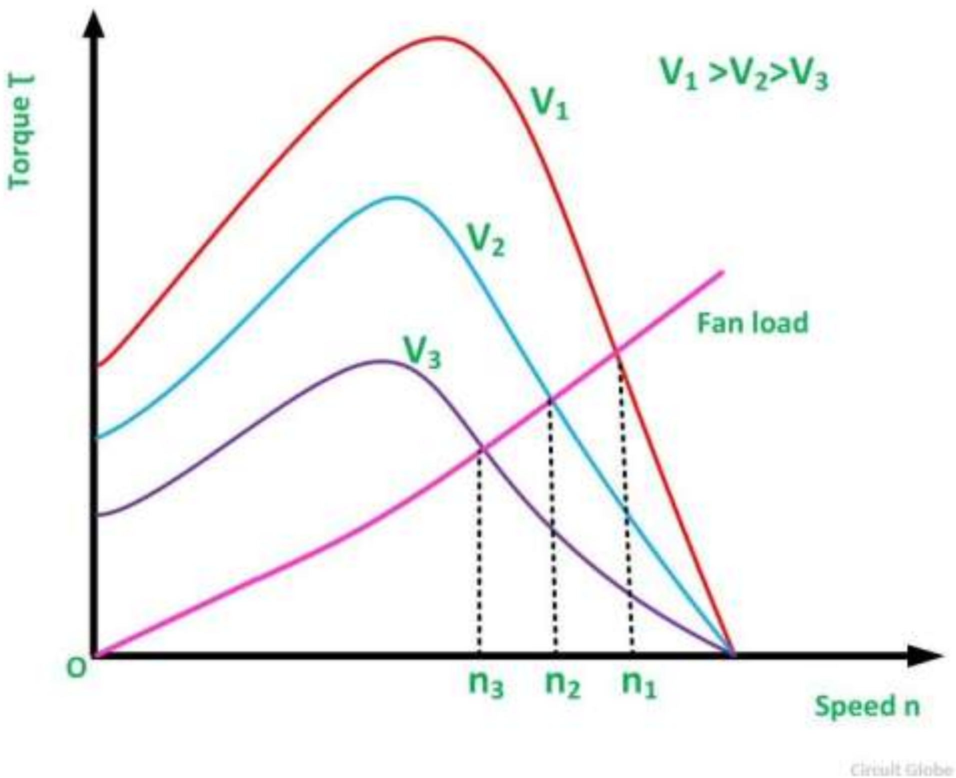

Fig.2-4 displaying speed torque characteristic with variable stator voltage

2.3.2 Stator frequency control method

The torque and speed of induction motors can be controlled by changing the supply frequency but keeping the voltage constant. This method result in saturation of air-gap flux .

At low frequency the reactance will decrease and the motor current may be too high.

If the frequency is increased above its rated value,then the air-gap flux and rotor current decrease and the development torque also decreases. Therefore this method is rarely used.

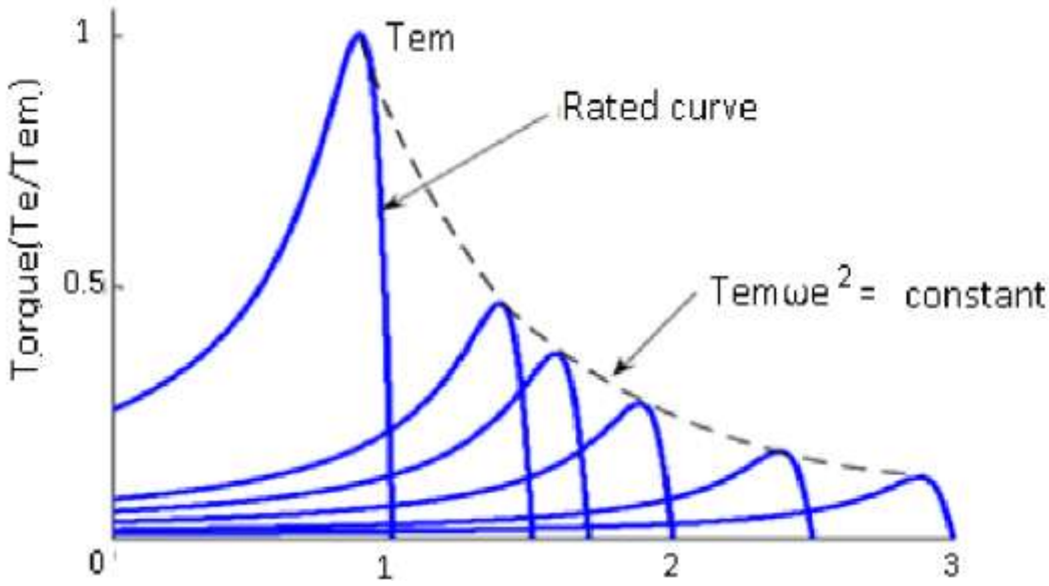

Fig2-5 below shows the torque speed curve of frequency control method

2.3.3 Constant v/f ratio control(Volts per hertz) method

The volts per hertz technology is the most economical and easiest method of speed control of induction motors. In this method drive controls shaft speed by varying the voltage and frequency of the signal powering the motor.

In volts per hertz technology when the frequency of supply changes, the voltage applied to the motor is also changed by the same amount as the frequency, in order to prevent deep saturation and overheating of the motor. In other words, drive maintains a constant V/Hz ratio. The ratio between voltage and frequency is called volts per hertz (V/Hz). To find the volts per hertz ratio, simply divide the rated nameplate voltage by the rated nameplate frequency. For example, the volt per hertz ratio for a 415 Volt, 50Hz will be 8.3 V/Hz.

This method is the most technique used by VFD drive

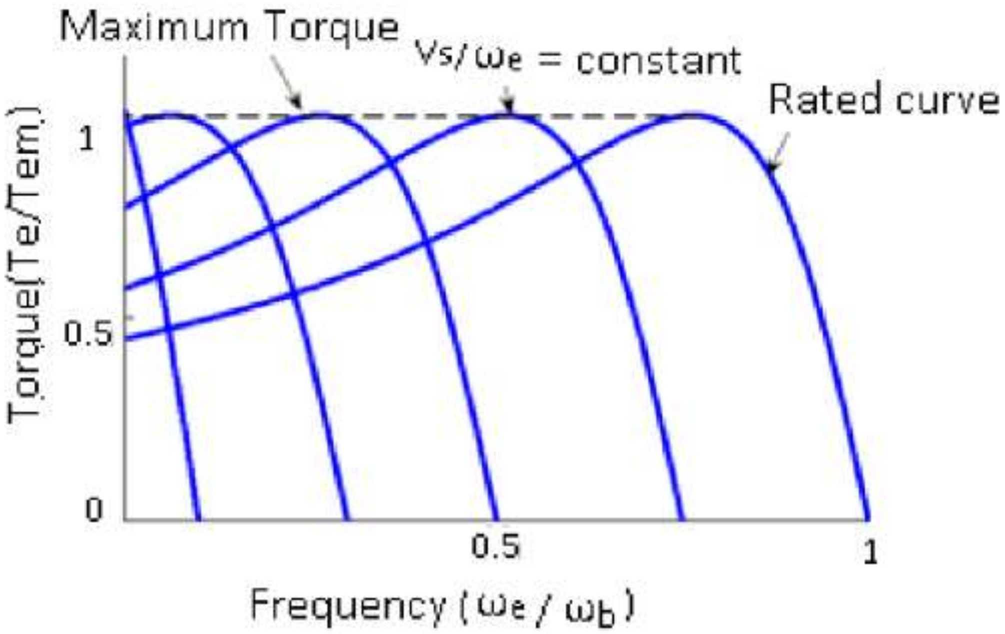

Fig 2.6 Speed torque-curve with constant v/f ratio

There are Various speed control techniques for implementing V/F such as space vector technique(advanced) and scalar.

2.3.3.1 V/F Scalar control or VVVF(Variable Voltage Variable Frequency):

This technique for controlling the motor speed can be achieved by using peripheral components (conventional technique) but due to the fast advance in power electronic devices now can be implemented using PWM controller.

The main components of an induction motor drive using v/f control consists of

- The converter section (AC to DC) which can be uncontrolled rectifier or controlled rectifier

- The DC-Bus/link filter which keep the input voltage the inverter stable and ripple-free
- The inverter section (DC to AC) which contains the switching devices such as IGBT or MOSFET
- The Pulse Width Modulation PWM which act as the controller and provide the switching scheme for the inverter in order to obtain the desired voltage and frequency.

2-4 Sinusoidal Pulse Width Modulation Technique:

The general principle of spwm, where a triangle carrier wave of high frequency fc is compared with the sinusoidal modulating wave of fundamental frequency f, and the points of intersection determine the switching points of power devices the three sine waves phase shifted by 120° with the frequency of the desired output voltage is compared with a very high frequency carrier triangle, the two signals are mixed in a comparator whose output is high when the sine wave is greater than the triangle and the comparator output is low when the sine wave or typically called the modulation signal is smaller than the triangle. figure shows the three phase full bridge inverter with spwm. [3]

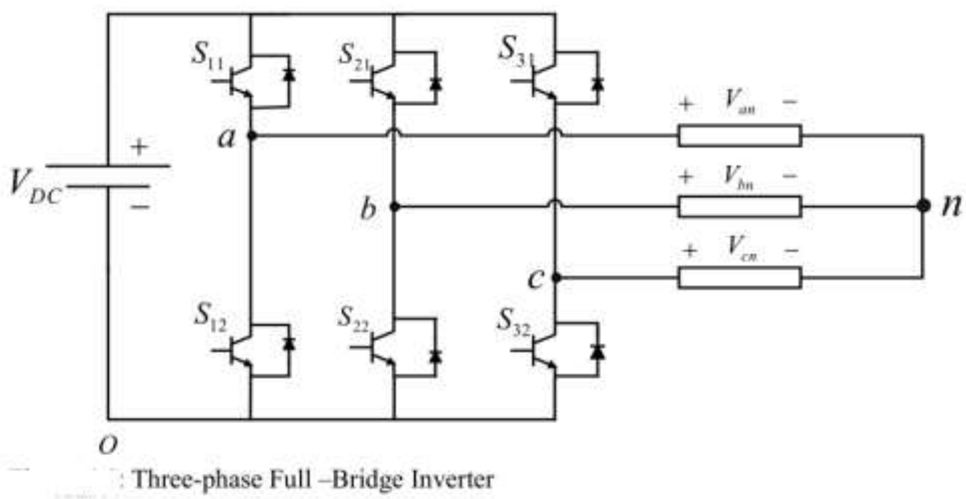

Fig 2.7 showing the three-phase Full-Bridge Inverter

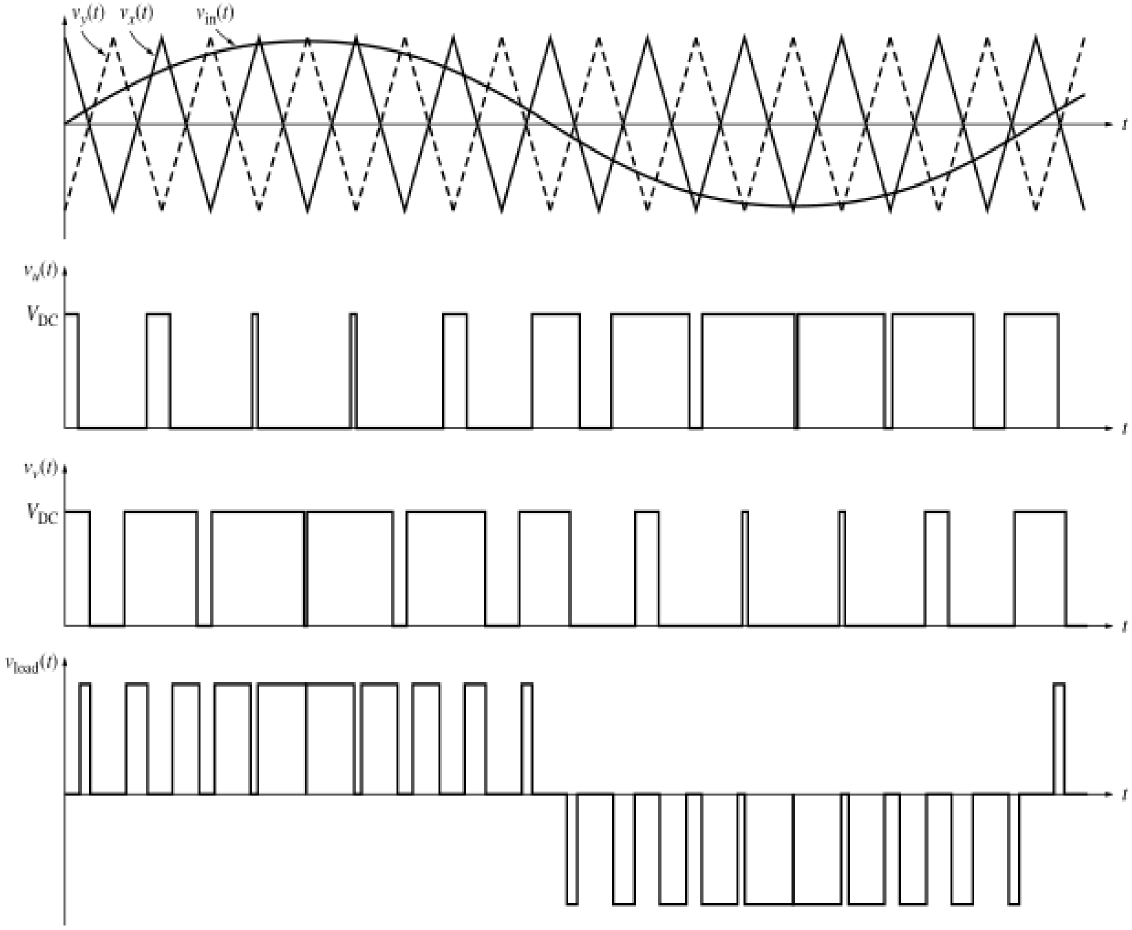

Fig.2-8 shows the three phase full bridge inverter with SPWM

CHAPTER3

VARIABLE FREQUENCY DRIVE IN INDUSTRIES

3-1 Introduction

Green Food for processing Industries is an old dream that found its way out to reality in 2014. Green Food is part of an integrate chain of business that in both Long Term and short term

will enhance and enrich the base of an economy of agriculture. Green Food is a huge project that holds an investment of almost 12 Million $ with a unique business case in terms of production processing capacity for sunflower, ground nut and Soy Beans seeds. Green food is capable of processing 300 MT of SF per day and producing more than 100 MT of Crude edible oil and more than 100 MT of de-oiled cake (DOC). Green Food state of art plant is providing our endorsers with quality oil and DOC with less than 0.7% of Oil content. Our gifted and exceptionally talented workforces are the absolute bottom of our quality and long haul achievement. Subsequently, our approach requires that we assume liability for guaranteeing their wellbeing and security and in addition defending their wellbeing and welfare. We additionally take awesome pride in adding to the group and society all in all through dynamic corporate social duty and engagement. Our definitive concentration in this way, is to utilize our important assets keeping in mind the end goal to make esteem included items and administrations, which would add to the monetary, social and ecological advance and flourishing of Sudan. Altogether, we mean to lead by worldview and to gain from regular encounters; we set our attempts to exclusive expectations for our kin at all levels and reliably meet them. [4]

3-2 Boiler System Operation

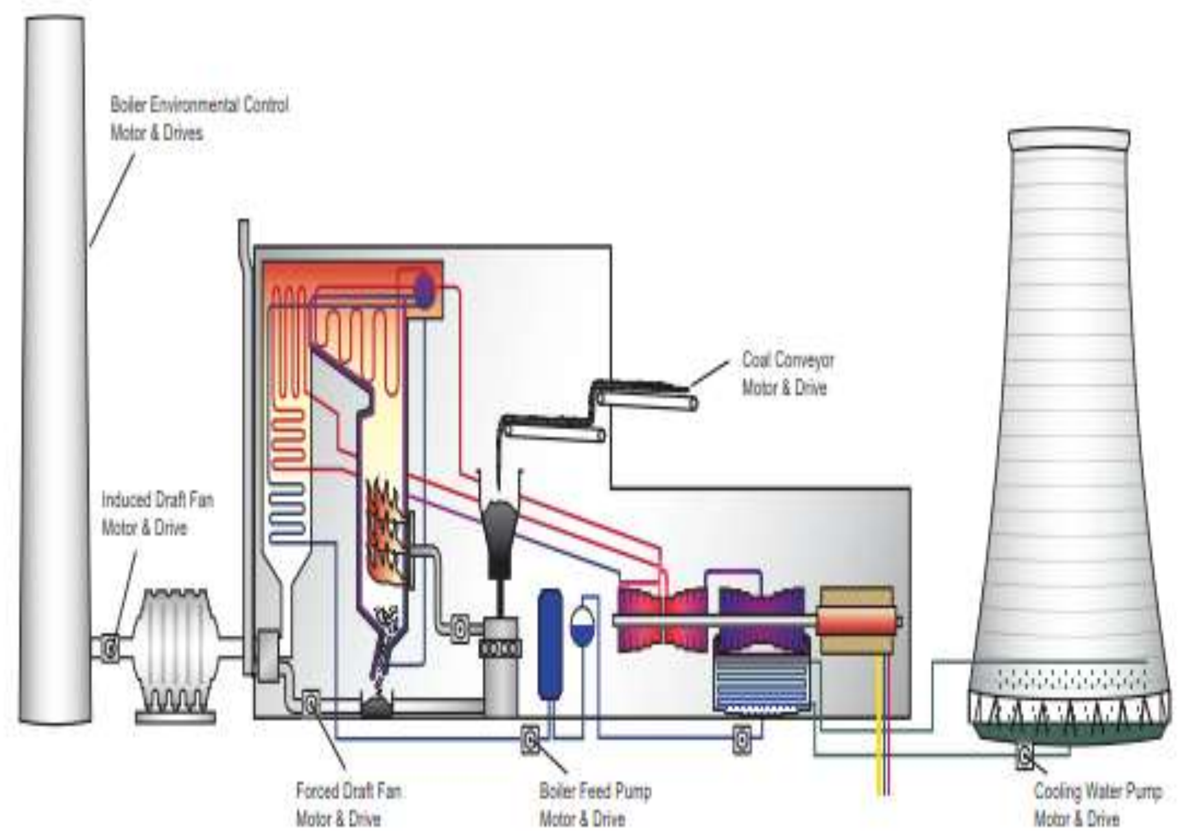

Fig.(3-1) represent the components of the boiler system.

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment that must be treated with utmost care. The process of heating a liquid until it reaches its gaseous state is called evaporation.

Traditional flow control methods use constant speed motors with mechanical flow reducing devices such as:

- Inlet louvers (dampers) in the ducting

- Outlet louvers (dampers) in the ducting
- Flow guide vanes in the fan casing
- Variable slip clutches in the fan drive shaft
- Hydraulic variable speed transmissions

These mechanical solutions have significant disadvantages:

- High energy consumption at reduced flow rates
- Mechanical wear and required maintenance
- Generation interruptions due to mechanical problems
- Limitations on motor starting duty

Controlling fan flow by adjusting speed avoids wasting energy in flow control vanes, dampers, and louvers. When large flows must be controlled and motor energy consumption is significant, varying the motor speed is the answer. With large machines, the electrical power savings can amount to hundreds of thousands of dollars per year. In addition, the drives smoothly start the motors, protecting them against starting inrush currents, thus avoiding thermal stress and extending motor life. [5]

3-3 Forced Draft fan (FD fan)

Fig.3-2 represent typical FD fan

Forced Draft Fan supplies most of the Combustion air. This fan takes air from the atmosphere and blows it into the furnace through air ducts. The Air Heater heats the air before it enters the Furnace. FD fan produce the positive pressure inside the system i.e. furnace. Forced draft fan draws the air and force it into the combustion chamber of the boiler, where it mixes with the fuel being supplied. FD fans are typically used to regulate the proper amount of air-to-fuel ratios in an effort to maximize fuel efficiency and to minimize emissions, such as NOx. (Nitrogen Oxides). [5]

3-4 Induced Draft Fan (Id Fan)

Fig. 3-3 illustrate the induced draft fan.

