AC/DC drives

Objectives: At the end of this lesson you shall be able to
- **state the classification and working of AC & DC drives**
- **state the applications of AC & DC drives**
- **describe the block diagram, parts of DC drive and advantages and disadvantages of DC drives.**

Electrical drives

An electric drive can be defined as an electromechanical device for converting electrical energy into mechanical energy to feed motion to different machines and mechanisms for various kinds of process control.

Motion control is required in large number of industrial and domestic applications like transportation, systems, rolling mills, paper machines, textile mills, machine tools, fans, pumps, robots, washing machines etc.

Systems employed for motion control are called Drives, and may employ any of prime movers such as diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors; Supplying mechanical energy for motion control Drives employing electric motors are known as Electrical drives.

Classification of electric drives

i According to mode of operation
- Continuous duty drives
- Short time duty drives
- Intermittent duty drives

ii According to means of control
- Manual
- Semi automatic
- Automatic

iii According to number of machines
- Individual drive
- Group drive
- Multi - motor drive

iv According to dynamics and transients
- Uncontrolled transient period
- Controlled transient period

V According to methods of speed control
- Reversible and non - reversible uncontrolled constant speed
- Reversible and non - reversible step speed control
- Variable position control
- Reversible and non - reversible smooth speed control

Advantage of electrical drives

1 They have flexible control characteristics.
2 Drives can be provided with automatic fault detection systems. Programmable logic controller (PLC) and computers can be employed to automatically control the drive operation in a desired sequence.
3 They are available in wide range of torque, speed and power.
4 They are suitable to almost any operating conditions such as explosive and radioactive environments.
5 It can operate in all the four quadrants of speed - torque plane.
6 They can be started instantly and can immediately be fully loaded.
7 Control gear requirement for speed control, starting and braking is usually simple and easy to operate.

Choice (or) selection of electrical drives

- Choice of an electric drive depends on the important factors are.

1 Steady state operating conditions requirements. Nature of speed torque characteristics, speed regulation, speed range, efficiency, duty cycle, quadrants of operation, speed fluctuations if any, rating etc.
2 Transient operation requirements
3 Values of acceleration and deceleration, starting, braking and reversing performance.
4 Requirements related to the source. Types of source and its capacity, magnitude of voltage, voltage fluctuations, power factor, harmonics and their effect on other loads, ability to accept regenerative power.
5 Space and weight restriction if any.
6 Environment and location.
7 Reliability

Group electric drive

This drive consists of a single motor, which drives one or more line shafts supported on bearings. The line shaft may be fitted with either pulleys and belts or gears, by means of which a group of machines or mechanisms may be operated. It is also some times called as **shaft drives.**

Advantages

A single large motor can be used instead of number of small motors.

Disadvantages

There is no flexibility. If the single motor used, develops fault, the whole process will be stopped.

Individual electric drive

In this drive each individual machine is driven by a separate motor. This motor also imparts motion to various parts of the machine.

Multi motor electric drive : In this drive system, there are several drives, each of which serves to actuate one of the working parts of the drive mechanisms.

e.g : Complicated metal cutting machine tools

Paper making industries.

Rolling machines etc.

A modern variable speed electrical drive system has the following components

- Electrical machines and loads
- Power modulator
- Sources
- Control unit
- Sensing unit

Electrical machine

Most commonly used electrical machines for speed control applications are the following.

DC machines

Shunt, series, compound, DC motors and switched reluctance machines.

AC machines

Induction, wound rotor, synchronous, permanent magnet synchronous and synchronous reluctance machines.

Special machines

Brush less DC motors, stepper motors, switched reluctance motors are used.

Power Modulators (Controller)

Functions

- It modulates flow or power from the source to the motor is imparted speed - torque characteristics required by the load.
- During transient operation, such as starting, braking and speed reversal, it reduces the motor current with in permissible limits.
- It converts electrical energy of the source in the from of suitable to the motor.
- It selects the mode of operation of the motor (i.e) motoring and braking.

Types of power modulators (Controllers)

- In the electric drive system, the power modulators can be any one of the following.
- Controlled rectifiers (AC to DC converter)
- Inverters (DC to AC converters)
- AC voltage controllers (AC to DC converters)
- DC choppers (DC to DC converters)
- Cyclo converters (Frequency conversion)

Electrical sources

Very low power drives are generally fed from single phase sources. Rest of the drives is powered from a 3-phase source. Low and medium power motors are fed from a 415V supply. For higher ratings, motors may be rated at 3.3KV, 6.6 KV and 11 KV. Some drives are powered from battery.

Sensing unit

- Speed sensing (from motor)
- Torque sensing
- Position sensing
- Current sensing and voltage sensing (from lines or from motor terminals from load)
- Temperature sensing

Control unit

Control unit for a power modulator are provided in the control unit. It matches the motor and power converter to meet the load requirements.

Comparison between DC and AC drives

DC Drives	AC Drives
The power circuit and control circuit are simple	The power circuit and control circuit are complicated
It requires frequent maintenance	Less maintenance
The commutator makes the motor bulky, costly, and heavy	These problems are not there in these motors and are inexpensive, particularly squirrel motors
Fast response and wide speed range of control, can be achieved smoothly by conventional and solid state control	In solid state control the speed range is wide and conventional method is stepped and limited
Speed and design ratings are limited due to commutations	Speed and design ratings have upper limits

Applications

- Paper mills
- Cement mills
- Textile mills
- Sugar mills
- Steel mills
- Electric traction
- Petrochemical industries
- Electrical vehicles

Another one type of electric drive is 'Eddycurrent drive'

Eddy current drives

An eddy current drive consists of a fixed speed motor and an eddy current clutch. The clutch contains a fixed speed rotor and an adjustable speed rotor separated by a small air gap. A direct current in a field coil produce a magnetic field that determines the torque transmitted from the input rotor to the output rotor. The controller provides closed loop speed regulation by varying clutch current, only allowing the clutch to transmit enough torque to operate at the desired speed. Speed feedback is typically provided via an integral AC tachometer.

Eddy current drives are slip - controlled systems the slip energy of which is necessarily all dissipated as heat. Such drives are therefore generally less efficient than AC/DC-AC conversion based drives. The motor develops the torque required by the load and operates at full speed. The power is proportinoal to torque multiplied by speed. The input power is proportional to motor speed and times, operating torque while the output power is output speed and times operating torque. The difference between the motor speed and the output speed is called the **slip speed**. Power proportional to the slip speed times operating torque is dissipated as heat in the clutch.

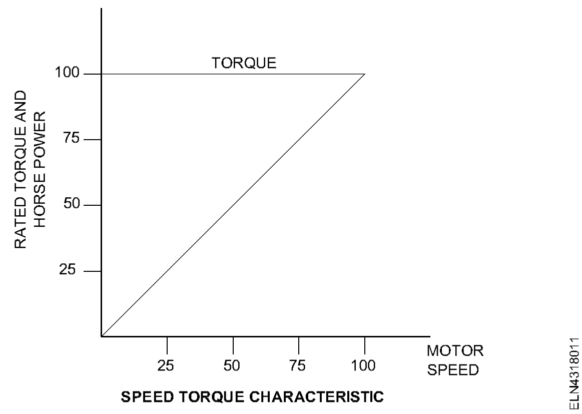
Working principle of DC drives

In DC motors, the speed is proportional to the armature voltage and inversely proportional to the field current. And also, the armature current is proportional to the motor torque. $N \propto \frac{E_b}{I_f}$ and $I_a \propto T$ Therefore, by increasing or reducing the applied voltage, the speed of the motor is varied. However, it is possible up to the rated voltage. If the speed greater than the base speed is required, the field current of the motor has to be reduced.

By reducing the field current, the flux in the motor reduces and it reduces the armature counter emf. Further, this armature current increases the motor torque and the speed will increase. These are the two basic principles employed in DC drives to control the speed of the motor.

In armature controlled DC drives, by varying the armature voltage, variable speed is obtained as in Fig 1.

