WEEK-02
Morning session:
Video links:

1. https://youtu.be/g7jFGOn6xfU (What is a VFD? (Variable Frequency Drive))
2. https://youtu.be/yEPe7RDtkgo (Variable Frequency Drives Explained - VFD Basics IGBT inverter).
3. https://youtu.be/wDZANW2HeJ8 (What is VFD/ Inverter. Practical unit)

(Related links for theory:
1. https://vfds.com/blog/what-is-a-vfd/
2. https://realpars.com/variable-frequency-drive/
3. https://instrumentationtools.com/variable-frequency-drive-working-principle/
4.https://www.nrcan.gc.ca/energy-efficiency/energy-star-canada/about/energy-star-announcements/publications/variable-frequency-drives/principles-operation-ac-vfd-drives/15433
5.https://www.automate.org/industry-insights/vfds-the-next-best-thing-to-motion-control#:~:text=A%20PWM%20VFD%20consists%20of,inverter%2C%20see%20figure%201).

6.Industrial and domestic applications of VFDs. http://www.vfds.org/applications.html#:~:text=Variable%20Frequency%20Drive%20(VFD)%20can,variable%20speed%20with%20variable%20torque.

Variable Frequency Drive (VFD)

- Introduction
- Building blocks of VFDs.
- Specifications, types and working principles.

Introduction:

VFD stands for Variable Frequency Drive. They are used for running an AC motor at variable speeds or let them ramp up (Increase) their speed to give them a smooth start-up. Some simply call them drives. They work by adjusting the frequency of the motor to adjust the rpms.

OR

A Variable Frequency Drive (VFD) is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor. Other names for a VFD are **variable speed drive (VSD)**, **adjustable speed drive (ASD)**, **adjustable frequency drive (AFD)**, **AC drive**, **microdrive**, and **inverter**.

Frequency (or hertz) is directly related to the motor's speed (RPMs). In other words, the faster the frequency, the faster the RPMs. If an application does not require an electric motor to run at full speed, the VFD can be used to ramp down (Decrease) the frequency and voltage. As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement.

Types of VFDs

There are three common types of VFDs.
1. Current source inversion (CSI) VFD
2. Voltage source inversion (VSI) VFD
3. Pulse-width modulation (PWM) VFDs

1. Current source inversion (CSI) VFD

Current source inversion (CSI) has been successfully used in signal processing and industrial power applications. CSI VFDs are the only type that has regenerative power capability. In other words, they can absorb power flow back from the motor into the power supply. CSI VFDs give a very clean current waveform but require large, expensive inductors in their construction and cause cogging (pulsating movement during rotation) below 6 Hz.

2. Voltage source inversion (VSI) VFD

Voltage source inversion (VSI) drives have poor power factor, can cause motor cogging below 6 Hz, and are non-regenerative. Consequently, CSI and VSI drives have not been widely used.

3. Pulse-width modulation (PWM) VFDs

Pulse-width modulation (PWM) VFDs are most commonly used in industry because of excellent input power factor due to fixed DC bus voltage, no motor cogging, higher efficiencies, and lower cost.

s**Building blocks of VFDs (PWM VFD)**

A PWM VFD consists of three basic components:
1. The AC to DC conversion block (the rectifier)
2. The filtering block (the DC bus or DC link) and
3. The DC to AC conversion block (Inverter) where the frequency modulation takes place.