The ID fan creates furnace air flow, which must be continuously varied to match the fuel flow. The process control system continuously monitors process conditions such as fuel feed, inlet air temperature, flue oxygen content, and required fuel-air ratio. The control system then directs the fan to provide the air flow for optimum combustion. [5]

3-5 Speed control of induced draft fan motor using VFD

Variable speed control is an important means of solving problems. Generally, combustion air control is effected by throttling dampers fitted at induced draft fans. Though dampers are simple means of control, they lack accuracy, giving poor control characteristics at the top and bottom of the operating range. In general, if the load characteristic of the boiler is variable, and refers to Cube Load Torque:(Most loads are of the fan or centrifugal pump types and therefore can be described as cube law loads. The torque and power requirement at zero speed is zero. See Fig. 4.3. Power requirement increases with the cube of the increase in speed. Therefore, there is a large increase in power requirement for a small increase in speed. For example: To double the machine speed would require eight times the power to drive it.Conversely, ifthe speed of the machine is halved, the power requirement is reduced to 1/8 of the original power).

Fig.3-4 represent the relation between torque and speed in centre fugal pumps and fan

%Torque/Power

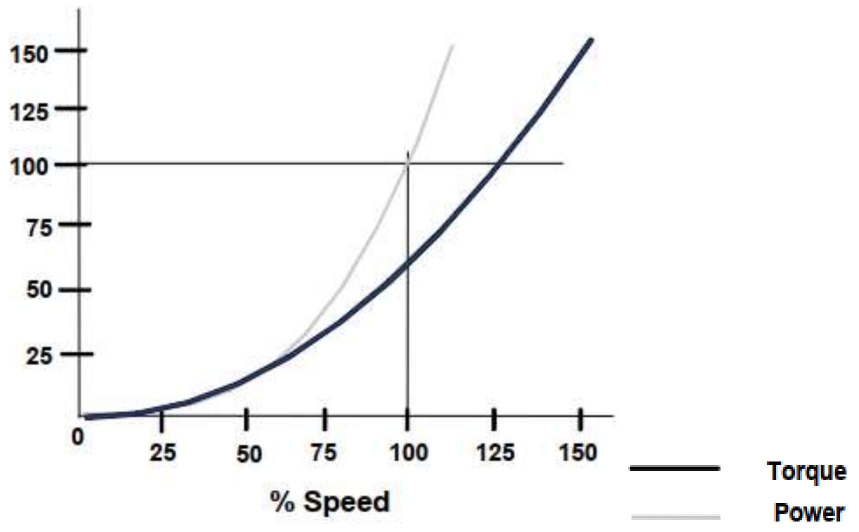

Fig. 3-4 Cube law torque load torque/power curve.

Centrifugal pumps and fans operate like this; power changes sharply with small speed changes. The possibility of replacing the dampers by a VSD should be evaluated.

3-6 Technical data of VFD

Product Name:	55KW - 75HP VFD/Inverter
Model No:	WSTG600-4T55P
Brand:	Winston
Function:	Change Motor Speed
Nature of DC Power:	Voltage Variable-Frequency Drive
Link of Transformation:	AC-AC Variable-Frequency Drive
Voltage of Power Supply:	380VAC/415VAC - 50/60HZ
Main Circuit Type:	Voltage
Switch Mode:	Sensor Control
Principle of Work:	V/F Control Transducer
Output Type:	Triple
Application:	High-performance Transducer,3phase Transducer, High Frequency Converter
Input Voltage:	380VAC/450VAC
Power Capacity:	85KVA
Input Current:	113A
Output Current:	112A
Adaptation Motor:	55KW 75HP
Origin:	China
HS Code:	8467299000

3.7 The electrical circuit

Fig.3-5 and Fig. 3-6 illustrate the electrical circuit and Braking resistor.

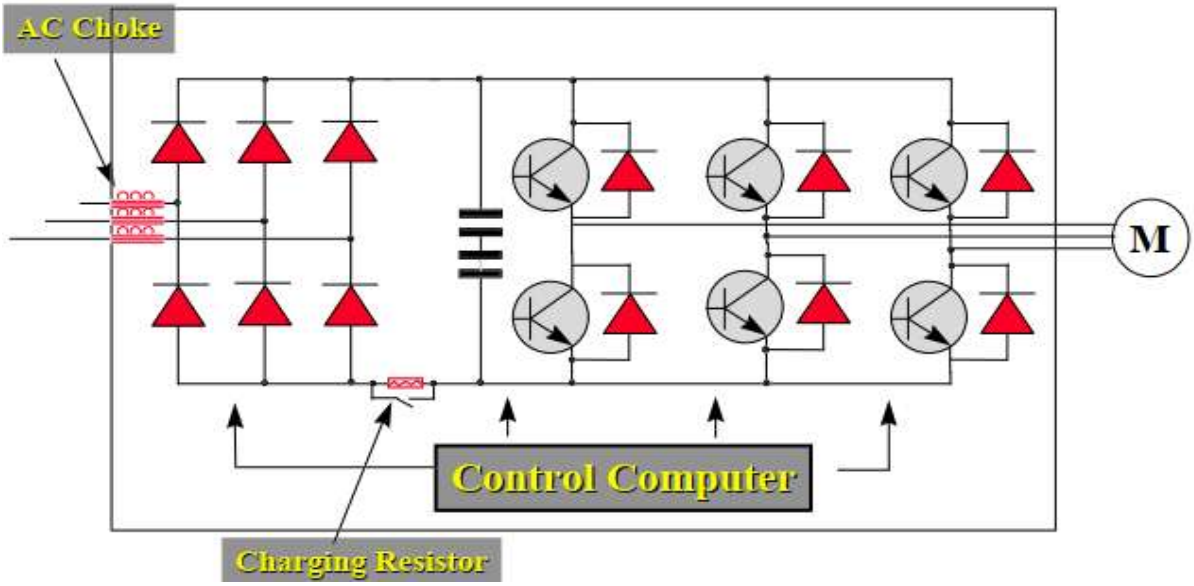

Fig.3-5 electrical circuit of VFD.

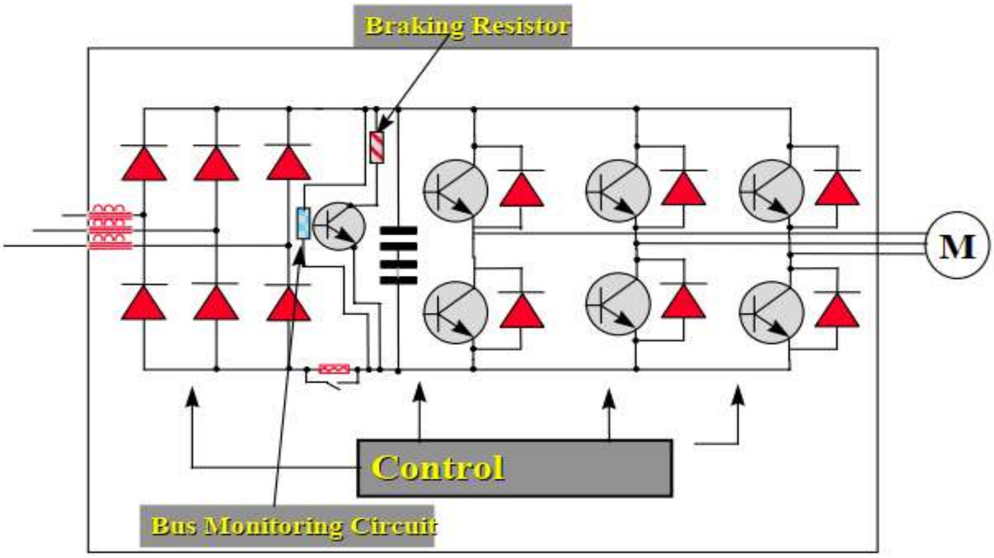

Fig.3-6 VFD Braking resistor.

The majority of general purpose VFDs produced today have four fundamental sections (see Fig. 4.5). These are:

i. The input rectifier or converter.

ii. The DC bus.

iii. The output stack or VFD.

iv. The controller.

The input rectifier or converter can be either three-phase or, in small machines, single phase. This input rectifier converts the Vac input into DC volts and charges the capacitors in this part of the circuit. The DC bus acts as a small reservoir for power on which the output VFD draws. If any regenerated energy from the load remains, it is stored on the DC bus in the capacitors.

The output stack or VFD draws power from the DC bus and creates a synthesized Vac power supply, the frequency of which can be varied by the controller. The output of the converter is used to drive the electric motor. Supervising the whole machine is a computerized controller, which is capable of making decisions based on the demands and on state of motor and load. It is driving and taking protective measures to ensure that no damage occurs to the machinery it is controlling or the VFD itself. [6]

-Charging Resistor

The charging resistor is included in the DC bus to provide current limiting during the initial power up stages of the VFD. When a fully discharged VFD is switched on to the power supply, the capacitors on the DC bus are seen by the power supply as a very low impedance load. If the design does not include a charging resistor, the current surge magnitude would be so high that the input bridge can be damaged, or require up-rating far beyond that required for normal running. The power supply capacity, cable lengths have a bearing on the magnitude of this surge current. With the charging resistor in the circuit, the current surge is limited until the V dc rises above about 380 volts. At this point, a contactor or solid state switch shorts out the resistor.

The charging circuit is short time rated, repeated power down/up cycles will ultimately cause failure. Typically, 10 power up/down cycles per hour are acceptable.

-AC Line Choke

The AC Line choke design provides some smoothing on the DC bus and reduces the amount of ripple current that must be tolerated by the main capacitors. This has an effect of extending the life of these components. The choke provides a limiting function to the magnitude of the DC bus current during normal operation. This results in an improved overall power factor of the VFD and reduced harmonic currents flowing in the power distribution network.

- Be aware that if multiple VFDs or one large VFD installed on a distribution network that supports equipment that also produces harmonic currents, the effects are cumulative.
- If power factor correction equipment is also installed on the network, damage can occur to the correction equipment capacitors.
- Limiting the amount of harmonic current flowing in the network can require additional power line reactors, or under extreme conditions, a filter network.
- Only a Harmonic Survey can guarantee the quality of the power supply.

Braking Resistor.

Under normal circumstances, with the motor under load, the flow of energy through the system is from the commercial power supply to the VFD and from the VFD to the motor and finally from the motor to the load. There are operating conditions where the load tries to overrun the motor. An example of this would be a high inertia load. For example: a large diameter fan, running at high speed, where the control system calls for the fan to run at low speed. The VFD begins to lower its output frequency and the motor follows. However, due to the inertia in the fan, the fan resists the change in speed, causing the motor to run above the frequency output from the VFD. This situation will cause energy to flow from the load back through the motor and into the VFD. A general purpose VFD does not normally have the ability to pass this energy back into the commercial power supply. However, if required, additional equipment can do this. The result of this regeneration is a build-up of energy in the DC bus capacitors, which manifests itself as an increasing voltage.

If this were allowed to occur unchecked, damage would occur to the components in the VFD due to exceeding the operating voltage limits. To ensure problems do not occur, the VFD has a bus voltage monitoring circuit. This circuit attempts to reduce regeneration until bus voltage falls to an acceptable level. If, however it is important that the motor and load follow the control signal exactly, it may be necessary to add a braking resistor system to the VFD. (See Fig. 4.6).

This would take the form of a power transistor, a power resistor and a control circuit, the layout of which is shown above. In the event that the DC bus voltage exceeds the threshold of the control circuit, the power transistor switches on. It also connects the positive and negative sides of the DC bus together, via a large power resistor. This action dissipates the excess energy as heat from the resistor. This resistor is subjected to high voltages and currents, so it is a highly stressed component and has to be carefully selected to ensure reliability.

3.8 VFD Technology

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 had a capability of smoothing start of large motors, both the speed and torque of an induction motor, and furthermore VFDs are an excellent choice for users because they allow operators to fine-tune processes while reducing costs for energy and equipment maintenance. 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. [7]

When investigating VFD technology, the following implications should be considered:

i. Electrical.
ii. Harmonic.
iii. Motor.
iv. Physical and environmental issues.
v. Vibration and resonance.

3.8.1 Electrical Considerations:

Successful application and maintenance of VFD drives requires an understanding of their impact on the motor and electrical distribution system.

The application of VFDs to induction motors can cause effects that must be considered for successful operation.

Examples include:

- The ability of a motor to cool itself effectively is reduced as the motor is slowed down. Over-sizing the motor or providing external forced air ventilation may be required with extended operation at low speeds and high loads.
- Operation at different speeds can cause mechanical resonances in driven equipment. These speeds should be identified and programmed out of the motor's operating range.
- VFDs generate harmonic voltages and currents that can, in some cases, cause undesirable effects on the electrical distribution system and affect equipment operation. If a power quality problem is suspected, the electrical system should be examined by a qualified person. Sometimes isolation transformers, line reactors or filtering devices will be required to minimize these effects. Installation of filtering devices should be considered at the time of purchase of VFDs to minimize power quality issues in the electrical system.
- The nominal supply voltage of the distribution system is normally higher than the drive nameplate voltage to allow for voltage drops from the distribution transformer to the point of utilization.

3.8.2 Harmonic Considerations

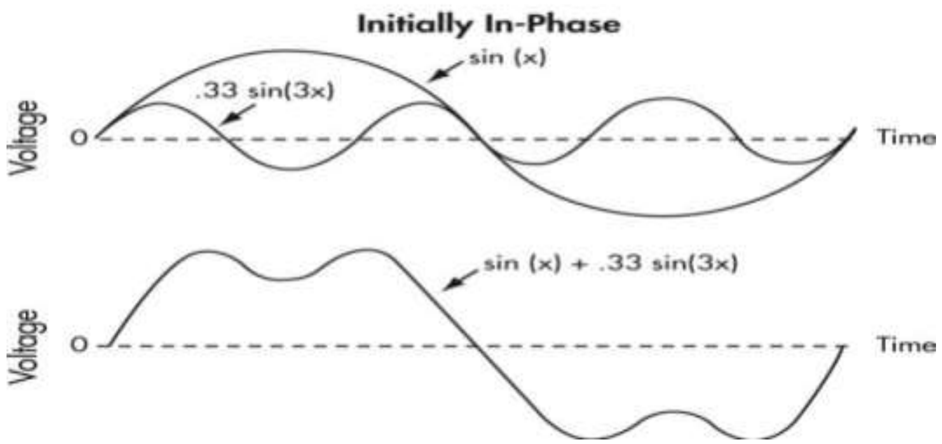

Fig.3-7 Harmonic Amplitudes

Harmonic distortion: Voltage and current is produced in electrical systems by non-linear loads such as VFDs, welders, rectifiers, Uninterruptible Power Supplies (UPS), arc furnaces, etc. Harmonics cause electrical waveform distortion that can propagate through the entire power system and even outside of the plant.

The odd harmonic amplitudes usually decrease with increasing frequency, so the lowest order harmonics are the most significant. Even numbered harmonics are not normally generated by VFD drive systems. Harmonics occur as long as the harmonic generating equipment is in operation and tend to be of a steady magnitude. Harmonics may be greatly magnified by power factor correction capacitors. The supply system inductance can resonate with capacitors at certain harmonic frequencies developing large currents and voltages, which can damage equipment.

Motors run at higher temperatures in the presence of harmonic currents. Motors consume more energy as they have to overcome ‘counter rotating’ torques created by odd harmonics. This may cause premature breakdown of insulating materials and a reduction in life. The motor will also drop in overall efficiency, experience voltage stresses on its windings and experience torque pulsations.

-Dealing with Harmonics: If a harmonic problem is suspected, it should be confirmed before any attempt at corrective action is taken. A fairly simple test consists of viewing the power system waveforms on an oscilloscope or using a portable power meter with harmonic analysis functions. Significant waveform distortion is an indication of harmonic presence. Power harmonic analysers can be used to measure the magnitude of the individual harmonics. This work is often best left to an expert in power quality services. There are a variety of ways in which users can resolve these problems, after ensuring the installation meets the applicable electrical code including adequate grounding:

- Separate Supply

Ideally, loads producing harmonics and sensitive loads should be supplied from entirely separate feeders and independent transformers.

- Isolation Transformers and Line Reactors

Isolation transformers and line reactors are frequently used to protect the drive as well as the AC line from distortion.

- Filters

Harmonic filters can be used to reduce the amplitude of one or more fixed frequency currents to prevent them from entering the rest of the system. Filters can be custom designed to suit the electrical environment.

- Cable Length

Cable length should be kept as short as possible (i.e. less than 15 meters or 50 feet wherever possible). As a general rule of thumb, it is considered good practice to buy a complete drive system that includes line reactors rather than just purchasing the drive on its own. Generally, a 3% to 5% impedance line reactor will prevent harmonics generated by a VFD from interfering with sensitive equipment on the distribution system. If non-linear loads exceed 20% of the total plant load, special consideration should be given to performing a harmonic study and minimizing potential harmonic impact through the use of isolation transformers in addition to line reactors. From a practical drive application point of view, meeting harmonic requirements for drives means having less than 5% total harmonic distortion of the current at the terminals of the drive at rated load. At low power demand with variable torque loads, the current's total harmonic distortion (THD) may be higher than 5% as measured by a harmonic analyser, but the magnitude of the harmonic current will be less than those produced at full load.

3.8.3 Motor Consideration

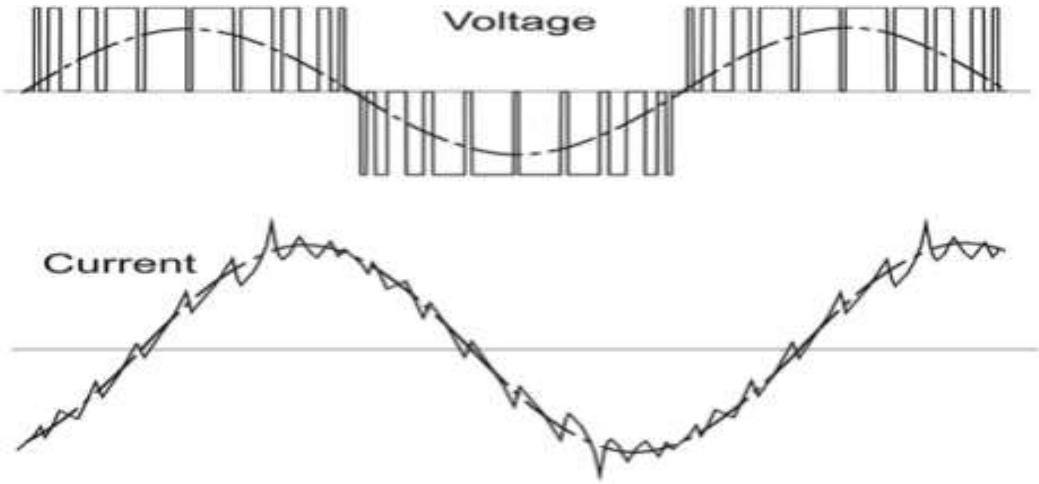

Fig.3-8 Typical PWM VFD

(The fundamental-frequency component is shown by the dotted line.)

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.

As the motor speed is reduced, the amount of cooling available from the motor's ventilation system is reduced, so motor torque must be limited at reduced speed to avoid overheating. In addition to the reduced cooling capability, motors have additional internal heating due to the non-sinusoidal voltages and currents from the inverter operation.

- Vibration and Resonance Considerations

There is a general assumption that slowing down rotating equipment leads to less wear and tear and hence promotes more favourable maintenance conditions. Frequently, equipment life can be extended through the benefits of variable speed. However, there are a number of detrimental mechanical conditions that can arise when equipment is slowed down.

Most machines are designed to operate at a speed that is selected at a calculated safe margin below the first critical speed or natural frequency of the shaft. In certain cases, to facilitate shaft design, some high speed machines are designed to operate between the first and second critical speeds. A speed reduction for a machine of this type could result in operation at the first critical speed. For larger installations, contact should be made with the machine manufacturer to ensure that the critical speeds are known and dealt with appropriately.

Resolving vibration and resonance usually involves programming the VFD so that it will not operate equipment in the critical speed range. If the design data cannot be located, field tests should be performed or the complete apparatus should be measured and the critical speeds recalculated.

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.

Table 3-1 shows some typical loads and their energy savings potential.

Table 3-1 Potential VFD Energy Saving

Type Of Load	Applications	Energy Consideration
Variable Torque Load - HP varies as the cube of the speed - Torque varies as the square speed	- Centrifugal Fans - Centrifugal Pumps - Blowers - HVAC Systems	Lower speed operation results in significant energy savings as power to the motor drops with the cube of the speed.
Constant Torque Load - Torque remains the same at all speeds - HP varies directly with the speed.	- Mixers - Conveyors - Compressors - Printing Presses	Lower speed operation saves energy in direct proportion to the speed reduction.
Constant Horsepower Load - Develops the same horsepower at all speeds. - Torque varies inversely with the speed.	- Machine tools - Lathes - Milling machines - Punch presses	No energy savings at reduced speeds; however, energy savings can be realized by attaining the optimized cutting and machining speeds for the part being produced.