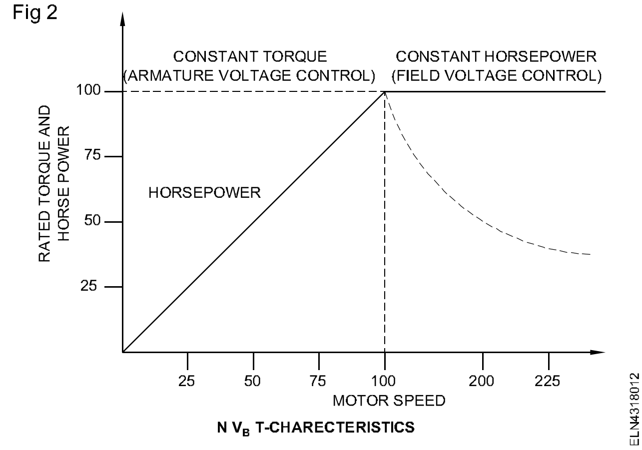
Fig 1



Generally, a fixed field supply is provided in these DC drives. As the torque is constant (which describes a load type) over the speed range, the motor output horse power is proportional to the speed. The motor characteristics of this drive are in Fig 1.

Constant torque operation

In case of armature and field controlled drives, the armature voltage to the motor is controlled for constant torque-variable HP operation up to the base speed of the motor. And for the above base speed operation, drive switches to the field control for constant HP- reduced torque operation up to maximum speed as in Fig 2 In this case, reducing the field current increases the speed of the motor up to its maximum speed as in Fig 2.



In most instances the shunt field winding is excited, with a constant - level voltage from the controller . The SCR (silicon controller rectifier), also known as thyristor, which converts the alternating current (AC) of the power source to variable DC output which is applied to the armature of a DC motor. Speed control is achieved by regulating the armature voltage to the motor.

A thyristor bridge is a technique commonly used to control the speed of a DC motor by varying the DC voltage. Important to note that the voltage applied to a DC motor can not be greater than the rated name plate voltage.

The tachometer (feedback device) converts actual speed in to an electrical signal that is summed with the desired reference signal. The output of the summing junction provides an error signal to the controller and a speed correction is made.

In modern DC drives, SCRs are completely replaced by MOSFET s and IGBTs in order to achieve high speed switching so that distortion to the AC incoming power and currents during switching is eliminated. Hence, the drive becomes more efficient and accurate.

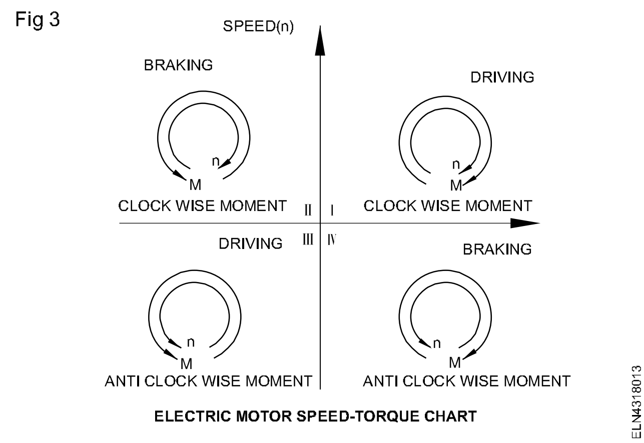
Silicon controlled rectifier (SCRs) are widely used thyristors for large DC motor drives in its power conversion unit. An SCR conducts when a small voltage applied to its gate terminal. Its conduction continues till the starting of negative cycle and it turned OFF automatically once the voltage across the SCR goes through natural zero till next gated signal.

The purpose of using these SCRs in DC drives is to convert the fixed AC supply to variable DC supply that controls the motor speed. Some SCR DC drives are supplied from single phase AC supply and use four SCRs in the form of bridge for the DC rectification. In case of high power DC drives, a three phase supply with six SCRs is used for DC rectification.

In case of four quadrant operation (forward motoring, forward braking, reverse motoring and reverse braking) of the DC drive, a bridge rectifier consisting of 12 SCRs with a three phase incoming supply is used. During each quadrant operation, SCRs are triggered at a phase angle in order to provide required DC voltage to the motor.

Drive operation

The drive applications can be categorized as single - quadrant, two - quadrant, three-quadrant or four- quadrant; the chart's four quadrants (Fig 3) are defined as follows.



Quadrant I : Driving or motoring forward accelerating quadrant with positive speed and torque

Quadrant II : Generating or braking, forward braking-decelerating quadrant with positive speed and negative torque.

Quadrant III: Driving or motoring, reverse accelerating quadrant with negative speed and torque.

Quadrant IV : Generating or braking, reverse braking - decelerating quadrant with negative speed and positive torque.

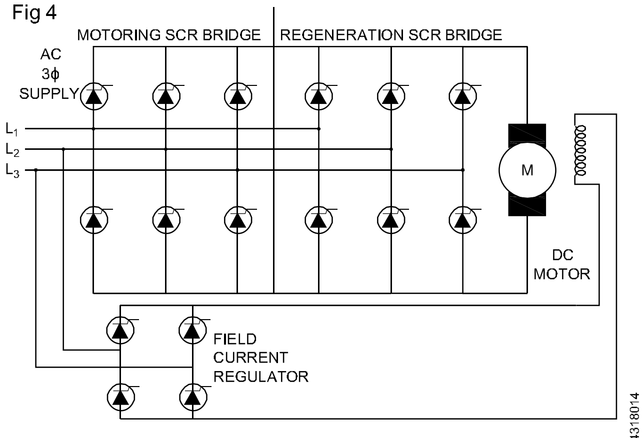
Most applications involve single quadrant loads operating in quadrant I, such as in variable - torque (e.g. centrifugal pumps or fans. etc.

Certain applications involve two - quadrant loads operating in quadrant I and II where the speed is positive but the torque changes polarity Some sources define two - quadrant drives as loads operating in quadrants I and III where the speed and torque is same (positive or negative) polarity in both directions.

Certain high - performance applications involve four - quadrant loads (Quadrants I to IV) where the speed and torque can be in any direction such as in hoists, elevators and hilly conveyors. Regeneration can occur only in the drive's DC link bus when inverter voltage is smaller in magnitude than the motor back - EMF and inverter voltage and back - EMF are the same polarity.

The connection of SCRs for four quadrant operation of the drive) from incoming three phase AC supply to the DC output is in Fig 4. In this, the motoring SCR bridge and regeneration SCR bridge achieve the drive four quadrant operation by receiving the appropriate gate signals from (analog or digital) controller.

Fig 4

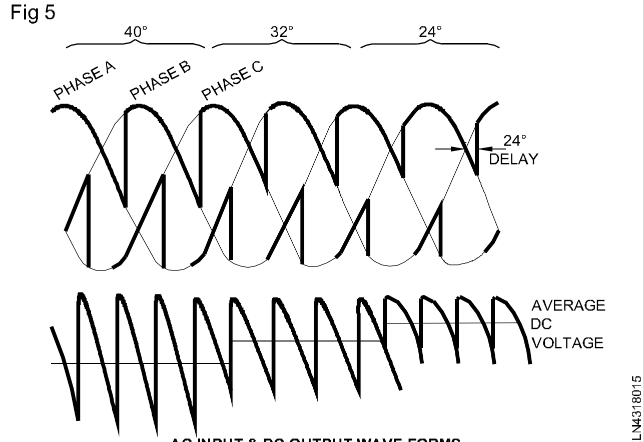


3 PHASE SCR BRIDGE RECTIFIER

If the SCRs were gated with a phase angle of zero degrees, then the drive function as a rectifier which feeds the full rectified rated DC supply to the motor and by varying the firing angle to the SCRs, a variable DC supply is applied to the motor.

The DC output voltage waveform is related to the AC waveform for above circuit is in Fig.5. This average DC output voltage is obtained for 40°, 32° and 24° firing phase angles. By this way, the average output is controlled by varying the firing phase angles to the SCRs.

