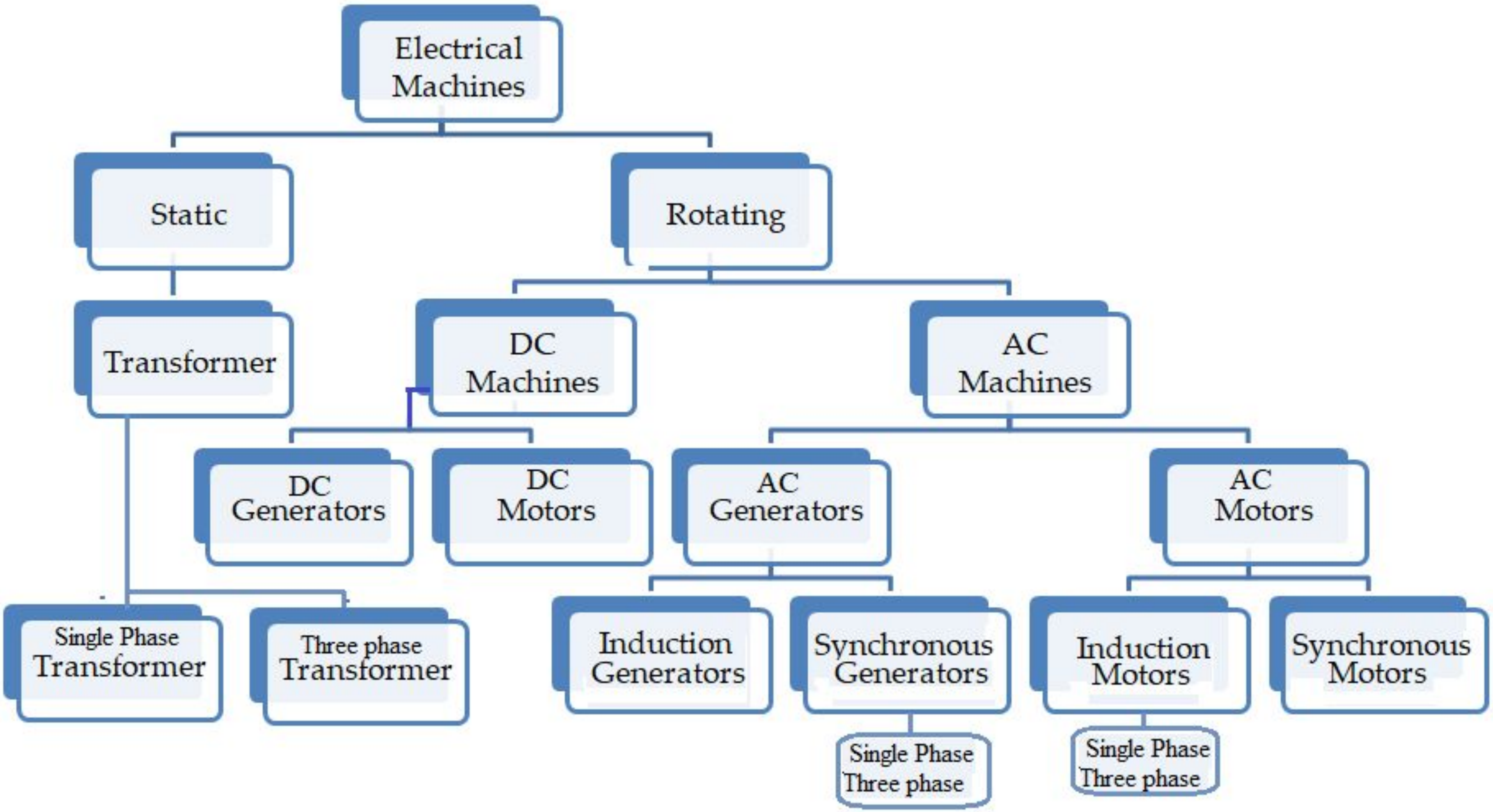
Unit-3

Electrical Machines

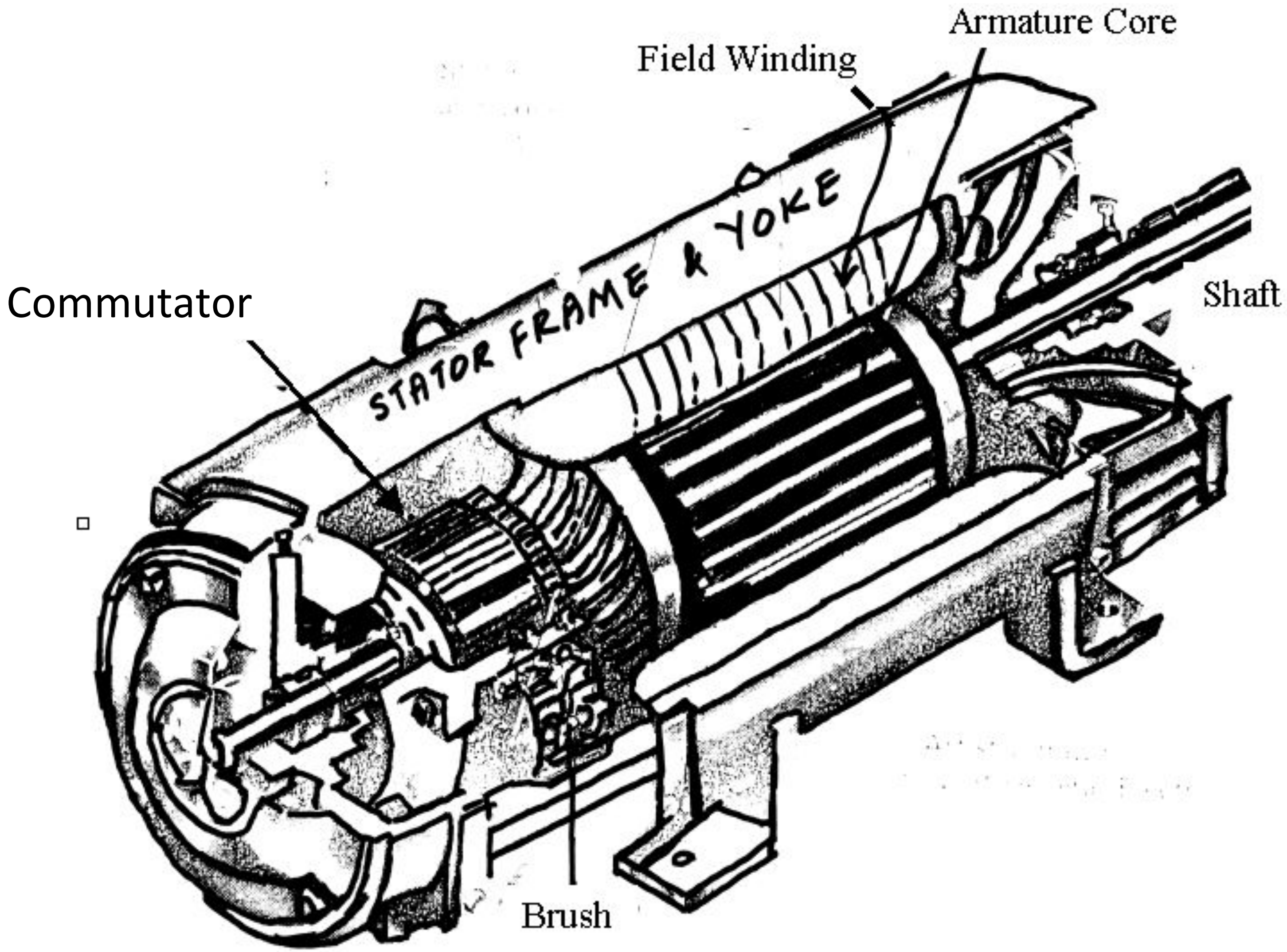
Classification of Electrical Machines



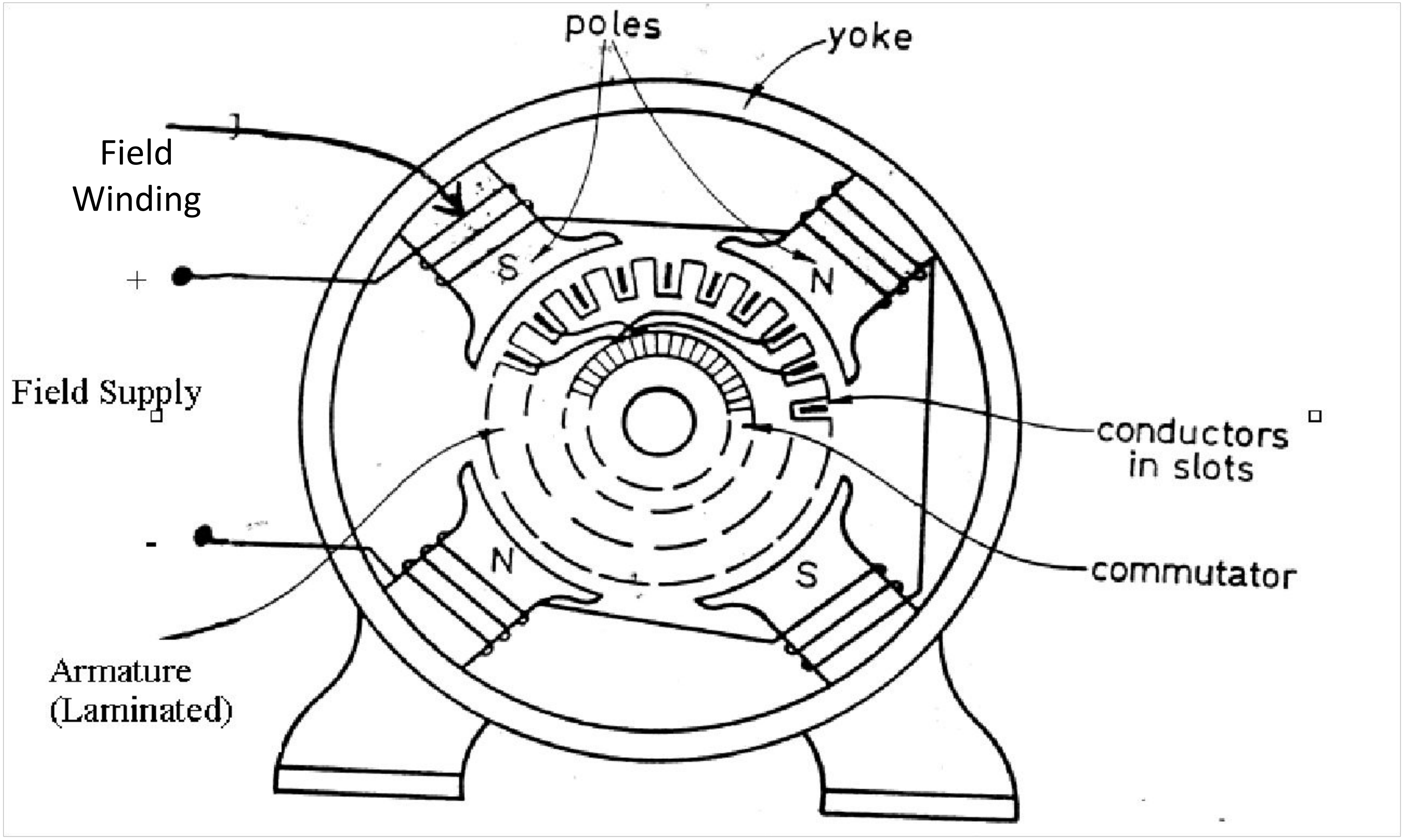
Overview of Direct Current (DC) Machines

- Direct-current (DC) machines are divided into dc generators and dc motors.
- Most DC machines are similar to AC machines: i.e. they have AC voltages and current within them.
- DC machines have DC outputs just because they have a mechanism converting AC voltages to DC voltages at their terminals. This mechanism is called a commutator; therefore, DC machines are also called commutating machines.
- DC generators are not as common as they used to be, because direct current when required is mainly produced by electronic rectifiers.
- While dc motors are widely used, such automobile, aircraft, and portable electronics, in speed control applications…

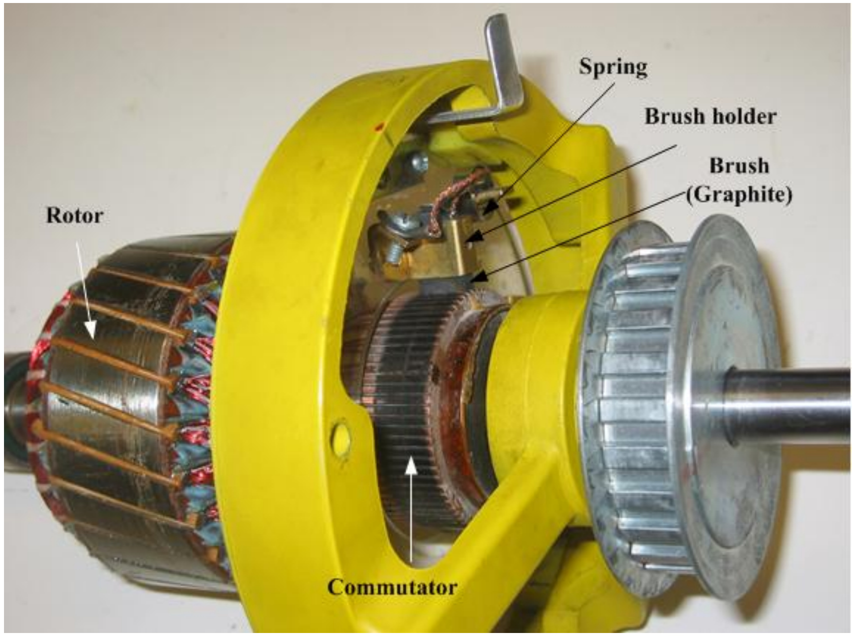
DC Machine Construction



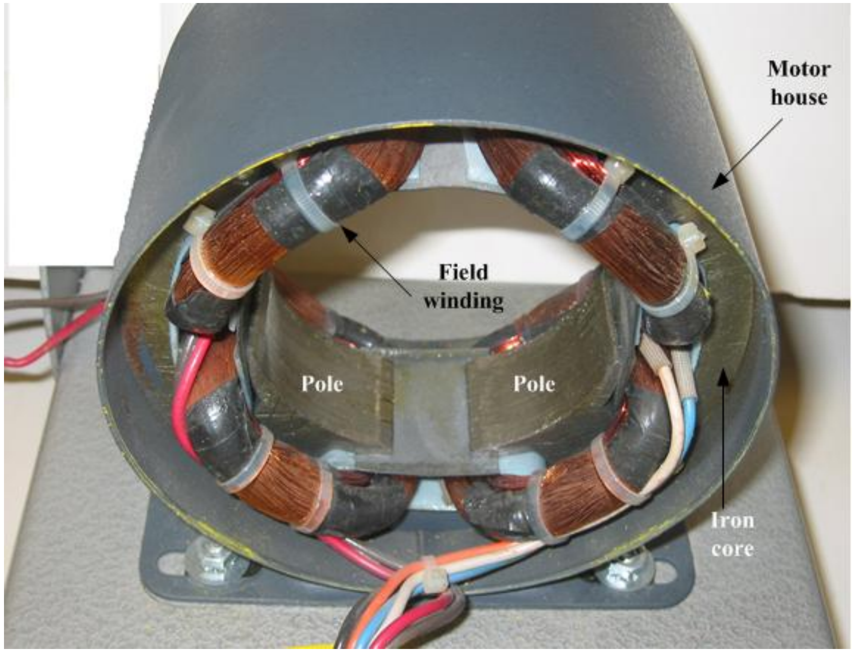
DC Machine Construction



Construction of DC machine

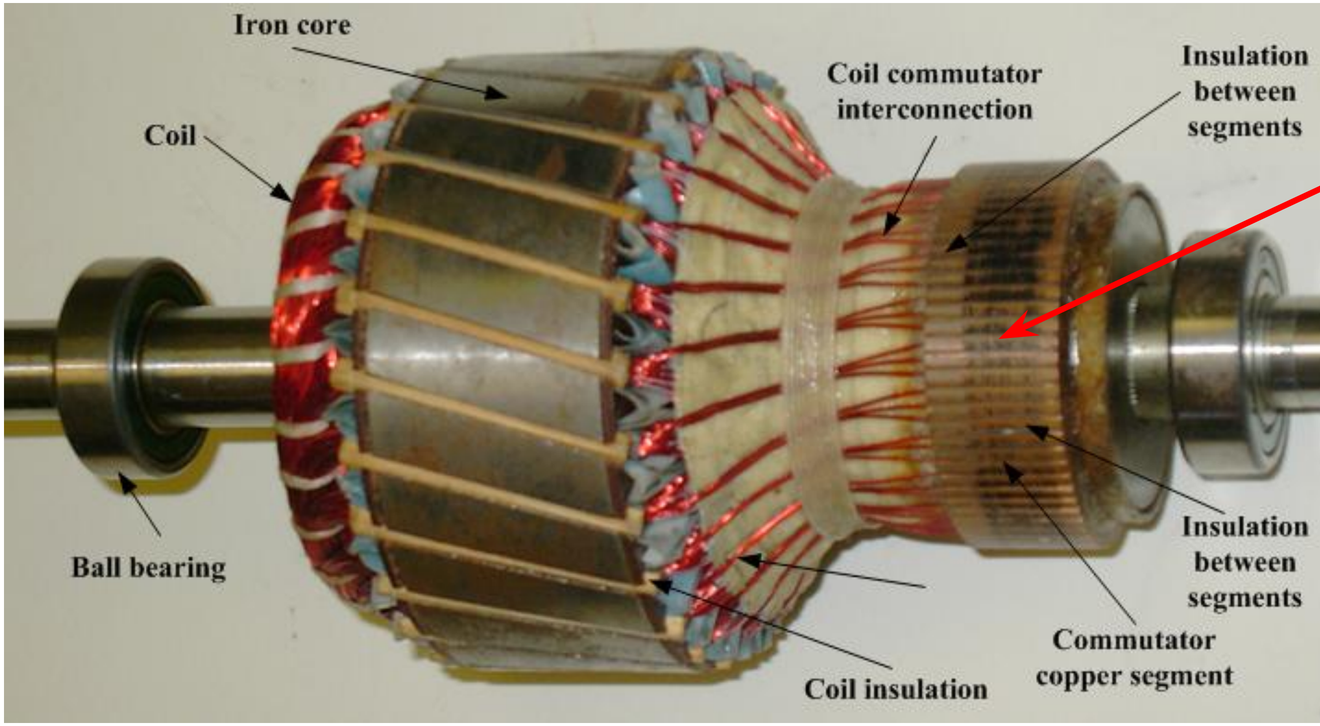


Cutaway view of a dc motor



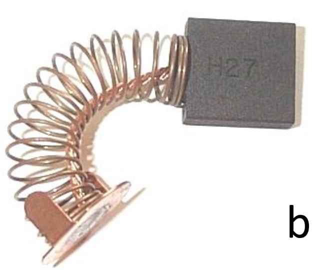
Stator with poles visible.

Construction of DC machine



segments

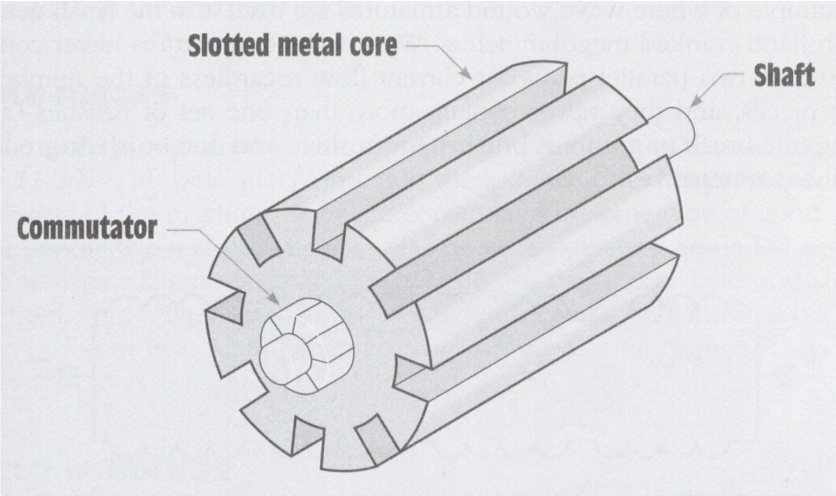
Rotor of a dc motor.