3.9 VFD Operation

Electronic VFDs can vary the voltage and frequency to an induction motor using a technique called Pulse Width Modulation (PWM). VFDs have become the preferred way to achieve variable speed operation, as they are relatively inexpensive and very reliable. VFDs 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. 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).Theoutput 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. [6]

The entire process is controlled by a microprocessor which monitors the:

i. Incoming voltage supply;
ii. Speed set-point;
iii. DC link voltage; and output voltage and current to ensure operation of the motor within established parameters.

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 SCRs or Thyristors 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 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.

3.10 VFD Voltage to Frequency (v/f) Ratio.

When connected to a VFD, motor speed is no longer fixed by supply frequency, since the VFD can vary its output frequency. Under perfect conditions, at zero speed the terminal voltage would also be zero. Obviously if this was the case then the motor would produce zero torque and in many cases this would be unacceptable. Also at very low speeds the motor winding appears more like a resistive load than an inductive load.

To overcome this problem with a general purpose VFD, a degree of fixed voltage boost is applied at zero speed. As the motor accelerates, a proportion of fixed boost is replaced by normal V/F ratio until, at some speed above zero, governed by the amount of fixed boost applied, all boost is replaced by the normal V/F ratio. If an excessive amount of fixed boost is applied, the motor can become overheated due to over fluxing. It is also possible to program the drive to adjust the V/F ratio automatically according to the load applied to the motor.

Within limits, as the current drawn increases the drive responds to this as an increase in load and to maintain torque and speed, the drive increases the terminal voltage, within predefined limits.

If the drive has been programmed correctly, the maximum terminal voltage will be reached at maximum speed. However, the application can require that the motor run over speed. Normally, 20% over speed is acceptable, providing the load can withstand the stresses caused by this additional speed. Fig. 3-9 illustrates that at maximum speed terminal voltage is at maximum. Therefore, there can be no increase in voltage due to speed increases. This point is called the field weakening point, as a constant motor flux can no longer be maintained. According to the V/F ratio, therefore the motor torque capability begins to reduce. If the motor continues to increase in speed, then it passes into an area of operation called the constant power area. [6]

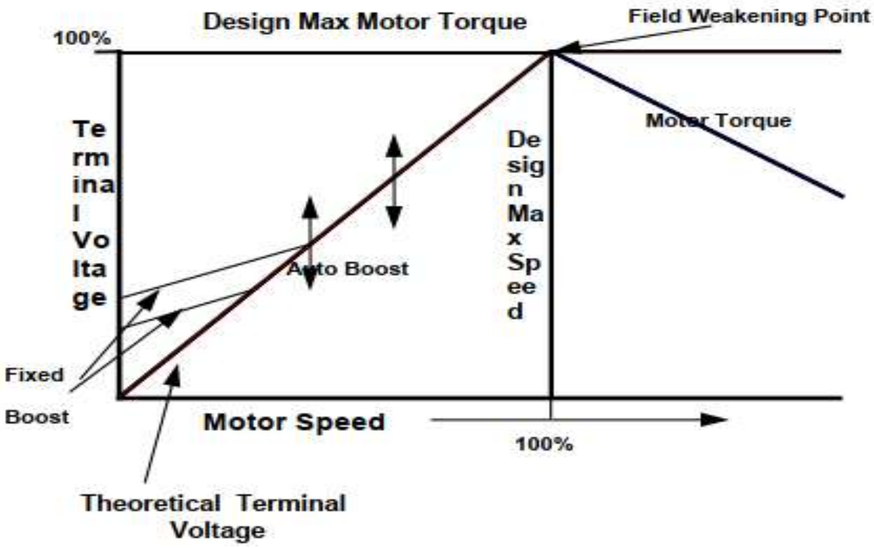

Fig. 3-9 VFD v/f Ratio

3.11 Comparison with Conventional Control Methods

Fans and pumps are designed to be capable of meeting the maximum demand of the system in which they are installed. However, quite often the actual demand could vary and be much less than the designed capacity. These conditions are accommodated by adding outlet dampers to fans or throttling valves to pumps. These are effective and simple controls, but severely affect the efficiency of the system. Using a VFD to control the fan or pump is a more efficient means of flow control than simple valves or inlet or outlet dampers. The power input to fans and pumps varies with the cube of the speed, so even seemingly small changes in speed can greatly impact the power required by the load. The table below (3-2) shows the power required by a fan or pump as the speed of the machine is reduced.

Table 3-2 Power Required by a Fan or Pump

Speed of Fan/Pump	Mechanical Power Required
100%	100%
90%	73%
75%	42%
50%	13%

CHAPTER 4

SIMULATION WITH MATLAB / SIMULINK

4.1 Introduction:

The speed control of three phase induction motor (squirrel-cage type) by scalar v/f constant ratio has been simulated using Matlab/Simulink. First scalar V/F control method using conventional technique such as controlled voltage source without PWM is achieved and investigated, then the variable frequency drive for induction motors is achieved using a three phase inverter controlled by SPWM technique is achieved and modelled (both open and closed loop system) then from the results it is found that the latter one provides better efficiency and higher performance. The motor speed, torque the stator current and voltage are investigated at rate load.

In addition, the harmonic analysis also performed using FFT tool to observe the harmonics content in Voltage Source Inverter. The closed loop PI controller was designed at rated load based on dynamic behaviour of error signal. Where trial and error technique is used to find the proper parameters of the PI controller (Kp and Ki) at which the motor stays at its specific reference speed (the desired input speed). PI controller can eliminate the steady state error to zero if configured with the proper parameters and provides high performance and smooth speed response. The block diagrams and the complete mathematical model of the system is described and simulated in MATLAB/SIMULINK. The simulation results provide a smooth speed response and high performance that match the expected theory values.

The induction motor parameters specified in the appendix.

And the motor application is considered as Fan.

4.2 The required Equations:

The rotor speed ω in rad per second is calculated as follow:

$$\omega = Ns*pi/30 \quad \ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

Where Ns is the rotor speed in rpm. And

$$Ns = 120*f/P \quad \ldots\ldots\ldots\ldots\ldots..(4.2)$$

Where P is the number of poles and f is the frequency supply.

The nominal/rated current (Irated) is found as follow

$$Irated = Prated/Vrms \quad \ldots\ldots\ldots \ldots.(4.3)$$

Where Prated is the motor nominal power in watt and

Vrms is the output voltage of the voltage source controller or the voltage source inverter.

The rated/nominal Torque is found as follow

$$Trated = Prated/\omega \quad \ldots\ldots\ldots\ldots\ldots.(4.4)$$

Where ω is rated rotor speed in rad/s.

In case of variable torque load type the value of the K constant is calculated first as follow

$T \alpha \omega$^2 (as in the case of most fan or pump applications)

$T = K \omega$^2, therefore the constant is

$$K = T/\omega\text{^}2 \quad \ldots\ldots\ldots\ldots..(4.5)$$

In case of using PWM the output of Voltage source inverter can be found by using the equation:

$$Vdc = \sqrt{2}\frac{Vrms}{\sqrt{3}} \ldots\ldots\ldots\ldots\ldots \quad (4.6)$$

Where m is the modulation index. And Vdc is the DC source voltage of the three phase inverter.

The modulating index m can be defined as follow

$$m=Vp/Vt \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.7)$$

where Vp is the peak value of the modulating wave and Vt is the peak value of the carrier wave. Ideally, m can be varied between 0 and 1 to give a linear relation between the modulating and output wave.

4.3 Block diagram of open loop system without PWM

Figure 4.1 below displaying the block diagram of open loop system for controlling the speed using controlled voltage source without PWM.

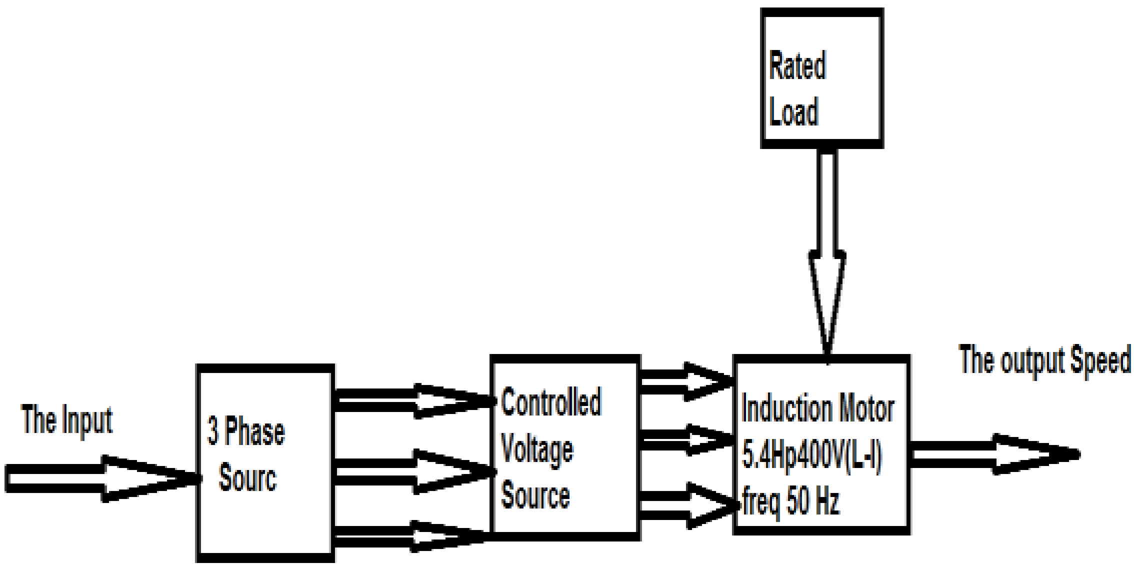

Fig 4.1 the block diagram of the open loop v/f without PWM

4.3.1 Simulink Model system at rated load without PWM:

The figure 4.2 below showing the model system in Simulink/Matlab that represents the block diagram in figure 4.1 above. The rotor speed in rad/s is calculated by Eq.(4.1) which is 149.75 rad/s. the rated current is calculated by Eq.(4.3) which is 10.07 A.

The rated nominal torque is found by Eq.(4.4) which is 26.9 N.m. the constant K is found by Eq(4.5) Which is 0.0012 or 1.2*e-3.The block fcn3 is configured to represent the IM application (Fan) where the torque is proportional to the 1.2*e-3*u(1)^2, u(1) here represents the rotor speed in rad/s. The blocks Fcn1, Fcn2 and Fcn3 which represent the sine waves are configured so that they are apart from each other by 120 deg assuming the first one is reference (phase a).

The repeating sequence is configured to provide ramping function that change gradually with the simulation time (10 s) with parameters as below:

Time values: [0 0.1 10]

Output values: [0 50 50]

The two inputs u(1) and u(2) of the Mux block represent the voltage amplitude and the frequency (ωt) respectively, where ωt=2*pi*f*t.

Using conventional scalar v/f control required additional devices such as controlled voltage source to control both magnitude of voltage and frequency to keep the v/f ratio constant during the operation and avoiding any deep saturation of the motor which results in heating the core and windings which may reduce the life time of the IM or even burning it.

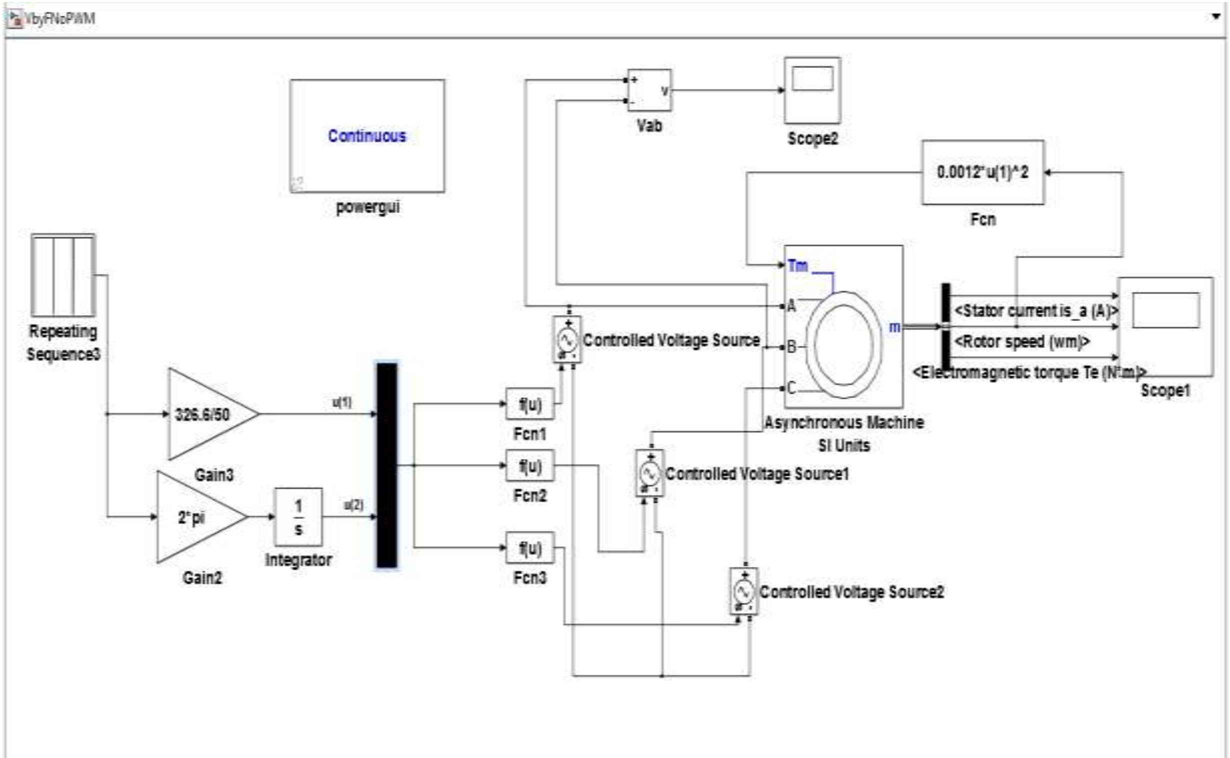

Fig 4.2 The open loop Simulink model of the 3 phase IM without PWM.

4.3.2 Simulation Results of open loop speed control without PWM

The figure 4.3 below shows the results of the scope in Simulink which represents the time responses of the stator current in the phase a (is-a in A), the rotor speed in rad/s and the electromagnetic torque Te in N-m respectively. From the measurements of the oscilloscope the current is as expected. at starting the current is very high above 30 A which is multiple times the rated current then it is settle to its steady state value at 10.07 A rms (the mean value of the noisy signal) as peak 14.24 A after 1 second.

As for the rotor speed measured by the oscilloscope it is also as expected where the calculated rated speed (149.75 rad/s) is reached after 1 s (the simulation time).As for the measured torque Te there are strong oscillation at starting and that normal because the starting torque is always is about 2 to 2.5 the rated torque, but eventually its steady state value is reached which is the mean value of the noisy signal 26.9 N-m corresponding to the load torque at rated speed.

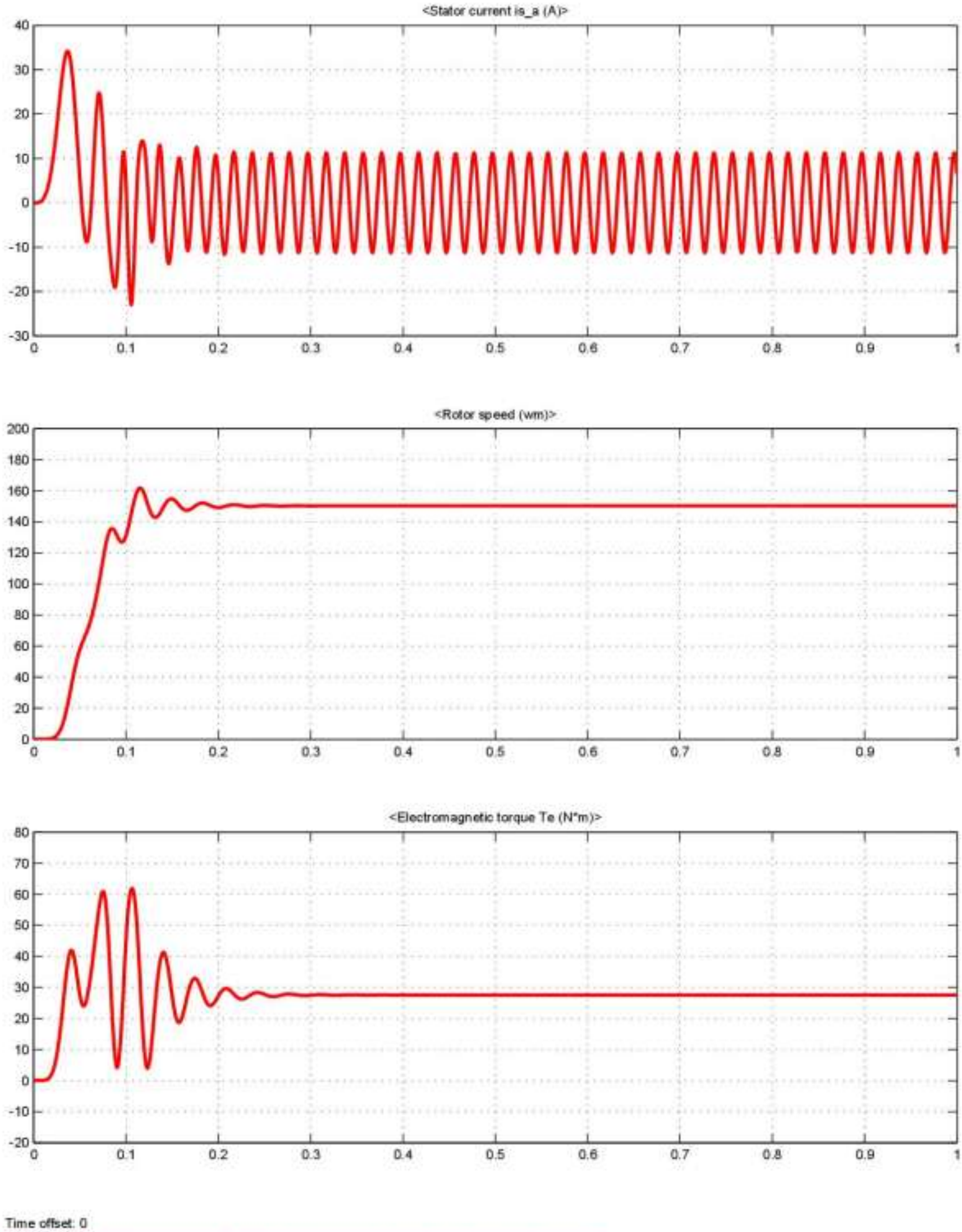

Fig 4.3 The rated stator current, rotor speed (rad/s), and the

electromagnetic torque respectively at rated load torque.