Fig 5



AC INPUT & DC OUTPUT WAVE FORMS

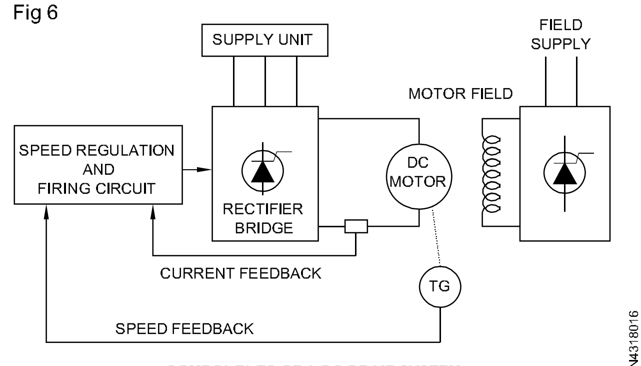
As the field winding also requires the regulated DC supply, only four SCRs are used in the field bridge converter. This is because field never requires a negative current and hence another set of SCRs is not required, which were used in armature for reversing the motor.

Block diagram of DC drive

The block diagram of a DC drive system is in Fig 6

DC drive input : Some thyristor based DC drives operate on a single phase supply and use four thyristors for full wave rectification. For larger motors 3 phase power supply is needed because the waveforms are much smoother. In such cases, six thyristors are needed for full wave rectification.

Fig 6



COMPONENTS OF A DC DRIVE SYSTEM

Rectifier Bridge : The power component of a controlled DC drive is a full wave bridge rectifier which can be driven by three phase or single phase supply. As mentioned above the number of thyristor may vary depends on the supply voltage.

A six - thyristor bridge (in case of three phase converter) rectifies the incoming AC supply to DC supply to the motor armature. The firing angle control of these thyristors varies the voltage to the motor.

Field Supply Unit (FSU) : The power is to be applied to the field winding is much lower than the armature power.

In many cases a two - phase supply is drawn from the three phase input (that supplies power to the armature) and hence the field exciter is included in the armature supply unit.

The function of the field supply unit is to provide a constant voltage to the field winding to create a constant field or flux in the motor. In some cases, this unit is supplied with thyristors to reduce the voltage applied to the field so as to control the speed of the motor above the base speed incase of permanent magnet DC motors, the field supply unit is not included in the drive.

Speed Regulation unit : It compares the operator instruction (desired speed) with feedback signals and sends appropriate signals to the firing circuit. In analog drives, this regulator unit consists of both voltage and current regulators. The voltage regulator accepts the speed error as input and produces the voltage output which is then applied to the current regulator.

The current regulator then produces required firing current to the firing circuit. If more speed is required, additional current is drawn from the voltage regulator and hence thyristors conduct for more periods. Generally, this regulation (both voltage and current) is accomplished with proportional -integral- derivative controllers.

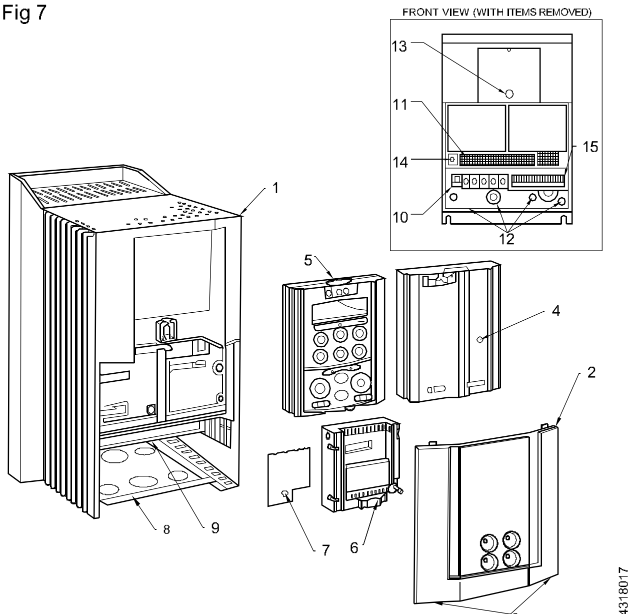
The field current regulator is also provided where speed greater than the base speed is required.

Parts of DC drive

DC drives of various brands with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power terminals, control terminals, keypad for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts of DC drive are given below.(Fig 7)

Fig 7



PARTS OF DC DRIVE

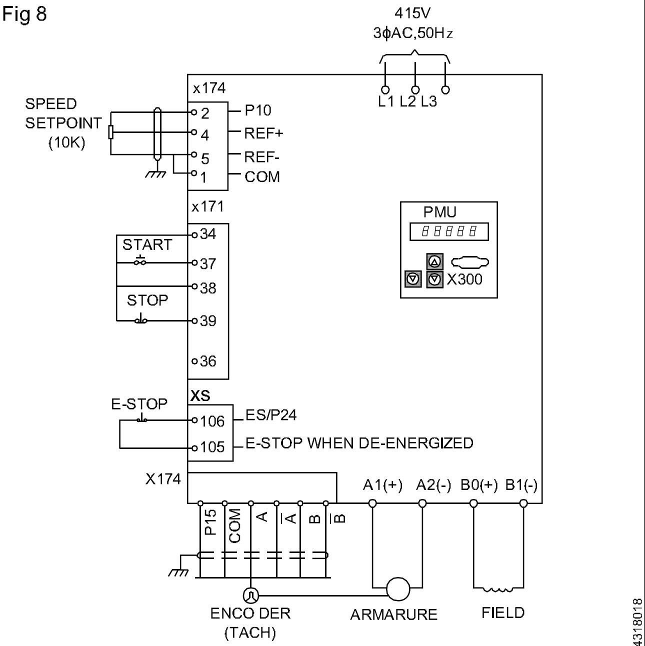
1 Main drive assembly
2 Terminal cover
3 Terminal cover retaining screw
4 Blank cover
5 Keypad
6 COMMS technology box (optional)
7 Speed feedback technology card (optional)
8 Gland plate
9 Power terminal shield
10 Power terminals
11 Control terminals
12 Earthing / grounding points
13 Keypad part
14 Programming part
15 Auxiliary power, external contactor, blower and isolated thermistor terminals

Power and control terminals

In DC drive, the front panel has the power terminals L1, L2 and L3 where 3 phase input supply of 415V can be connected.

There are control terminals given for speed adjust potentiometer, Torque adjust potentiometer, START/RUN/ STOP switch, JOG/RUN/ switch, AUTO/MAN switch, FORWARD/REVERSE switch etc. Terminal A1 & A2 and B_0 & B_1 are meant for armature and field connections respectively. Names and locations are illustrated in Fig 8

Fig 8



CONTROL TERMINALS OF DC DRIVE

Advantages of DC drive

- DC drives are less complex with a single power conversion from AC to DC.
- DC drives are normally less expensive for most horsepower ratings.
- DC motors have a long tradition of use as adjustable speed machines and a wide range of options have evolved for this purpose.
- Cooling blowers and inlet air flanges provide cooling air for a wide speed range at constant torque.
- Accessory mounting flanges and kits for mounting feedback tachometers and encoders.
- DC regenerative drives are available for applications requiring continuous regeneration for overhauling loads. AC drives with this capability would be more complex and expensive.
- Properly applied brush and commutator maintenance is minimum.
- DC motors are capable of providing starting and accelerating torques in excess of 400% of rated value.
- Some AC drives may produce audible motor noise which is undesirable in some applications.

Disadvantages of DC drive

- More complicated because of commutators and brushes.
- Heavier than AC motors.
- High maintenance is required.
- Large and more expensive than AC drive.
- Not suitable for high speed operation.