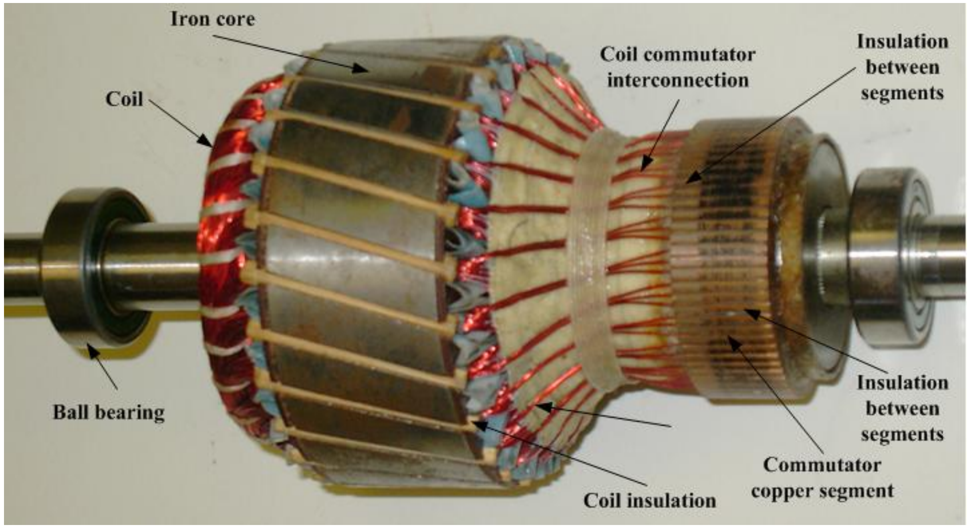
brushes

ARMATURE

- More loops of wire = higher rectified voltage
- In practical, loops are generally placed in slots of an iron core
- The iron acts as a magnetic conductor by providing a low-reluctance path for magnetic lines of flux to increase the inductance of the loops and provide a higher induced voltage.
- The commutator is connected to the slotted iron core.
- The entire assembly of iron core, commutator, and windings is called the armature.
- The windings of armatures are connected in different ways depending on the requirements of the machine.



Loops of wire are wound around slot in a metal core

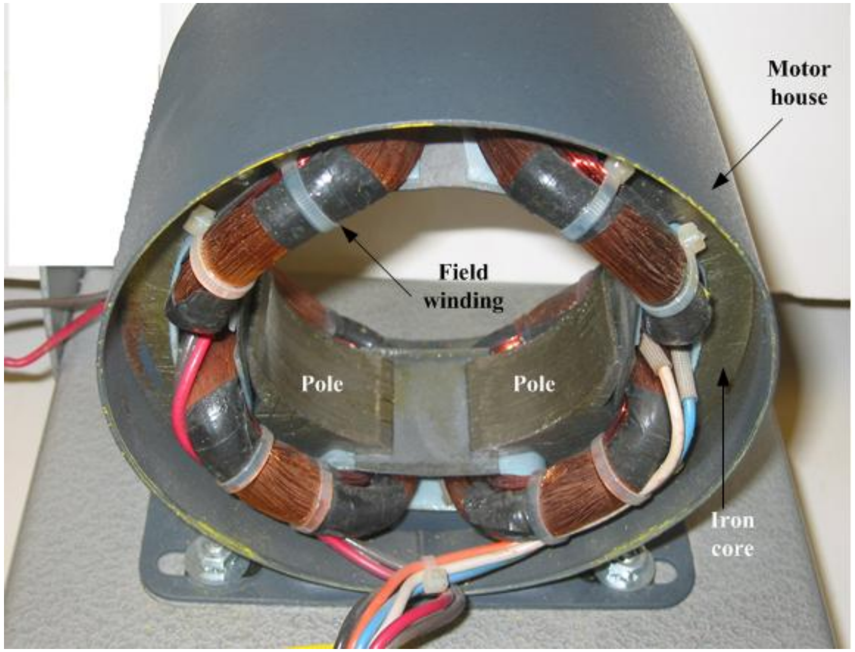


DC machine armature

FIELD WINDINGS

- Most DC machines use wound electromagnets to provide the magnetic field.

- Two types of field windings are used :
  - series field
  - shunt field

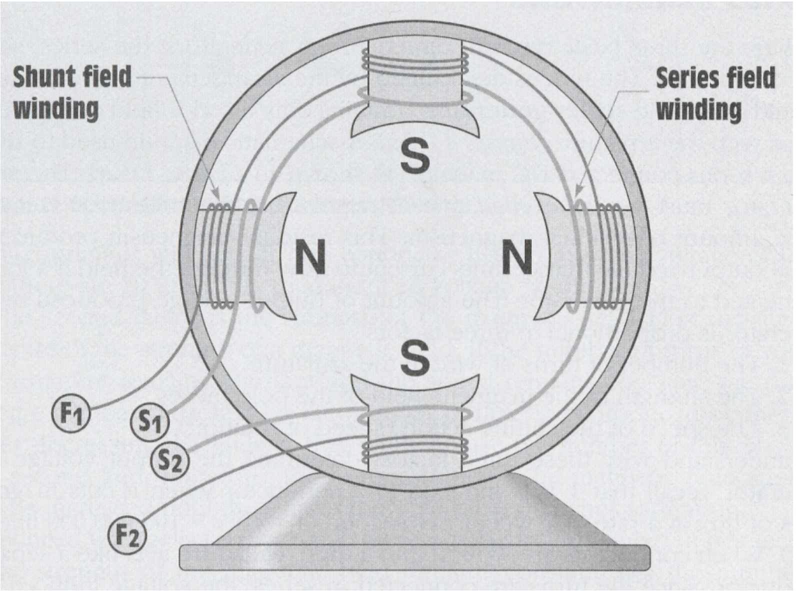


FIELD WINDINGS (Cont)

- Series field windings
  - are so named because they are connected in series with the armature
  - are made with relatively few windings turns of very large wire and have a very low resistance
  - usually found in large horsepower machines wound with square or rectangular wire.
  - The use of square wire permits the windings to be laid closer together, which increases the number of turns that can be wound in a particular space

FIELD WINDINGS (Cont)

- When a DC machine uses both series and shunt fields, each pole piece will contain both windings.
- The windings are wound on the pole pieces in such a manner that when current flows through the winding it will produce alternate magnetic polarities.



Yoke or Frame It is the outermost solid metal part of the machine. It forms part of magnetic circuit and protects all the inner parts from mechanical damage.

Field System This consists of main field poles and field winding. The field poles are made of laminations of a sutiable magnetic material. Such a magnetic material has very high relative permeability and very low hysteresis loss. The pole face is in the form of horse shoe so that a uniform flux distribution is obtained in the air gap between the poles and the rotating part. The field winding is placed over the each pole and all these are connected in series. Again the field winding is so arranged on the different poles that when a direct current is passed through this winding, the poles get magnetized to N and S polarities alternately. Thus, the field system is responsible for producing the required working flux in the air gap.

Brushes A set of brushes made of carbon or graphic are fixed such that they are always in gentle touch with the revolving armature. The generator is connected to external circuits by means of these brushes. Thus, the brushes are used to tap the generated electrical energy off the rotating part of the generator.

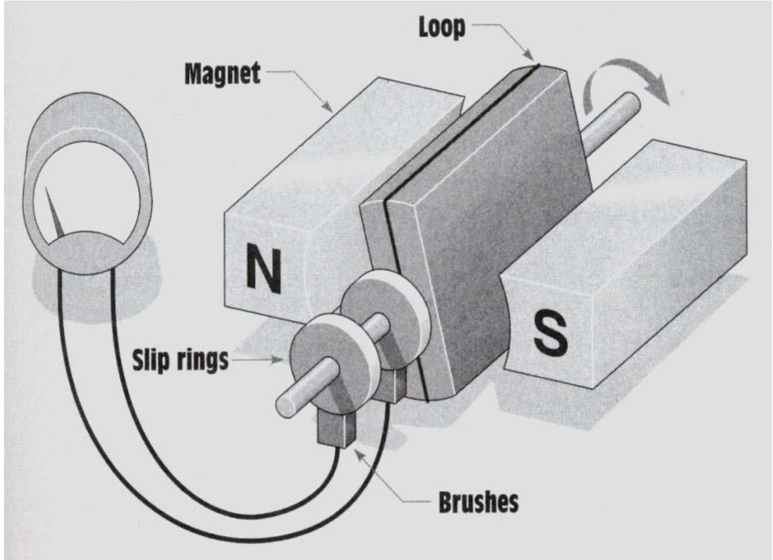
Armature The armature of a dc generator is in the form of laminated slotted drum. Slots are provided over the entire periphery of the armature

Commutator The commutator is similar in shape to armature. But, it has less diameter than that of the armature. Required number of segments are provided over the complete periphery of the commutator. There is an electrical insulation between every pair of segments. A minimum of two conductors are connected to each segment. But, at the same time the two conductors making a single coil are connected to different commutator segments. The brushes are so placed that they are always keeping to such with the revolving commutator segments.

DC Generator

- A dc generator is a machine that converts mechanical energy into electrical energy (dc voltage and current) by using the principle of magnetic induction.

- In this example, the ends of the wire loop have been connected to two slip rings mounted on the shaft, while brushes are used to carry the current from the loop to the outside of the circuit.

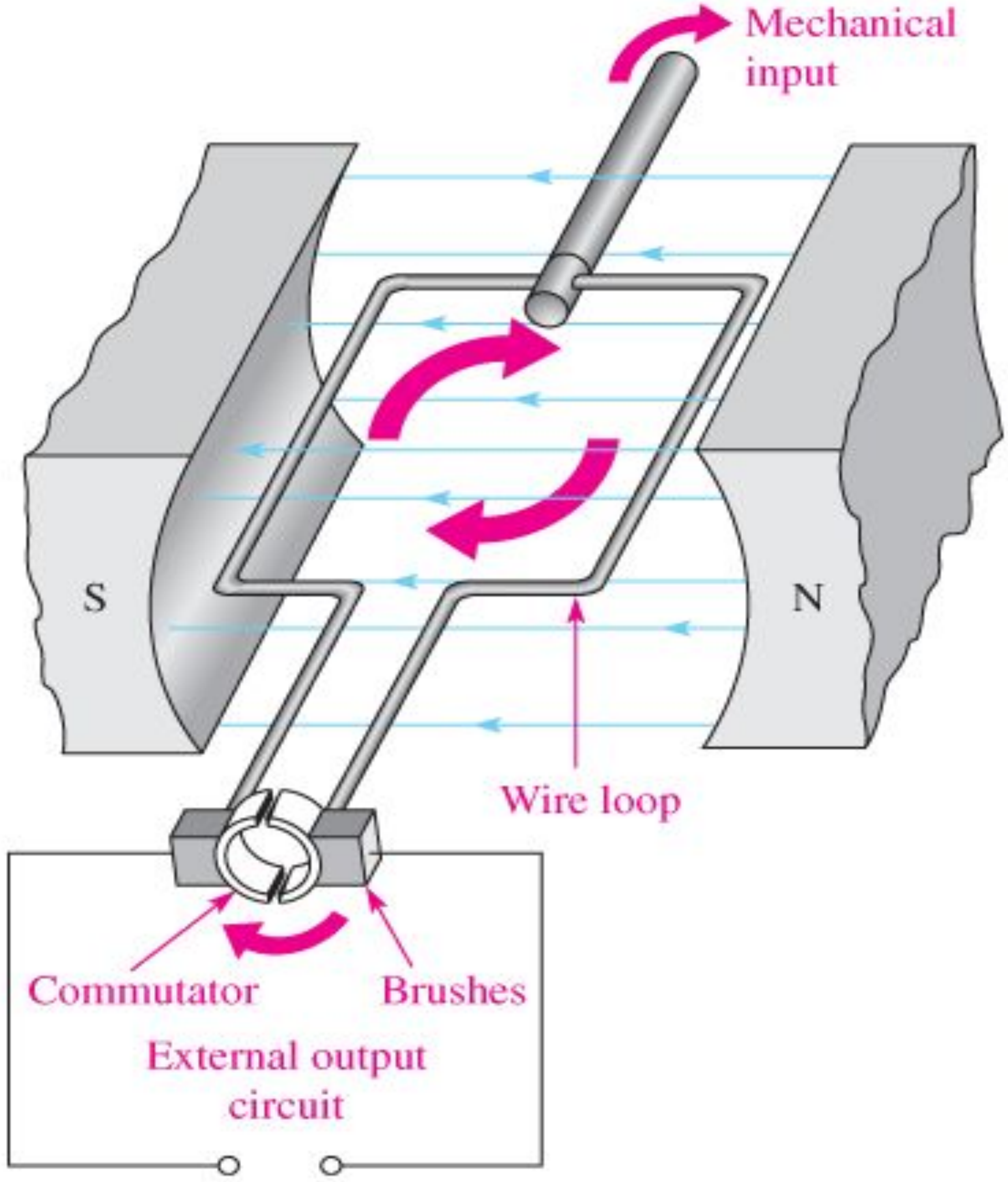


Principle of magnetic induction in DC machine

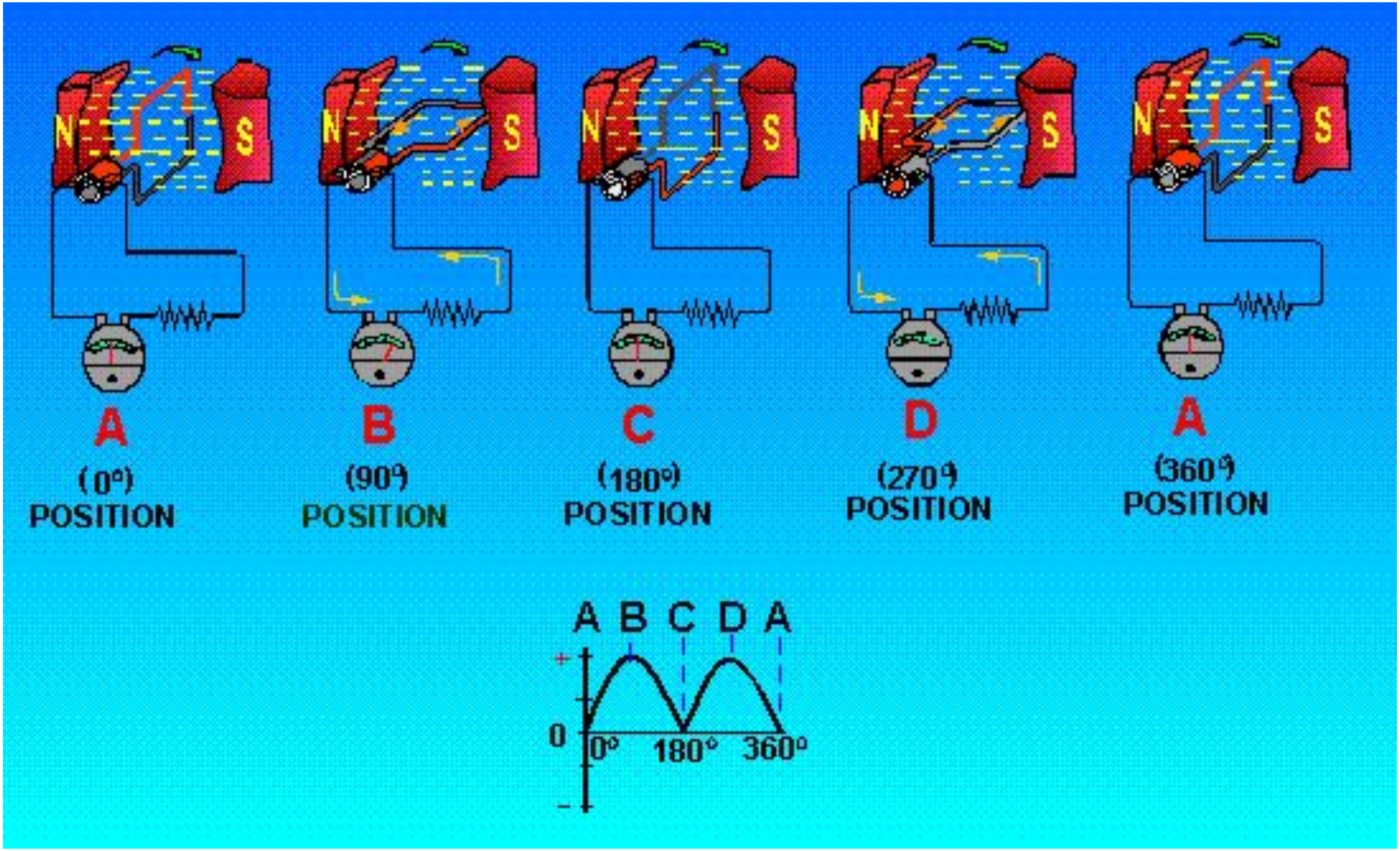
Principle operation of Generator

- Whenever a conductor is moved within a magnetic field in such a way that the conductor cuts across magnetic lines of flux, voltage is generated in the conductor.

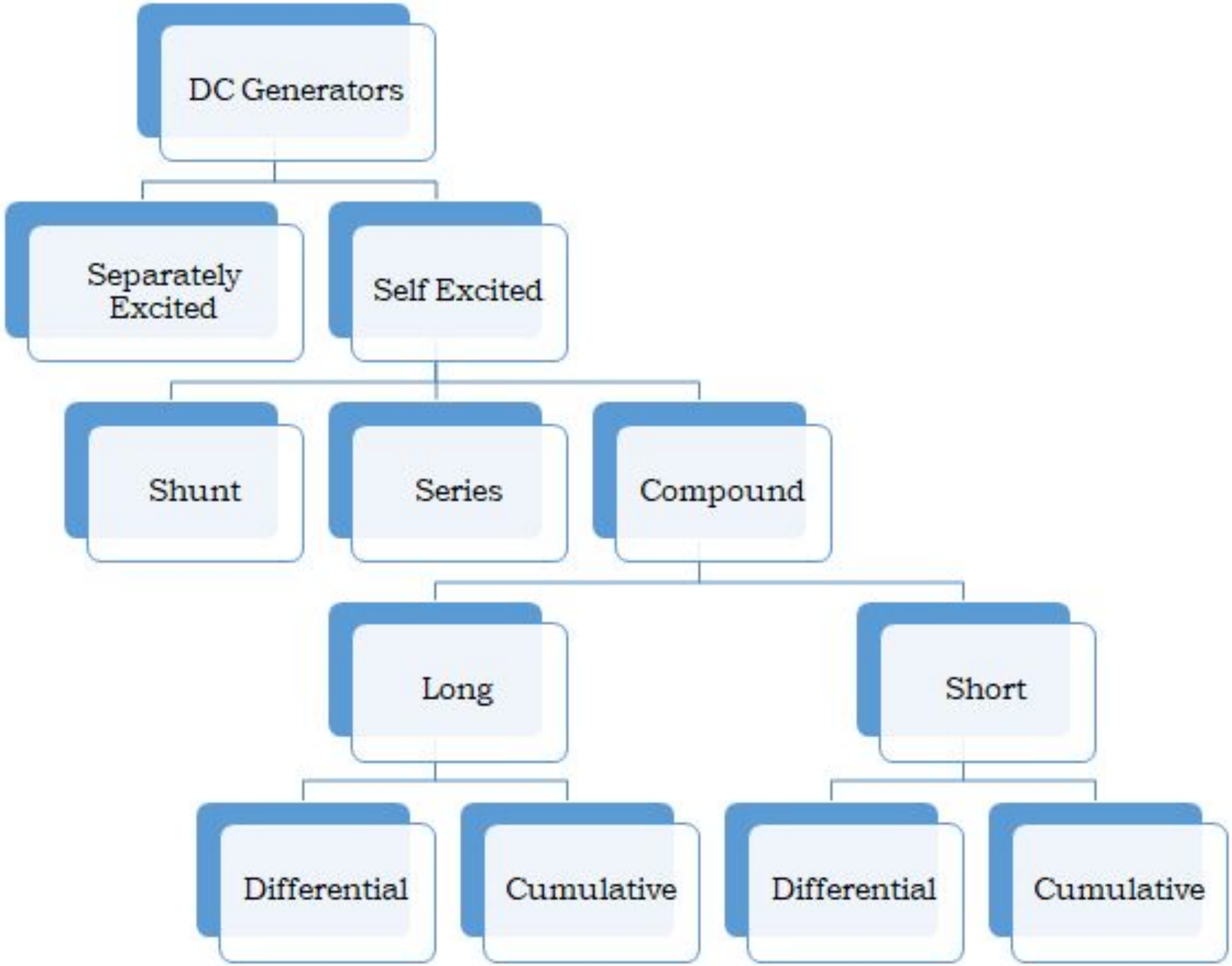
- The AMOUNT of voltage generated depends on:
  1. the strength of the magnetic field,
  2. the angle at which the conductor cuts the magnetic field,
  3. the speed at which the conductor is moved, and
  4. the length of the conductor within the magnetic field