The figure 4.4 below shows the output voltage of the controlled voltage source that enter the IM this voltage wave should be with frequency equal to the fundamental frequency 50 Hz. And peak value of 326V

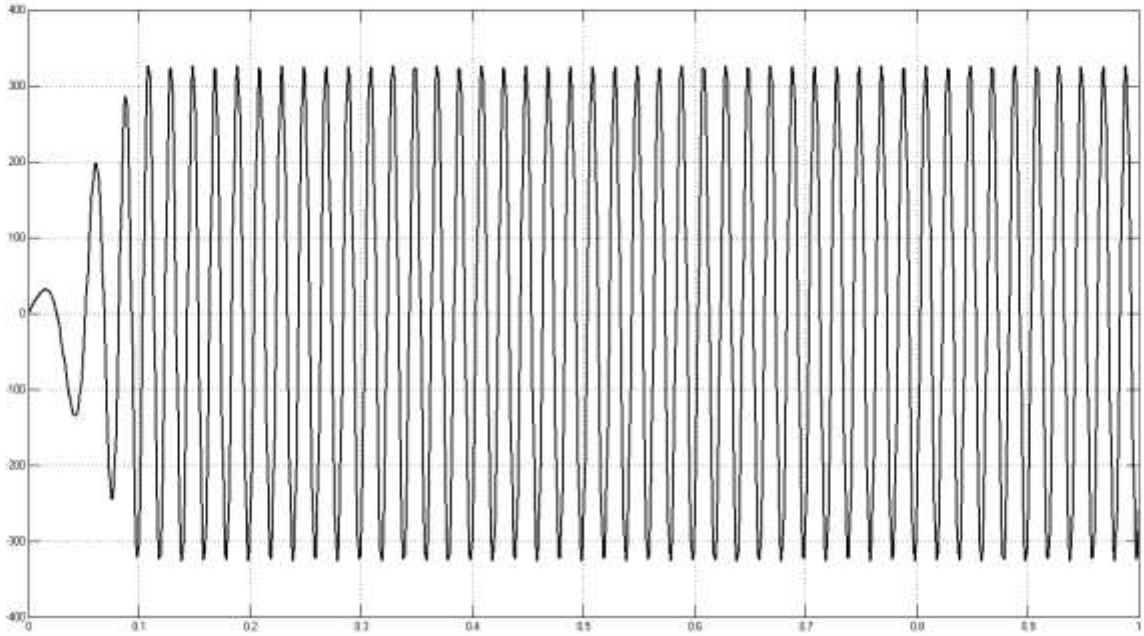

Fig. 4.4 RMS Line voltage at the output of voltage source controller.

The figure 4.5 below shows The fundamental component and total harmonic distortion (THD=46.69 %) of the Vab voltage. The magnitude of the fundamental is 321.2 V with required fundamental frequency 50 Hz which compares well with the theoretical value 326.6 V and that gives good modulating index m = 321.2/326.6=0.98.

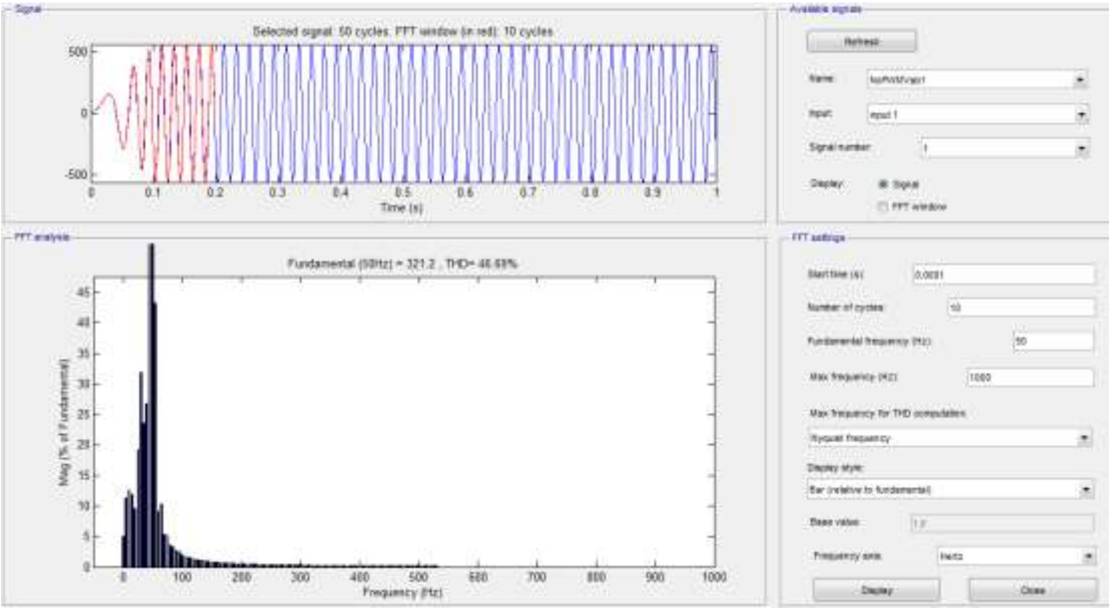

Fig 4.5 The THD in the output voltage of controlled source voltage

4.4 Block diagram of open loop system with PWM (3-phase VSI):

The figure 4.6 below shows the block diagram of open loop system for controlling the speed of the IM using VSI with SPWM.

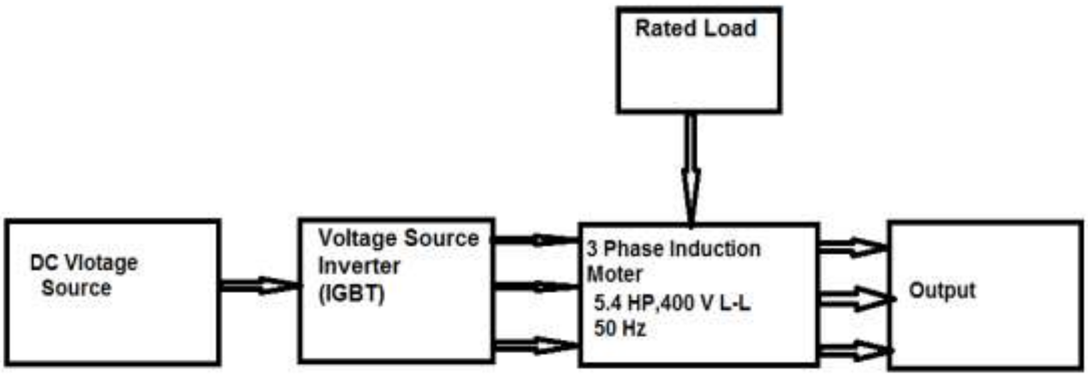

Fig 4.6 The block Diagram of the open loop system(SPWM)

4.4.1 Simulink Model Open Loop (SPWM) (3-Phase VSI):

The figure 4.7 below shows the SIMULIK model of the block diagram in figure 4.6 of open loop speed control with SPWM, Where DC voltage source value is found by Eq (4.6) assuming m=1 which is about 650V,in case of IM this Vdc represents the output of the three phase inverter coming out through the bus-link. the repeating sequence1 is configured in same manner as in the section 4.3.2 to act as ramping function. and so that the function blocks that represent the three sine waves fcn1,fcn2 and fcn3 are phase shifted by 120 deg.

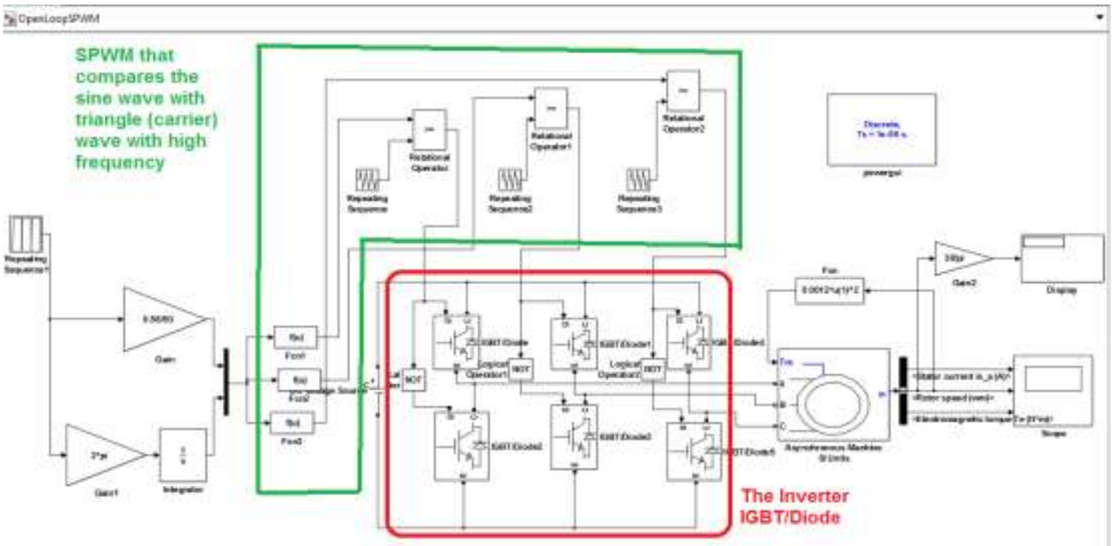

Fig 4.7 open loop Simulink model at rated load

4.4.2 Simulation Results of open loop speed control (3-Phase VSI)

The figure 4.10 below shows the results of all three output responses, at starting it has been noticed that the stator current is increased gradually to high value then it decreases and eventually it reaches its steady-state value of 10.07 A RMS (14.2 A as peak), as for the rotor speed (rad/s) it has been noticed the speed increases gradually in smooth manner with little oscillations and then it reaches its steady-state value of 149.75 rad/s. As for the electromagnetic torque it increases gradually and smooth manner to its starting value with some oscillations but eventually it reaches its steady-state value of 26.9 N-m corresponding to the rated load torque.

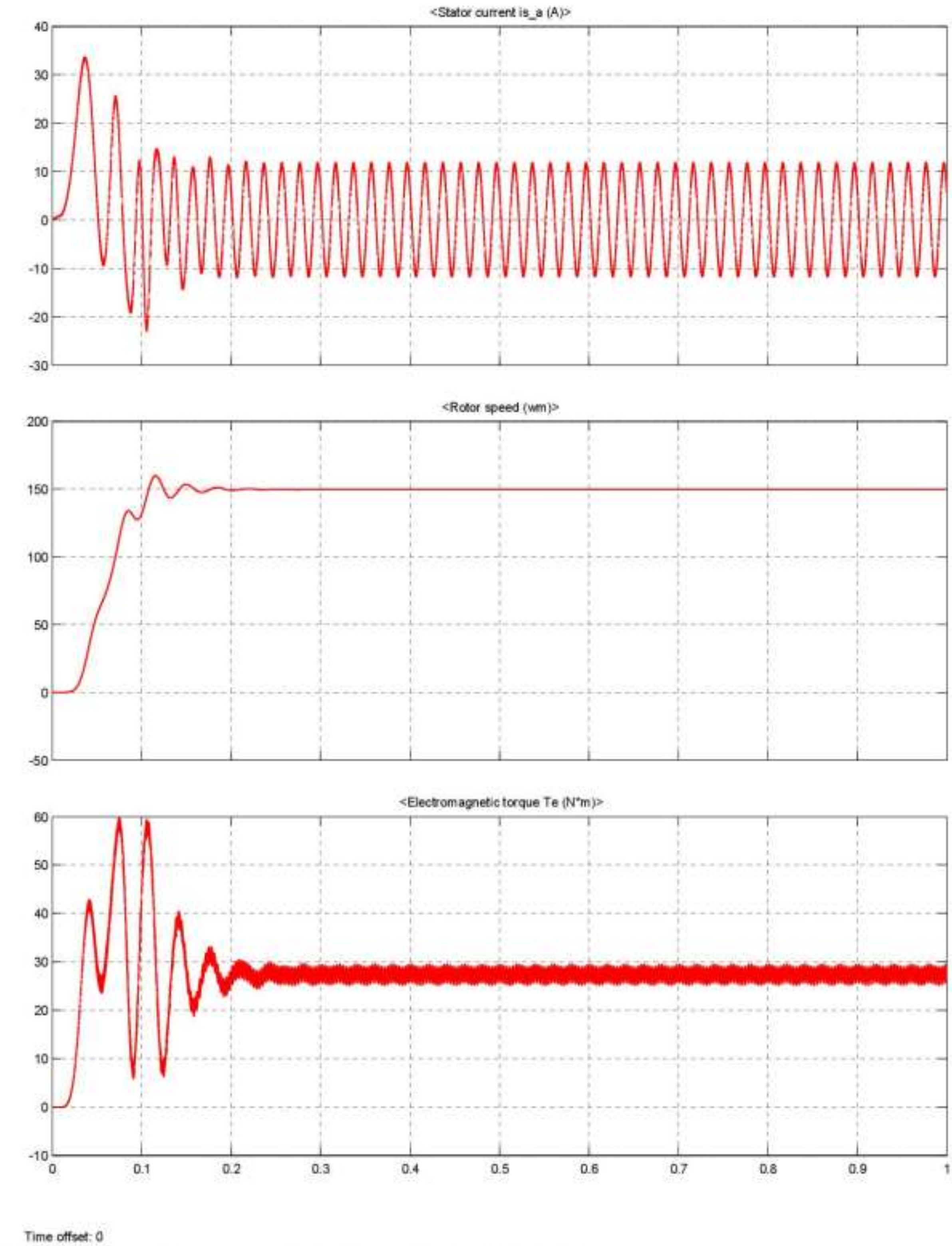

Fig 4.10 the rated stator current, rotor speed(rad/s),and the electromagnetic torque respectively at rated load.

The figure show the THD (Total Harmonics Distortion) of the stator current at magnitude of 10 A and with the fundamental frequency of 50 Hz.

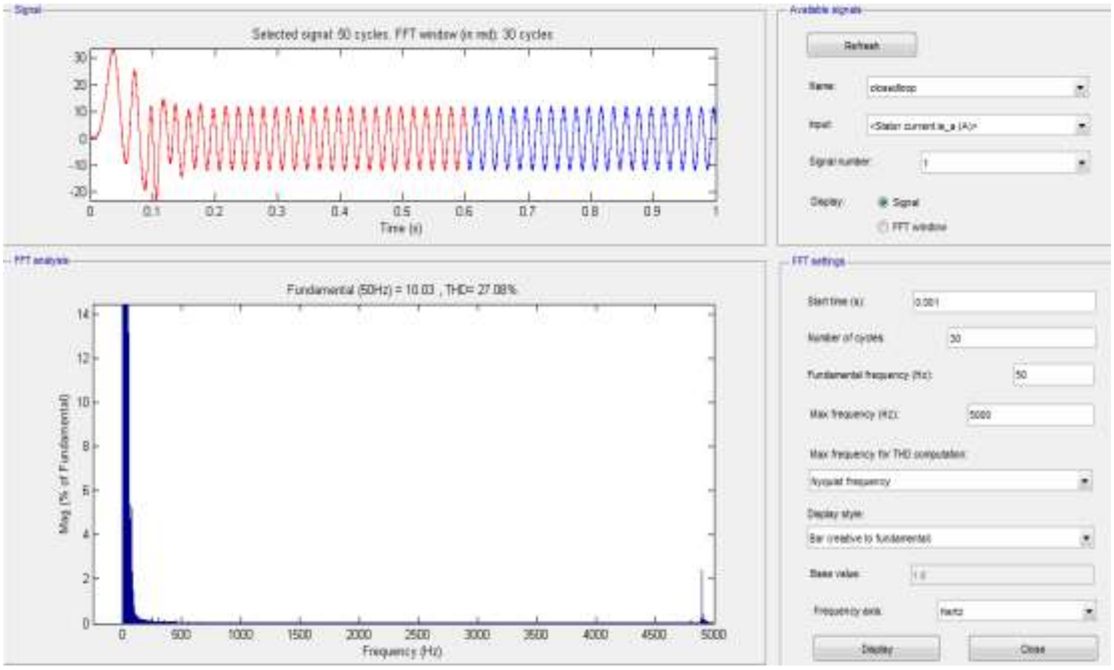

Fig 4.11 THD of the stator current is-a.

The figure shows the output voltage of VSI which gives mean values of 326 V that fit with the maximum magnitude of the RMS voltage value of the IM which is 326.6 V.

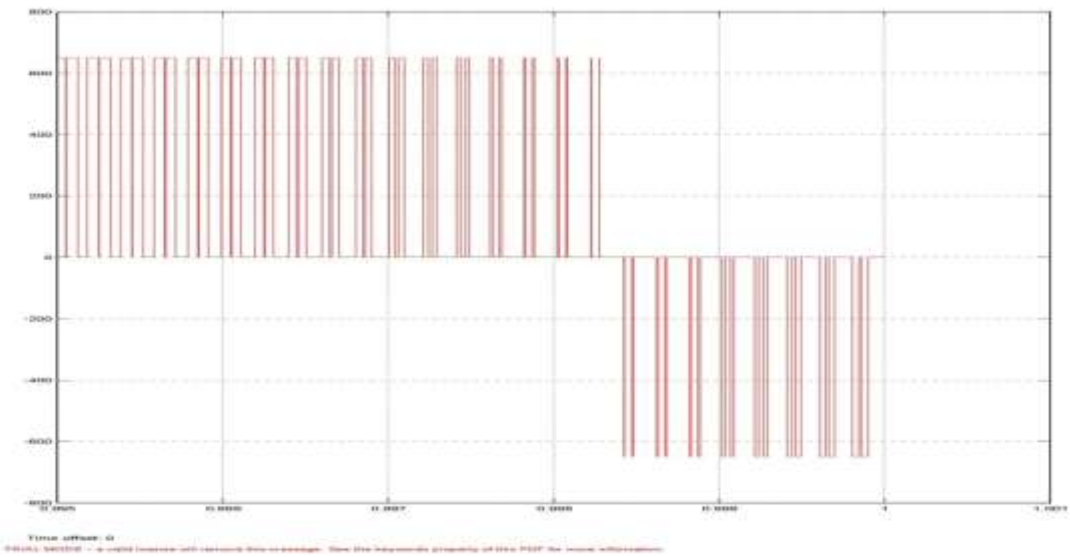

Fig 4.12 The RMS voltage output of the VSI

4.5 Block diagram of close loop system

The figure 4.13 below shows the block diagrams of closes loop system it consists of PI (Proportional Integral) controller, VSI (Voltage Source Inverter) which used SPWM technique and three phase induction motor. In addition to the feedback signal which represent the actual measured speed of the IM. The ref speed it represents the required speed that need to be kept during operating of the IM.

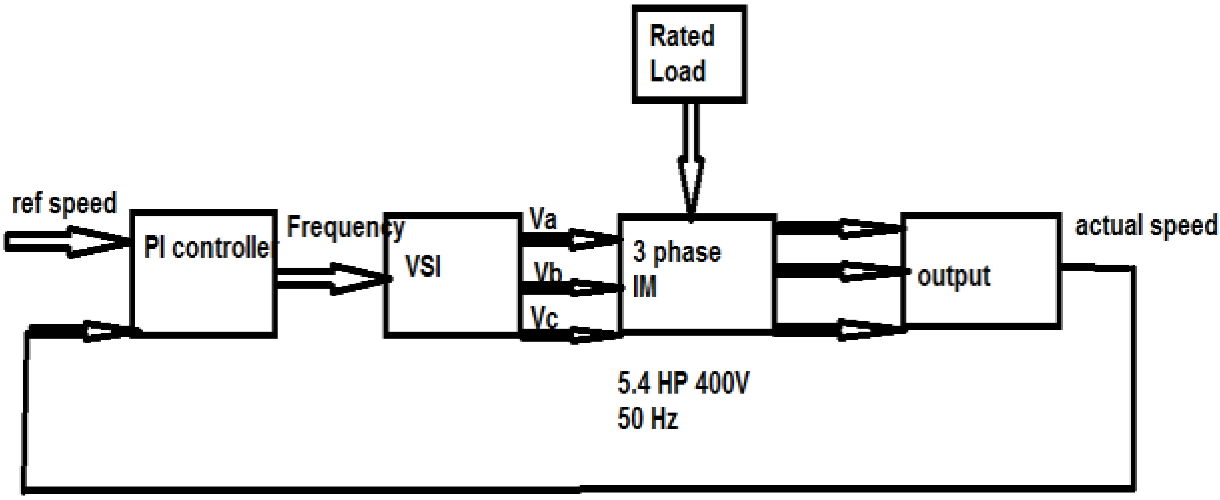

Fig 4.13 The Block diagram of closed loop v/f scalar control of IM

4.5.1 The Simulink Model of closed loop speed control

The figure 4.14 shows the SIMULINK model of the block diagram of the closed loop system mentioned in figure 4.13**.** the constant block represents the reference speed 1400 rpm that must be kept during motor operating.