Speed control of 3 phase induction motor by VVVF/AC drive

Objectives: At the end of this lesson you shall be able to
- **state about AC drives (VFD/VVFD) and changing of speed of AC motor by AC drive**
- **explain the operation of AC drive with block diagram**
- **list out the advantages and disadvantages of AC drive**
- **explain the components / parts and power and control terminals of AC drive**
- **state the parameter setting - speed control changes of direction of AC & DC drives / VFD/VVVFD (variable frequency drive/ variable voltage variable frequency drive)**
- **state the speed control of universal motor.**

Variable Voltage Variable Frequency Drive (VVVFD)

The AC drive industry is growing rapidly and it is now more important than ever for technicians and maintenance personnel to keep AC drive installations running smoothly. AC drives change the speed of AC motor by changing voltage and frequency of the power supplied to the AC motor. In order to maintain proper power factor and reduce excessive heating of the motor, the name plate volts / hertz ratio must be maintained. This is the main task of VFD (Variable frequency drive).

Applications of AC drives

1 AC drives are used to stepless speed control of squirrel cage induction motors mostly used in process plants due to its ruggedness and maintenance free long life.

2 AC drives control the speed of AC motor by varying output voltage and frequency through sophisticated microprocessor controlled electronics device.

3 AC drive consists of rectifier and inverter units. Rectifier converts AC to DC voltage and inverter converts DC voltage back to AC voltage.

Changing of speed of AC motors by using AC drive

From the AC motor working principle, that the synchronous speed of motor N_s in rpm, is dependent upon frequency. Therefore by varying the frequency of the power supply through AC drive, it can control the synchronous speed.

Speed (rpm) = Frequency (Hertz) x 120 / No. of poles.

Where

Frequency = Electrical frequency of the power supply in Hz., No. of poles = Number of electrical poles in the motor stator. Thus the speed of AC motor can conveniently be adjusted by changing the frequency applied to the motor. There is also another way to make the AC motor work on different speed by changing the no. of poles, but this change would be a physical change of the motor. The VFD provides the controls over frequency and voltage of motor input to change the speed of a motor. Since the frequency is easily variable as compared with the poles variation of the motor. AC drives are frequently used.

Constant V/F ratio operation

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the ϕ_m constant.

All AC drives maintain the voltage -to- frequency (V/F) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency F and the magnetic flux ϕ of motor are related by the equation.

$V=4.444 \, f \, N \, \phi_m$

or

$V/f = 4.444 x \, N \, \phi_m$

Where N = number of turns per phase

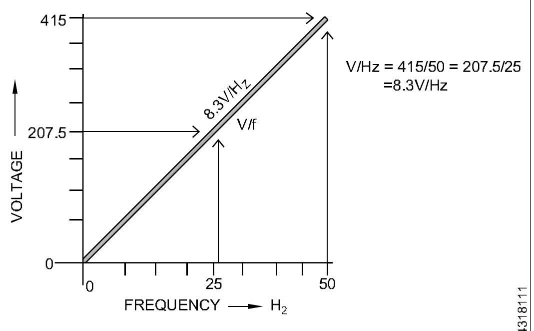
ϕ_m = magnetic flux

Moreover, the AC motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage - to - frequency (V/f) ratio constant.

An AC drive is capable of operating a motor with constant flux (Φ) from approximately zero (0) to the motor's rated nameplate frequency (typically 50Hz). This is the constant torque range. As long as a constant volts per hertz ratio is maintained the motor will have constant torque characteristics. AC drives change frequency to vary the speed of a motor and voltage proportionately to maintain constant flux. The Fig1 is the graph illustrates the volts per hertz ratio of a 415 volt, 50 hertz motor. To operate the 415 volt motor at 50% speed with the correct ratio, the applied voltage and frequency would be 207.5V volts, 25 Hz. The voltage and frequency ratio can be maintained for any speed up to 50Hz. This usually defines the upper limits of the constant torque range.

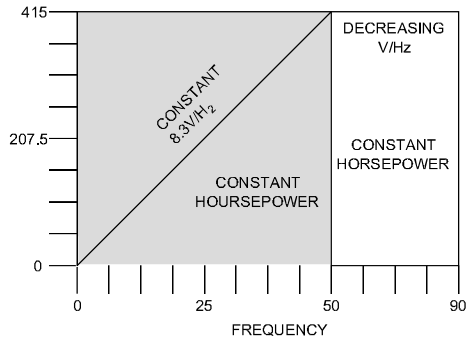
Some applications require the motor to be operated above base speed. The nature of these applications requires less torque at higher speeds. Voltage, however, cannot be higher than the available supply voltage. This can be illustrated as in Fig 2. Voltage will remain as 415 volts for any speed above 50Hz. A motor operated above its rated frequency is operating in a region known as a constant horsepower. Constant volts per hertz and torque is maintained up to 50Hz. Above 50Hz the volts per hertz ratio decreases. The V/Hz ratio at 25 Hz is 8.3, at 50Hz is 8.3, at 70Hz is 5.93 and at 90Hz is 4.61. Flux (Φ) and torque (T) decrease. Operation of the motors above rated nameplate speed (base speed) is possible, but is limited to conditions that do not require more power than the nameplate rating of the motor. This is sometimes called "field weakening" and, for AC motors, means operating at less than rated V/Hz and above rated nameplate speed.

Fig 1



V/F RATIO CHART

Fig 2



V/F CHART

Block diagram of AC drive

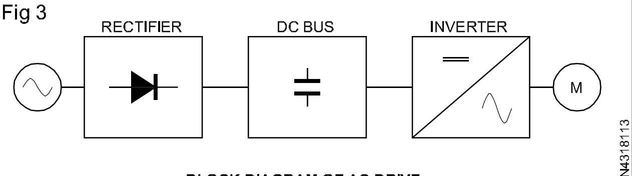
The Insulated - Gate - Bipolar- Transistor (IGBT) is in the past two decades come to dominate VFD as an inverter switching device.

IGBTs (insulated gate bipolar transistor) provide a high switching speed necessary for PWM (Pulse width Modulation) inverter operation. IGBTs are capable of switching ON and OFF several thousand times a second. An IGBT can turn on in less than 400 nanoseconds and off in approximately 500 nanoseconds. An IGBT consists of a gate, collector and an emitter. When a positive voltage (typically +15 VDC) is applied to the gate the IGBT will turn on. This is similar to closing a switch. Current will flow between the collector and emitter.

An IGBT is turned off by removing the positive voltage from the gate. During the off state the IGBT gate voltage is normally held at a small negative voltage (-15 VDC) to prevent the device from turning on. So the gate can control the switching on/off operation of an IGBT.

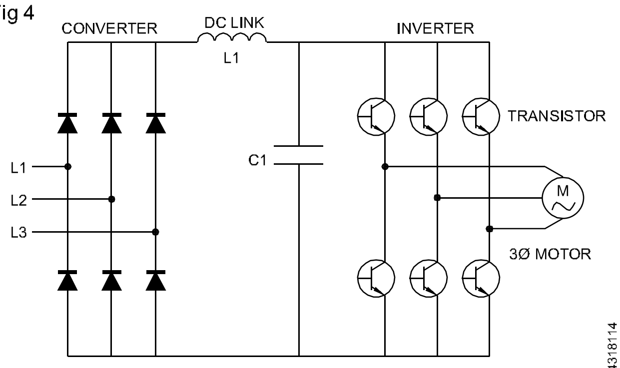
Fig 3 shows the block diagram of AC drive and Fig 4 shows the internal connection diagram. There are three basic sections of the AC drive; the rectifier, DC bus, and inverter.

Fig 3



BLOCK DIAGRAM OF AC DRIVE

Fig 4



INTERNAL CONNECTION OF AC DRIVE

The rectifier in an AC drive is used to convert incoming AC power into direct current (DC) power. Rectifiers may utilize diodes, silicon controlled rectifiers (SCR), or transistors to rectify power . An AC drive using transistors in the rectifier section is said to have an "active front end.

After the power flows through the rectifiers it is stored on a DC bus. The DC bus contains capacitors to accept power from the rectifier, store it, and later deliver that power through the inverter section. The DC bus may also contain inductors, DC links, chokes, or similar items that add inductance, thereby smoothing the incoming power supply to the DC bus.