Mechanical
input
S
N
Wire loop
Commutator
Brushes
External output
circuit

DC GENERATOR Working



Types of DC Generator



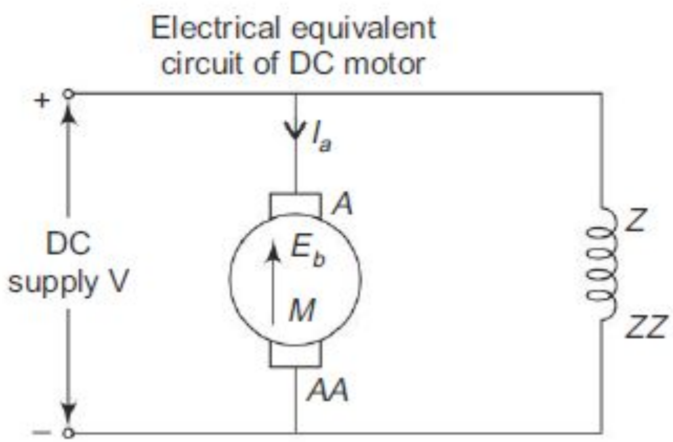
DC MOTOR

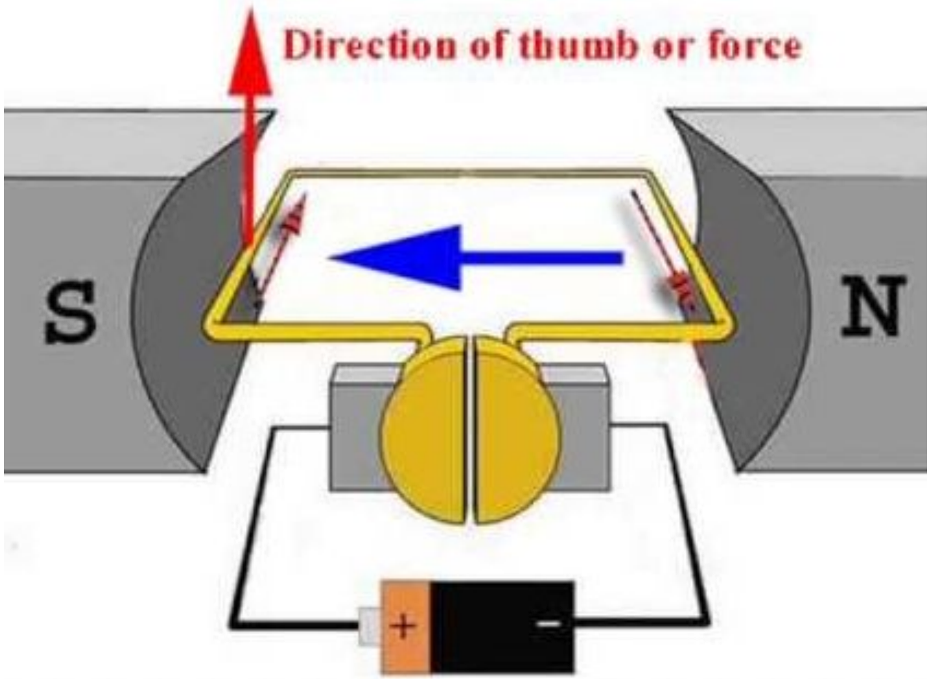
Principle

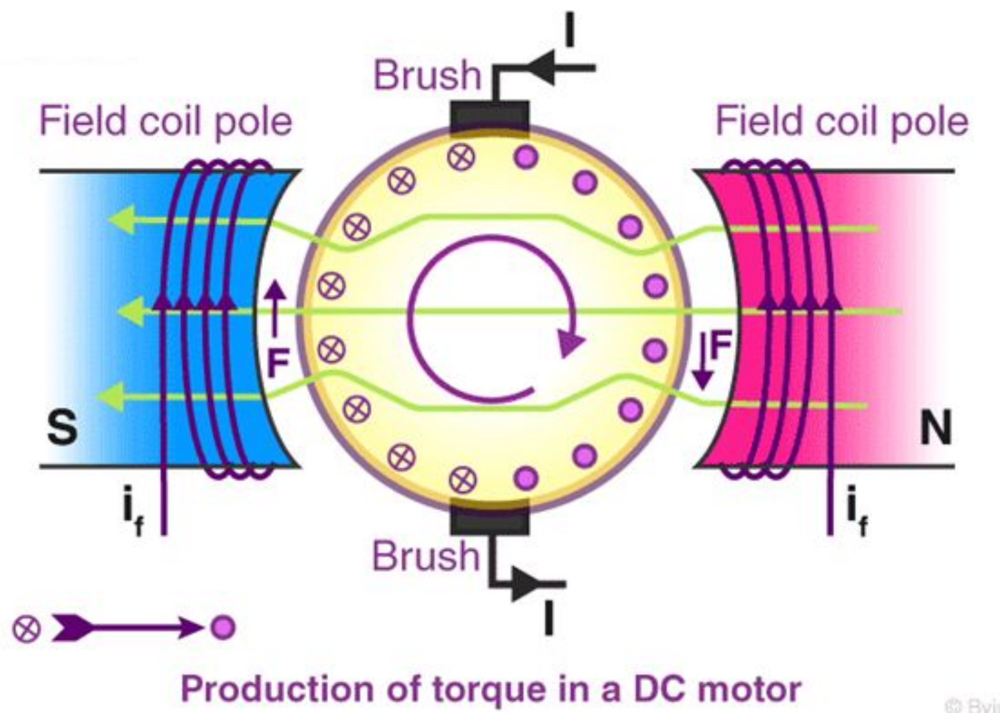
Whenever a current carrying conductor is kept in a stationery magnetic field an electromagnetic force is produced. This force is exerted on the conductor and hence the conductor is moved away from the field. This is the principle used in d.c. motors.

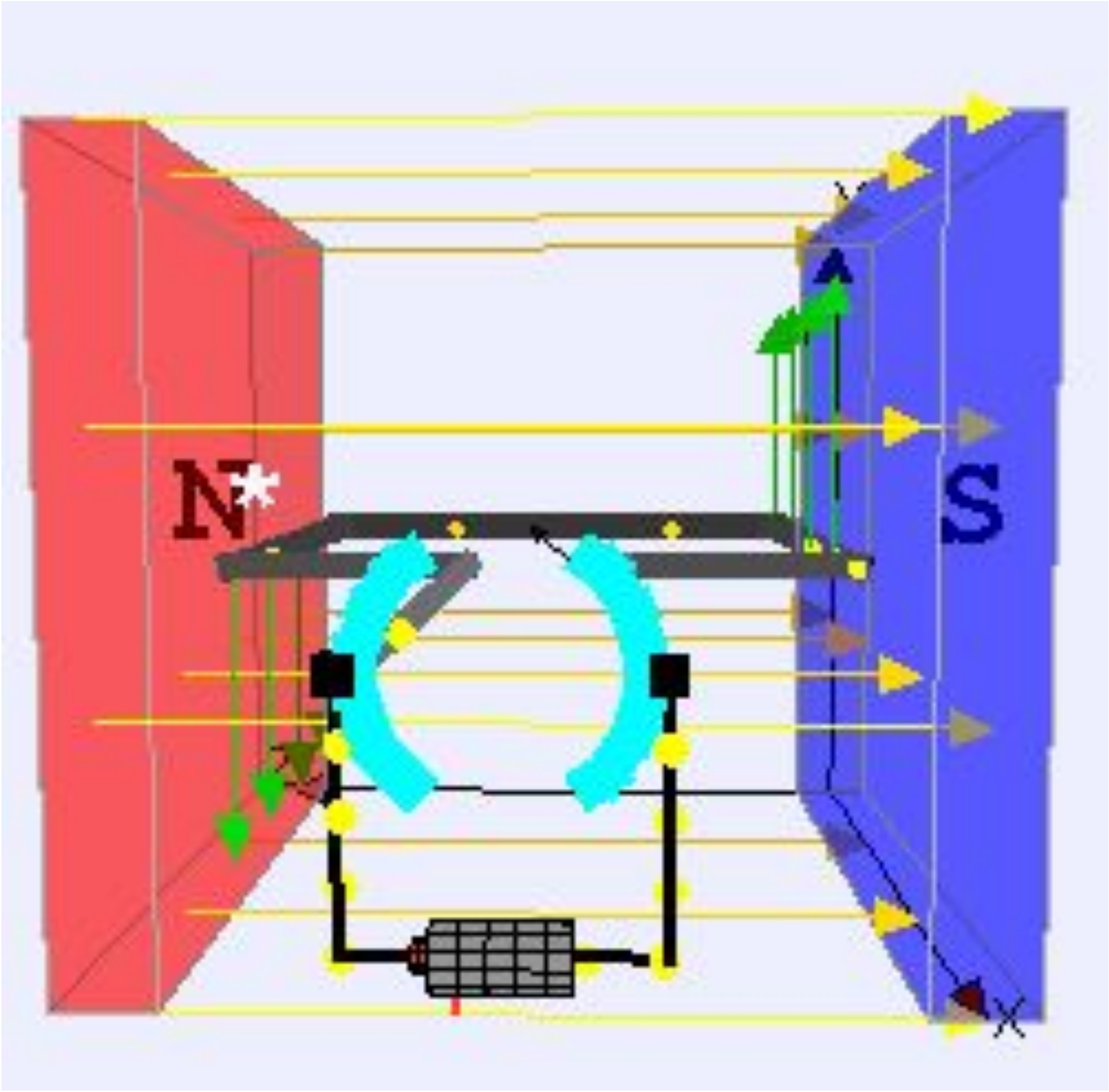
Construction

The construction of dc motor is exactly similar to dc generators. The salient parts of a dc motor are yoke or frame, main field system, brushes, armatures and commutator.




Direction of thumb or force
S
N
+
-


I
Brush
Field coil pole
Field coil pole
F
F
S
N
i_f
i_f
Brush
I
Production of torque in a DC motor
© Byjus


N
S

Working

In a dc motor, both the armature and the field windings are connected to a dc supply. Thus, we have current carrying armature conductors placed in a stationery magnetic field. Due to the electromagnetic torque on the armature conductors, the armature starts revolving. Thus, electrical energy is converted into mechanical energy in the armature. When the armature is in motion, we have revolving conductors in a stationery magnetic field. As per Faraday's Law of electromagnetic induction, an emf is induced in the armature conductors. As per Lenz's law, this induced emf opposes the voltage applied to the armature. Hence, it is called the counter or back emf. There also occurs a potential drop in the armature circuit due to its resistance. Thus, the applied voltage has to overcome the back emf in addition to supplying the armature circuit drop and producing the necessary torque for the continuous rotation of the armature.

Figure gives the electrical circuit of a d.c. shunt motor where

E_b = back EMF

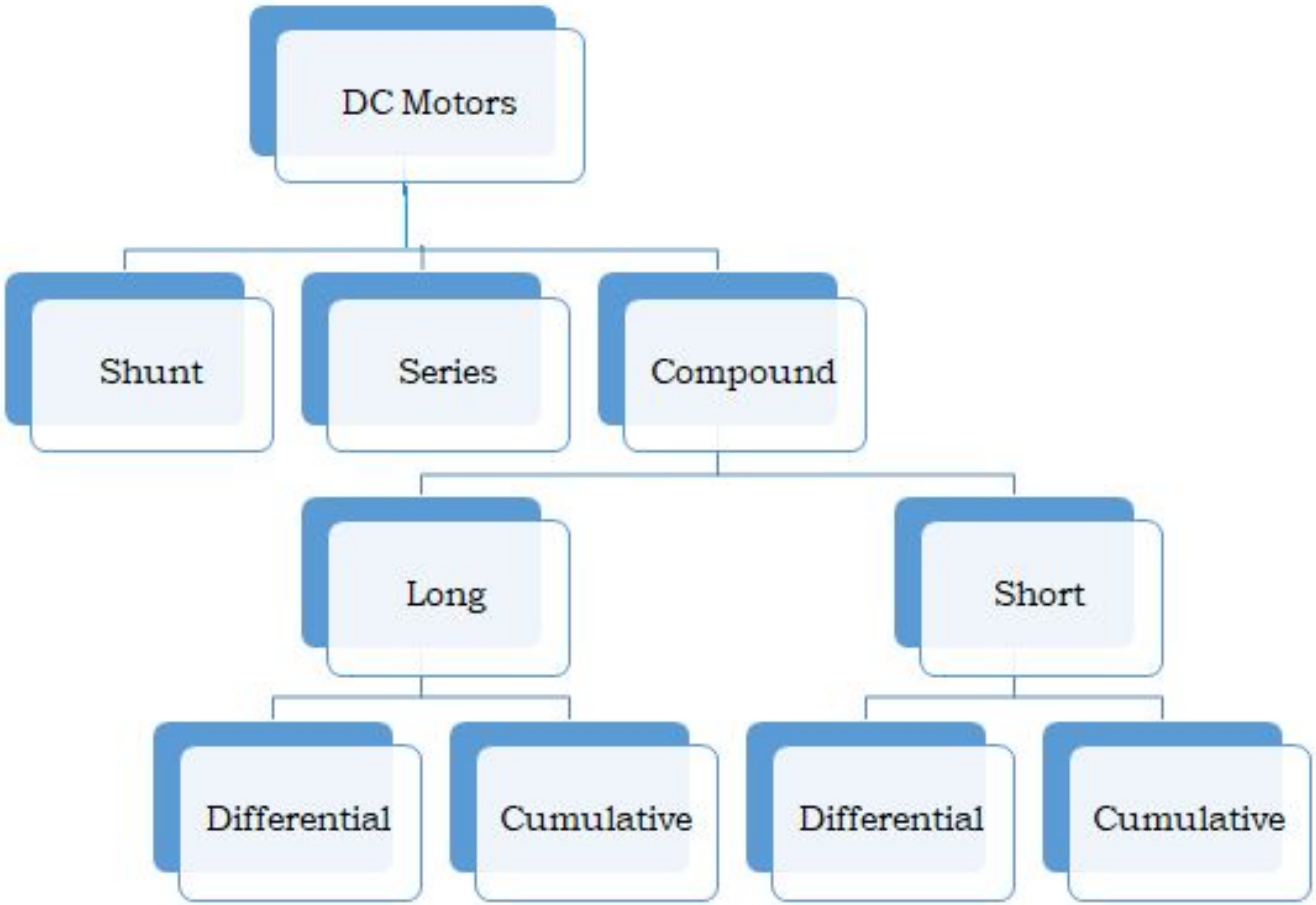
I_a = current flowing in the armature circuit

R_a = resistance of armature circuit

V = applied voltage

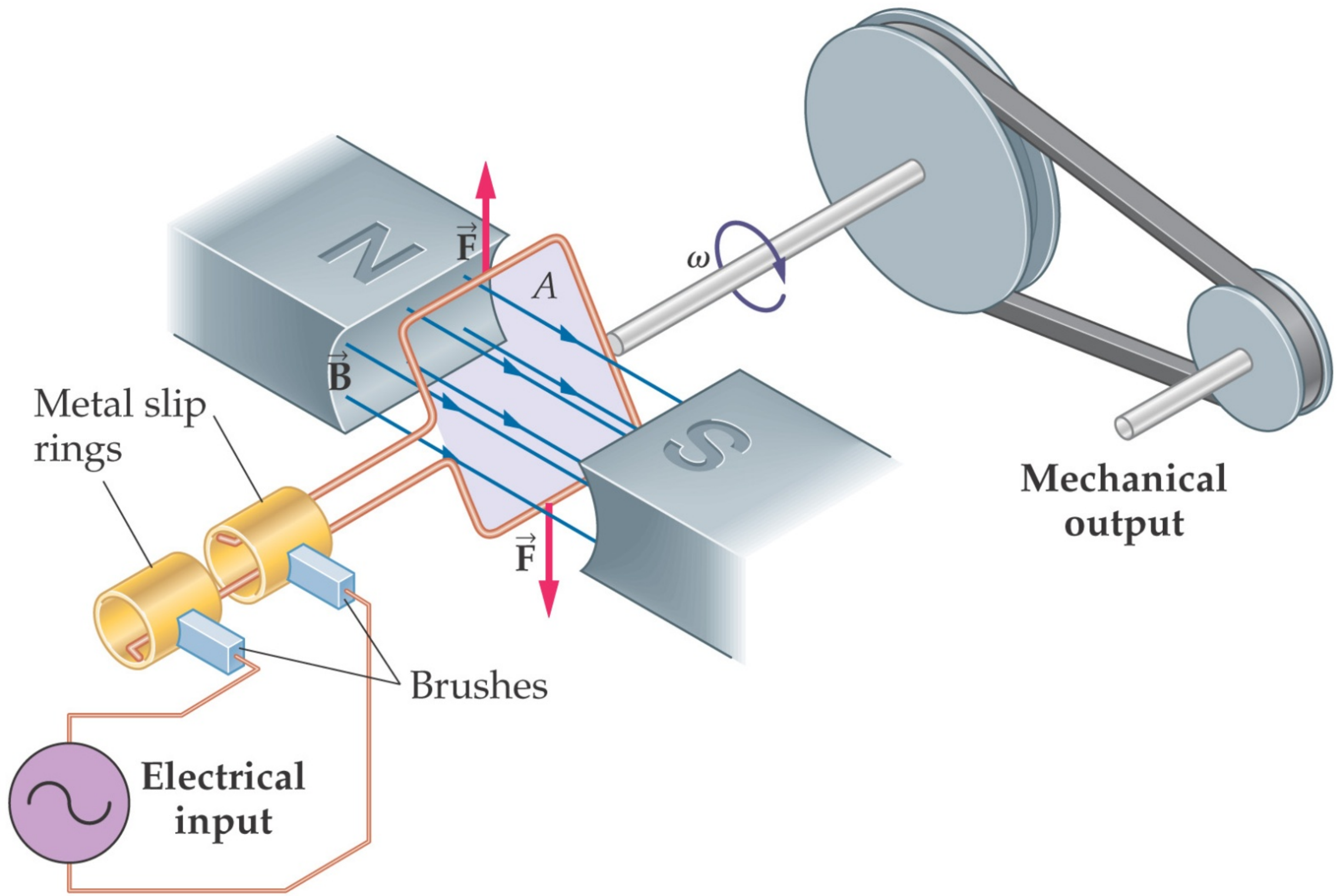
Thus, the characteristics equation of a dc motor is $V = E_b + I_aR_a$, where I_aR_a represents the potential drop in the armature circuit.

Types of Motor



Generators and Motors

An electric motor is exactly the opposite of a generator – it uses the torque on a current loop to create mechanical energy.

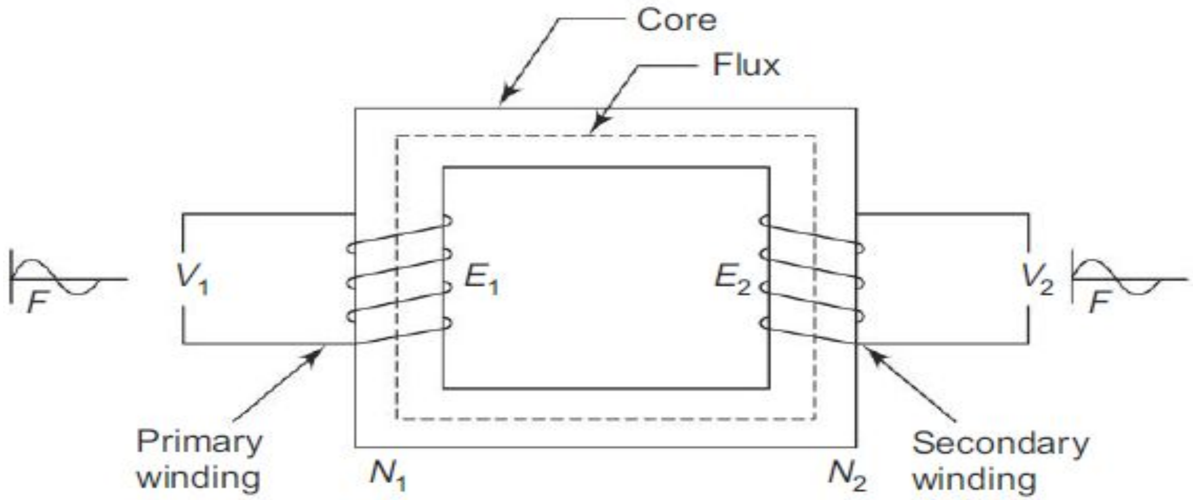


Single Phase Transformer

Principle of operation

The transformer works on the principle of electromagnetic induction. In this case, the conductors are stationary and the magnetic flux is varying with respect to time. Thus, the induced emf comes under the classification of statically induced emf.

- The transformer is a static piece of apparatus used to transfer electrical energy from one circuit to another.
- The two circuits are magnetically coupled. One of the circuits is energized by connecting it to a supply at specific voltage magnitude, frequency and waveform.
- Then, we have a mutually induced voltage available across the second circuit at the same frequency and waveform but with a change in voltage magnitude if desired. These aspects are indicated in Fig.