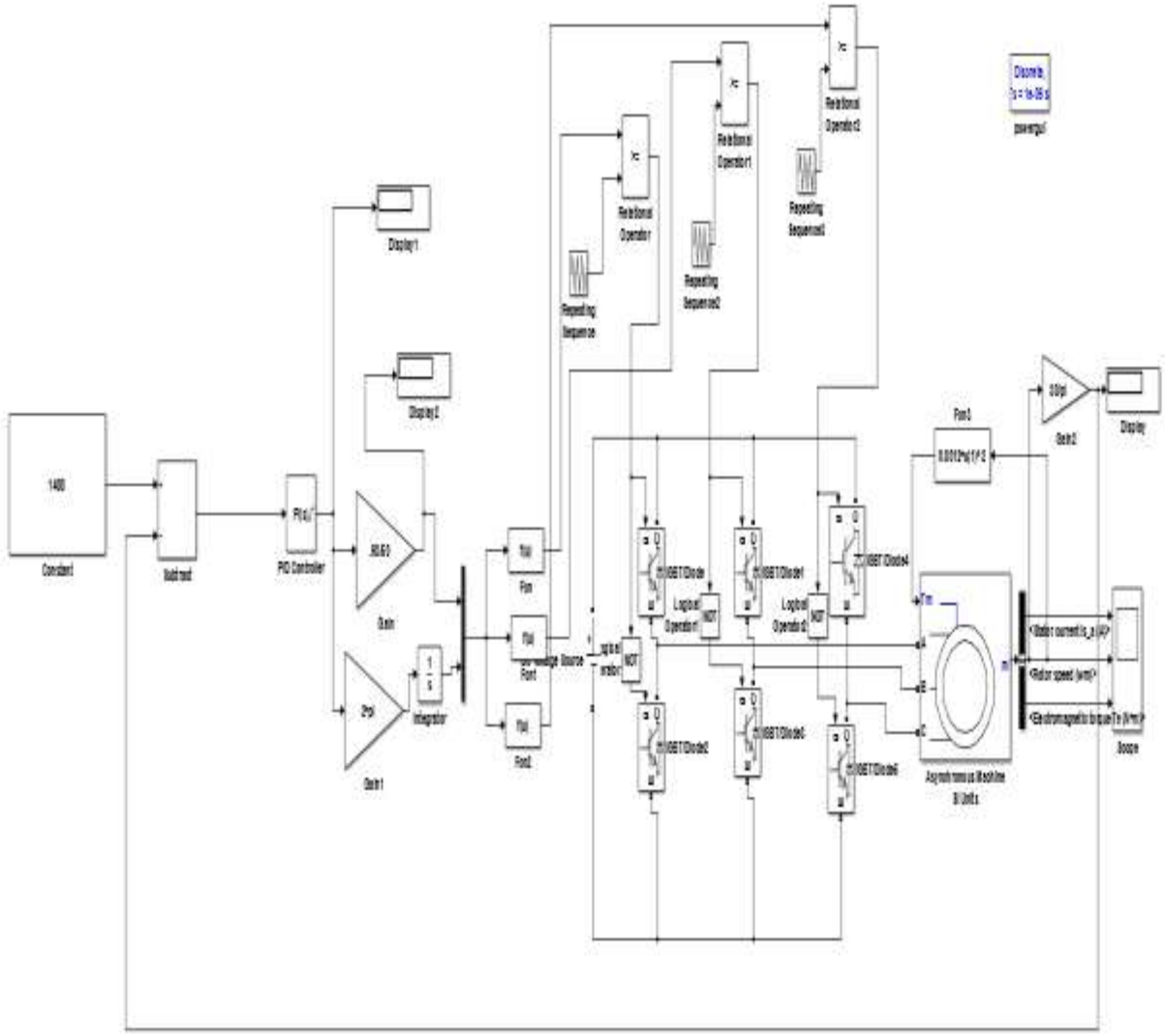

Fig 4.14 The closed loop Simulink model with VSI used SPWM.

The figures 4.15 and 4.16 show how the parameters of the repeating sequences and the functions (sine waves) blocks are adjusted respectively.

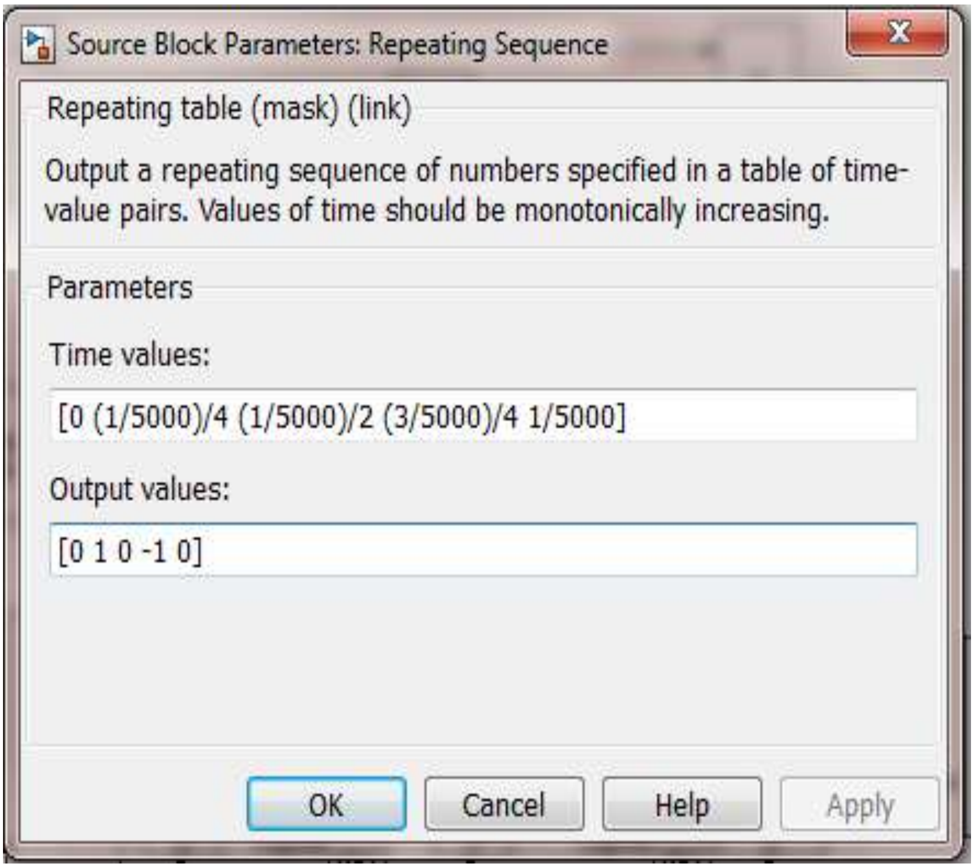

Fig 4.15 Showing the parameters of the Repeating Sequence

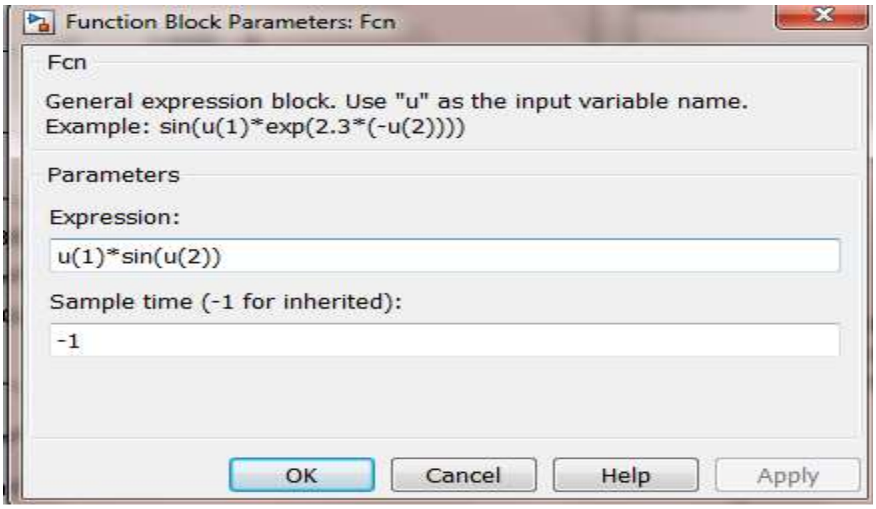

Fig 4.16 Showing the parameters of the Fcn blocks first one

4.5.2 Mathematical model of PI controller

The PI (proportional-plus-integral) controller is one of the most common controller that used in the industry not just to improve the steay-state error and eliminate it but also to improve the dynamic response of the system by adjusting its parameters Kp and Ki the desired response can achieved.

The equation of the PI controller is:

$$U(s) = (Kp + Ki/s)E(s) \quad \text{..........(4.8)}$$

Where U(s) is the output of the PI controller which represent the control signal and Kp is the proportional gain and Ki is the integral gain and E(s) is the error signal which act as the input of the PI controller.

The parameters values of Kp and Ki are adjusted using trail and error starting at random chosen values to obtain the best value that meet the requirement and keeping the desired input speed (the reference input) at 1400 rpm, and the optimized values of the parameter are found as follow

Kp = 0.0001 and

Ki = 0.2405

4.5.3 Simulation Result of close loop speed control at rated load

The figure 4.17 shows the results of oscilloscope for all three time responses of the stator current (A), the rotor speed (rad/s) and the electromagnetic torque Te (N-m). It has been noticed that the starting current is-a is reduced very much comparing to the open loop control speed which save energy in the electrical bill.the rotor speed also increases gradually and then it kept and follows it reference value and stay at speed of 1400 rpm. As for the starting torque it increases gradually in smooth manner to its starting value then it reaches its steady state value which is 26.9 N-m

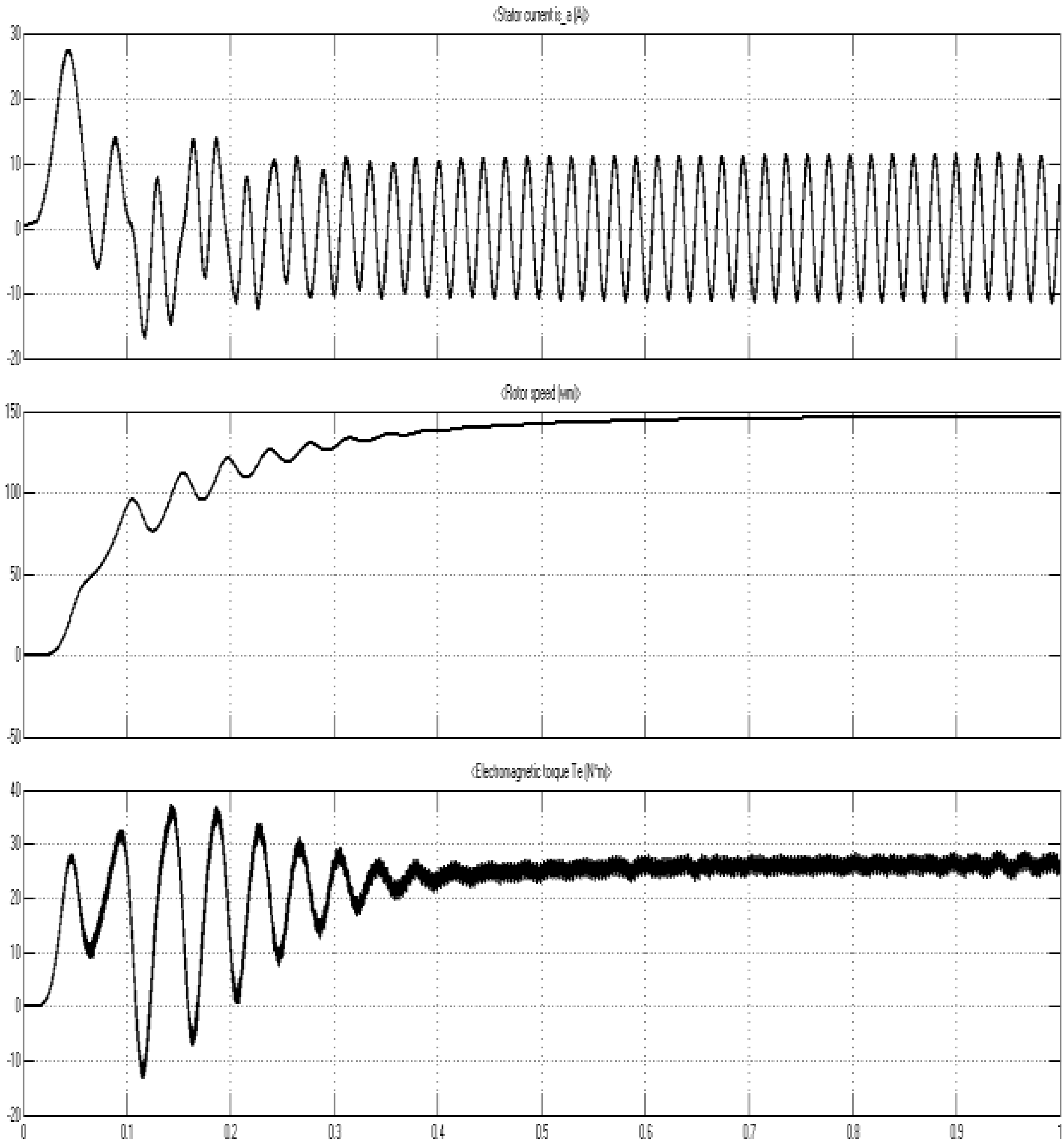

Fig 4.17 display the rated stator current, speed rotor and the torque at rated load

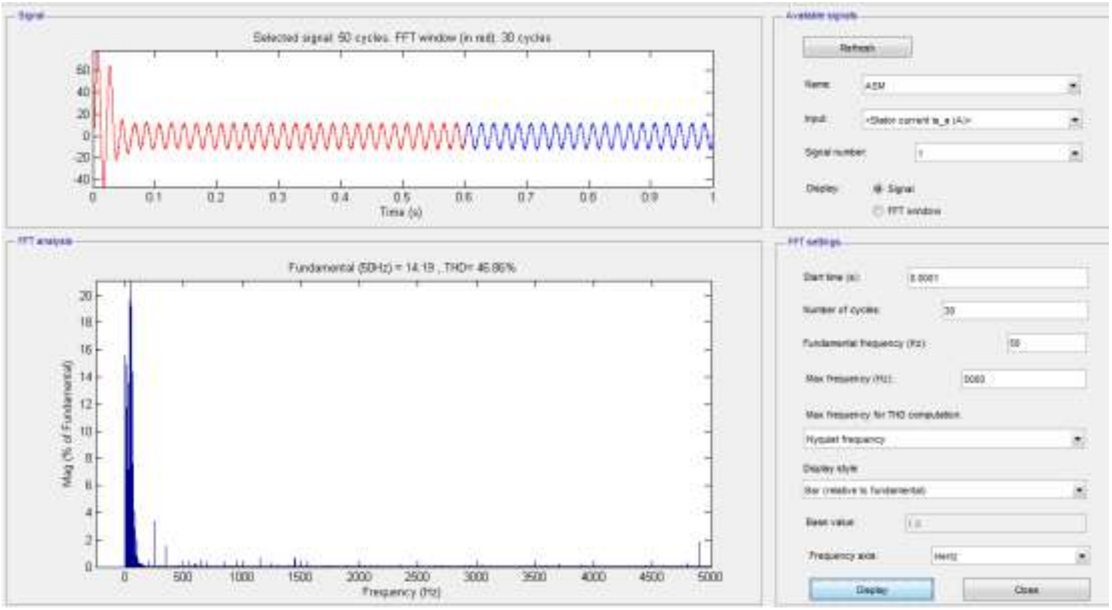

Fig 4.18 Display the stator current is for phase A and the THD

From the results it has been found thatKp and Ki both affect the response of the closed loop system where Kp causes increase in the maximum output of the transient response and cannot eliminate the steady state error also it reduces the rise time, whereas the Ki can eliminate the steady state error but on other hand it may cause increasing the output oscillation which may results in unstable system, also the effect of Ki take long time to response which mean slow response time. By choosing the correct values of the parameters of the PI controller It has been found that motor measure speed efficiently follows the reference speed of 1400 rpm. In addition to that the starting current is much reduced.

It can be concluded that by proper designing of PI (Prortional Integral) controller help much in reducing and eliminating the steady state error and reducing the stator current thus high performance and good speed response is achieved.

As for open loop it considered cheap and effective and can treats constant speed application, but on the other hand the starting current in the open loop system is high that causes drop voltage and makes the life time of the IM is shorter. In contrast with the closed loop PI controller system the starting current is very less and PI controller can improve steady state but the PI controller may cost more.

The figures 4.19 and 4.20 showing the parameters of the IM that used in the Simulink

4.5.4 The parameters of the IM used in Simulink

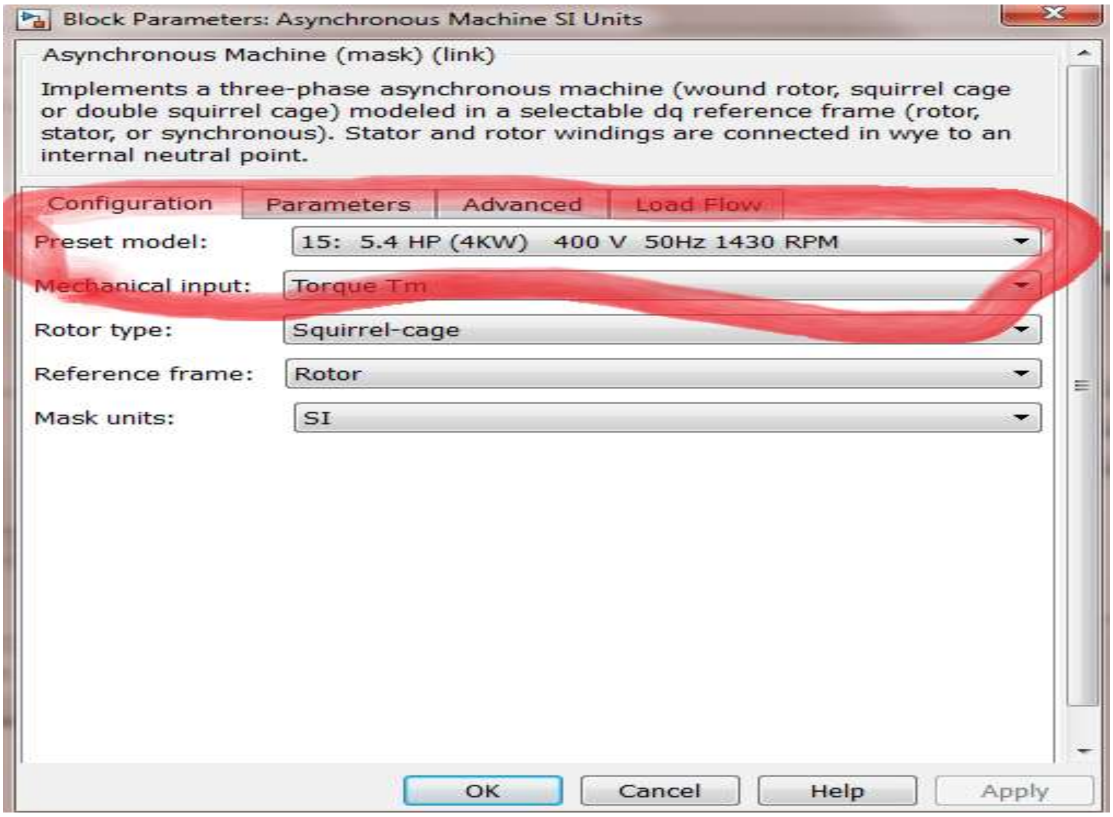

Fig 4.19 showing the parameter of used IM

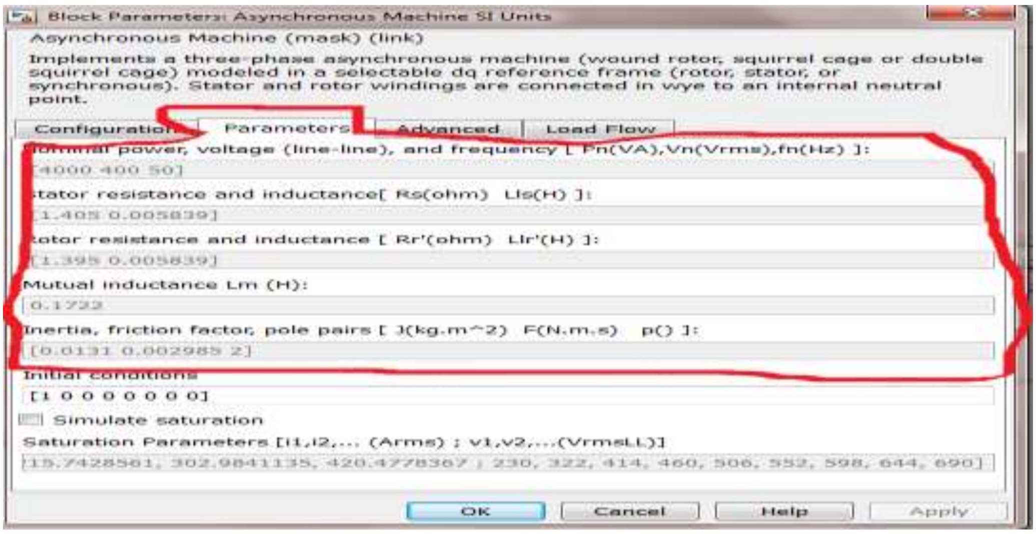

Fig 4.20 showing values of resistors, inductance of rotor and stator

CHAPTER 5
CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The v/f scalar speed control of three phase induction motor has been studied first without PWM then with SPWM for open and close loop. It can be concluded that by proper designing a PI speed controller help much in reducing and eliminating the steady state error and reducing the stator current thus high performance and good speed response is achieved.