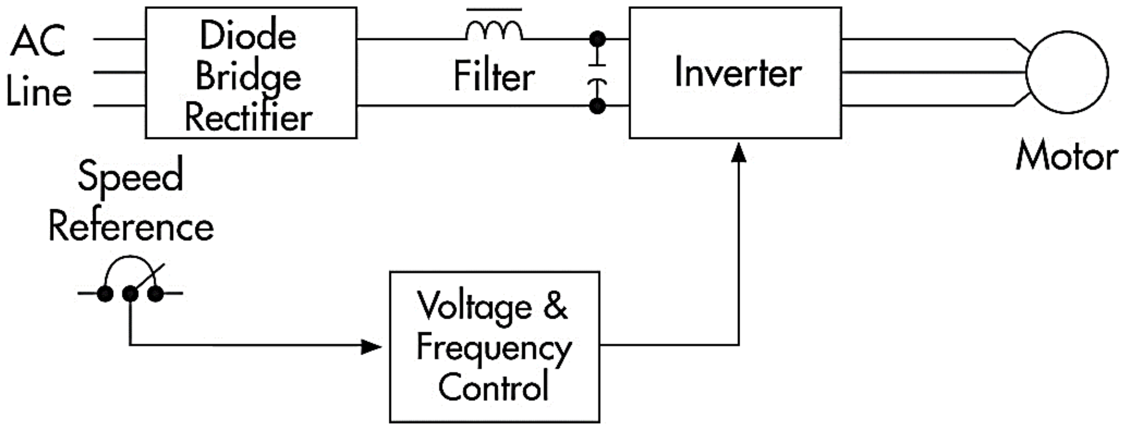


Fig 1: Block diagram of a typical PWM VFD

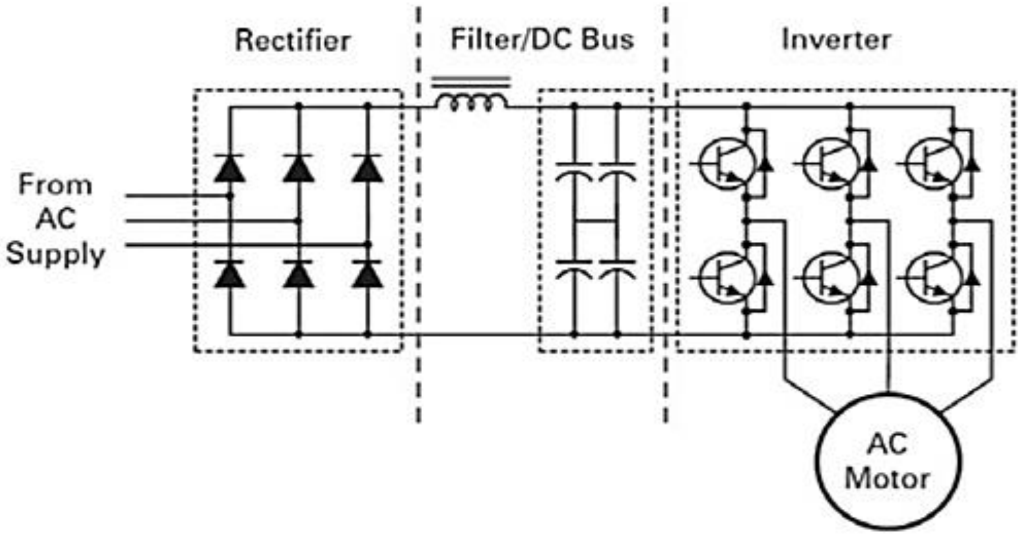


Fig (a)

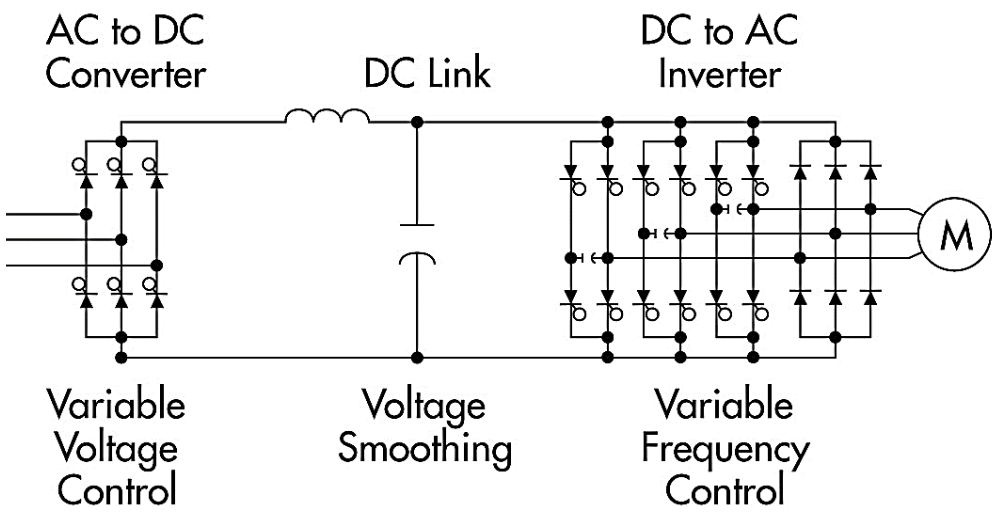


Fig (b)

NOTE: Fig (a) & (b) are the simplified block diagrams of PWM VFD

Working Principle of PWM VFD:

1. The AC to DC conversion block (the rectifier)

The **first stage** of a Variable Frequency AC Drive, or VFD, is the **Converter/Rectifier**. The Converter/Rectifier comprised of six diodes. They allow current to flow in only one direction; the direction shown by the arrow in the diode symbol.

For example, whenever A-phase is more positive than B or C phase voltages, then ssthat diode will open and allow current to flow. When B-phase becomes more positive than A-phase, then the B-phase diode will open and the A-phase diode will close. The same is true for the 3 diodes on the negative side of the bus. Thus, we get six current "pulses" as each diode opens and closes. This is called a "six-pulse VFD", which is the standard configuration for current Variable Frequency Drives.