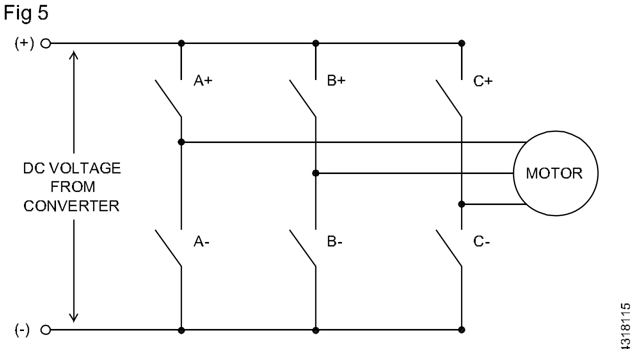
Inverter : An inverter is a device which converts DC into AC. The inverter contains transistors that deliver power to the motor. The "Insulated Gate Bipolar Transistor" (IGBT) is a common selection in modern AC drives. The IGBT can switch on and off several thousand times per second and precisely control the power delivered to the motor. The IGBT uses a method named "Pulse Width Modulation" (PWM) to simulate a current sine wave at the desired frequency to the motor.

The following example, explains how one phase of a three-phase output is developed and controlled. Switches replace the IGBTs for convenience. A voltage that alternates between positive and negative is developed by opening and closing switches in a specific sequence. For example, during steps one and two A+ and B- are closed. The output voltage between and A and B is positive. During step three A+ and B+ are closed. The difference of potential from A to B is zero. The output voltage is zero.

During step four and five A- and B+ are closed. The output voltage from A to B is negative. During step 6. A- and B- closed. The difference of potential A to B is again zero.

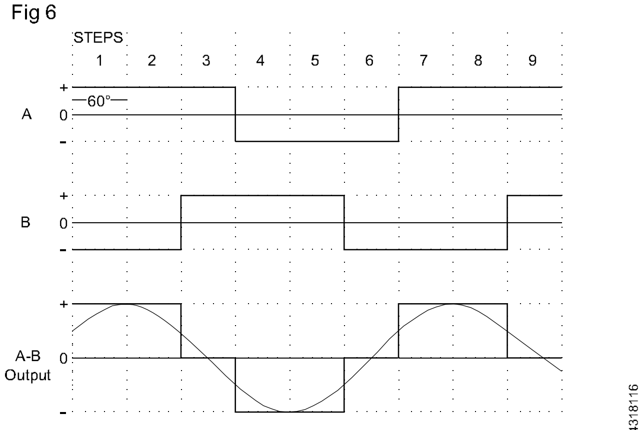
The same action from step 1 to 6 is repeated from step 7 onwards. This will continue. The Fig 5 shows the internal connection of inverter which converts DC into AC. The Fig 6 shows the output wave form of inverter. Only one single waveform due to switching action between A and B is shown. There are other two waveforms between B & C and A & C together which form a 3 phase AC supply. The magnitude and frequency of output voltage is dependent on the speed of the switching action of IGBTs.

Fig 5



INVERTER CONNECTION

Fig 6



OUTPUT WAVE FORM OF INVERTER

Advantages and disadvantages of AC drive

Advantages

- They use conventional low cost 3 phase AC induction motors for most applications
- AC motors require virtually no maintenance and are preferred for application where the motor is mounted in an area not easily reached for servicing or replacement.
- AC motors are smaller, lighter, more commonly available and less expensive than DC motors.
- AC motors are better suited for high speed operation (over 2500 rpm) since there are no brushes, and commutation is not a problem.
- Whenever the operating environment is wet, corrosive or explosive, special motor enclosures are required. Special AC motor enclosure types are more readily available at lower prices.
- Multiple motors in a system must operate simultaneously at a common frequency/speed.

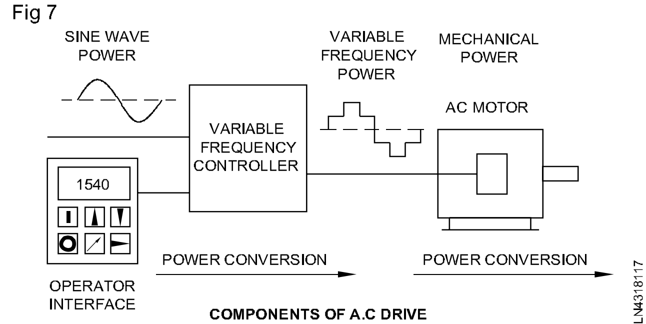
Disadvantages

- A standard motor can not adequately cool its winding at slow speed or handle the irregular electrical waveform from the AC drive.
- An AC drive requires installation of motor with heavier windings.
- AC drive has complicated electronics circuit, so fault rectification is costly.
- AC drives produce a simulated waveform, not a perfect sine wave. That degrade the power equality.

Components of AC drive

A variable frequency drive is a device used in a drive system consisting of the following three main sub-systems. AC motor, main drive controller assembly, and drive / operator interface as in Fig 7.

Fig 7



COMPONENTS OF A.C DRIVE

AC motor

The AC electric motor used in a VFD system is usually three - phase induction motor. Some types of single - phase motors can be used, but three - phase motors are usually preferred. Various types of synchronous motors offer advantages in some situations, but three - phase induction motors are suitable for most purposes and are generally the most economical motor choice. Motors that are designed for fixed - speed operation are often used. Elevated - voltage stresses imposed on induction motors that are supplied by VFDs require that such motors are designed for definite - purpose inverter-fed duty.

Controller

The VFD controller is a solid - state power electronics conversion, system consisting of three distinct sub-systems, a rectifier bridge converter, a direct current (DC) link, and an inverter. Voltage - source inverter (VSI) drives are the most common type of drives. Most drives are AC to AC drives in that they convert AC line input to AC inverter output. However, in some applications such as common DC bus or solar applications, drives are configured as DC-AC drives. The most basic rectifier converter for the VSI drive is configured as a three -phase, six -pulse, full-wave diode bridge.

In a VSI drive, the DC link consists of a capacitor which smooths out the converter's DC output ripple and provides a stiff input to the inverter. This filtered DC voltage is converted to quasi-sinusoidal AC voltage output using the inverter's active switching elements. VSI drives provide higher power factor and lower harmonic distortion than phase- controlled current - source inverter (CSI) and load - commutated inverter (LCI) drives.

In variable -torque applications suited for volts - per- Hertz (V/Hz) drive control. AC motor characteristics require that the voltage magnitude of the inverter's output to the motor be adjusted to match the required load torque in a linear V/Hz relationship. For example, 415V, 50Hz motors, this linear V/Hz relationship is 415/50=8.3V/Hz.

Although space vector pulse- width modulation (SVPWM) is becoming increasingly popular, sinusoidal PWM (SPWM) is the most straight forward method used to vary drives motor voltage (or current) and frequency. With SPWM control quasi- sinusoidal, variable - pulse-width output is constructed from intersections of a saw-toothed carrier signal with a modulating sinusoidal signal which is variable in operating frequency as well as in voltage (or current).

An embedded microprocessor governs the overall operation of the VFD controller. Basic programming of the microprocessor is provided as user - inaccessible firmware. User programming of display, variable, and function block parameters is provided to control, protect, and monitor the VFD, motor, and driven equipment.

Operator interface

The operator interface provides a means for an operator to start and stop the motor and adjust the operating speed. Additional operator control functions might include reversing, and switching between manual speed adjustment and automatic control from an external process control signal. The operator interface often includes an alphanumeric display and /or indication lights and meters to provide information about the operation of the drive.

An operator interface keypad and display unit is often provided on the front of the VFD controller shown in the Fig 7. The keypad display unit can often be cable - connected and mounted a short distance from the VFD controller. They are also provided with input and output (I/O) terminals for connecting push buttons, switches, and other operator interface devices or control signals. A serial communications port is also often available to allow the VFD to be configured, adjusted, monitored, and controlled using a computer.