Construction

The following are the essential requirements of a transformer:

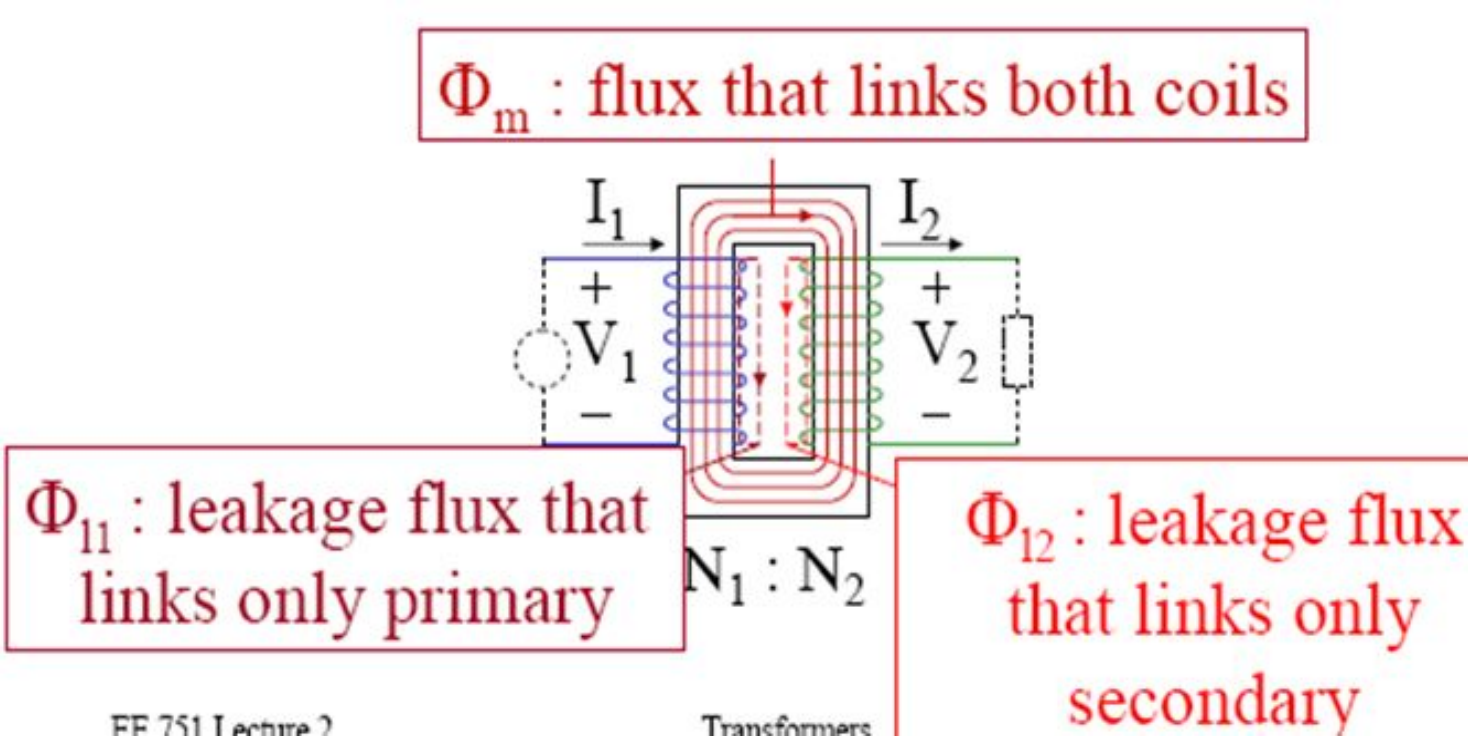
(a) A good magnetic core

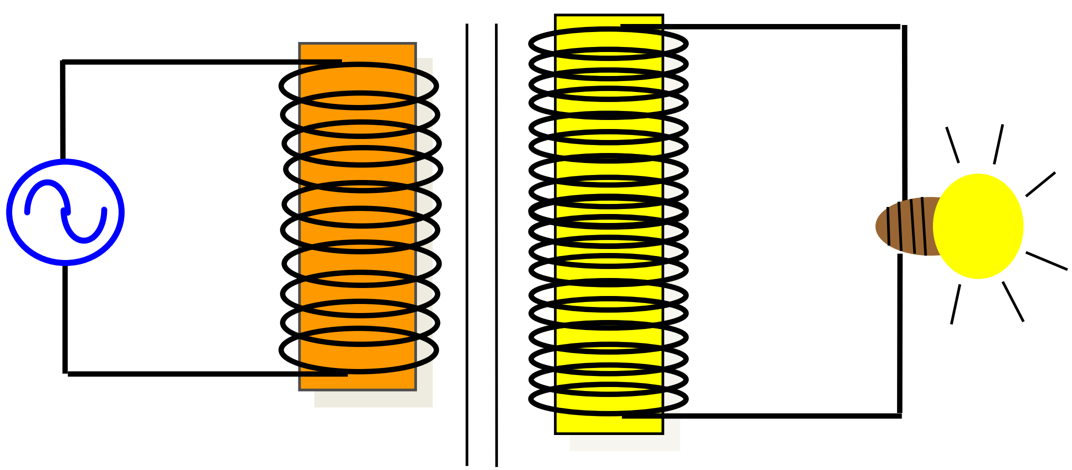
(b) Two windings

(c) A time varying magnetic flux

The transformer core is generally laminated and is made out of a good magnetic material such as transformer steel or silicon steel. Such a material has high relative permeability and **low hysteresis loss**. In order to reduce the **eddy current loss**, the core is made up of laminations of iron. ie, the core is made up of thin sheets of steel, each lamination being insulated from others.

Transformers- principle of operation





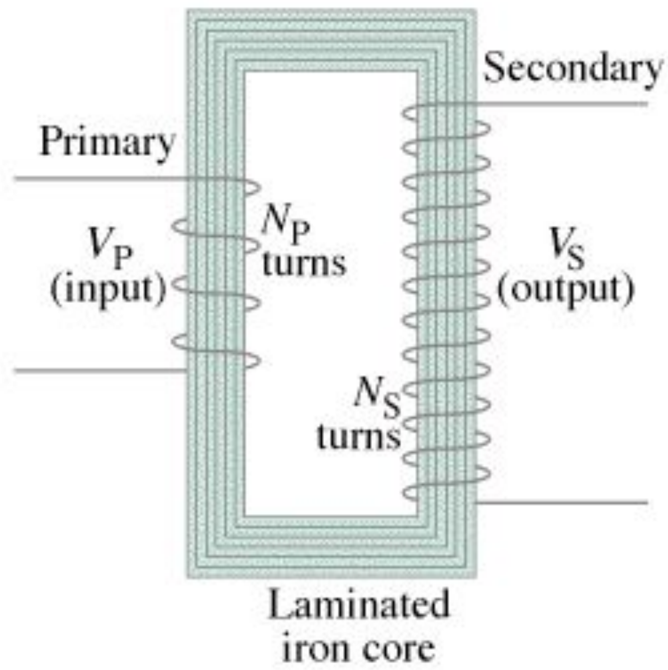
Transformers- principle of operation

Purpose: to change alternating (AC) voltage to a bigger (or smaller) value

input AC voltage in the primary produces a flux

$$V_p = N_p \frac{\Delta\Phi_B}{\Delta t}$$

$$\frac{\Delta\Phi_B}{\Delta t} = \frac{V_p}{N_p}$$



changing flux in secondary induces emf

$$V_s = N_s \frac{\Delta\Phi_B}{\Delta t}$$

- ✔ When the secondary is an open-circuit and an alternating voltage V_1 is applied to the primary winding, a small current – called the no-load current I_0 – flows, which sets up a magnetic flux in the core. This alternating flux links with both primary and secondary coils and induces in them e.m.f.'s of E_1 and E_2 respectively by mutual induction.

- ✔ The induced e.m.f. E in a coil of N turns is given by

$$\mathbf{E = - N(d\phi/dt)\ volts,}$$

where $(d\phi/dt)$ is the rate of change of flux. In an ideal transformer, the rate of change of flux is the same for both primary and secondary and thus **$(E_1/N_1)=(E_2/N_2)$** i.e. the induced e.m.f. per turn is constant.

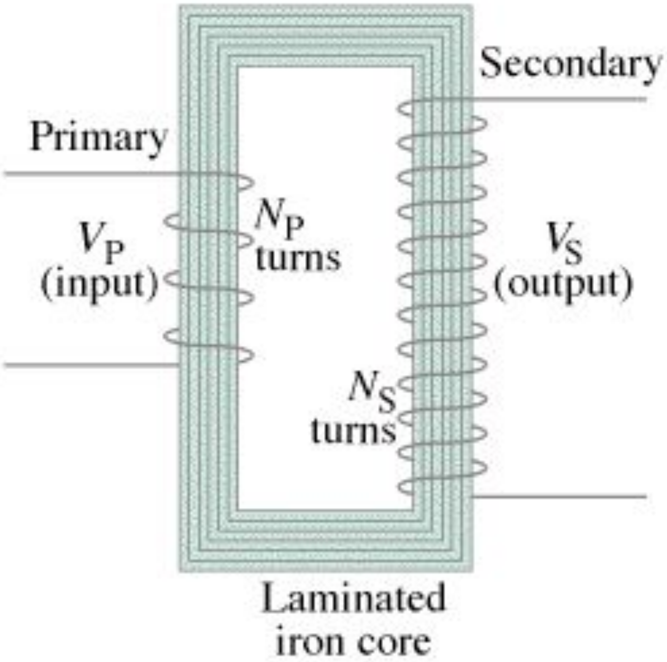
Transformers- principle of operation

Increase in voltage comes at the cost of current.

- Output power cannot exceed input power!
- power in = power out

$$I_p V_p = I_s V_s$$

$$\boxed{\frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_p}{N_s}}$$

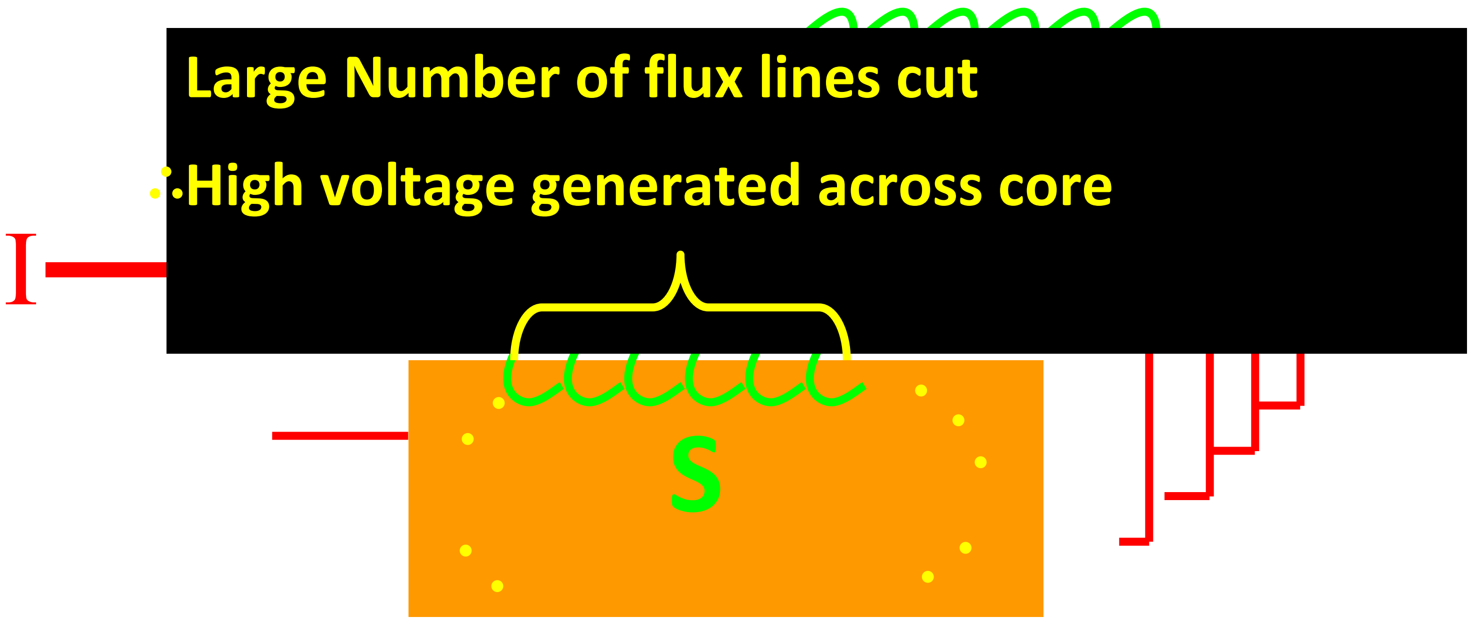


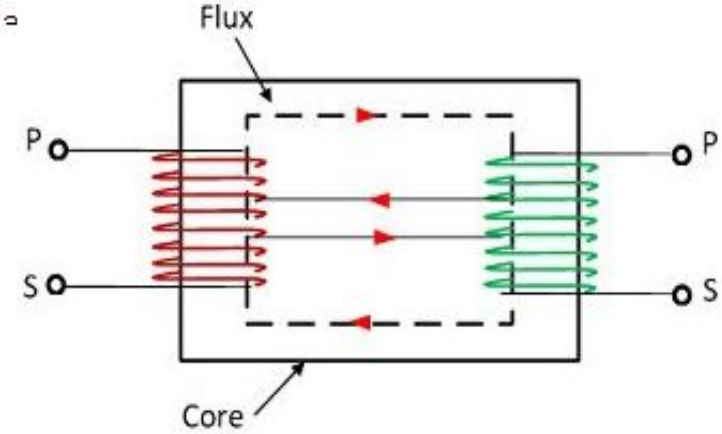
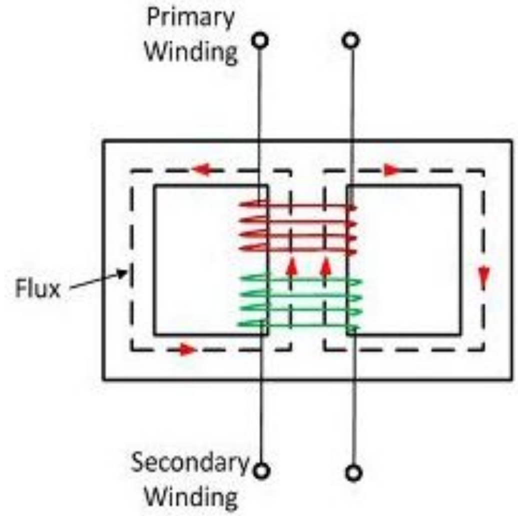
Why do we laminate the core?

Eddy currents are large & losses are great

Large Number of flux lines cut

∴High voltage generated across core



Basis for Comparison	Core Type Transformer	Shell Type Transformer
		
Winding	In this type, winding surrounds the core	In this type, core surrounds the winding
Limbs	It has two limbs	It has three limbs
Copper requirement	Requires less	Requires more
Lamination	Laminations are usually in the form of alphabet letter L	Laminations are usually in the form of alphabet letter E and L
Flux distribution	Flux is equally distributed on the side limbs	Side limbs carry the half of the flux while the central one carries the whole flux

Induction Motor

Why induction motor (IM)?

–Robust; No brushes. No contacts on rotor shaft

–High Power/Weight ratio compared to DC motor

–Lower Cost/Power

–Easy to manufacture

–Almost maintenance-free, except for bearing and other mechanical parts

Disadvantages

–Essentially a “fixed-speed” machine

–Speed is determined by the supply frequency

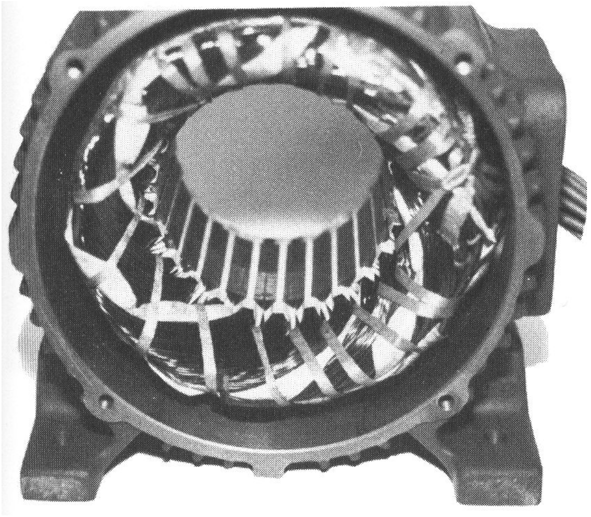
–To vary its speed need a variable frequency supply

Introduction - Induction Motor

- Three-phase induction motors are the most common and frequently encountered machines in industry
  - simple design, rugged, low-price, easy maintenance
  - wide range of power ratings: fractional horsepower to 10 MW
  - run essentially as constant speed from no-load to full load
  - Its speed depends on the frequency of the power source
    - not easy to have variable speed control
    - requires a variable-frequency power-electronic drive for optimal speed control

Construction - STATOR

- An induction motor has two main parts
  - a stationary stator
    - consisting of a steel frame that supports a hollow, cylindrical core
    - core, constructed from stacked laminations (why?), having a number of evenly spaced slots, providing the space for the stator winding

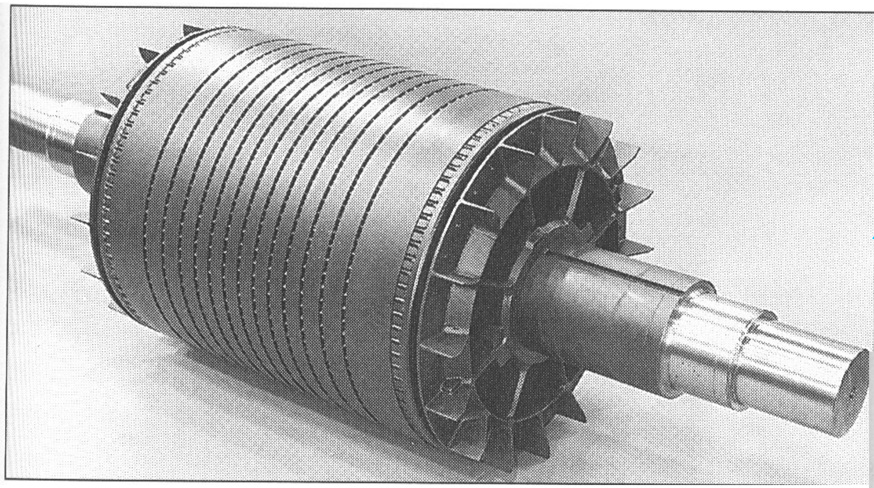


Stator of IM

Construction - ROTOR

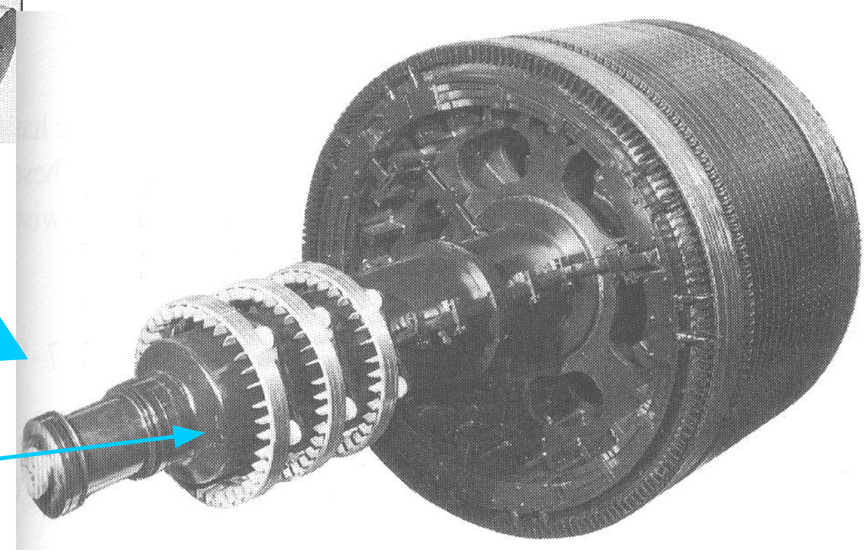
- Composed of punched laminations, stacked to create a series of rotor slots, providing space for the rotor winding
- one of two types of rotor windings
- conventional 3-phase windings made of insulated wire (**wound-rotor**) » similar to the winding on the stator
- aluminum bus bars shorted together at the ends by two aluminum rings, forming a squirrel-cage shaped circuit (**squirrel-cage**)

Construction



Squirrel cage rotor

Wound rotor



Notice the slip rings

Principle of operation

- This rotating magnetic field cuts the rotor windings and produces an induced voltage in the rotor windings
- Due to the fact that the rotor windings are short circuited, for both squirrel cage and wound-rotor, and induced current flows in the rotor windings
- The rotor current produces another magnetic field
- A torque is produced as a result of the interaction of those two magnetic fields

$$\tau_{ind} = kB_R \times B_s$$

Where τ_{ind} is the induced torque and B_R and B_S are the magnetic flux densities of the rotor and the stator respectively

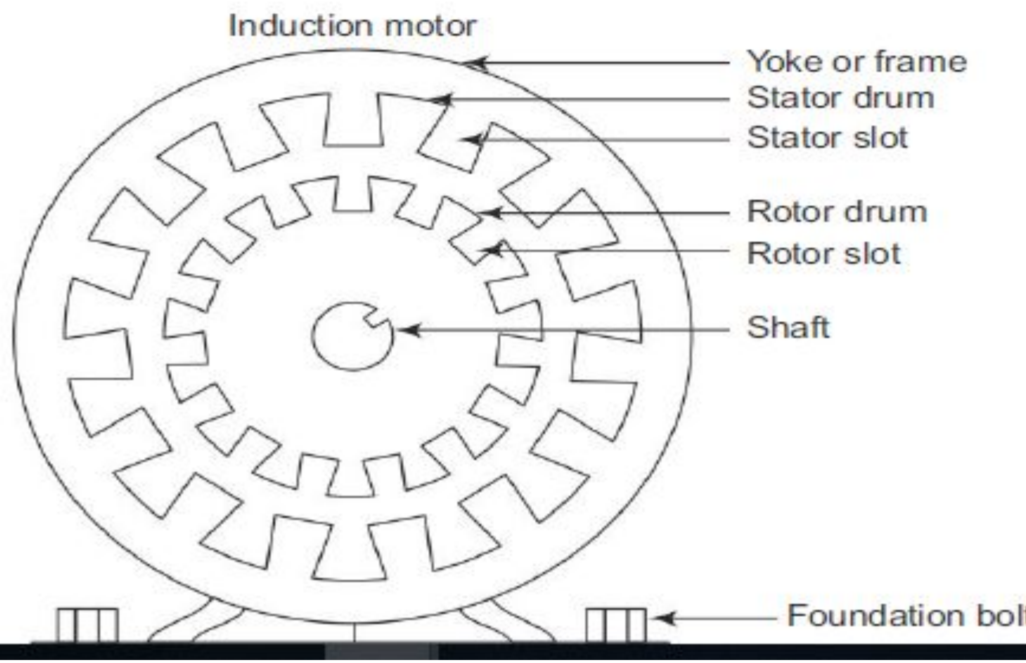
THREE PHASE INDUCTION MOTOR

Principle

When a three phase balanced voltage is applied to a three phase balanced winding, a rotating magnetic field is produced. This field has a constant magnitude and rotates in space with a constant speed. If a stationary conductor is placed in this field, an emf will be induced in it. By creating a closed path for the induced current to flow, an electromagnetic torque can be exerted on the conductor. Thus, the conductor is put in rotation.