As for open loop it considered cheap and effective and can treats constant speed application, but on the other hand the starting current in the open loop system is high that cause drop voltage and make the life time of the IM is shorter. In contrast with the closed loop PI controller system the starting current is very less and PI controller can improve steady state but the PI controller can cost more.

The optimal choice of the electric motor and the adequate VFD, and how to deal with them determine the extent of the electrical engineer`s professionalism.

The device used in this application provides very low switching losses, and also very fast operating speed. It is inexpensive versus much benefits whose obtained. Higher operating speed gives higher performance that is high starting torque and good performance at lower speeds. Furthermore, we can save energy up to maximum limit by controlling the motor speed. Additional benefits obtained in the followings:

i. Better process control and regulation.
ii. Speeding up or slowing down a machine or process.
iii. Inherent power-factor correction.
iv. Bypass capability in the event of an emergency.
v. Protection from overload currents.
vi. Safe acceleration.

Installation profile and wiring (diagrams, quantities, and sizing) tend with the corresponding (Induction Motor and Variable Frequency Drive).

5.2 Recommendations

- Its recommended when using V/F control speed to consider first the cost so if good dynamic performance is required then it’s better to use Space vector technique, whereas in case of constant speed it is enough to use V/F scalar.
- This application is ready for using PID controller.
- To meet the modern control method it is available for using PLC or Fuzzy control systems.

References:

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[3] NCSW Publications: 1924 – 1962: Authors, Bibliography, Key words.

[4] www.greenfoodpi.com

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[9] M. V. Bakashi, U. A. Bakashi "Modern Control Theory".

APPENDIX

Physical and Environmental Issues

VFDs must be selected to ensure that they have adequate protection from their environmental conditions. VFDs are usually mounted into an electrical enclosure with other electrical devices, or as a standalone unit in its own enclosure. NEMA has determined standard enclosure types to protect electrical equipment and to protect people from exposure to that equipment for standard environmental conditions.

They are designated as in Table.

Type	NEMA Enclosure
1	General Purpose-indoor
2	Drip proof-indoor
3	Dust tight, Rain tight, Sleet tight-Outdoor
3R	Rain proof, Sleet Resistant-Outdoor
3S	Dust tight, Rain tight, Sleet proof-Outdoor
4	Watertight, Dust tight, Sleet Resistant
4X	Watertight, Dust tight, Corrosion Resistant
5	Dust tight-indoor
6	Submersible, Water tight, Dust tight
6P	Watertight-Prolonged Submersion
7	Class 1, Group A, B, C or D Hazardous Locations, Air-Break-Indoor
8	Class 1, Group A, B, C or D Hazardous Locations, Oil-immersed-Indoor
9	Class II, Group E, F, or G Hazardous Locations Air-Break-Indoor
10	Bureau of Mines
11	Corrosion-Resistant and Drip proof Oil-Immersed
12	Industrial Use, Dust tight and Drip tight-Indoor
12K	Industrial Use, Dust tight and Drip tight with knockouts
13	Oil tight and Dust tight-Indoor

Table: NEMA's Standard Enclosure Types

More detailed description for commonly used enclosure types:

Type 1—Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts and to provide a degree of protection for the equipment inside the enclosure against the ingress of solid foreign objects (falling dirt).

Type 2—Enclosures constructed for indoor use to provide a degree of protection to personnel against access to hazardous parts, to provide a degree of protection for the equipment inside the enclosure against the ingress of solid foreign objects (falling dirt) and to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (dripping and light splashing).

Type 3—Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts, to provide a degree of protection of the equipment inside the enclosure against the ingress of solid foreign objects (falling dirt and windblown dust), to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (rain, sleet, snow) and that will be undamaged by the external formation of ice on the enclosure.

Type 4X—Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against access to hazardous parts, to provide a degree of protection for the equipment inside the enclosure against the ingress of solid foreign objects (windblown dust), to provide a degree of protection with respect to harmful effects on the equipment due to the ingress of water (rain, sleet, snow, splashing water, and hose directed water), to provide an additional level of protection against corrosion and that will be undamaged by the external formation of ice on the enclosure.

In addition to protection from contamination and the ingress of dirt, dust, water, etc., operation within the following limits would be considered usual operating conditions:

. Exposure to an ambient temperature in the range of -15˚C to 40˚C.

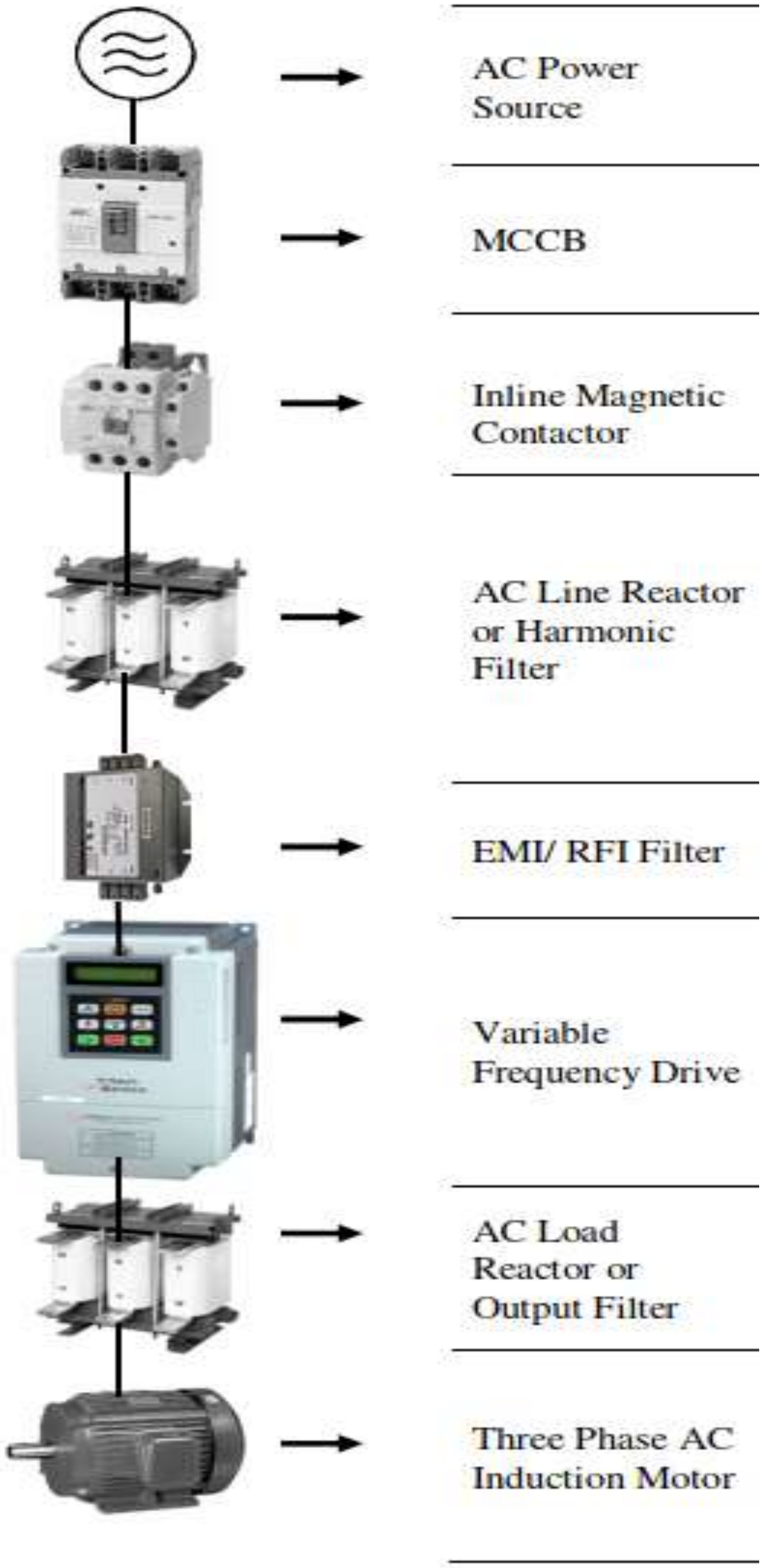
. Exposure to an altitude that does not exceed 3300 feet (1000 meters).

. Installation on a rigid mounting surface.

. Installation in areas or supplementary enclosures that do not seriously interfere with the ventilation of the drive.

Basic Configurations

The following are the most common devices used in motor control branch operated by VFD. Adequate peripheral devices must be selected and correct connections made to ensure proper VFD operation. An incorrectly applied or installed VFD can result in system malfunction or reduction in product life as well as component damage.


AC Power Source
MCCB
Inline Magnetic Contactor
AC Line Reactor or Harmonic Filter
EMI/ RFI Filter
Variable Frequency Drive
AC Load Reactor or Output Filter
Three Phase AC Induction Motor

Installation and Wiring

i. Installation

Safety Precautions:

- Handle VFD with care to prevent damage to the plastic components. Do not hold VFD by the front cover.

- Do not mount VFD on the equipment with excessive vibration above 5.9 m/sec2.

- Install VFD in a location where temperature is within the permissible range 14~104°F (-10~40°C).

- Install it on a non-combustible surface because VFD generates heat during normal operation.

- Mount VFD vertically (top up) for proper heat dissipation. Provide sufficient clearance for an airflow around VFD. Increase minimum clearance by one inch for 50~75HP VFDs, by two inches for 100~150HP VFDs, by three inches for 200~300HP VFDs, by four inches for 350~700HP VFDs to provide sufficient cooling airflow (look fig.4.8).

- Do not mount VFD in direct sunlight or near other heat sources.

- VFD shall be mounted in a Pollution Degree 2 environment. If VFD is going to be installed in an environment with a high probability of dust, metallic particles, mists, corrosive gas or other contaminants, the VFD must be mounted inside the appropriate electrical enclosure with proper NEMA, UL or IP rating and adequate cooling. If VFD is mounted inside enclosure, the maximum allowed ambient temperature would be 12°F less than VFD rating (104°F-12°F= 92°F). If VFD is de-rated by 20%, the maximum allowed ambient temperature for it will be increased to 122°F and for the enclosed VFD to 110°F (122°F-12°F= 110°F). If VFD is enclosed in ventilated enclosure and installed in direct sun light, the maximum ambient temperature for gray enclosure will be approximately 25°F less than VFD rating (104°F-25°F= 79°F) and for 20% de-rated VFD

97°F (122°F-25° F= 97°F). Thus, the VFD for direct sun light installation should be enclosed in an air-conditioned enclosure. For white enclosures the temperature difference is about 15°F.

- Mount VFD using proper screws or bolts.

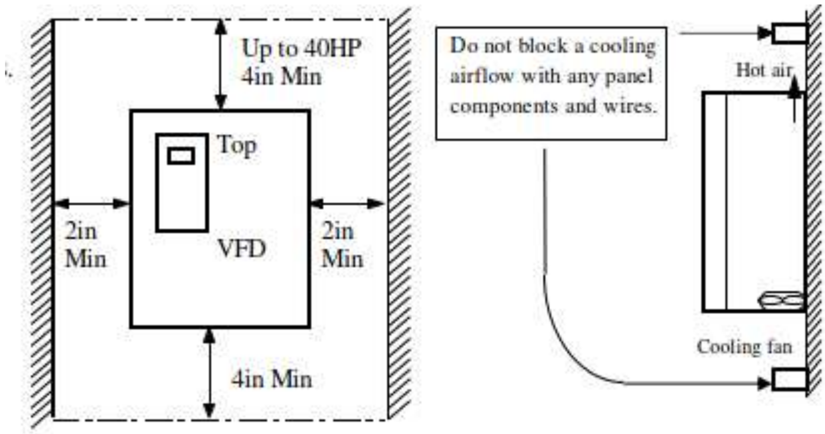


Figure VFD installation

ii. Wiring

Safety Precautions:

- Do not connect input power to VFD Motor Terminals U, V, and W otherwise VFD can be damaged.
- Do not run input power and motor wires in the same conduit, otherwise the VFD can malfunction or be damaged.
- Do not run input power wires or motor leads for multiple VFDs in common conduit.
- Do not connect power factor correction capacitors, surge suppressors, or RFI filters on the VFD output. These devices can trigger some VFD faults or even damage the VFD.
- Use ring type terminals for the VFD power wiring.
- Do not leave wire fragments, metal shavings or other metal objects inside the VFD, otherwise VFD can be damaged.

- Size power wire to maintain a voltage drop less than 2% at VFD or motor terminals.

General Wiring Standards

Sensitive equipment should not be installed within 1 foot of the VFD and its associated input and output cables. Parallel runs ofany control signal cables and the input and output cables should be avoided.

Where this is not possible then the control cablesshould be correctly shielded but not installed with 1 foot of the input and output cables of the VFD. See Fig.

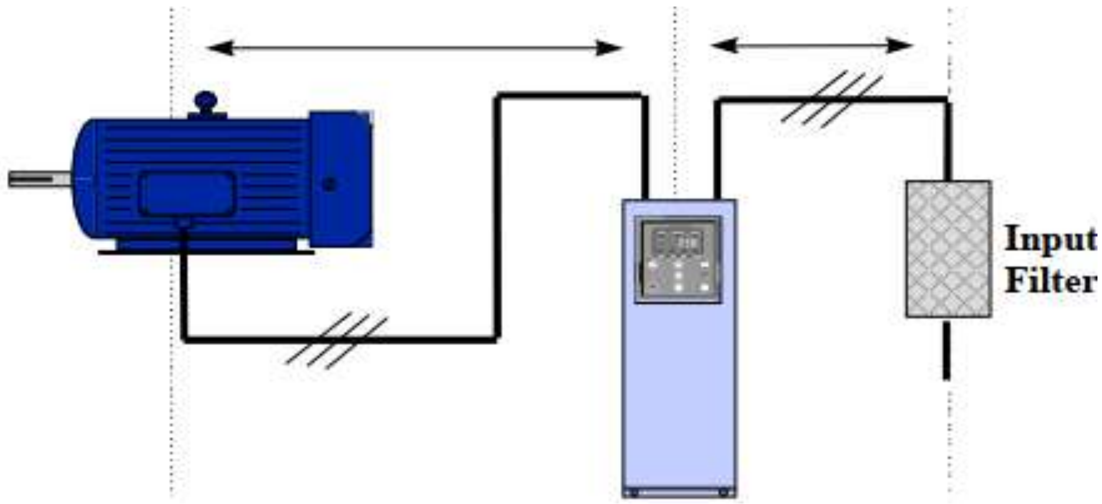


Fig. Distances to keep as short as possible.

Where control signal cables need to cross VFD input and output cables this should be done at right angles with no parallel runs. See Fig.

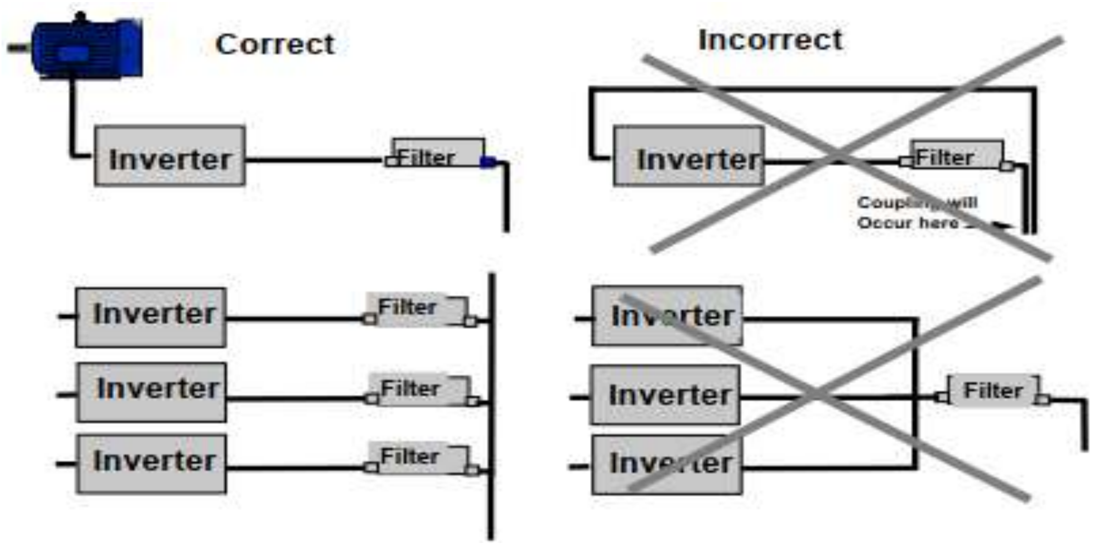
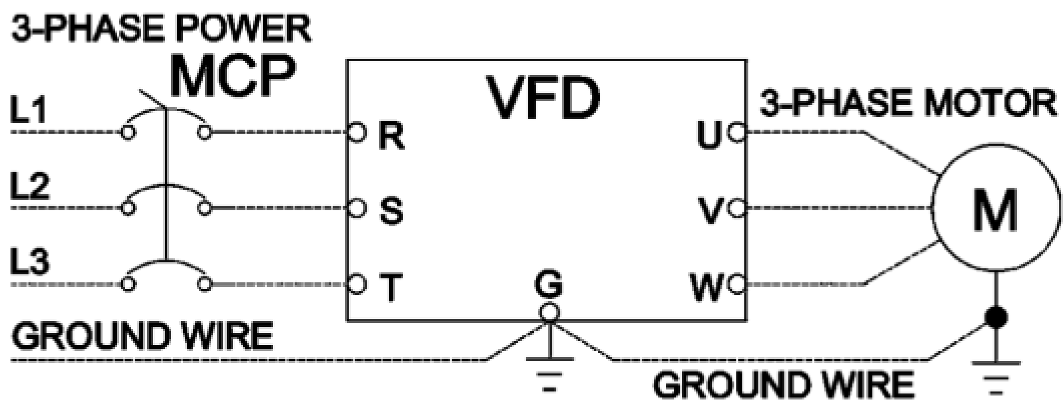
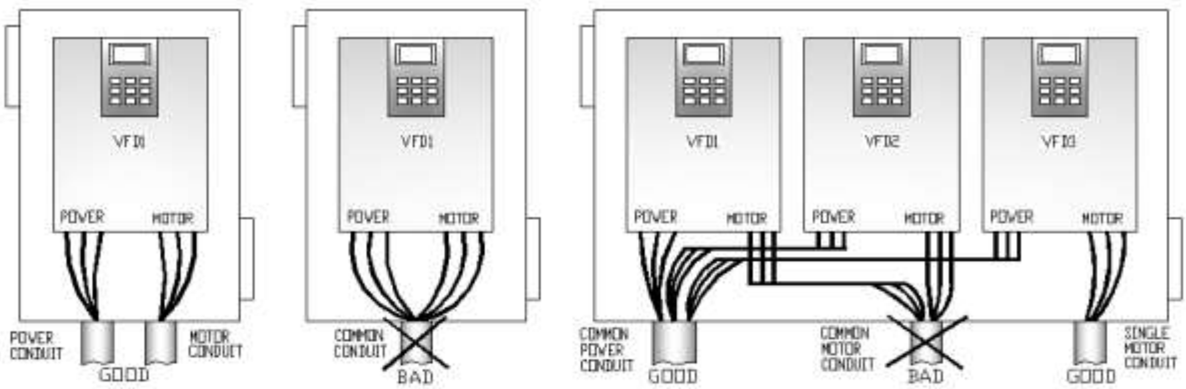


Fig. Locating filter and VFD control signal cables.