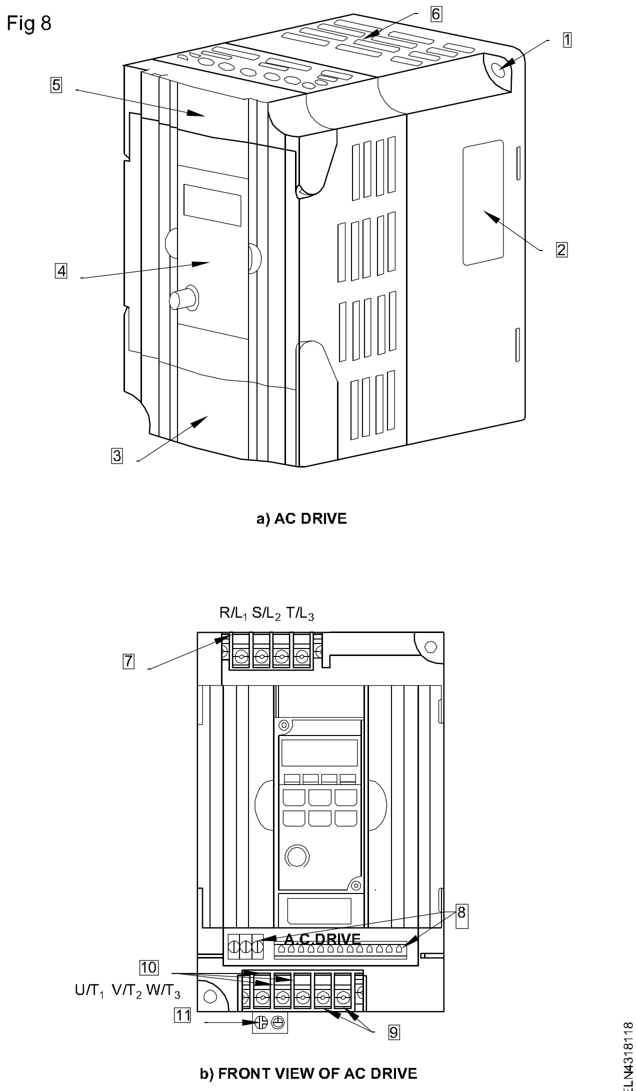
Operation of AC drive

When the VFD is started the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low - speed range. A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. However, motor cooling deteriorates and can result in overheating as speed decreases such that prolonged low -speed operation with significant torque is not usually possible without separately motorized fan ventilation.

With a VFD, the stopping sequence is just the opposite as the starting sequence. The frequency and voltage applied to the motor are ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. Additional braking torque can be obtained by adding a braking circuit (resistor controlled by a transistor) to dissipate the braking energy.

Part of AC drive (Fig 8a & 8b)

Fig 8



a) AC DRIVE

b) FRONT VIEW OF AC DRIVE

AC drives of various brand with different ratings are available in the market. It is generally assembled in a metallic enclosure. The front panel has the power input and output terminals, control terminals, keypad (operator interface) for controlling the drive etc. It has provision for connecting to PC for programming the drive.

The main parts are given below and shown in Fig 8a and 8b.

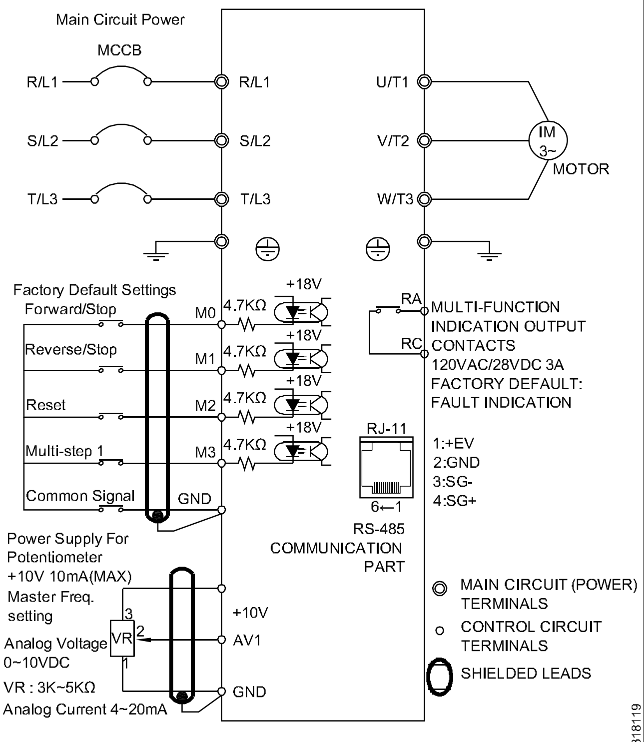
1 Mounting screw holes
2 Name plate label
3 Bottom cover
4 Digital keypad
5 Upper cover
6 Ventilation hole
7 Input terminals
8 Control Input/Output terminals
9 External brake resistor terminal
10 Output terminals
11 Grounding

Power and control terminals

In AC drive, the front panel has the input power terminals viz R/L_1, S/L_2 and T/L_3 where 3 phase AC 415V, 50Hz supply is connected. The 3 phase induction motor is connected of output power terminals viz. U/T1, V/T2 and W/T3.

There are control terminals viz M0, M1, M2, M3, GND, +10V, AV1 etc. for starting/stopping/ reversing and speed control actions. Names and locations are given in Fig 9

Fig 9



CONNECTION DIAGRAM OF AC DRIVE & MOTOR

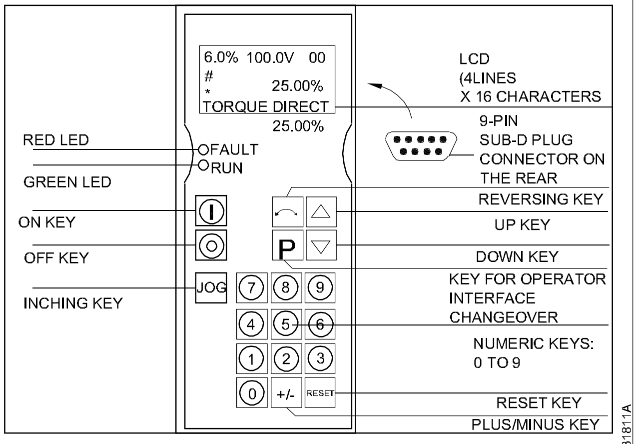
Parameter settings of DC drive

As discussed in previous chapter, the speed of DC motor is directly proportional to the armature voltage (E_b) and inversly proportional to the field current(I_f) and also the armature current (Ia) is proportional motor torque.

In armature controlled DC drives, the drive unit provides a rated current and torque at any speed up to rated speed.

The Fig 10 shows **Basic Operator Panel (BOP)** keypad provided on the front panel meant for controlling the drive.

Fig 10



BASIC OPERATOR PANEL (BOP) KEY PAD

The LCD is used to monitor the parameter. To start the motor, 'ON' key is to be pressed, and to stop the motor 'OFF' key is to be pressed. There is 'JOG' key provided for inching operation.

There is a key 'P' given for operator interface, changing over the parameter setting can be done by using this key in association with (Δ) key and key (∇). Parameters like, voltage current, Torque etc will be displayed turn by turn on each pressing of 'P' key /button.

The (Δ) or (∇) keys are used to increase or decrease the values. Numeric keys are also can be used to enter the values directly.

LED indicators are provided to indicate the status of drive. Green LED indicates the system running where as Red LED indicates when fault is occurred.

Programming of DC drive is possible through, personal computer (PC) also. For this purpose a connector for connecting PC through interfacing cable is provided at the rear panel.