Construction

The important parts of a three phase induction motor are schematically represented in Fig. 6.47. Broadly classified, they are stator and rotor. Each of these is described below.



Stator This is the stationary part of the motor. It consists of an outer solid circular metal part called the yoke or frame and a laminated cylindrical drum called the stator drum. This drum ash number of slots provided over the entire periphery of it. Required numbers of stator conductors are embedded in the slots. These conductors are electrically connected in series and are arranged to form a balanced three phase winding. The stator is wound to give a specific number of poles. The stator winding may be star or delta connected.

Rotor This is the rotating part of the induction motor. It is also in the form so slotted cylindrical structure. The air gap between stator and rotor is as minimum as mechanically possible. There are two types of rotors—squirrel cage rotor and slip-ring or wound rotor.

Working

A three phase balanced voltage is applied across the three phase balanced stator winding. A rotating magnetic field is produced. This magnetic field completes its path through the stator, the air gap and the rotor. In this process, the rotor conductors, which are still stationary, are linked by the time varying stator magnetic field. Therefore, an emf is induced in the rotor conductors. When the rotor circuit forms a closed path, a rotor current is circulated. Thus, the current carrying rotor conductors are placed in the rotating magnetic field. Hence, as per the law of interaction, an electromagnetic force is exerted on the rotor conductors. Thus, the rotor starts revolving.

According to Lenz's law, the nature of the rotor induced current is to oppose the cause producing it. Here the cause is the rotating magnetic field. Hence, the rotor rotates in the same direction as that of the rotating magnetic field.

In practice, the rotor speed never equals the speed of the rotating magnetic field (called the synchronous speed). The difference in the two speeds is called slip. The current drawn by the stator is automatically adjusted whenever the motor is loaded.

Synchronous Machine

❖ The stator is similar in construction that of a induction motor.

❖ The rotor can be Salient or Non-Salient (cylindrical rotor).

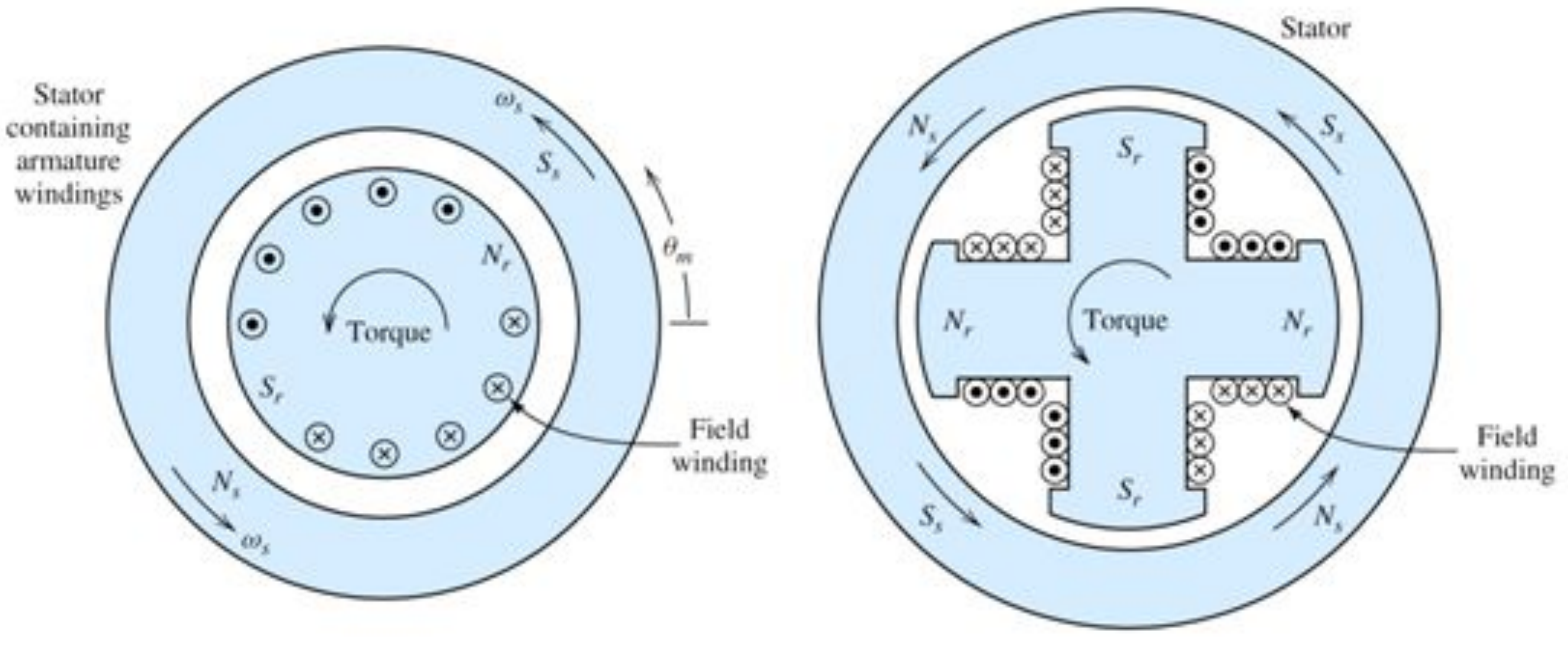
❖ Field excitation is provided on the rotor by either permanent or electromagnets with number of poles equal to the poles of the RMF caused by stator.

❖ Non-excited rotors are also possible as in case of reluctance motors.

❖The rotor gets **locked** to the RMF and rotates **unlike induction motor** at **synchronous speed** under all load condition.

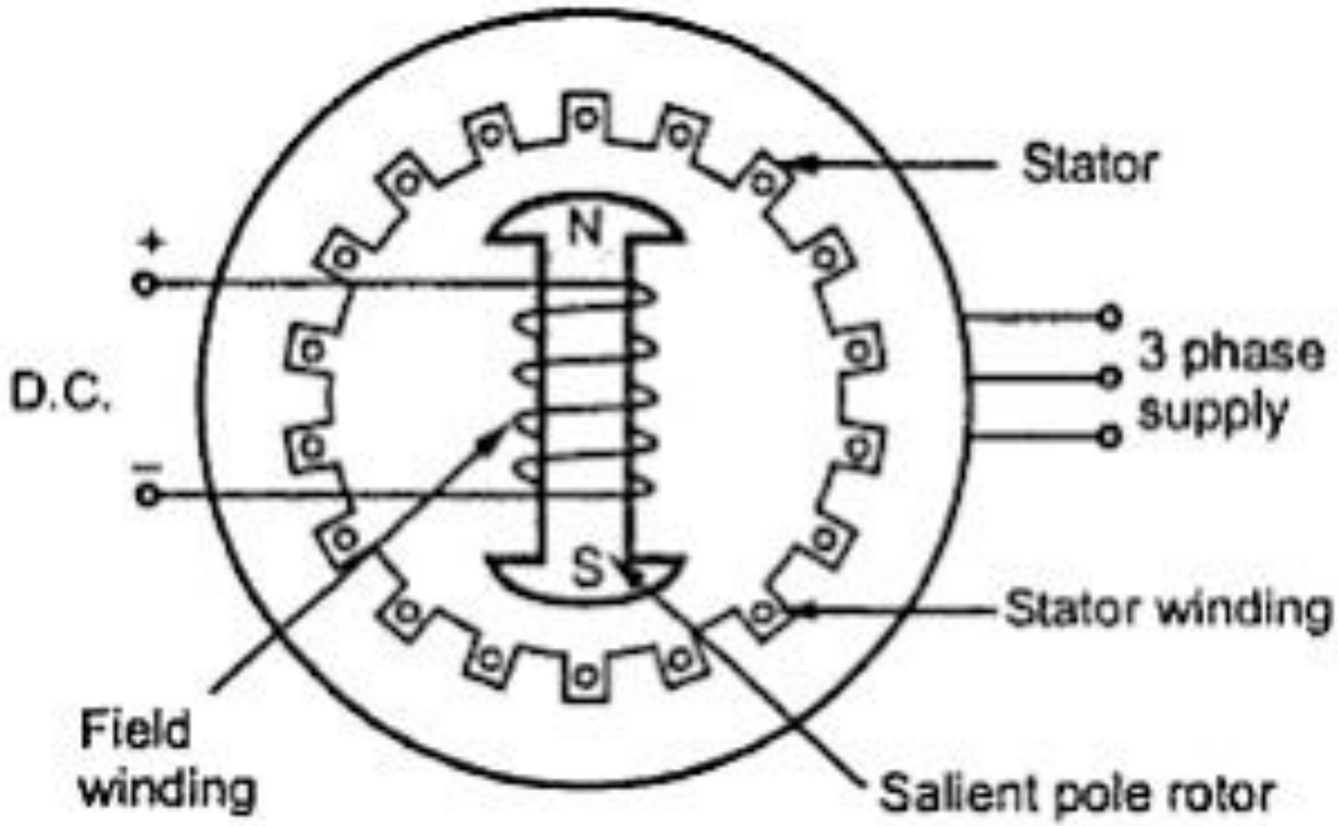
Synchronous Machine Construction

(a) CRSM (b) SPSM



(a) Two-pole cylindrical rotor machine (b) Four-pole salient rotor machine

Synchronous Motor



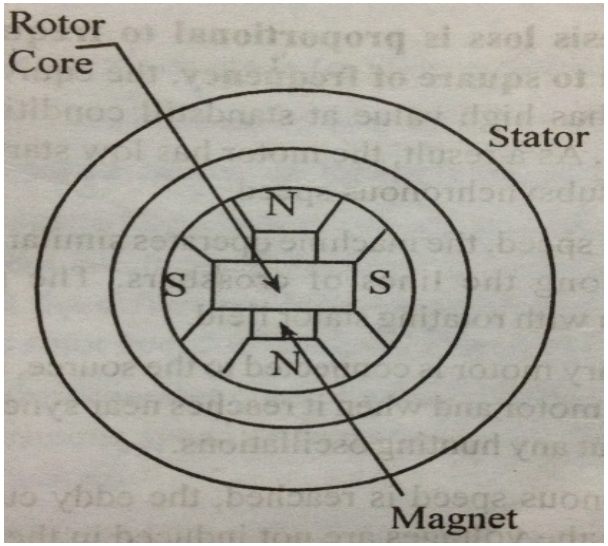
Synchronous Motors

- Therefore, at this instant the rotor experiences a counterclockwise torque tending to make it rotate in the direction opposite to that of the stator poles.
- The net torque on the rotor in one revolution will be zero, and therefore the motor will not develop any starting torque.
- Because it not self-started, two methods are normally used to start a synchronous motor:
  - **Use a variable-frequency supply**
  - **Start the machine as an induction motor.**

Permanent magnet syn motor (PMSM)

- ❖ Field excitation is obtained by mounting permanent magnets on the rotor. This eliminates dc source; losses associated with the field winding and frequent maintenance associated with slip rings and brushes in a wound field motor.
- ❖ Power factor cannot controlled – field excitation cannot be controlled.
- ❖ The permanent motors designed to operate at unity power factor at full load. The power developed by the motor,

$$P_m = \frac{3VE}{X_s} \sin \delta$$



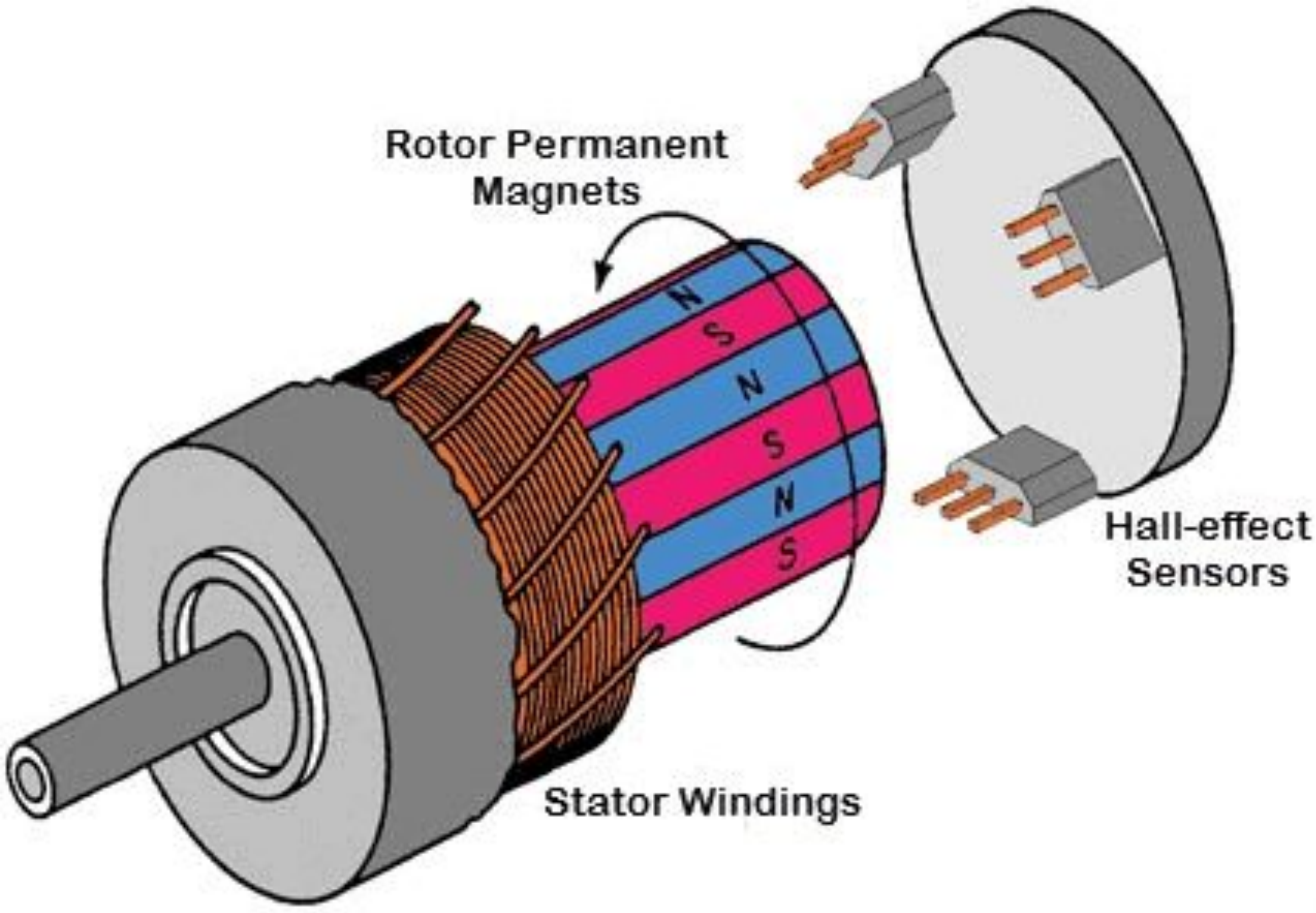
- **PMSM – eliminates field copper loss, higher power density, lower inertia and more robust.**

BLDC (Brushless DC motor)

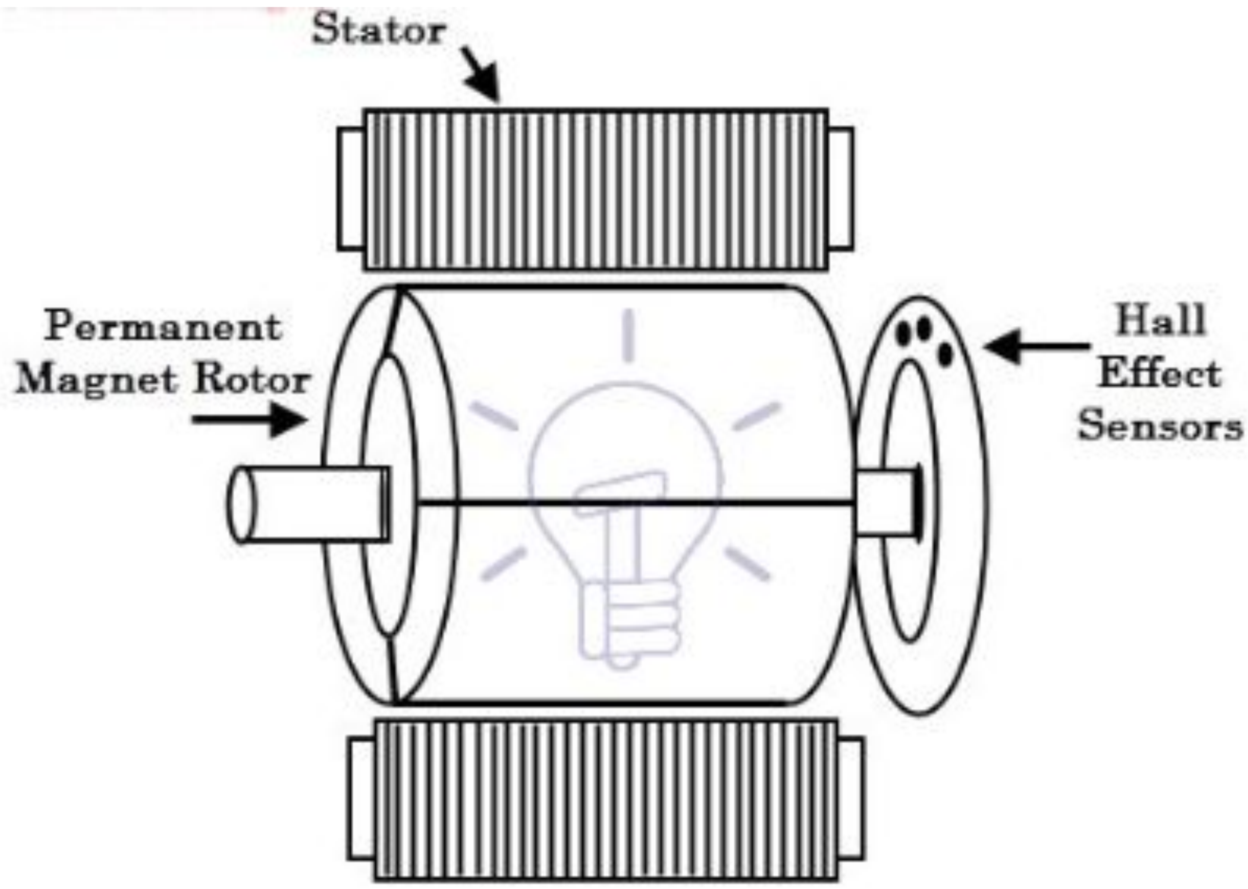
- *A brushless DC motor (known as BLDC) is a permanent magnet synchronous electric motor* which is driven by direct current (DC) electricity.
- it accomplishes electronically controlled commutation system (commutation is the process of producing rotational torque in the motor by changing phase currents through it at appropriate times) instead of a mechanically commutation system. BLDC motors are also referred as trapezoidal permanent magnet motors.
- BLDC motor employs electrical commutation with permanent magnet rotor and a stator with a sequence of coils. In this motor, permanent magnet (or field poles) rotates and current carrying conductors are fixed.