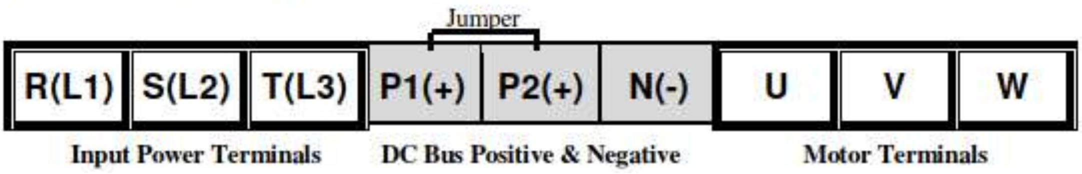
Basic Power wiring for 7.5~700HP (5.5~450kW) VFDs.





VFD can malfunction or be damaged if motor and power wires are in the same conduit or motor wires from two or more VFDs are in the same conduit!

Power terminals for 50~125HP (400V/600V) VFDs



Notes:

a) Do not connect any wires except dynamic braking unit to P1(+), P2(+) and N(-) terminals.

b) Do not remove the jumper between terminals P1(+) & P2(+) except for DC bus reactor wiring.

Grounding:

a) Connect a dedicated ground wire from power transformer or power distribution panel to VFD ground terminal and dedicated ground wire from VFD to the motor for ground fault protection proper operation.
If metalconstruction or conduits are used as a ground leak current path, the VFD can have inadequate grounding and ground fault protection.

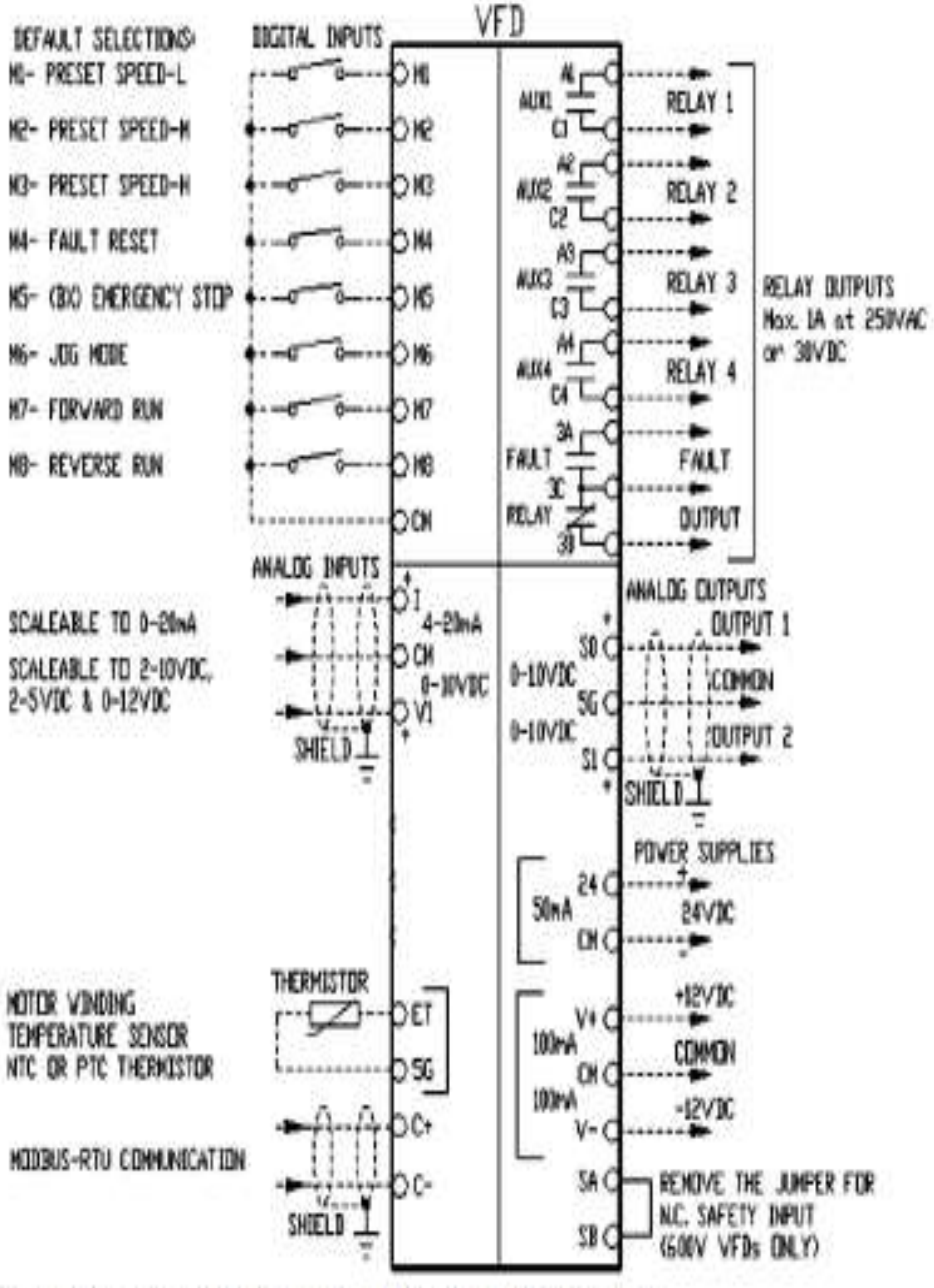
b) Ground VFD to the power source ground and motor ground to avoid electrical shock. The ground impedance for 230VAC VFDs should be less than 100 Ω and 10 Ω for 460VAC and 600VAC VFDs.

c) Connect ground wire first before any other wires and only connect it to the dedicated ground terminal of the VFD. Do not use the case or the chassis assembly screws for grounding.

d) VFD Grounding wire should be as short as possible.

e) Do not install a ground rod at VFD package if it is not a service entrance rated panel, otherwise the VFD cannot provide proper ground fault protection or it can intermittently trip on Ground Fault.

Basic Control wiring for 50~700HP (37~525kW) VFDs



Note: Use terminal CM for analog inputs and ±12VDC power supply common.

Speed Control Potentiometer Wiring

VFD speed control potentiometer wiring with VFD internal 12VDC power supply (see fig. 4.11). The recommended potentiometer parameters: Resistance from 1kΩ to 10kΩ and Wattage 0.5W or higher. The multi-turn potentiometer provides more precise speed adjustment compare to a single-turn potentiometer. The internal power supply provides 12VDC and in order to have full range of speed control by potentiometer, change the I/O-04 parameter from 10VDC to 12VDC.

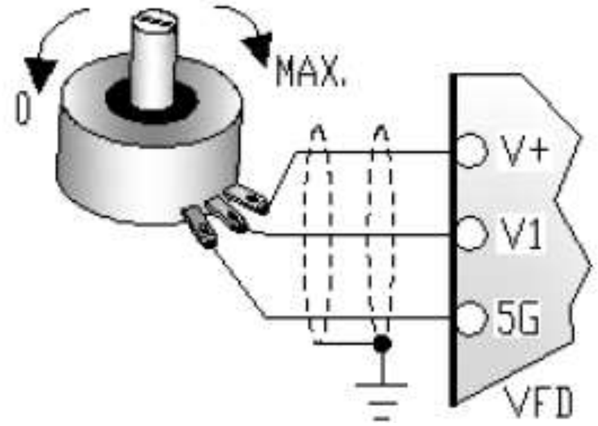
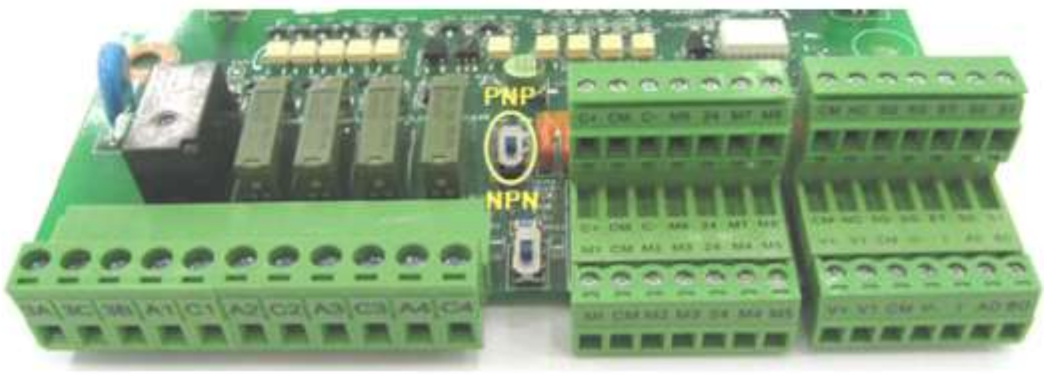
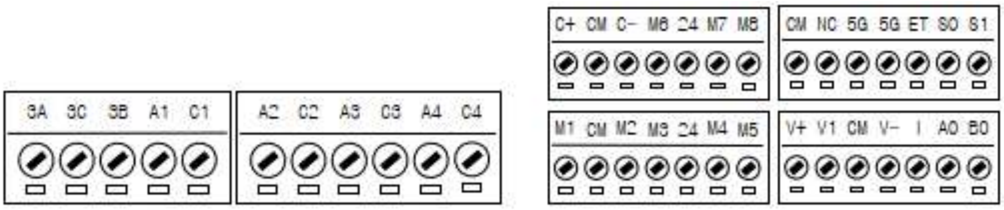


Figure Potentiometer Wiring

Digital and analogue control circuits terminals layout

50~700HP (37~525kW) 400V and 50~150HP (37~110kW) 600V Class VFDs





Control Inputs and Outputs Description

Type		Symbol	Name	Description
Input signal	Digital Inputs Selections	M1, M2 & M3[1]	Programmable Digital Inputs 1, 2 & 3	Multi-Function Programmable Digital Inputs. (Factory setting: Multi-Step Frequencies 1, 2 & 4)
		FX [M7][1]	Forward Run Command	Forward Run When Closed and Stopped When Open.
		RX [M8][1]	Reverse Run Command	Reverse Run When Closed and Stopped When Open.
		JOG [M6][1]	Jog Run	Runs at Adjustable Jog Frequency when the Jog Signal is ON. The Direction is set by the FX (or RX) Signal.
		BX [M5][1]	VFD Disable	When the BX Signal is ON the Output of VFD is Turned Off. When Motor uses an Electrical Brake to Stop, BX is used to Turn Off the Output Signal. Take caution when BX Signal is OFF (Not Turned Off by Latching) and FX Signal (or RX Signal) is ON. If so, motor continues to Run.
		RST [M4][1]	Fault Reset	Used for Fault Reset.
		CM	Digital -24VDC Common	All CM (digital inputs common) terminals are connected together internally.
		24	+24VDC Power Supply	24VDC power supply for digital inputs and external loads with maximum current consumption of 50mA
		V+ & V- [2]	Bipolar +/-12VDC 100mA Power Supply	DC power to sensors, potentiometer etc. Provides +12VDC and -12VDC corresponding to Common terminal 5G (CM)[2]
	Analog Inputs	V1[2]	0-10VDC Analog Input Impedance 20 kΩ	Analog input for speed reference or process feedback transducer can be set to any configuration up to 12VDC.
		I [2]	4-20mA Analog Input. Impedance 249Ω	Analog input for speed reference or process feedback transducer can be set to 0-20mA range.
		5G (CM) [2]	Analog I/O Common Terminal	Common Terminal for Analog Inputs, outputs and +12VDC and -12VDC power supplies.
	Motor sensor	NT (ET)	External motor thermal sensor	Motor thermal sensor input is used to prevent motor from overheating by monitoring NTC or PTC thermistor sensor.
		5G	Common for NT(ET)	Common Terminal for External motor thermal detection.
RS485 terminal		C+ & C-	RS485 signal (High and Low)	RS485 signal (See RS485 communication in the manual for more details.)
Output signal	Voltage	S0, S1, 5G	Programmable analog Voltage Output	Voltage output for one of the following: Output Frequency, Output Current, Output Voltage, DC Link Voltage. Default is set to Output Frequency. (Maximum Output Voltage range is 0-12V at 1mA).
	Relay Contacts	3A, 3C, 3B	Fault Contact Output	When VFD trips, the fault relay will be activated. Normal contact state: 3A-3C Open and 3B-3C Closed. Contact ratings: 1A up to 250VAC/30VDC
		A1/C1~A4/C4	Programmable Digital Outputs	Programmable Digital Output Relays. Contact ratings: 1A up to 250VAC/30VDC

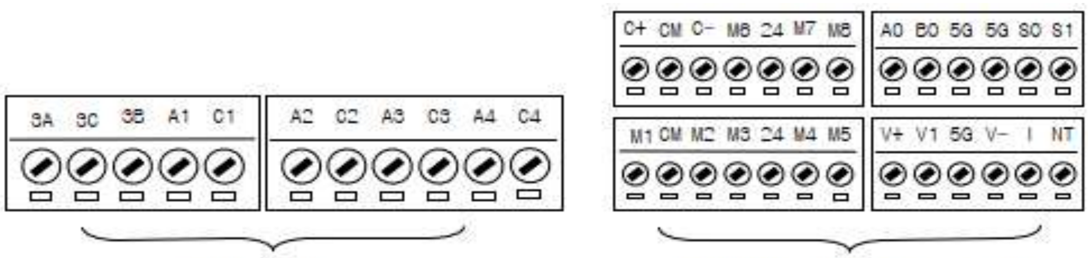
Wire sizes and terminal lugs

VFD capacity HP (kW)	Screw Size Metric	Screw Torque kgf · cm	Screw Torque lb · in	Wire size R(L1), S(L2), T(L3) mm²	Wire size R(L1), S(L2), T(L3) AWG or kcmil	Wire size U, V, W mm²	Wire size U, V, W AWG or kcmil
30~40HP (22~30kW)	M8	61.2~91.8	**53.1~79.7**	22	**4**	22	**4**
50~75HP (37~55kW)	M8	67.3~87.5	**58.4~75.9**	38	**2**	38	**2**

Control Circuits Wiring

The CM and 5G terminals are isolated from each other and from the ground. Do not connect these terminals to the ground, otherwise it can cause some electrical noise in control circuits and unstable VFD operation or malfunction. Use shielded cable or twisted wires for 24VDC digital control circuits wiring and separate these wires from the main power and motor wiring and other high voltage circuits. Use shielded cable for analogue control circuits with shield connected to the ground.

Control terminals layout and recommended wire gauge.



Relay outputs
22 AWG (0.33mm²) ~ 14 AWG (2.0mm²)

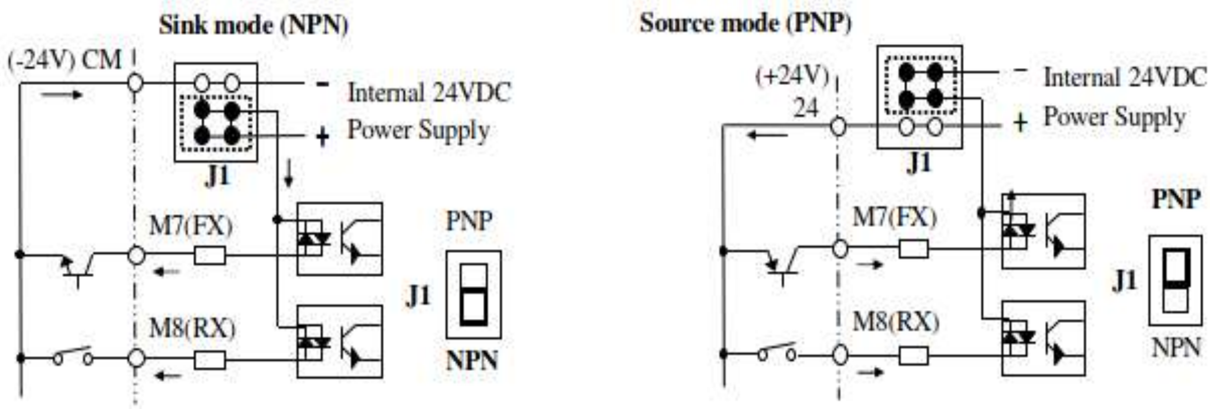
Digital and analog control
28 AWG (0.08mm²) ~16 AWG (1.25mm²)

NPN and PNP 24VDC Digital Control Modes

P Series provides Sink or Source (NPN or PNP) modes for digital control inputs. The digital inputs configurations are selectable by J1 switch between Sink mode (NPN) and Source mode (PNP).

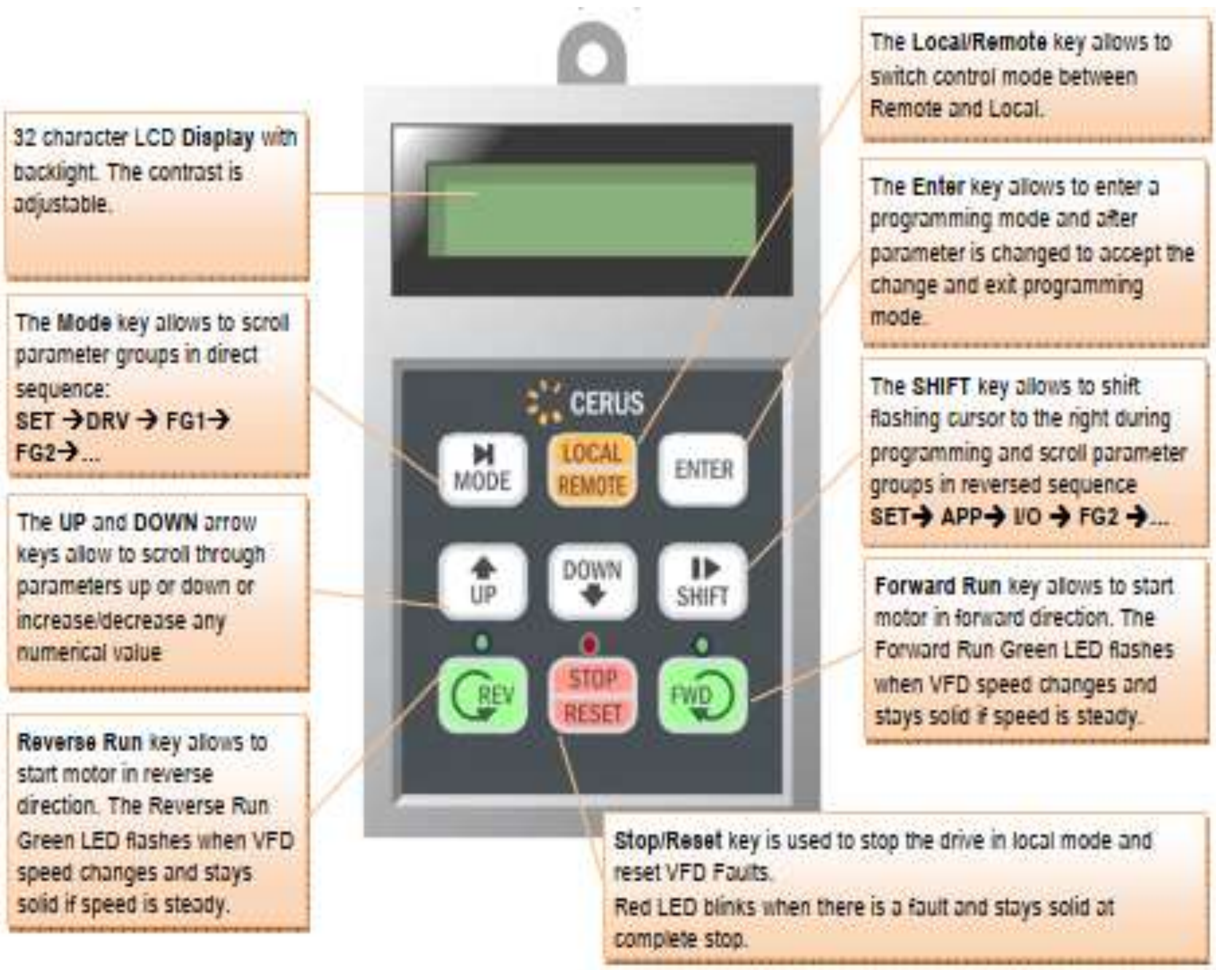
• Sink (NPN) mode. Put J1 switch down to NPN position. CM terminal (-24VAC) is common terminal for digital inputs. The factory default is Sink mode (NPN).

• Source (PNP) mode with internal power supply. Put J1 switch up to PNP position. Terminal 24 (+24VDC) is common terminal for digital inputs.