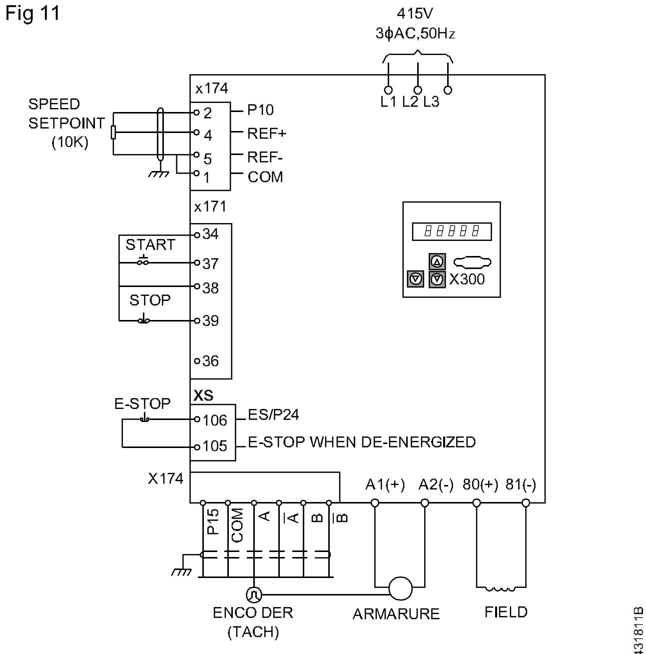
There may be variations in terms of names of key, display setting etc for different brands.

Operation of motor through DC drive

Fig 11 shows the operation of controls arrangement which is called as basic operator panel (BOP) .

The input supply connections and armature and field connections are well illustrated in Fig 11. Input 3 phase AC, 415V, 50Hz supply can be connected L_1, L_2 and L_3. The armature is connected across A_1 and A_2 where as the field is connected across B_0 and B_1 (The terminal names may vary depends on the type and make) an equipment ground conductor (Ground wire) must be connected to the controller mounting panel. Separate equipment grounding conductors from other major components Viz, motor, drive enclosure isolation transformer case (if used) in the system must also be connected continuously to a control connection point.

Fig 11



CONTROL ARRANGEMENT OF BOP

The AC input supply is provided should match the voltage and frequency given on the controller's name plate. Improper voltage may damage the equipment and insufficient current will cause erratic operation of the drive.

The shielded cable is recommended for the tachometer and all low level signal circuit to eliminate the possibility of electrical interference.

In some DC drives a speed adjusting potentiometer is provided to vary motor speed by controlling armature input voltage after the controller has been started. Some time a torque adjusting potential meter is used in place of speed adjusting potentiometer. It controls motor torque by controlling the DC current in the motor armature.

Starting and controlling the speed of DC motor

When the ‘ON’ button in BOP is pressed, the motor will start running. The desired speed can be attained by using ‘P’ button and Δ & ∇ buttons.

When the “OFF” button is pressed the motor will stop but AC line voltage remains connected to the controller and full field voltage is present. Armature voltage is reduced to zero. When pressing the “ON” button again the motor will accelerate to the preset speed.

Inching operation

For inching operation the ‘JOG’ position should be selected. Then the controller will operate only as long as the “ON” button is held pressed.

Changing the direction of rotation

In some model a ‘reversing switch’ is provided to change the direction of rotation of the motor. This switch is responsible for changing the polarity at the motor armature connection. First start the motor by pressing ‘ON’ button. The motor will run in forward direction. To change the direction of rotation, press “OFF” button and ensure that the motor is completely stopped. Now press the reversing button and then press the “ON” button. The motor will now run in the reverse direction. The reversing key has a provision which prevents direct transfer from one direction to the other.

Precautions during installation, connection and operation of DC drive

- Ensure all screws are tightened to the proper torque rating.
- During installation, follow all local electrical and safety codes.
- Ensure that appropriate protective devices (circuit breaker MCB or fuses) are connected between the power supply and DC drive.
- Make sure that the drive is properly earthed.
- Do not attach or remove wiring when power is applied to the DC drive.

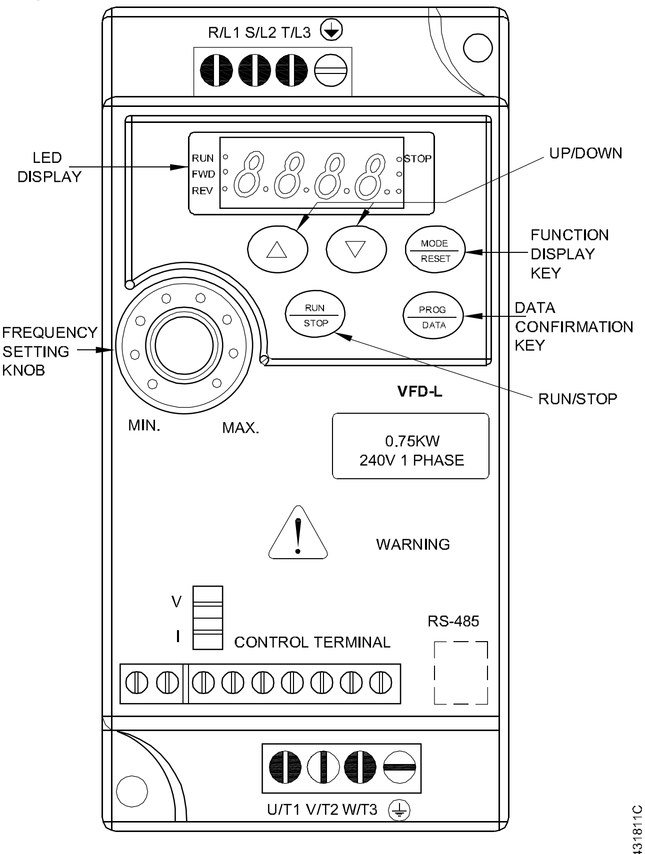
Parameter setting of AC drive

As explained earlier the speed (N) of AC induction motor is directly proportional to the voltage (V) and frequency (f) of the applied power supply. Within the base speed limit, the torque (T) can be kept constant by maintaining a constant voltage / frequency (V/F) ratio. By increasing of speed to above base speed limit is also possible but at the cost of the torque.

(VFD /VVVFD (Variable Voltage Variable Frequency Drive) drives are used for efficient speed control of AC motors. The advantages of using drives to control the speed is already explained.

The AC drive has a front panel which includes two parts. Display panel and keypad. The display panel is provided with the parameter display and shows operation status of the AC drive. Keypad provides programming interface between users and AC drives. The Fig 12. shows the location of buttons and display unit on the front panel of AC drive.

Fig 12



DISPLAY UNIT OF AC DRIVE

Mode /Reset button

By pressing this button repeatedly the display will show status at the AC drive such as the reference frequency and output current. If the drive stops due to a fault, correct the fault first, then press this button to reset the drive.

Prog/Data button

By pressing this button will store the entered data or can show factory stored data.

Run/Stop button

To 'start' or 'stop' the AC drive operation this button is to be pressed.

This button can only be used to 'stop' the AC drive, when it is controlled by the external control terminals.

UP∆ / down ∇ button

By pressing the 'Up' or 'Down' button momentarily parameter setting can be changed. These key may also be used to scroll through different operating values or parameters. Pressing the 'Up' or 'Down' button momentarily it will change the parameter setting in single unit increments. To quickly run through the range of settings, press 'Down' and hold the button.

Frequency setting knob

By using this knob, the frequency variation can be done.