- The armature coils are switched electronically by transistors or silicon controlled rectifiers at the correct rotor position in such a way that armature field is in space quadrature with the rotor field poles. Hence the force acting on the rotor causes it to rotate. **Hall sensors** or rotary encoders are most commonly used to sense the position of the rotor and are positioned around the stator. The rotor position feedback from the sensor helps to determine when to switch the armature current.
- This electronic commutation arrangement eliminates the commutator arrangement and brushes in a DC motor and hence more reliable and less noisy operation is achieved. Due to the absence of brushes BLDC motors are capable to run at high speeds. The efficiency of BLDC motors is typically 85 to 90 percent, whereas as brushed type DC motors are 75 to 80 percent efficient.

BLDC - Construction



BLDC - Construction



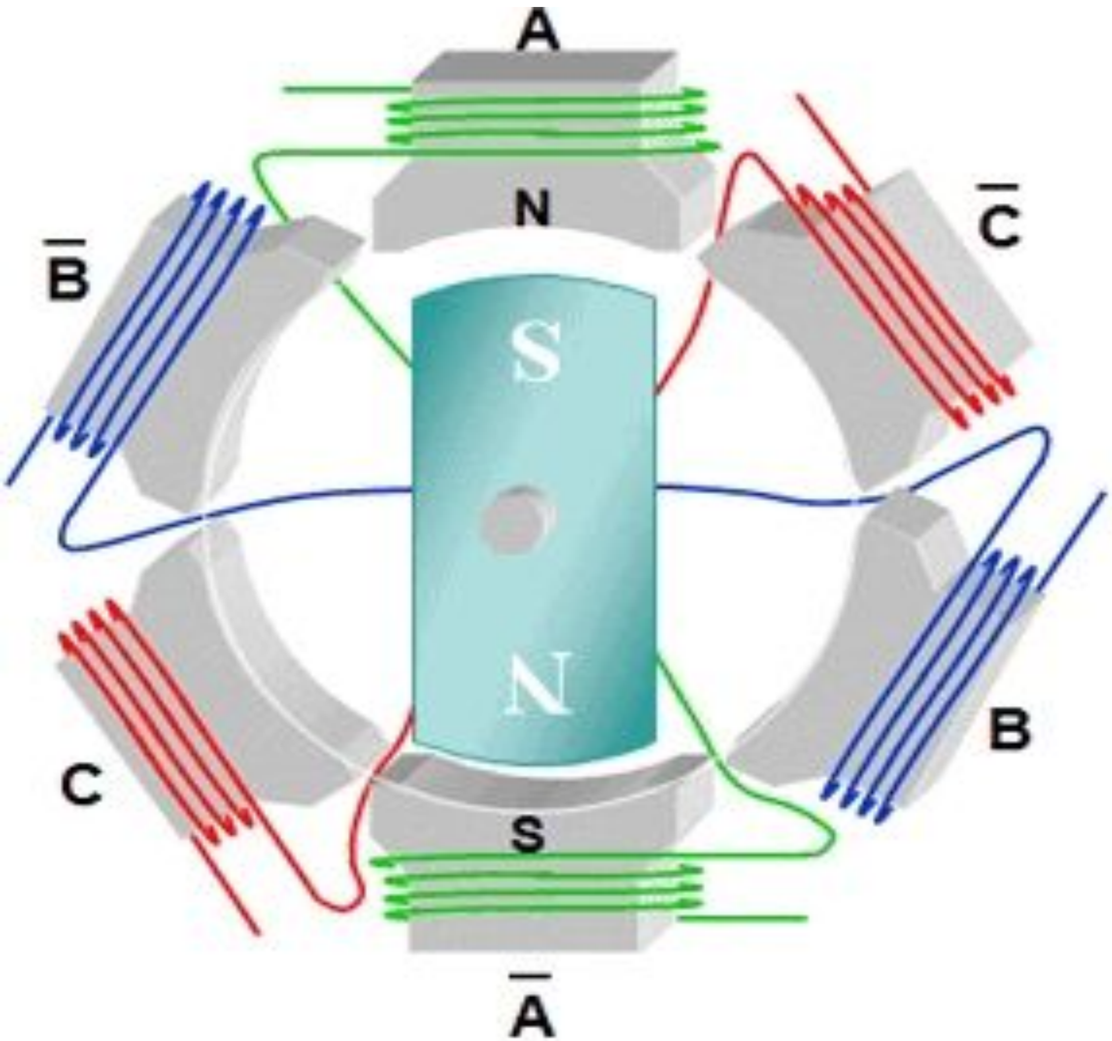
Rotor

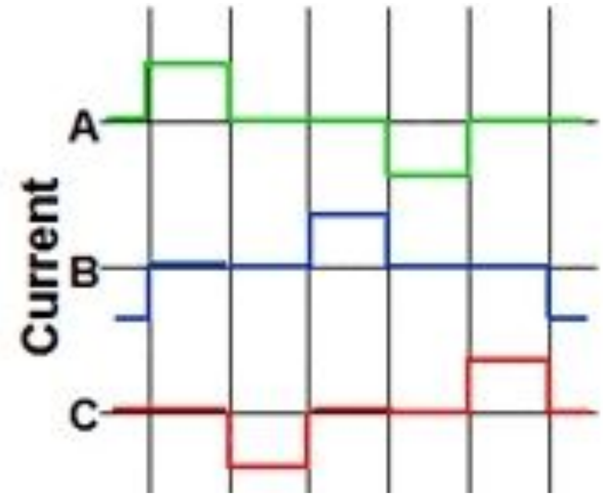
BLDC motor incorporates a permanent magnet in the rotor. The number of poles in the rotor can vary from 2 to 8 pole pairs with alternate south and north poles depending on the application requirement. In order to achieve maximum torque in the motor, the flux density of the material should be high. A proper magnetic material for the rotor is needed to produce required magnetic field density.

Hall Sensors

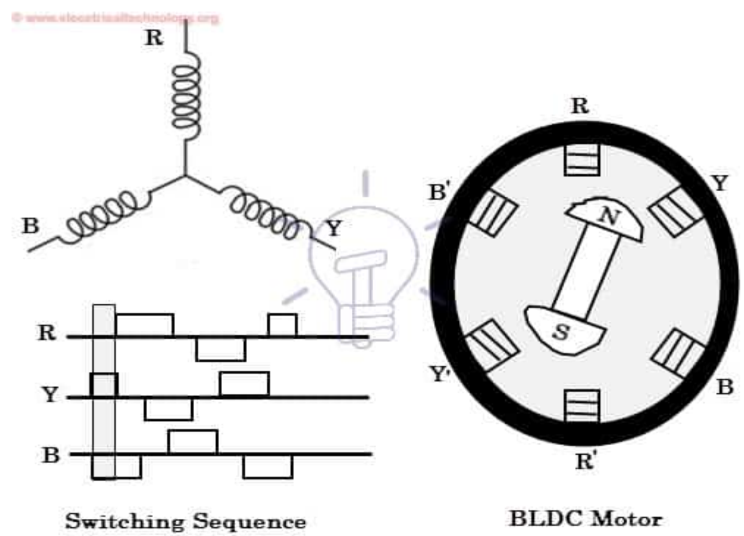
- Hall sensor provides the information to synchronize stator armature excitation with rotor position. Since the commutation of BLDC motor is controlled electronically, the stator windings should be energized in sequence in order to rotate the motor. Before energizing a particular stator winding, acknowledgment of rotor position is necessary. So the Hall Effect sensor embedded in stator senses the rotor position.
- Most BLDC motors incorporate three Hall sensors which are embedded into the stator. Each sensor generates Low and High signals whenever the rotor poles pass near to it. The exact commutation sequence to the stator winding can be determined based on the combination of these three sensor's response.

Working

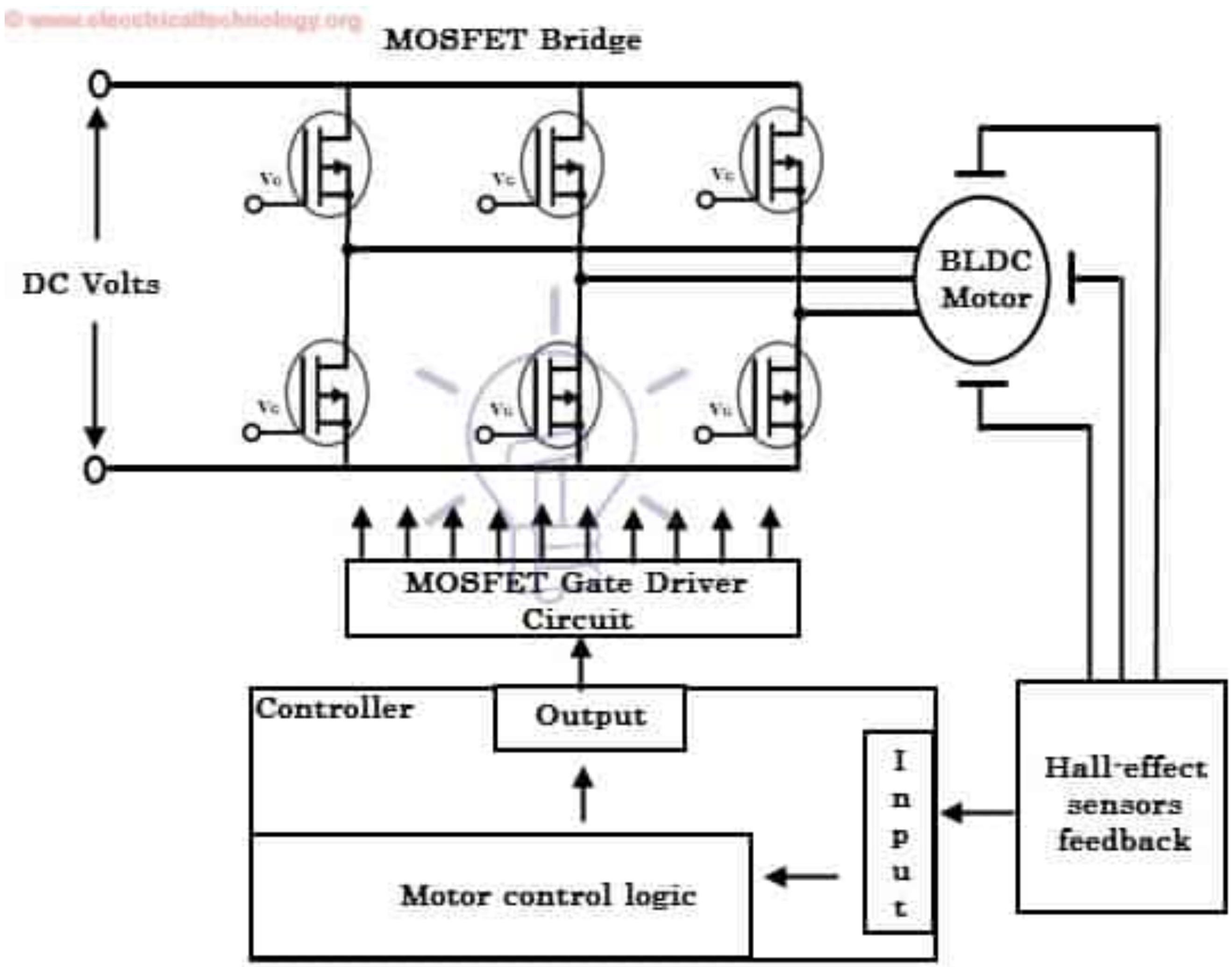




- In case BLDC motor, the current carrying conductor is stationary while the permanent magnet moves.
- When the stator coils are electrically switched by a supply source, it becomes electromagnet and starts producing the uniform field in the air gap. Though the source of supply is DC, switching makes to generate an AC voltage waveform with trapezoidal shape. Due to the force of interaction between electromagnet stator and permanent magnet rotor, the rotor continues to rotate.



Brushless DC Motor Drive



- Electronic controller circuit energizes appropriate motor winding by turning transistor or other solid state switches to rotate the motor continuously. The figure shows the **simple BLDC motor drive circuit** which consists of MOSFET bridge (also called as inverter bridge), electronic controller, hall effect sensor and BLDC motor.
- Here, Hall-effect sensors are used for position and speed feedback. The electronic controller can be a microcontroller unit or microprocessor or DSP processor or FPGA unit or any other controller. This controller receives these signals, processes them and sends the control signals to the MOSFET driver circuit.

Applications of Brushless DC Motors

- Computer hard drives and DVD/CD players
- Electric vehicles, hybrid vehicles, and electric bicycles
- Industrial robots, CNC machine tools, and simple belt driven systems
- Washing machines, compressors and dryers
- Fans, pumps and blowers

Servo Motor

- Servo is an electromagnetic device uses a negative feedback mechanism to converts an electric signal into controlled motion. Basically, servos behave like as actuators which provide precise control over velocity, acceleration, and linear or angular position.
- It consists of four things: DC motor, position sensor, gear train, and a control circuit. The gear mechanism connected with the motor provides the feedback to the position sensor.
- If the motor of the servo is operated by DC then it is called a DC servo motor and if it is operated by AC then it is called as AC servo motor. The gear of the servo motor is generally made up of plastic but in high power servos, it is made up of metal.

Types of Servo Motors on the Basis of Rotation

Positional Rotation Servos: Positional servos can rotate the shaft in about half of the circle. Also, it has the feature to protect the rotational sensor from over-rotating. Positional servos are mainly used in limbs, robotic arms, and in many other places.

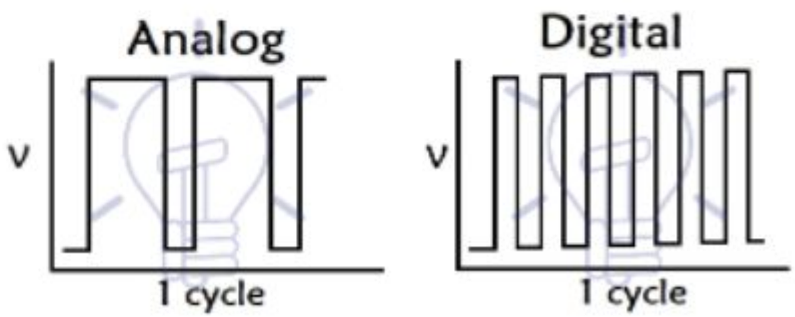
Continuous Rotation Servos: Continuous servos are similar in construction to the positional servo. But, it can move in both clockwise and anticlockwise directions. These types of servos are used in radar systems and robots.

Linear Servos: Again linear servos are also like a positional servo, but with additional gears to the adjust the output from circular to back-and-forth. These type of servos are used in high model airplanes and are rare to find on the stores.

On the Basis of Operating Signal

(i) Analog Servomotors: Analog servos are operated over PWM (Pulse Width Modulation) signals.

(ii) Digital Servomotors: Digital Servo receives signal and acts at high-frequency voltage pulses. Digital servo gives a smooth response and consistent torque, due to faster pulse. Digital servos consume more power than an analog servo.

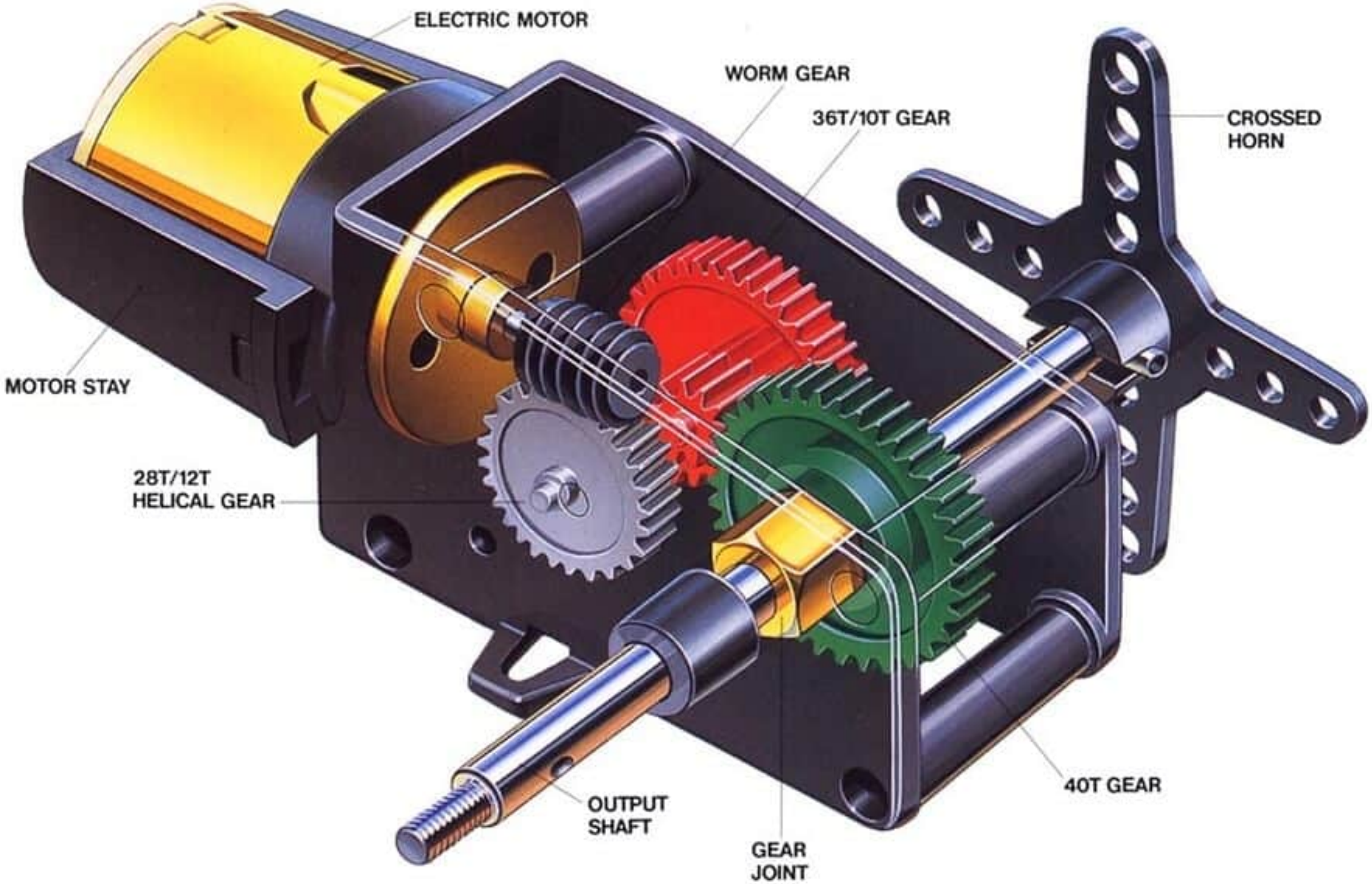


On the Basis of Operating Power

(i) DC Servo Motor

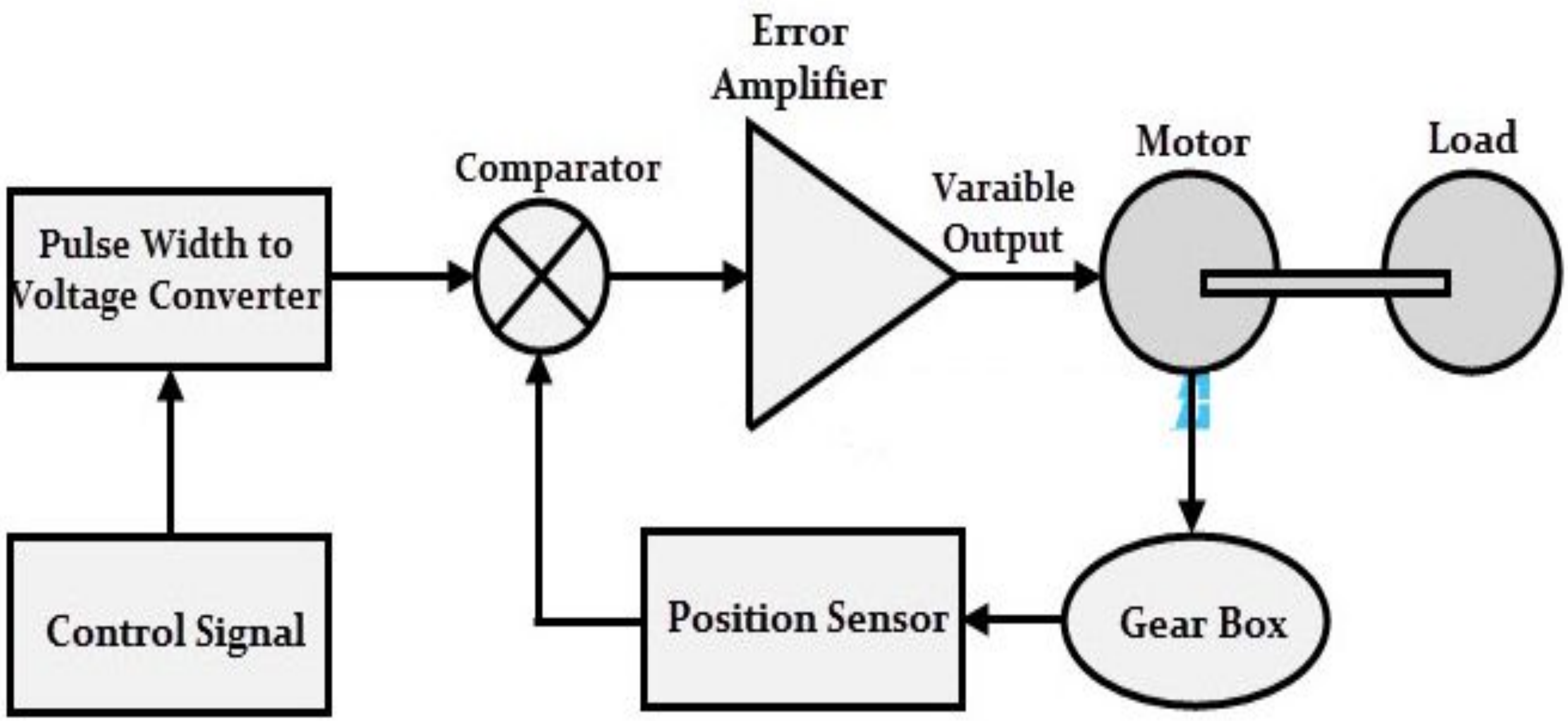
(ii) AC Servo Motor

Construction of Servo Motor:



Construction of Servo Motor

Closed loop system - Servo Motor:



Stator Winding: This type of winding wound on the stationary part of the motor. It is also known as field winding of the motor.