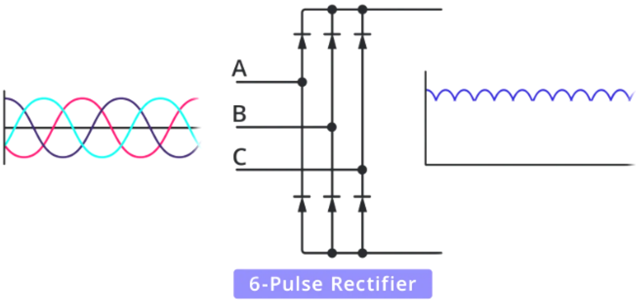


Fig 2: six-pulse converter

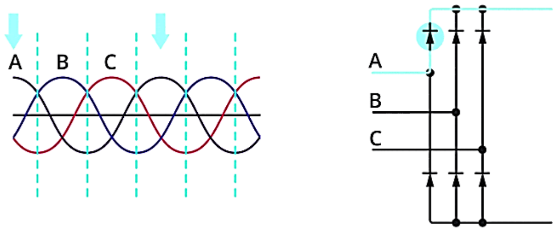
This is called a **six-pulse rectifier** or converter, and it's where the three-phase alternating current gets converted into direct current by the use of diodes**.**

When we connect a three-phase alternating current to the converter:

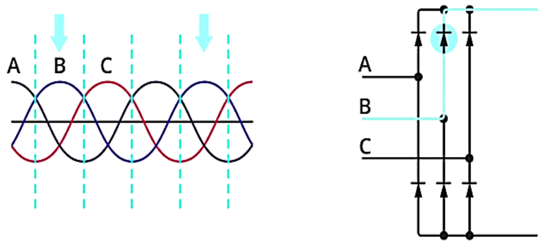
– When phase A is greater than phase B or C voltages, this diode opens, allowing current to flow.

– When phase B becomes greater than phase A, then it is phase B diode that opens while phase A diode is closed.

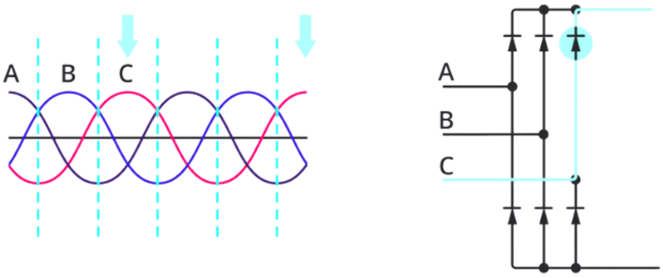
- The same is true for C, as well as for the three diodes on the negative side of the bus.

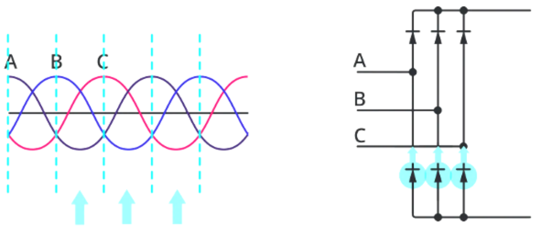


A-diode starts conduct



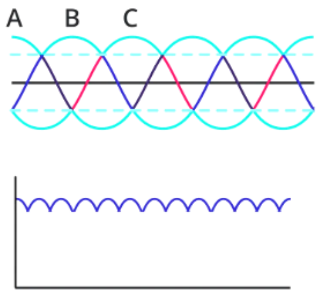
B- diode starts conduct

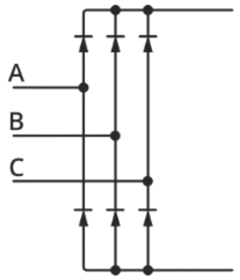




C- diode starts conduct **Same is true for diodes on negative side of Bus**

That results in six **pulses** of currents as each diode opens and closes. The resultant waveform will look like this:

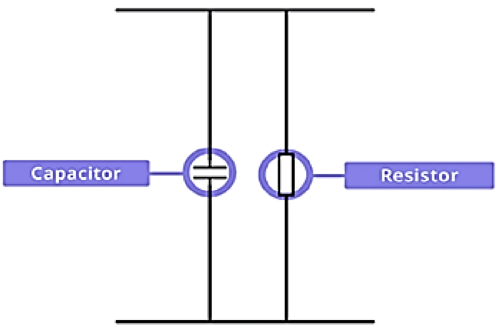


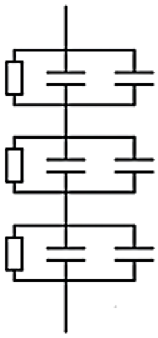


2. The filtering block (the DC bus or DC link)

Next, we have the DC filter and buffer, also known as the DC bus/DC link. The DC bus is represented by only one capacitor and resistor on the diagram, but in reality, there are various capacitors and resistors associated in series and in parallel.

Resistor function is to divide voltage and it will guarantee that all capacitors have the same voltage.