'RS 485' communication port

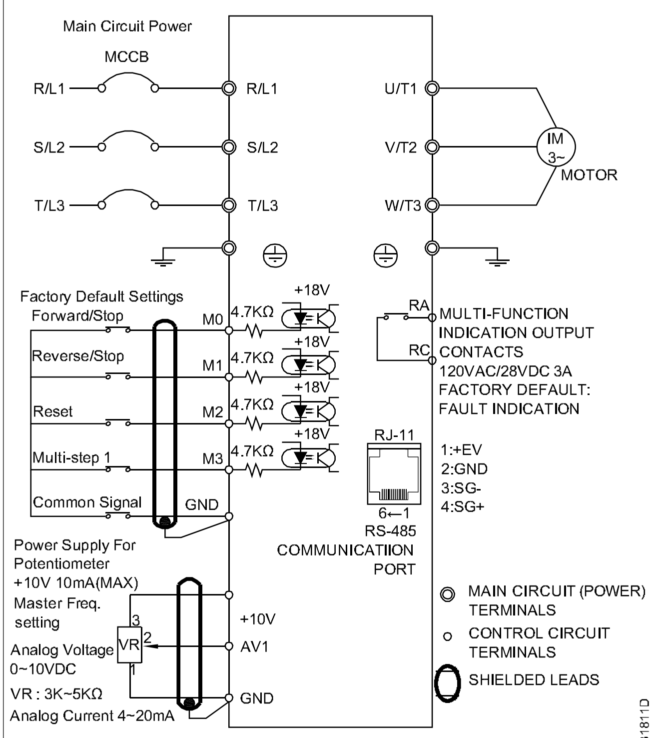
Programming of AC drive can be done through personal computer (PC) also. For this, the drive should be interfaced with PC through 'RS 485' port.

LED displays are also given in the display unit to indicate the status of drive like 'RUN', 'FWD' and 'REV'.

Operation of AC motor through drive

The motor and drive connections are well illustrated in Fig 13. A 3∅ , 415V, 50Hz AC supply is connected to the drive input terminals R/L_1, S/L_2 & T/L_3. Similarly output terminals of this drive is such as U/T_1, V/T_2 & W/T_3 are connected to 3 phase induction motor. (The terminal names may vary depends on the type and make)

Fig 13



CONNECTION DIAGRAM OF AC DRIVE AND MOTOR

Both input end and output ends are earthed separately.

Changing of speed

The AC input supply provided, should match the voltage and frequency given on the nameplate. Improper voltage may damage the drive.

Programming can be done through 'MOD/RESET' button in association with ∆ and ∇ button and the drives speed can be changed by using these buttons. The drive is started through 'RUN'/STOP' button.

The motor can be run at different speed by programming for the required speed.

Changing the direction of rotation

The direction of rotation can be changed. To do this, press 'RUN/STOP' button. When the motor is completely stopped, select 'rev' parameter and press 'RUN/STOP' button again. Now the motor will run in opposite direction.

> **Same procedure can be followed to change the direction of rotation of double cage induction motor also.**

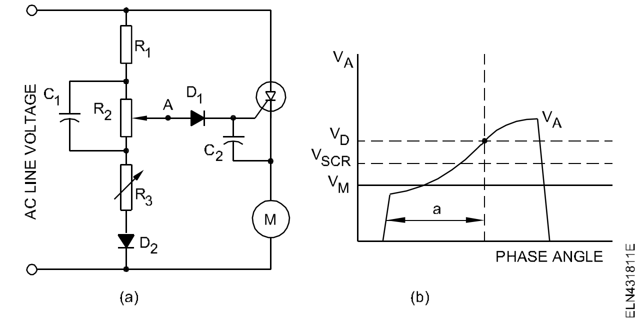
Precautions to be observed during installation, connection and operation of AC drive

- Do not connect the AC power to the U/T1, V/T2, W/T3 terminals, as it will damage the AC drive.
- Ensure all screws are tightened to the proper torque rating.
- During installation, follow all local electrical and safety codes.
- Ensure that the appropriate protective devices (circuit breaker or fuses) are connected between the power supply and AC drive.
- Make sure that the leads are connected correctly and the AC drive is properly grounded. (Ground resistance should not exceed 0.1Ω)
- Use ground leads that comply with standards and keep them as short as possible.
- Multiple VFD-L units can be installed in one location. All the units should be grounded directly to a common ground terminal.
- Make sure that the power source is capable of supplying the correct voltage and required current to the DC drive.
- Do not attach or remove wiring when power is applied to the AC drive.
- Do not monitor the signals on the circuit board while the AC drive is in operation.
- If filter is required for reducing EMI (Electro Magnetic interference), install it as close as possible to AC drive.

Speed control of universal motors using SCR : Majority of domestic appliances like electric drilling machine, mixer etc., incorporate universal electric motors. Any of the half wave or full wave controls discussed earlier can be used to control speed of universal motors. Universal motors have some unique characteristics which allow their speed to be controlled very easily and efficiently with a feedback circuit is in Fig 14.

The circuit at Fig 14a provides phase controlled half wave power to the motor; that is, one the negative half cycle, the SCR blocks current flow in the negative half cycle, the SCR blocks current flow in the negative direction causing the motor to be driven by a pulsating direct current whose amplitude is dependent in the phase control of the SCR. The operation of the circuit shown in Fig 14 is as follows.

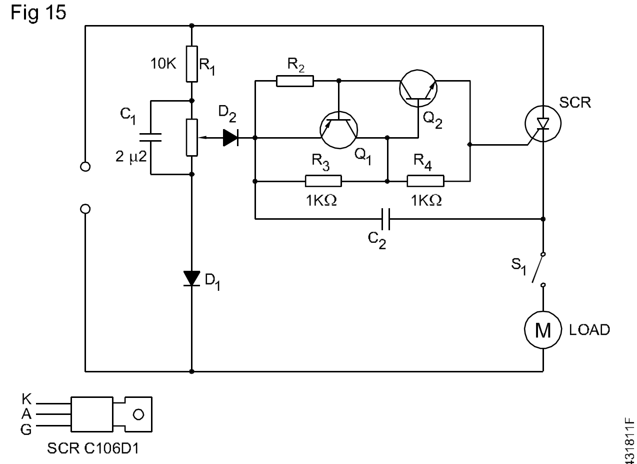
Fig 14



- Assuming that the motor is running, the voltage at point A in the circuit must be larger than the forward drop of diode D_1, the gate to cathode drop of the SCR, and the emf generated by the residual mmf in the motor, to get sufficient forward flow to trigger the SCR.
- The wave form at point A (V_A) for one positive half cycle is in Fig 14b and with V_{SCR}, V_D and motor generated emf V_M. The phase angle at which the SCR would trigger is shown by the vertical dotted line.
- For any reason if the motor speed increases, then V_M will increase, the trigger would move upwards and to the right along the curve so that the SCR would trigger later in the half - cycle thus providing less power to the motor, causing it to slow down. Similarly, if the motor speed decreases, the trigger point will move to the left and down the curve, causing the SCR to trigger earlier in the half cycle providing more power to the motor thereby speeding it up.
- Resistors R_1, R_2, R_3 along with diode D_1 and C_1 forms a ramp generator. Capacitor C_1 is charged by the voltage divider R_1, R_2 and R_3 during the positive half cycle. Diode D_2 prevents negative current flow during the negative half cycle, therefore C_1 discharges through R_2 and R_3 during negative half cycle. Varying the value of R_2 varies the trigger angle α.

A practical version of the circuit for controlling the speed of universal motors is in Fig 15.

Fig 15



CIRCUIT DIAGRAM OF UNIVERSAL MOTOR SPEED CONTROLLER

As can be seen, the circuit at Fig 15 is quite similar to that at Fig 14 but for the addition of two transistors and a few resistors.

In Fig 6, the action of Q_1 - Q_2 is to provide adequate gate current to trigger the SCR into conduction.

Q_1 - Q_2 and their associated resistors acts as a voltage sensitive switch. In each half cycle, C_2 is able to charge via R_1. As soon as voltage across C_2 rises to suitable value. Q_1 and Q_2 both switch- on and partially discharge C_2 into the gate of the SCR, thus delivering a pulse of high current to the SCR gate, independent of any current drive limitations of RV1. The Q_1 - Q_2 and C_2 network thus enables virtually any SCR to be used in the circuit almost irrespective of its sensitivity characteristics.

The universal motor speed control circuit is in Fig 15 enables the motor speed to be smoothly varied from zero to 75% of maximum via a single control. It also incorporates built - in feedback compensation to maintain the motor speed virtually constant at any given speed setting, regard-less of load changes.