Rotor Winding: This type of winding wound on the rotating part of the motor. It is also known as an armature winding of the motor.

Bearing: These are of two types, i.e, font bearing and back bearing which are used for the movement of the shaft.

Shaft: The armature winding is coupled on the iron rod is known as the shaft of the motor.

Encoder: It has the approximate sensor which determines the rotational speed of motor and revolution per minute of the motor.

Working of Servo Motors

- The servo has a position sensor, a DC motor, a gear system, a control circuit. The DC motor run at high speed and low torque when getting power from a battery. The position of shaft senses by position sensor from its definite position and supply information to the control circuit.
- The reduction gearbox is connected to a shaft which decreases the RPM of the motor. The output shaft of the reduction gearbox is the same as of motor which is connected with encoder or potentiometer.
- The output of the encoder is then connected to the control circuit. The wires of the servomotor are also connected to the control circuit.
- The motor control through microcontroller by sending signals in the form of PWM which decodes the control circuit to rotate the motor in required angle the control circuit moves the motor in a clockwise or anticlockwise direction, with this the shaft also rotates in the desired direction.

Applications of Servo Motors

- They are used to control the positioning and movement of elevators in radio controlled airplanes.
- They play an important role in robotics information of robot because of their smooth switching on or off and accurate positioning.
- They are used in hydraulic systems to maintain hydraulic fluid in the aerospace industry.
- In radio controlled toys these are also used.
- They are used to extend or replay the disc trays in electronic devices such as DVDs or Blue-ray Disc players.
- They are used to maintain the speed of vehicles in the automobile industries.

Stepper Motor

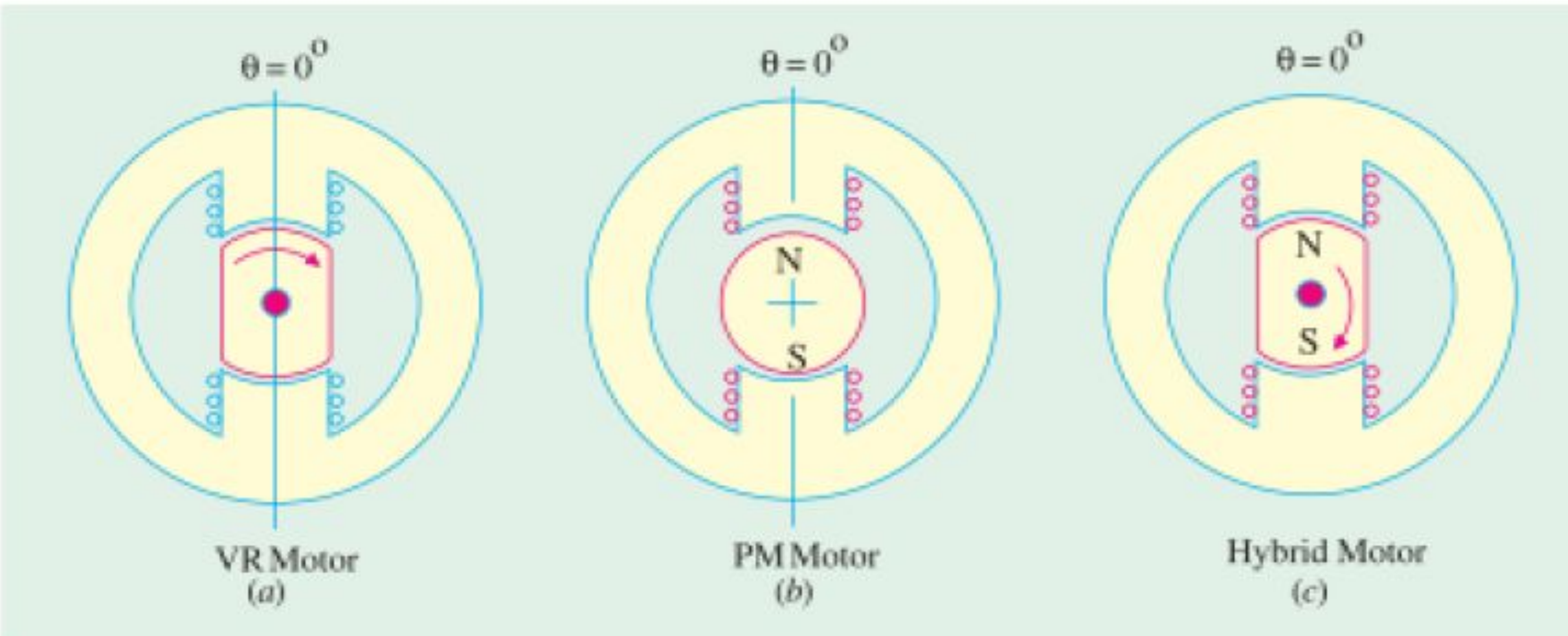
- A stepper motor is a “pulse-driven” motor that changes the angular position of the rotor in “steps”
- Stepper motor is a motor which rotates step by step and not continuous rotation. When the stator is excited using a DC supply the rotor poles align with the stator poles in opposition such that reluctance is less.
- Define
  - β = the step angle (per input pulse)
  - Resolution = the number of steps/revolution
  - θ = total angle traveled by the rotor
    - = β X No. of steps
  - n = the shaft speed = $(\beta \times f_p) / 360°$
    - f_p = No. of pulses/second
    - Step number (S) = $360° / \beta$

Why Stepper Motor?

- Motor that moves one step at a time
- A digital version of an electric motor
- Each step is defined by a Step Angle
- Relatively inexpensive
- Ideal for open loop positioning control − Can be implemented without feedback − Minimizes sensing devices − Just count the steps
- Torque − Holds its position firmly when not turning − Eliminates mechanical brakes − Produces better torque than DC motors at lower speeds
- Positioning applications

Types of Stepping Motors

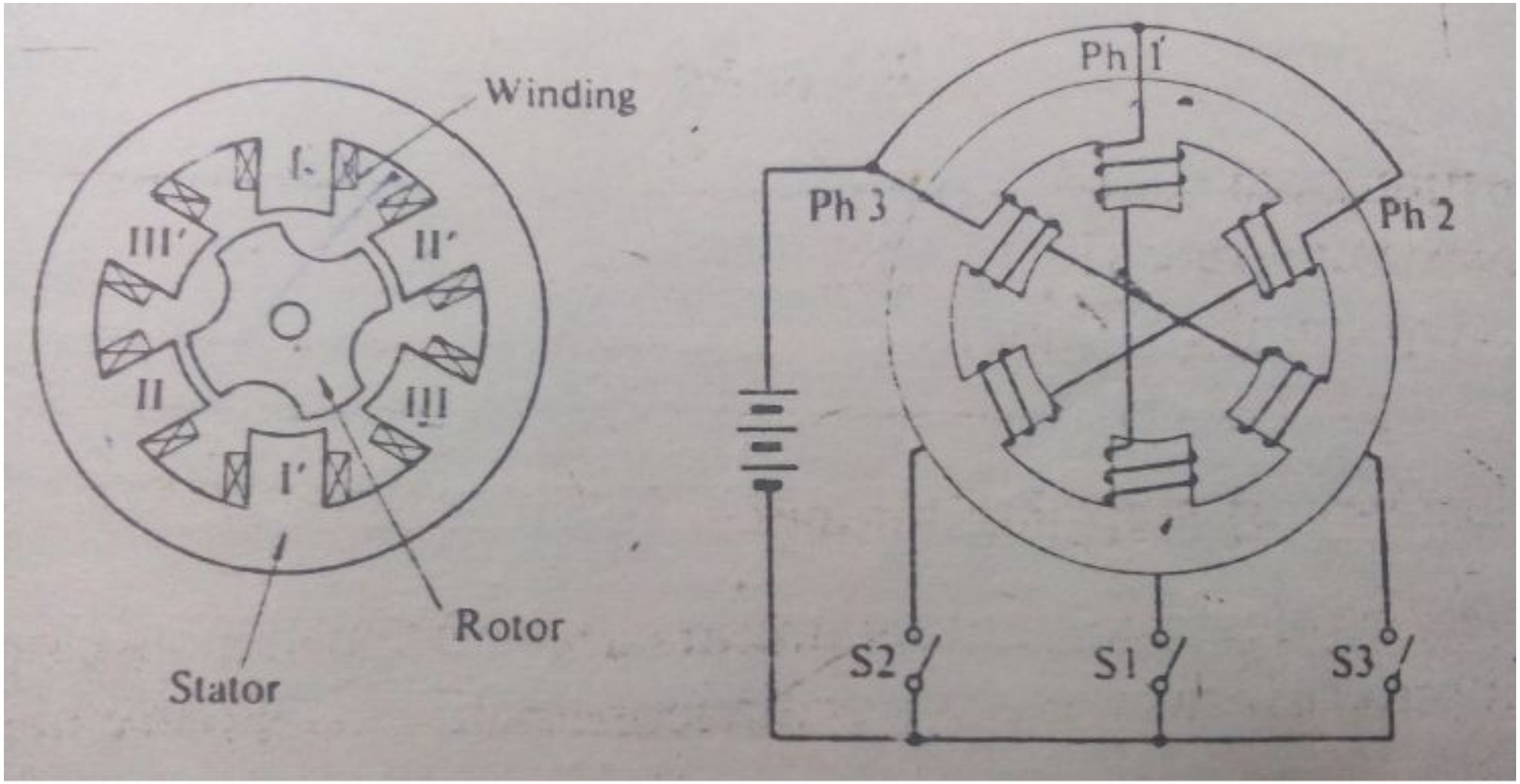
- Permanent Magnet
  - Magnetic rotor
- **Variable Reluctance**
  - Non-magnetic, geared rotor
- Hybrid
  - Combines characteristics from PM and VR
  - Magnetic, geared rotor


θ = 0°
θ = 0°
θ = 0°
N
S
N
S
VR Motor
(a)
PM Motor
(b)
Hybrid Motor
(c)

Variable Reluctance Stepper Motor

- It consists of a wound stator and a soft iron multi-tooth rotor.
- The stator has a stack of silicon steel laminations on which stator windings are wound.
- Usually, it is wound for three phases which are distributed between the pole pairs.
- The rotor carries no windings and is of salient pole type made entirely of slotted steel laminations.
- The rotor pole's projected teeth have the same width as that of stator teeth.
- The number of poles on stator differs to that of rotor poles, which provides the ability to self start and bidirectional rotation of the motor.

Cross section model of 3-ph VR stepper motor and winding arrangement



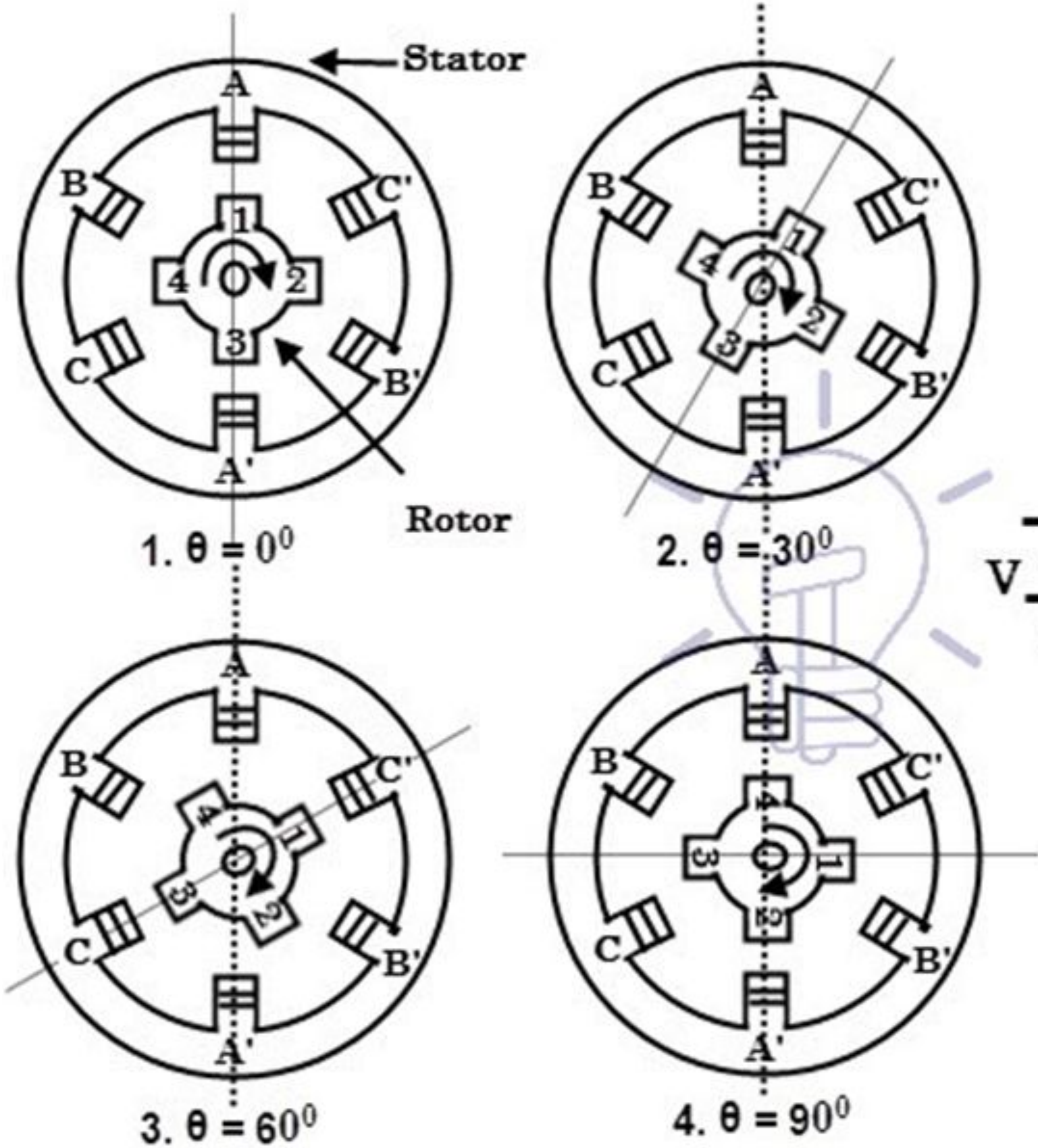
VR Stepper motor has following modes of operation

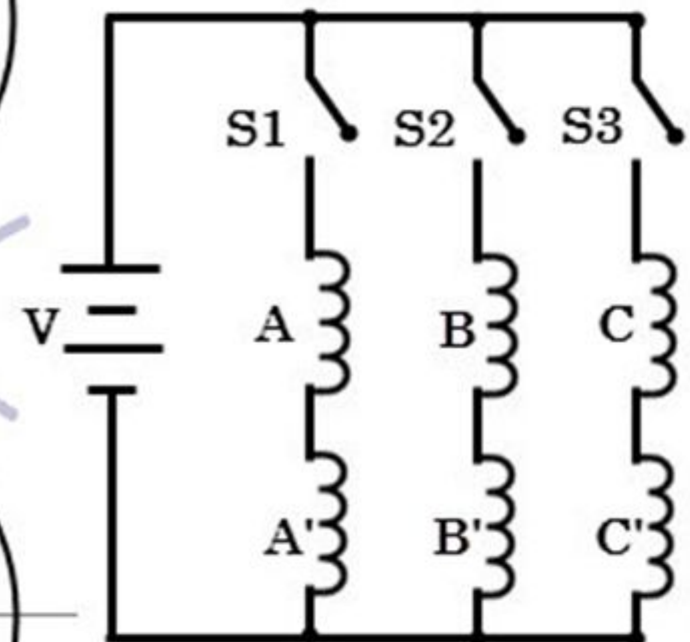
1. 1 phase ON (or) Full step operation mode
2. 2 phase ON mode
3. Alternate 1 phase ON and 2 phase ON mode (or) Half step operation mode
4. Micro stepping operation mode

Working of Variable Reluctance Stepper Motor

- The stepper motor works on the principle that the rotor aligns in a particular position with the teeth of the excitation pole in a magnetic circuit wherein minimum reluctance path exist.
- Whenever power is applied to the motor and by exciting a particular winding, it produces its magnetic field and develops its own magnetic poles.
- Due to the residual magnetism in the rotor magnet poles, it will cause the rotor to move in such a position so as to achieve minimum reluctance position and hence one set of poles of rotor aligns with the energized set of poles of the stator.
- At this position, the axis of the stator magnetic field matches with the axis passing through any two magnetic poles of the rotor.

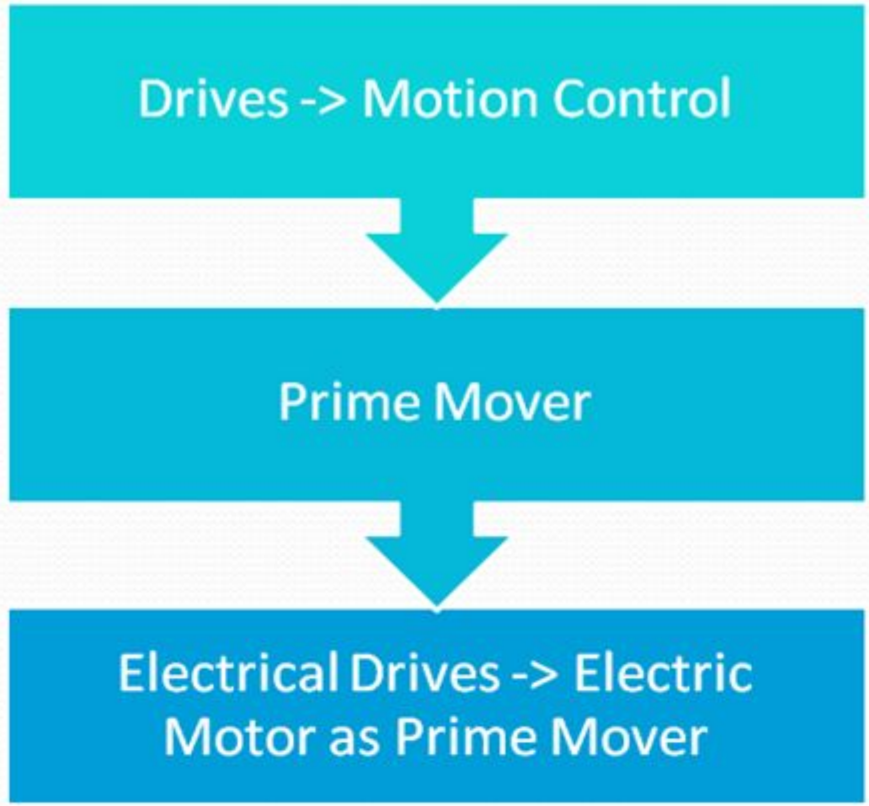
- When the rotor aligns with stator poles, it has enough magnetic force to hold the shaft from moving to the next position, either in clockwise or counter clockwise direction.
- The stepper motor works on the principle that the rotor aligns in a particular position with the teeth of the excitation pole in a magnetic circuit wherein minimum reluctance path exist.
- Whenever power is applied to the motor and by exciting a particular winding, it produces its magnetic field and develops its own magnetic poles.
- Due to the residual magnetism in the rotor magnet poles, it will cause the rotor to move in such a position so as to achieve minimum reluctance position and hence one set of poles of rotor aligns with the energized set of poles of the stator.
- At this position, the axis of the stator magnetic field matches with the axis passing through any two magnetic poles of the rotor.
- When the rotor aligns with stator poles, it has enough magnetic force to hold the shaft from moving to the next position, either in clockwise or counter clockwise direction.