3. The DC to AC conversion block (Inverter)

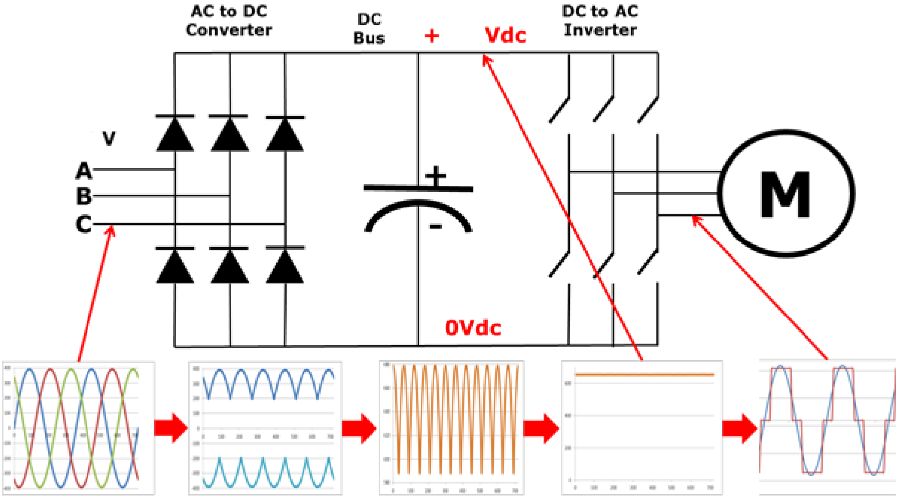
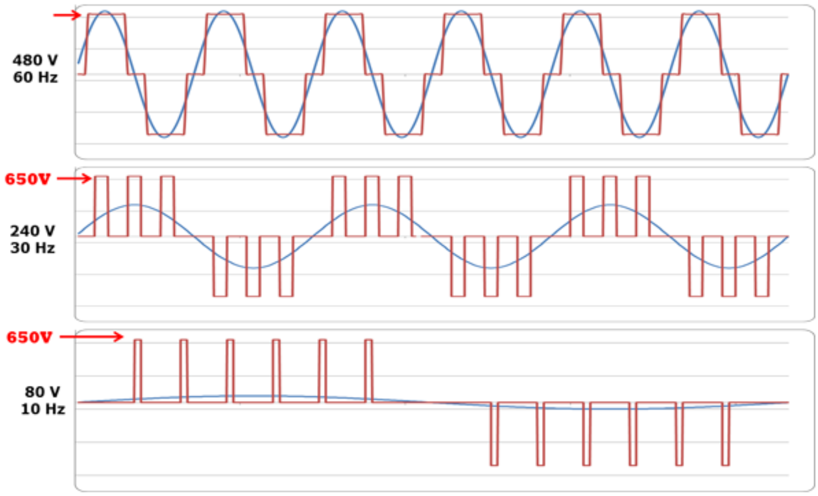


Fig 3. Inverter block

Note that in a real VFD, the switches shown would actually be transistors(IGBTs).

When we close one of the top switches in the inverter, that phase of the motor is connected to the positive dc bus and the voltage on that phase becomes positive. When we close one of the bottom switches in the converter, that phase is connected to the negative dc bus and becomes negative. Thus, we can make any phase on the motor become positive or negative at will and can thus generate any frequency that we want. So, we can make any phase be positive, negative, or zero.



Notice that the output from the VFD is a “rectangular” wave form. VFD’s do not produce a sinusoidal output. This rectangular waveform would not be a good choice for a general purpose distribution system, but is perfectly adequate for a motor.
If we want to reduce the motor frequency to 30 Hz, then we simply switch the inverter output transistors more slowly. But, if we reduce the frequency to 30Hz, then we must also reduce the voltage to 240V in order to maintain the V/Hz. This is called Pulse Width Modulation or PWM. Notice that during the first half cycle, the voltage is ON half the time and OFF half the time. Thus, the average voltage is half of 480V or 240V. By pulsing the output, we can achieve any average voltage on the output of the VFD.

Advantages of VFD:

1. Energy saving: More than 65% of the power is consumed by electric motors in industries. Both magnitude and frequency control technique to vary the speed consumes less power when variable speed is required by the motor. So a great amount of energy is conserved by these VFDs.
2. Closed-loop controlling: VFD allows accurate positioning of the motor speed by continuously comparing with reference speed even at changes in the loading conditions and input disturbances like voltage fluctuations.

3. Limits starting current: Induction motor draws current which is 6 to 8 times the nominal current at starting. Compared to conventional starters, VFD’s gives better results because it delivers low frequency at the time of starting. Due to low frequency, the motor draws less current and this current never exceeds its nominal rating at starting as well as operating.

4. Smooth operation: It offers smooth operations at starting and stopping and also reduces thermal and mechanical stress on motors and belt drives.

5. High power factor: The inbuilt power factor correction circuit in the DC link of VFD reduces the need for additional power factor correction devices. The power factor for the induction motor is very low for particularly no-load application, while at full load, it is 0.88 to 0.9. Low power factor results in poor utilization of power due to high reactive losses.