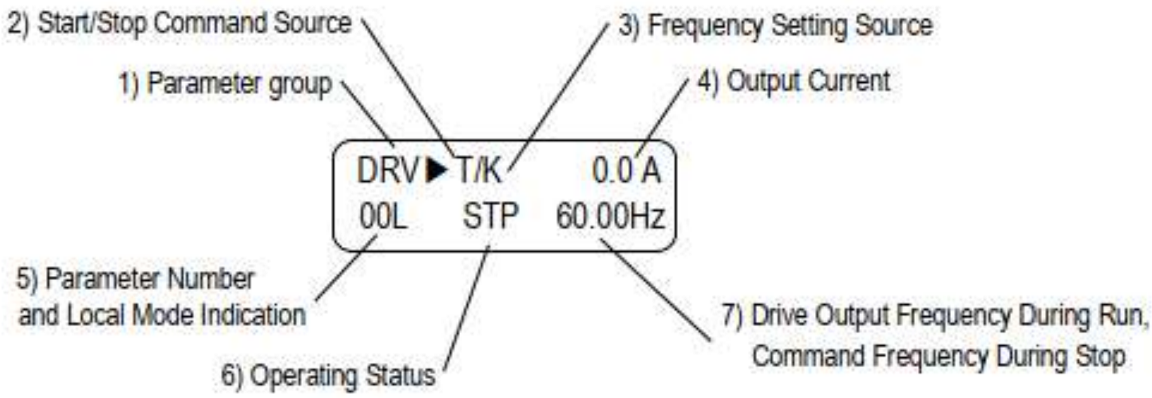
VFD Programming Keypad (LCD Keypad)

LCD keypad can display up to 32 alphanumeric characters, and various settings can be checked directly from the display. The following pictures are a dimensional drawing and illustration of the keypad.



Note: 1. Both green LEDs may flash during normal operation when run sequence activates internal time delays or during Auto Tuning and Pre-Heat modes.

Display Description



Displays	Description
1) Parameter Group	Displays the current parameter group. Parameter groups include: SET, DRV, FG1, FG2, I/O, EXT, COM and APP.
2) Start/Stop Source	Displays the source of VFD Start and Stop command. **K**: Keypad control. Start/Stop command from FWD or REV keys on the keypad **T**: Terminal Control. Start/Stop command from VFD digital inputs FX or RX **R**: Communication control. Start/Stop command from VFD RS485 port **O**: Option Board Control. Start/Stop from option communication board
3) Frequency Setting Source	Displays the source of VFD frequency reference command **K**: Frequency reference from keypad **V**: Frequency reference 0-10VDC from V1 analog input **W**: Frequency reference ±10VDC from V1S analog input **I:** Frequency reference 4-20mA from I analog input **P**: Frequency reference from A0-B0 Pulse Frequency input **R**: Frequency reference from RS485 port **U**: Up terminal input when Up/Down operation is selected **D**: Down terminal input when Up/Down operation is selected **S**: Stop status when Up/Down operation is selected **O**: Frequency reference from option communication board **X**: Frequency reference from Sub board **J**: Jog Frequency reference from Jog input **1 ~ 15**: Number of activated by digital input Step frequency
4) Output Current*	Displays the actual Output (motor) Current during operation.
5) Parameter Code	Displays two-digit parameter number (0-99). Use the ▲ (Up) or ▼ (Down) key to cycle through parameters. **L:** Local control mode. VFD is in local control mode and PID mode is disabled.
6) Operating Status	Displays the operation information. **STP**: Stop mode. VFD does not produce any output to the motor. **FWD**: During Forward operation **REV**: During Reverse operation **DCB**: During DC Braking or DC injection modes **LOP**: Loss of Reference from Option Board (DPRAM fault) **LOR**: Loss of Reference from Option Board (Communication network fault) **LOV**: Loss of 0-10VDC Analog Frequency Reference signal on V1 input **LOI**: Loss of 4-20mA Analog Frequency Reference signal on I input **LOS**: Loss of Reference from Sub-Board
7) VFD Output or Command Frequency	Displays the Output Frequency during run. Displays the Command Frequency during stop.

* The VFD displays a true value of a motor current measured by Hall Effect current sensors. The most of the current clamp meters have inductive current sensors and cannot properly read a VFD output current with high frequency components.

Programming the VFD Parameters

Finding a desired parameter in the parameter group is the same as finding a desired line on the book page- scroll Up or Down. The following steps illustrate how to find the desired parameter used for changing.

i. Press [MODE] key until the desired parameter group is displayed.

ii. Press [▲] or [▼] keys to scroll to the desired parameter. If you know the desired parameter number, you can set its number in the first parameter #00 "Jump code" of any parameter group (except SET
and DRV groups) and after pressing [ENT] key display will show that parameter.

iii. Press [ENT] key to enter the programming mode, which is indicated by a flashing cursor.

iv. Press [▲] or [▼] keys to change parameter selection or [SHIFT] key to move the cursor to the right to the desired digit.

v. Press [▲] or [▼] keys to change the digit in numerical parameter value.

vi. Press [ENT] key to finish programming for this parameter. The flashing cursor disappears.

Note:

.Some parameters cannot be changed during run mode and a flashing cursor will not appear. If Parameter Lock function activated in parameter FU2-94, all parameters are protected from programming.

. If two or more parameters are set to the same function, the "Overlap" message can be displayed.

Example: Changing Motor FLA setting from 9.6A to 9.9A.

The VFD display shows parameter DRV-00 in the DRIVE group. Press **[MODE]** key several times until display shows parameter SET-00 in parameter group SET.

```
DRV▶ T/K        0.0 A
00    STP   60.00 Hz
```

[MODE] ▶. . . . [MODE] ▶

```
SET▶  App. Select
00    Supp Fan
```

Press [▲] key three times to go to parameter SET-03 Motor FLA. (Some parameter groups have parameter #00 with Jump Code # that can be used to jump to any parameter directly).

```
SET▶  Motor   FLA
03            9.6 A
```

Press **[ENT]** key to start parameter programming and flashing cursor will appear on the left side of the FLA number. If [▲] or [▼] key is pressed, the number will be changed to a minimum or maximum possible value for this parameter.

```
SET▶  Motor   FLA
03          ▌ 9.6 A
```

Press **[SHIFT]** key to move the cursor to a digit "6" and press [▲] key three times to change this digit to "9".

```
SET▶  Motor   FLA
03           9.▌ A
```

Press **[ENT]** key and flashing cursor will disappear and VFD exits a programming mode.

```
SET▶  Motor   FLA
03            9.9 A
```

Press [▲] or [▼] key to go to another parameter in SET group or **[MODE]** or **[SHIFT]** key to go to another program group.

Parameter groups

All P Series VFD parameters are divided in eight program groups by functionality.

Parameter Group	Code	Description
Set Group	SET	Application selection, Motor Data, Basic control and timers' settings, PID.
Drive Group	DRV	Step Frequencies and monitoring parameters
Function Group-1	FG1	Max. Frequency, Control Modes selections, Pre-heat, Motor Overload Protection, VFD overload protection, and Run Delay.
Function Group-2	FG2	Fault History, Dwell Time, Jump Frequencies, Motor Slip, Auto Tune, Torque Boost, Parameter Save and Lock, Auto Reset, Power-up delay.
Input / Output Group	I/O	Programmable Digital and Analog Inputs and Outputs Settings, Damper/Lube Selection. RS485 communication settings.
Application Group	APP	External PID settings.
Extension Group	EXT	Shows the model of installed SUB board and settings for it. Available when SUB board is installed.

Control Modes

Easy Start Mode

Easy Start mode allows controlling VFD start/stop from keypad. This mode is activated by pressing [STOP] key on the Keypad for more than 3 seconds when VFD is at stop mode and VFD is ready for operation via Keypad (FWD/REV RUN and STOP). The Drive mode is set to V/F and frequency reference to JOG. Press [SHIFT] key when VFD is in stop mode in order to exit Easy Start mode.

Keypad Control Mode

In order to control Start/Stop Forward or Reverse command and speed reference of the VFD from a Keypad, set Drive Mode parameter **SET-09** to Keypad and Speed Ctrl parameter **SET-10** to a Keypad-1. The display should show the following screen. Now VFD is ready to be controlled by the keypad.

DRV▶K/K 0.0 A
00 STP 00.00 Hz

If frequency command needs to be changed, press **[ENTER]** key, then **[SHIFT]** key to move flashing cursor to proper position and **[▲]** or **[▼]** key to change the number, then press **[ENTER]** key to finish programming. Press **[FWD]** or **[REV]** key to start VFD in forward or reverse direction and **[STOP]** key to stop it. If VFD loses power during run mode and then receives power again, it stays in Stop mode until **[FWD]** or **[REV]** key is pressed.

Function settings and Descriptions

All VFD parameters have default factory settings based on application and can be changed in programming mode. Some parameters have critical role in VFD operation and motor protection and can be changed only in stop mode. The VFD will run a motor with default settings but for better performance and reliable operation it is recommended to set motor data, control and protection features based on the application. The following table shows common parameter settings that should be checked before VFD start up.

VFD and Motor Protection Parameters

Parameter Name	Code	Description (Default Setting for Basic application)
MOH Trip Sel	DRV-30~32	Motor Overheat Trip Selection (010). Requires thermistor sensor in motor.
VHT Value °C	DRV-34~36	Hot VFD Temperature settings (110°C). Hz limited by VFD temperature.
No Motor Sel	FG1-57~59	Trips VFD if motor is disconnected from VFD (Yes)
ETH Select	FG1-60~62	Electronic Motor Overload Protection (Yes)
OL Level	FG1-64~65	VFD Overload Warning Level to trigger an alarm output (105%)
OLT Selection	FG1-66~68	VFD Overload protection selection (YES)
Trip Select	FG1-69	111=At Exchange, In Phase, Out Phase (111)
Stall Mode	FG1-70~71	Motor Stall Protection works as a current limiter by lowering Hz (Yes)

Function parameters settings

Parameter Name	Code	Description (Default Value for Basic Application)
Application	SET-00	Application Selection (none)
Input Phase	SET-01	Single-Phase or 3-Phase power Selection (3-Phase)
Motor HP	SET-02	Motor Horse Power Rating (Full or half VFD rating based on SET-01)
Motor FLA	SET-03	Motor Nameplate Full Load Amperes (UL Table FLA based on SET-02)
Motor RPM *	SET-04	Motor Synchronous RPM (1800RPM)
VAC	SET-07	Input power voltage (230, 480 & 575)
Motor Volt	SET-08	Motor Voltage (230, 480 & 575)
Drive Mode	SET-09	Drive Start/Stop Control Mode (Remote-1)
Speed Ctrl.	SET-10	Speed Reference Source (I)
PID Mode	SET-20	Internal Proportional Control (No)
F/B Unit Max.	SET-25	Maximum Sensor Rating (Available if SET-20 is set to YES)
PID SetPoint	SET-26	PID control Set-point (50% of SET-25 if SET-20 is set to YES)
Local RemKey	SET-90	Local/Remote Mode Function (Cntl&RefRun)
Line Freq.	FG1-29	Power Line Frequency (60Hz)
Max. Freq.	FG1-30	VFD Maximum Output Frequency (60Hz)
Base Freq.	FG1-31	VFD provides full output voltage at this frequency (60Hz)
Rated Slip	FG2-42	Motor Slip= [SET-04]- [Motor Nameplate RPM] (50RPM)

*** Note:** The synchronous speed is a speed of the motor winding magnetic field without slip. Round the motor nameplate RPM to determine this speed. Example: 1750RPM is 1800RPM Synchronous with 50RPM slip and 3450RPM is 3600RPM Synchronous with 150RPM slip.

Function parameters descriptions

SET-02: Motor HP rating

```
SET▶ Motor HP/kW
02       7.5/ 5.5
```

The HP rating from the motor nameplate should be put in this parameter. The default setting will be changed if parameter SET-00 changed to "Const Trq" or SET-01 to 1-Phase. If VFD temperature rating needs to be increased up to 122°F, de-rate this parameter by 20%.

The kW rating is for 230V or 415V motor with FLA close to UL table for corresponding HP rating.

SET-01: Input Phase Selection

```
SET▶ Input Phase
01       3-Phase
```

The VFD is capable of running from 3-Phase or Single-Phase power source but it should be 50% de-rated for Single-Phase input power. When this parameter is set to Single-Phase mode, the motor HP rating is automatically changed to 50% of the VFD capacity. All protective and filtering devices on VFD power input should be sized based on doubled motor FLA.

SET-03: Motor Full Load Amps

```
SET► Motor FLA
03        11 A
```

This parameter is set automatically from UL FLA table based on motor HP rating selection in SET-02. All internal overload protection features for VFD and motor are calculated based on the value in parameter SET-03. Some motors FLA ratings are different of the UL table so this parameter should be set to the actual motor nameplate FLA rating. The service factor for a motor is set in parameter FG1-62. If SET-00 is set to Sub. Pump (submersible), SET-03 should be set to SFA motor rating.

SET-08: Motor Voltage

```
SET► Motor Volt
08       480 V
```

```
SET► Motor Volt
07       230 V
```

The motor voltage rating should be checked on the motor nameplate and set in SET-08 parameter. The VFD can produce output voltage equal to or less than input power voltage.

SET-11 & 12: Acceleration and Deceleration Time

```
SET► ACC. Time
11     20.0 sec
```

```
SET► DEC. Time
12     30.0 sec
```

The VFD increases and decreases the output Voltage and Frequency using acceleration and deceleration time.

If parameter FG1-73 is set to **Max. Frequency**, the ACC or DEC time will be applied from 0Hz to Max. Hz. It will take 10sec to accelerate from 20Hz to 30Hz with ACC set to 60sec. and max. speed set to 60Hz.

If parameter FG1-73 is set to **Delta Frequency**, the ACC or DEC time will be applied from Current Speed Reference to new Speed Reference. It will take 60sec to accelerate from 20Hz to 30Hz with ACC set to 60sec. and max. speed set to 60Hz.

The VFD can trip on ETH (Electronic Thermal) motor overload protection if ACC time is set to very small value.

The VFD can trip on Over Voltage protection because of regenerative power from the motor if DEC time is set to very small value.

DRV-21: Current Trip Display

DRV▶	Fault
21	None

DRV-21 shows None (VFD is ready) or the current fault if VFD is tripped. It is possible to check Hz, Amps, VFD mode and Trip time by pressing [ENTER] key and then [UP] key for each reading. When readings are checked, press [ENTER] key to return to the fault display.

DRV-17~ 19: Monitoring Displays

DRV▶	Current
17	7.6A

DRV▶	Speed
18	1350RPM

DRV▶	DC Link Vtg
19	646.0V

DRV▶	User Disp
20	Out 424.0V

DRV-17 shows the actual motor current.
DRV-18 shows the actual motor speed.
DRV-19 shows the actual DC bus voltage
DRV-20 shows the actual VFD output voltage or kW selected in FG2-81.
These parameters show actual (non-adjustable) values and can be used for monitoring and trouble-shooting purposes.

Trouble shooting and fault display

i. Trouble shooting

Condition	Checking and Fixing Procedures
The motor does not start.	Check if red light on keypad is not flashing (no VFD fault). Check if display shows FWD when start command is applied. • If not, check parameter I/O-28 for FWD and REV run bits, only one of them should be 1. 1. If not, check start contact wiring and closure and PNP-NPN dip switch position. 2. If yes, check parameter SET-15 for Run Prevention setting. • If yes, check if speed reference is greater than 0.5Hz 1. If not, check speed reference selection in SET-10, analog signal wiring and level. 2. If yes, check the motor wiring, motor disconnect or contactor. All disconnecting devices should be closed and motor should have connection to VFD output terminals. Check VFD output voltage corresponding to the output frequency. If VFD is running at some frequency and there is no output voltage, call Franklin Control Systems tech support.
The motor rotates in opposite direction.	If VFD is running and shows FWD but motor rotates in reverse direction, stop and power down VFD, wait at least 10 minutes, and then swap any two motor wires to change the motor rotation.
The VFD stays at high speed when speed reference decreases.	The electrical noise in analog signal can cause VFD not to follow a speed reference, especially for 0-10VDC signal with non-shielded cable. Increase I/O-1 filtering time up to 500ms. If this does not help, install shielded cable.
The Motor current is higher than FLA rating.	Check mechanical system for conditions that can overload the motor (dirty filter, closed valve or brake, etc.) In a new installation, check motor windings wiring. If motor windings wiring is correct, switch FG2-60 to Sensorless mode and run FG2-61 Auto Tuning.
The motor runs at very low speed regardless of speed reference signal.	Increase FG1-71 Stall level if FG1-70 is set to Yes. Decrease FG2-68 Torque Boost level.
The motor speed is not stable (oscillates).	Check motor winding configuration wiring. If motor speed oscillates because of speed reference oscillation, check analog signal for noise. Check mechanical system for conditions that can create load level oscillation (vibration, unbalanced load, etc.). If distance to the motor is more than 1500 feet, install output filter.

ii. Fault display

Keypad Display	Protective Function	Description
No Motor	No Motor Protection	Output current is below No Motor trip level for No Motor time delay. Motor circuit is open or has loose connection. [FG1-57]
Over Current 1 (OC1)	Over Current Protection	VFD trips when motor current exceeds 200% of VFD rated current. Reasons: motor miss wiring, partial motor winding short, undersized VFD, VFD overheat, long motor leads without filtering or very short ACC time for high inertia load.
Over Current 2 (OC2)	Output Short	VFD trips if internal IGBTs or motor wiring or winding are shorted. The motor winding can have intermittent insulation break downs in VFD applications. The Megger test most likely will not detect this damage.
Over Load (OLT)	VFD Overload Adjustable	VFD trips if the output current exceeds adjusted level (%) of VFD rated current.
Inv. OLT	VFD Overload Protection	VFD trips when the output current exceeds 110% for 1 minute or 130% for 4 seconds of the VFD rated current.
E-Thermal (ETH)	Motor Electronic Overload Protection	The electronic motor overload protection provides motor overload protection based on inverse curve. If the motor is overloaded, VFD trips to protect motor from overheating. For multi-motor array controlled by one VFD provide individual overload protection for each motor.
Ground Fault	Ground Fault Protection	VFD trips when ground fault current exceeds the internal ground fault level value. VFD may trip on Over Current fault when ground fault current value is too high.
Over Voltage	Over voltage protection	VFD trips if the DC Bus voltage exceeds the internal over voltage trip setting. It can happen when regenerative energy flows back to VFD during high inertia load deceleration, high power line voltage or power surge.
Low Voltage	Low Voltage Protection	VFD trips if the DC bus voltage is below the internal Low voltage trip setting.
Over Heat	VFD Over Heat	VFD turns off its output if the heat sink is over heated due to insufficient cooling (failed VFD cooling fan or dirty enclosure ventilation filter).
Ext. OHT	Motor Over Heat	VFD turns off its output if motor winding temperature sensor (Thermistor) reading exceeds a set value.
Over Pressure	System Over Pressure	System pressure exceeded the trip level to protect equipment from damage.
Ext. Trip	External Trip	The VFD trips when digital input set for Ext. Trip is activated. When input is deactivated, VFD can be reset by Stop key or by recycling the input power. Use for Dynamic Braking overheat protection.
BX	BX stop (Emergency Stop)	The VFD trips when digital input set for BX is activated. When BX input is deactivated, VFD can be reset automatically or by Stop key (selectable).
Pipe Broken	Pipe Broken	VFD trips when system pressure is below Pipe Broken F/B level and time delay is expired. This fault requires a manual reset.
Pipe Leak	Pipe Leak	VFD trips when system pressure drops below wakeup level slower than at minimum demand. DRV-43 shows last wakeup time.
Output Phase Open	Out Phase open	VFD detects the output current of all three phases and trips when any output phase (U, V or W) is open.
Input Phase Open	In Phase open	VFD monitors an amplitude of DC bus ripples and trips when it exceeds set value. Disable it in [FG1-69] for single-phase power input. MAK-06 is an IPO level (V).
HW-Diag	VFD H/W Fault	Hardware diagnostic fault includes the control PCB malfunction, the EEP error, NTC open and A/D Offset.
COM Error CPU Error	Communication Error	VFD trips when it cannot communicate with the keypad. Reasons: Loose keypad cable connectors, damaged keypad or damaged control board.
NTC open	NTC Open	This fault is displayed when VFD cannot read an internal temperature sensor.
LOP LOR LOV LOI LOX	Frequency Reference is Lost (Loss of … signal)	LOP: Frequency reference is lost from I/O Option board (DPRAM time out) LOR: Frequency reference is lost from Communication Option board LOV: Frequency reference is lost from 'V1' analog input. LOI: Frequency reference is lost from 'I' analog input. LOX: Frequency reference is lost from analog sub-board (V2, ENC).