Stator
Rotor
A
B
C'
C
B'
A'
1
2
3
4
1. θ = 0⁰
2. θ = 30⁰
3. θ = 60⁰
4. θ = 90⁰


S1
S2
S3
V
A
A'
B
B'
C
C'

Electrical Drives

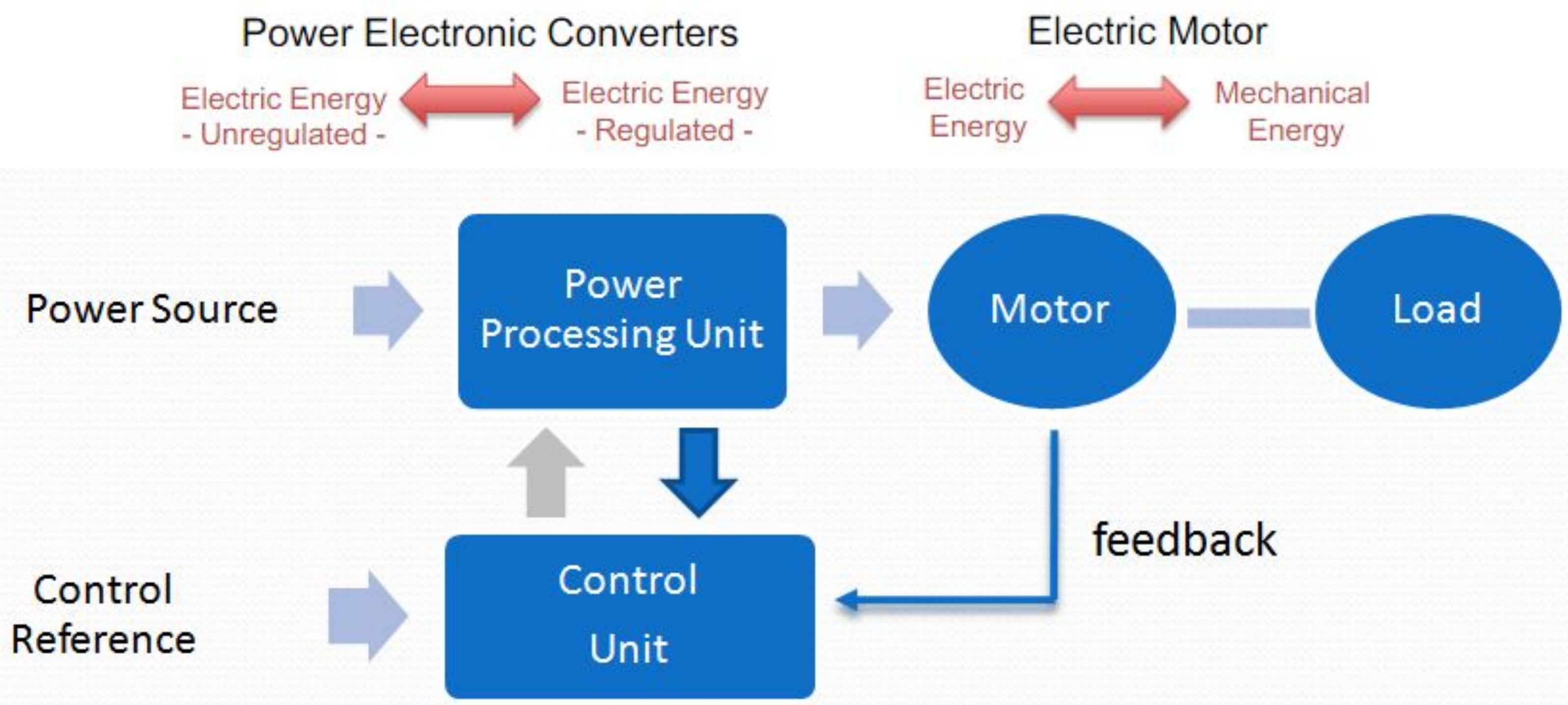
- Drives – system employed for motion control
- Motion control requires prime movers
  Diesel/petrol/gas/stream engines, hydraulic motors, electric motors
- Electrical Drives – Drives that employ Electric Motors as prime movers



Advantages of Electrical Drives

- Flexible control characteristic
  - particularly when power electronic converters are employed
- Wide range of speed, torque and power
- High efficiency – low no load losses
- Low noise
- Low maintenance requirements, cleaner operation
- Electric energy easily transported
- Adaptable to most operating conditions
- Available operation in all four torque-speed quadrants

Block Diagram of Electric Drive System



- Power Source
- Motor
- Power Processing Unit (Electronic Converter)
- Control Unit
- Mechanical Load

Components in electric drives

Motors

- DC motors - permanent magnet – wound field
- AC motors – induction, synchronous
- brushless DC
- Applications, cost, environment
- Natural speed-torque characteristic is not compatible with load requirements

Power sources

- DC – batteries, fuel cell, photovoltaic - unregulated
- AC – Single- three- phase utility, wind generator - unregulated

Power processor

- To provide a regulated power supply
- Combination of power electronic converters
  - More efficient
  - Flexible
  - Compact
  - AC-DC, DC-DC, DC-AC, AC-AC

Components in electric drives

Control unit

- Complexity depends on performance requirement
- analog- noisy, inflexible, ideally has infinite bandwidth.
- DSP/microprocessor – flexible, lower bandwidth - DSPs perform faster operation than microprocessors (multiplication in single cycle), can perform complex estimations
- Electrical isolation between control circuit and power circuit is needed:
  - Malfunction in power circuit may damage control circuit
  - Safety for the operator
  - Avoid conduction of harmonic to control circuit

Components in electric drives

Sensors

- Sensors (voltage, current, speed or torque) is normally required for closed-loop operation or protection.
- Electrical isolation between sensors and control circuit is needed.
- The term ‘sensorless drives’ is normally referred to the drive system where the speed is estimated rather than measured.

Applications of Electric Drives

Transportation Systems

Rolling Mills

Paper Mills

Textile Mills

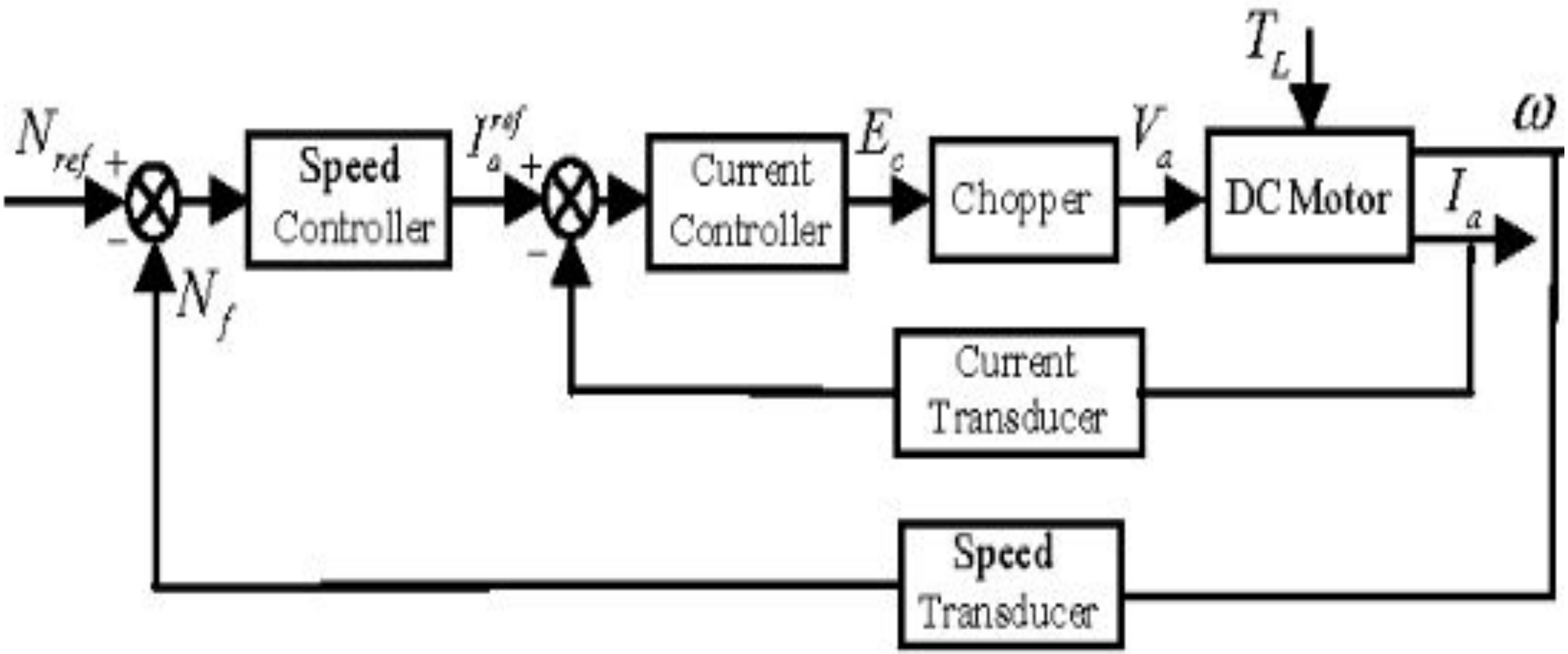
Machine Tools

Fans and Pumps

Robots

Washing Machines etc

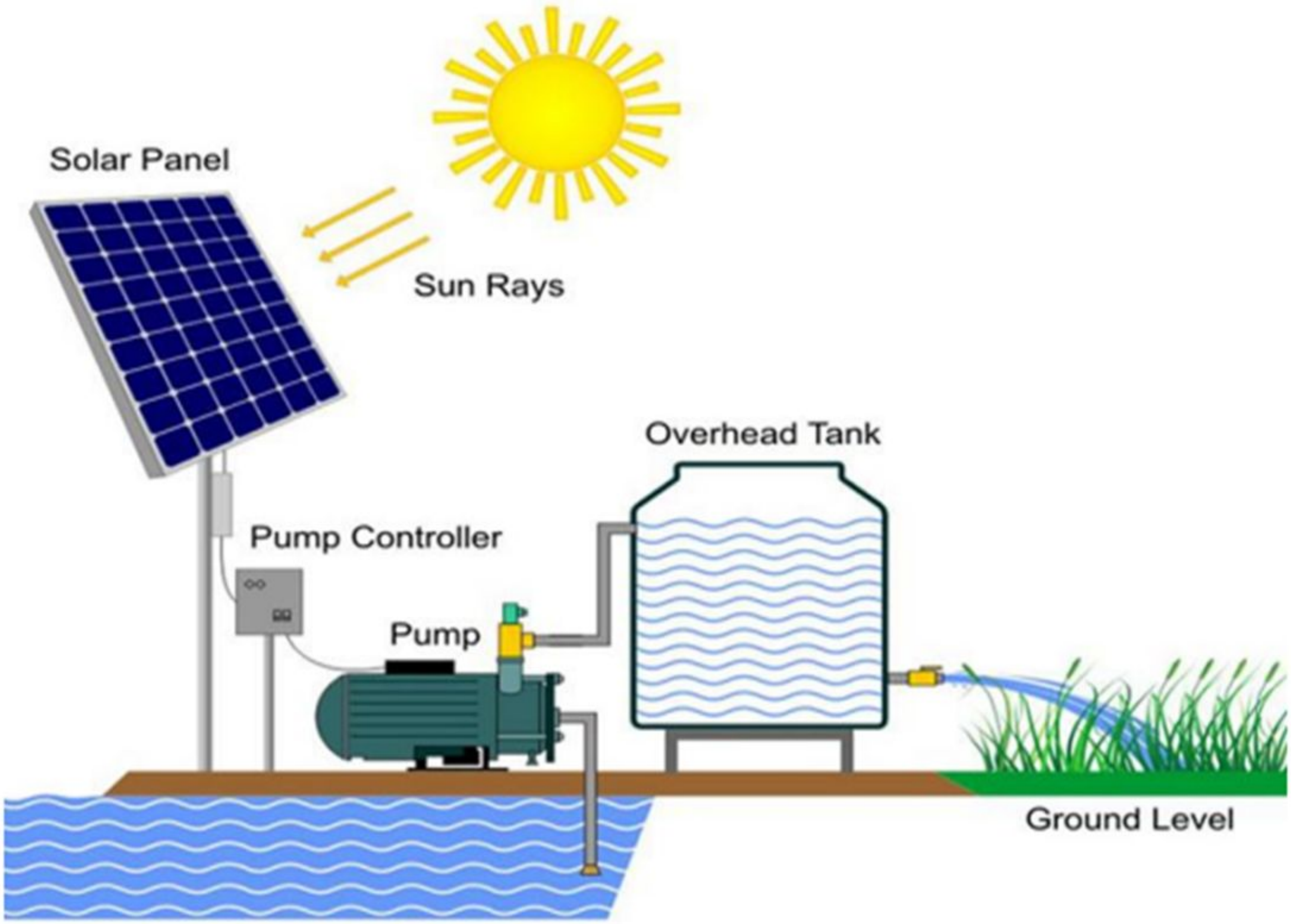
Chopper fed dc drive



Factors for selection of Electrical Drives

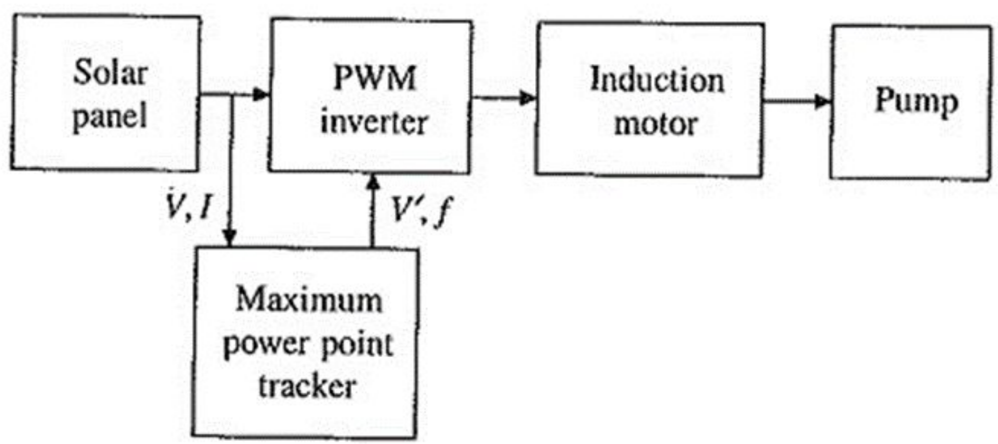
- Several factors affecting drive selection:
  - Steady-state operation requirements
    - nature of torque-speed profile, speed regulation, speed range, efficiency, quadrants of operations, converter ratings
  - Transient operation requirements
    - values of acceleration and deceleration, starting, braking and reversing performance
  - Power source requirements
    - Type, capacity, voltage magnitude, voltage fluctuations, power factor, harmonics and its effect on loads, ability to accept regenerated power
  - Capital & running costs
  - Space and weight restrictions
  - Environment and location
  - Efficiency and reliability

Solar Powered Pump System



Solar Powered Pump Drives with reciprocating pump

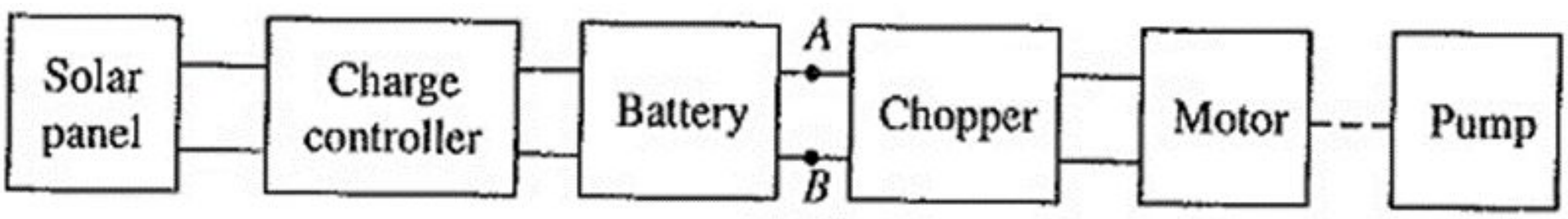
- For pump ratings of 1 kW and above, three phase induction motor drive is employed.
- A PWM voltage source inverter with maximum-power-point-tracker is used for variable frequency control of the squirrel-cage induction motor.



Solar pump drive using induction motor

Solar Powered Pump Drives with battery

- Solar Powered Pump Drives with an intermediate battery, can also be used.
- The drive is fed from the battery charged by solar panel.



Solar pump with a battery

Selection of drives and control schemes for lifts and cranes

Selection of drives and control schemes for lifts and cranes

1) **Quick Lift:** To allow a lightly loaded or empty hoist to move up and down faster than the base speed of the motor

2) **Reverse Plug Simulation:** When reversing directions, the inverter will decelerate at a faster rate than the normal deceleration rate.

3) **Load Hold (Hang Time):** To hold a load aloft at zero speed without setting the brake. Permit precise positioning of the load without delays normally associated with mechanical operation of the brake.

4) **Fast Stop:** To Rapidly decelerate the drive when the run command is removed i.e. when back-up limit switch is tripped

Selection of drives and control schemes for lifts and cranes

4) **Speed Control:** To accommodate five-speed cabin/pendant control, infinitely variable speed control, and a bi-polar voltage or analog current input speed command

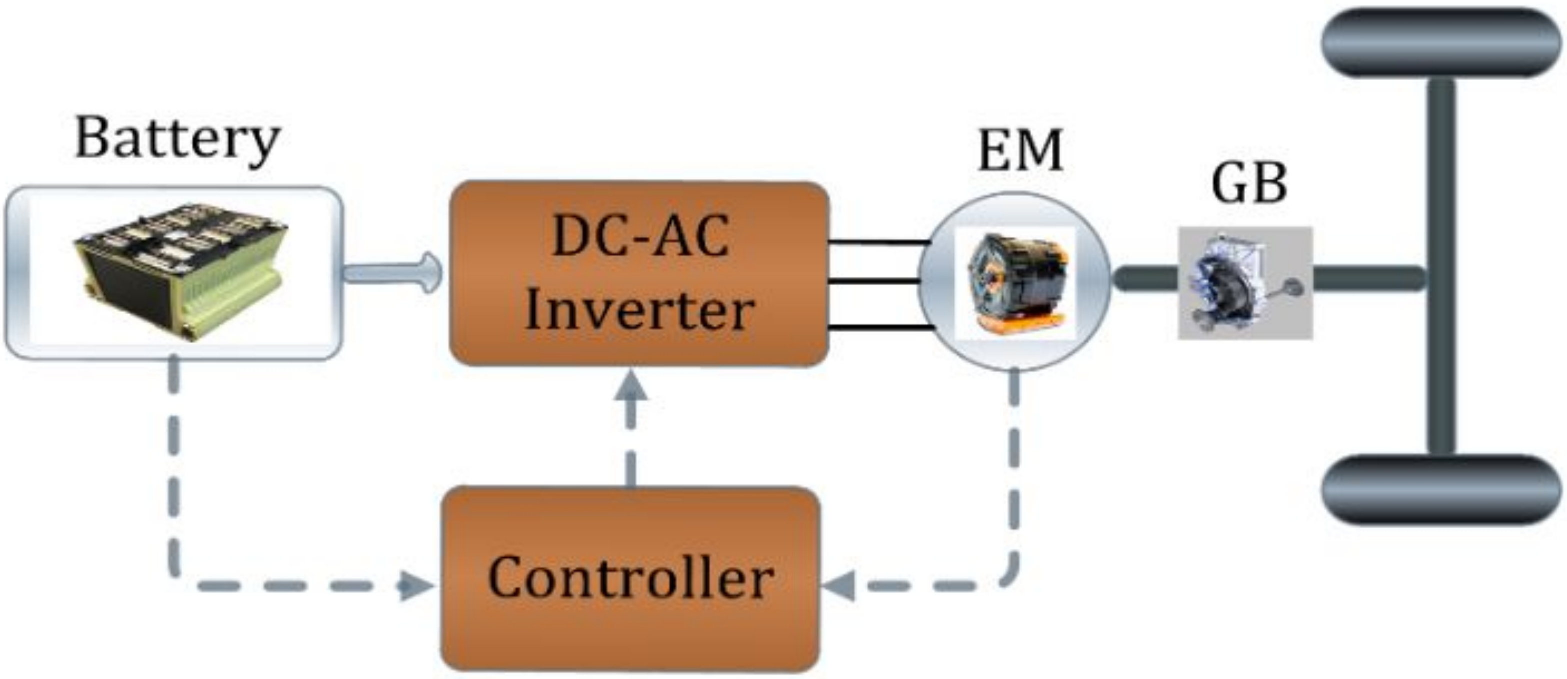
5) **Micro speed Positioning Control:** To Permit extremely slow movements for greater positioning accuracy

6) **Dual Upper and Lower Limit Switch Inputs:** To accommodate limit-switch inputs on both the upper and lower travel of the hoist displayed. Further movement in hoist direction is prevented.

7) **Torque Limits:** Two sets of Fwd and rev torque limits are provided.

8) **Torque Limited Acceleration / Deceleration Times:** For smooth starts and stops to prevent load sway

EV Control schemes



EV Control schemes