6. Easy installation: Pre-programmed and factory wired VFDs offer an easy way for connection and maintenance.

After Noon session
Week-2 day-2
(VFD with motor control panel
http://www.vfds.org/vfd-panels-321225.html)

VFD Panel (Variable Frequency Drive Panel):

VFD Control Panel

Variable frequency drive control panel (also named VFD panel, AC drive electrical control panel) is consisting of VFD inside the cabinet with external control, protect, display and other electrical connections. It's a frequency conversion device to controls three phase AC motor (including fans and pumps) in variable speed to save energy.

VFD panels adopt enclosed cabinet structure. Generally, the protection class is IP20, IP21, IP30, and some panels may reach IP64, IP65 and even IP66 where the application environments need weather proof, waterproof. The panels surfaces are coated by spray by suppliers, and easy to install in parallel.

Variable speed drive is a dedicated component of the electrical control panel, the panel's frequency convention and main features are depending on the VFD and other components configuration. VFD panels are different according to their different functions and applications. Generally, it needs customized manufacture base, on specified environment, like in constant water supply panels (one panel control 1, 2, 3 pumps, etc.), escalators control panels, central air condition circulating pump panels, and fan's control panels.

Industrial applications of VFD:
(VFD applications link & case study: http://www.vfds.org/applications.html)

1. Pharmaceutical industry
2. VFD for Compressor in oil and gas industry
3. VFD for Virtual Vibration Testing in Railway System.
4. Variable frequency drive on Cooling Tower
5. Using variable frequency drive PID control for pump motor
6. Static head of submersible sewage pump
7. VFD for Centrifugal Pumps
8. VFD for conveyor systems
9. Variable frequency drive for Crane & Hoist
10. VFD in Cement Industry

Domestic applications of VFD:

1. VFD energy saving for Fans
2. VFD selection for refrigeration compressor
3. Variable frequency drive on Booster Pumps
4. VFD on Swimming Pool Filtration System
5. Variable speed drives control duplex pumps
6. To control AC compressor motor

- ✓ **Present a Case study on application of VFD drives for speed control in industry/ institute**
- ✓ **submit a report on the above**

https://energysolutionsindia.wordpress.com/2015/05/23/case-study-report-application-of-variable-frequency-drive/

Give a presentation on an industry application to INTEGRATE VFD WITH PLC

1. How to Control a VFD with a PLC - Part 1 (Configuring ControlLogix 5000 and HMS Anybus gateway) → https://youtu.be/Uoj9V62WHvc (part 1).
2. How to Control a VFD with a PLC - Part 2 (Configuring HMS Anybus gateway and Siemens Robicon VFD) → https://youtu.be/mlKqMXWeGws (part 2).
3. How to Control a VFD with a PLC - Part 3 (Siemens VFD Configuration) → https://youtu.be/bqIf18tChFI (part 3)
4. How to Control a VFD with a PLC - Part 4 (Configuring Motor Data in the Siemens Starter Software) → https://youtu.be/gB4HpqW4vnQ

- **Case study: Video demonstration of Automatic potato chips production plant**
    1. https://youtu.be/L6IYy95ODDU

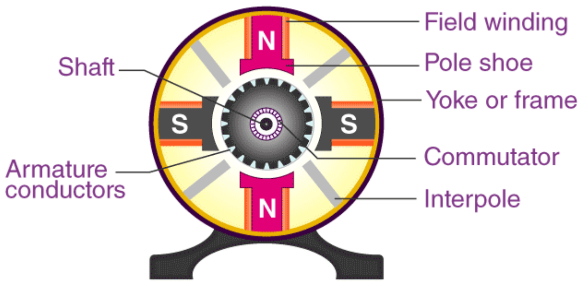
2. https://youtu.be/w_vTo0sEtc8
3. https://frenchfriesmachine.com/french-fries-line/large-scale-potato-chips-line.html

What is a DC Motor?

A DC motor is defined as a class of electrical motors that convert direct current electrical energy into mechanical energy.

From the above definition, we can conclude that any electric motor that is operated using direct current or DC is called a DC motor. We will understand the DC motor construction and how a DC motor converts the supplied DC electrical energy into mechanical energy in the next few sections.

DC Motor Diagram



DC motor construction parts

Different Parts of a DC Motors

A DC motor is composed of the following main parts::

Armature or Rotor

The armature of a DC motor is a cylinder of magnetic laminations that are insulated from one another. The armature is perpendicular to the axis of the cylinder. The armature is a rotating part that rotates on its axis and is separated from the field coil by an air gap.

Field Coil or Stator

A DC motor field coil is a non-moving part on which winding is wound to produce a magnetic field. This electro-magnet has a cylindrical cavity between its poles.

Commutator and Brushes

Commutator

The commutator of a DC motor is a cylindrical structure that is made of copper segments stacked together but insulated from each other using mica. The primary function of a commutator is to supply electrical current to the armature winding.

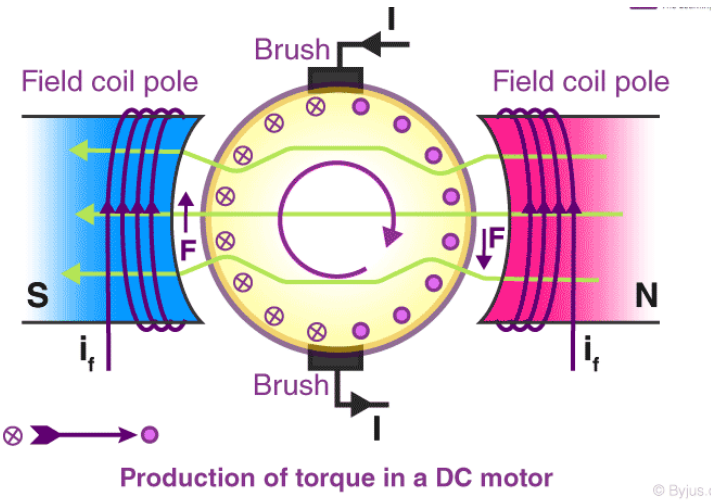
Brushes

The brushes of a DC motor are made with graphite and carbon structure. These brushes conduct electric current from the external circuit to the rotating commutator. Hence, we come to understand that the **commutator and the brush unit are concerned with transmitting the power from the static electrical circuit to the mechanically rotating region or the rotor**.

DC Motor Working

In the previous section, we discussed the various components of a DC motor. Now, using this knowledge let us understand the working of DC motors.

A magnetic field arises in the air gap when the field coil of the DC motor is energised. The



created magnetic field is in the direction of the radii of the armature. The magnetic field enters the armature from the North pole side of the field coil and “exits” the armature from the field coil’s South pole side.

The conductors located on the other pole are subjected to a force of the same intensity but in the opposite direction. These two opposing forces create a torque that causes the motor armature to rotate.

What is an AC Motor : Types, Working & Its Applications

We know that the main function of an electric motor is to convert the energy from electrical to mechanical. There are different types of electric motors available in the market like ac motor and dc motor where its classification can be done based on different parameters like type of power source, output motion type, construction & application. These motors operate through the interaction among the magnetic field of the motor & the flow of current within the winding of a wire to produce force in the torque form that is applied on the shaft of the motor.

These motors can be power-driven through AC (alternating current) sources or DC (direct current) sources, where ac sources are inverters, power grids, generators, and dc sources are rectifiers, batteries. Electric motors are more efficient as compared to other prime movers utilized in transportation, industry & the ICE (internal combustion engine). This article discusses an overview of one of the types of electric motor like AC motor and its working.

What is an AC Motor?

An electric motor like an AC motor works with an alternating current to generate mechanical energy through magnetism blended with AC. The AC motor structure includes

coils to generate a rotary magnetic field within an attached rotor toward an output shaft so that a second magnetic field can be generated.

AC Motor

These motors have been used for several years by designers and engineers to apply in different applications. These motors are very helpful in generating stable torque equal to the rated speed. These motors are very simple to handle & can be configured at a less cost.

AC Motor Working Principle

The basic working principle of an AC Motor mainly depends on magnetism. The basic AC Motor includes a wire coil & two permanent magnets nearby a shaft. Once an alternating current is supplied to the wire coil, then it turns into an electromagnet that produces a magnetic field. This motor includes two essential parts like stator and rotor. This stator includes a wire loop, a solid metal axle, freely moving metal parts that conduct electricity, a coil, a squirrel cage, etc.

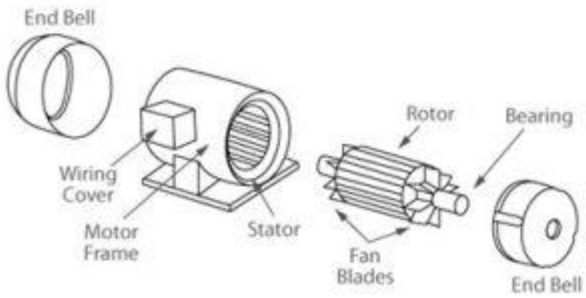
In the stator of an AC motor, we can transmit the power toward the external coils to make up the stationary part like the stator. The coils of wire can be activated in pairs, in series to generate a magnetic field that turns approximately the exterior of the ac motor.

The rotor is balanced within the magnetic field which is changing constantly because of the rotation thus, based on the electromagnetism law; the magnetic field can generate an electric current within the rotor.

If the conductor used in this is a wire or a ring, then current supplies in a loop around it, or if the conductor is a solid metal piece simply, then eddy current will flow around it. The current induced can generate its magnetic field & based on another electromagnetism law, the rotary magnetic field will rotate also. Once the magnets interact, then the coil of wires & shaft will start to turn the motor.

AC Motor Construction

In an AC motor, there are two essential parts like stator (stationary part) and rotor (rotating part). Apart from these, there are some other parts which are discussed below.



AC Motor Construction

Stator

The stator in the ac motor is an inactive part and the main function of this is to transmit a rotary magnetic field for interacting through the rotor.

Stator Core

The stator core in the motor is designed with laminations or thin metal sheets which are mainly used to decrease energy loss.

Stator Windings

Stator windings in the motor will load together to form a hollow cylinder. The stator core coils slots for the insulated wires are protected. Once the ac motor which is assembled is in process, the connection of stator windings can be done toward a power source. Every coils group with the steel core will turn into an electromagnet once the current supply is provided.

Rotor

The rotating part in the motor is the rotor and it is an essential part that is connected to the shaft. In an AC motor, the most common type of rotor used is the squirrel cage rotor. It is a cylindrical shape that is made through stacking slight steel laminations.

Shaft

The rotor assembly can be formed by pressing onto a steel shaft which expands outside of the motor casing to let the connection to an outside system broadcast the rotating power.

Bearings

Bearings are placed on the shaft of the motor to give support to the rotor & allow rotating. Some types of motors utilize a fan by placing it on the shaft of the rotor to cool down the motor once the shaft is revolving.
In the ac motor, bearings are used to hold the shaft within the place. Here, bearings will reduce the friction of the shaft that is connected toward the casing so that motor efficiency can be enhanced.

Enclosure

The enclosure in the motor includes a yoke or frame & two end brackets. The stator is located within the frame and the rotor is arranged within the stator through a small air gap that separates it from the stator. There is no straight physical link between the rotor & the stator.
The enclosure within the motor guards the inside parts against ecological elements & water. This part includes two end brackets as well as a frame.

AC Motor Speed Control

The applications of AC motors involve mostly in industrial areas wherever these motors are required to control heavy-duty machines. In power plants wherever timeliness & accuracy are very essential for the operation, then AC motors have to be controlled. So, a variety of techniques may be used for controlling ac motor frequency & speed.

There are several techniques to control the AC motor speed like altering the number of poles within extremely small increments, altering the motor's slip & altering the AC signal's frequency. From the above techniques, altering the poles is not used regularly as it is not efficient for frequent control. Another technique like altering the rotor slip of the motor is mostly used once the AC motor is designed mainly for high slip. So by using this technique, this motor should be equivalent to the electric load. So when the power is changed then load speed will be changed. In addition, this load must include extensive inertial components.
The most frequently used technique for controlling the speed of an AC motor is altering the frequency of the motor. By using this technique, AC motor drives with variable speed are utilized to change the motor speed which is known as VFD (variable frequency drives), ASD (adjustable speed drives), or AC inverters. A six-step inverter, PWN, or vector flux is used to adjust the AC frequency. A variable voltage inverter or six-step inverter mainly changes the power from AC to DC & after that, it switches to reproduce a sine wave. By using the PWM technique, DC voltage is changed quickly to equivalent "area under the curve."
By considering these AC motor speed control techniques, we can operate a power plant where AC motors are utilized to power fans, pumps, etc. These applications need preciseness to maintain an operation running efficiently. The simple technique is to install consistent AC drives which are mainly designed to control the motor speed precisely.
These methods are available with different control settings so that one can simply discover speed controls to meet the requirements of your application. The main benefits of ac motor

speed controls are the operating of machines can be controlled smoothly, acceleration control, production rates can be adjusted, savings of energy, etc.

What is a Servo Motor?

A **servo motor** is a type of motor that can rotate with great precision. Normally this type of motor consists of a control circuit that provides feedback on the current position of the motor shaft, this feedback allows the servo motors to rotate with great precision. If you want to rotate an object at some specific angles or distance, then you use a servo motor. It is just made up of a simple motor which runs through a **servo mechanism**. If motor is powered by a DC power supply then it is called DC servo motor, and if it is AC-powered motor then it is called AC servo motor. For this tutorial, we will be discussing only about the **DC servo motor working**. Apart from these major classifications, there are many other types of servo motors based on the type of gear arrangement and operating characteristics. A servo motor usually comes with a gear arrangement that allows us to get a very high torque servo motor in small and lightweight packages. Due to these features, they are being used in many applications like toy car, RC helicopters and planes, Robotics, etc.

Servo motors are rated in kg/cm (kilogram per centimeter) most hobby servo motors are rated at 3kg/cm or 6kg/cm or 12kg/cm. This kg/cm tells you how much weight your servo motor can lift at a particular distance. For example: A 6kg/cm Servo motor should be able to lift 6kg if the load is suspended 1cm away from the motors shaft, the greater the distance the lesser the weight carrying capacity. The position of a servo motor is decided by electrical pulse and its circuitry is placed beside the motor.

Servo Motor Working Mechanism

It consists of three parts:

1. Controlled device
2. Output sensor
3. Feedback system

It is a closed-loop system where it uses a positive feedback system to control motion and the final position of the shaft. Here the device is controlled by a feedback signal generated by comparing output signal and reference input signal.

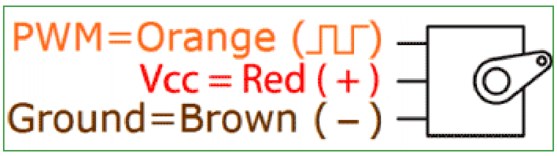
Here reference input signal is compared to the reference output signal and the third signal is produced by the feedback system. And this third signal acts as an input signal to the control the device. This signal is present as long as the feedback signal is generated or there is a difference between the reference input signal and reference output signal. So the main task of servomechanism is to maintain the output of a system at the desired value at presence of noises.

Servo Motor Working Principle

A servo consists of a Motor (DC or AC), a potentiometer, gear assembly, and a controlling circuit. First of all, we use gear assembly to reduce RPM and to increase torque of the motor. Say at initial position of servo motor shaft, the position of the potentiometer knob is such that there is no electrical signal generated at the output port of the potentiometer. Now an electrical signal is given to another input terminal of the error detector amplifier. Now the difference between these two signals, one comes from the potentiometer and another comes from other sources, will be processed in a feedback mechanism and output will be provided in terms of error signal. This error signal acts as the input for motor and motor starts rotating. Now motor shaft is connected with the potentiometer and as the motor rotates so the potentiometer and it will generate a signal. So as the potentiometer's angular position changes, its output feedback signal changes. After sometime the position of potentiometer reaches at a position that the output of potentiometer is same as external signal provided. At this condition, there will be no output signal from the amplifier to the motor input as there is no difference between external applied signal and the signal generated at potentiometer, and in this situation motor stops rotating.

Interfacing Servo Motors with Microcontrollers:

Interfacing hobby Servo motors like s90 servo motor with MCU is very easy. **Servos have three wires coming out of them**. Out of which two will be used for Supply (positive and negative) and one will be used for the signal that is to be sent from the MCU. An **MG995 Metal Gear Servo Motor** which is most commonly used for RC cars humanoid bots etc. The picture of MG995 is shown below:

The color coding of your servo motor might differ hence check for your respective datasheet.

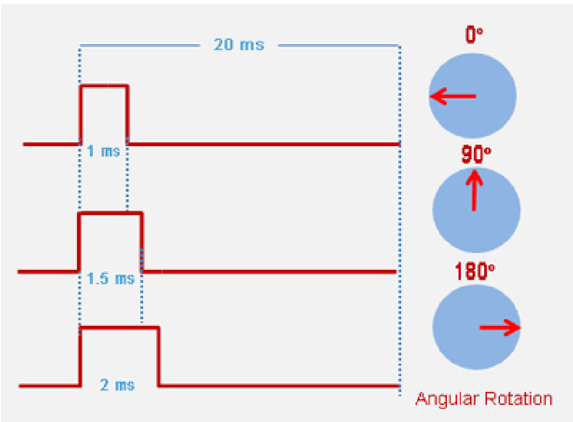
All servo motors work directly with your +5V supply rails but we have to be careful on the amount of current the motor would consume if you are planning to use more than two servo motors a proper servo shield should be designed.

Controlling Servo Motor:

All motors have three wires coming out of them. Out of which two will be used for Supply (positive and negative) and one will be used for the signal that is to be sent from the MCU.

Servo motor is controlled by PWM (Pulse with Modulation) which is provided by the control wires. There is a minimum pulse, a maximum pulse and a repetition rate. Servo motor can turn 90 degree from either direction form its neutral position. The servo motor expects to see a pulse every 20 milliseconds (ms) and the length of the pulse will determine how far the motor turns. For example, a 1.5ms pulse will make the motor turn to the 90° position, such as if pulse is shorter than 1.5ms shaft moves to 0° and if it is longer than 1.5ms than it will turn the servo to 180°.

Servo motor works on **PWM (Pulse width modulation)** principle, means its angle of rotation is controlled by the duration of applied pulse to its Control PIN. Basically servo motor is made up of **DC motor which is controlled by a variable resistor (potentiometer) and some gears**. High speed force of DC motor is converted into



torque by Gears. We know that WORK= FORCE X DISTANCE, in DC motor Force is less and distance (speed) is high and in Servo, force is High and distance is less. The potentiometer is connected to the output shaft of the Servo, to calculate the angle and stop the DC motor on the required angle.

Servo motor can be rotated from 0 to 180 degrees, but it can go up to 210 degrees, depending on the manufacturing. This degree of rotation can be controlled by applying the **Electrical Pulse** of proper width, to its Control pin. Servo checks the pulse in every 20 milliseconds. The pulse of 1 ms (1 millisecond) width can rotate the servo to 0 degrees, 1.5ms can rotate to 90 degrees (neutral position) and 2 ms pulse can rotate it to 180 degree.

All servo motors work directly with your +5V supply rails but we have to be careful about the amount of current the motor would consume if you are planning to use more than two servo motors a proper servo shield should be designed.