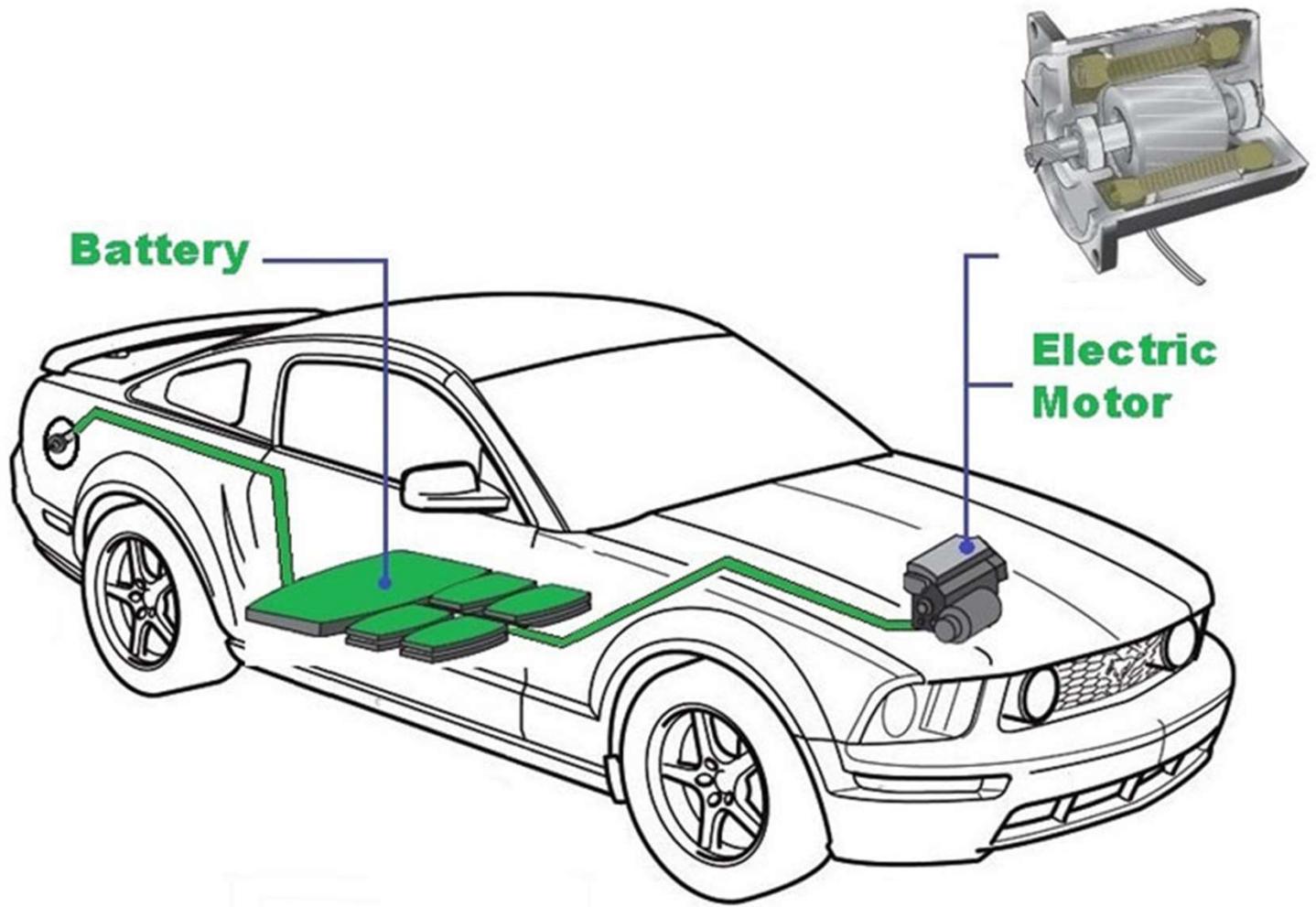
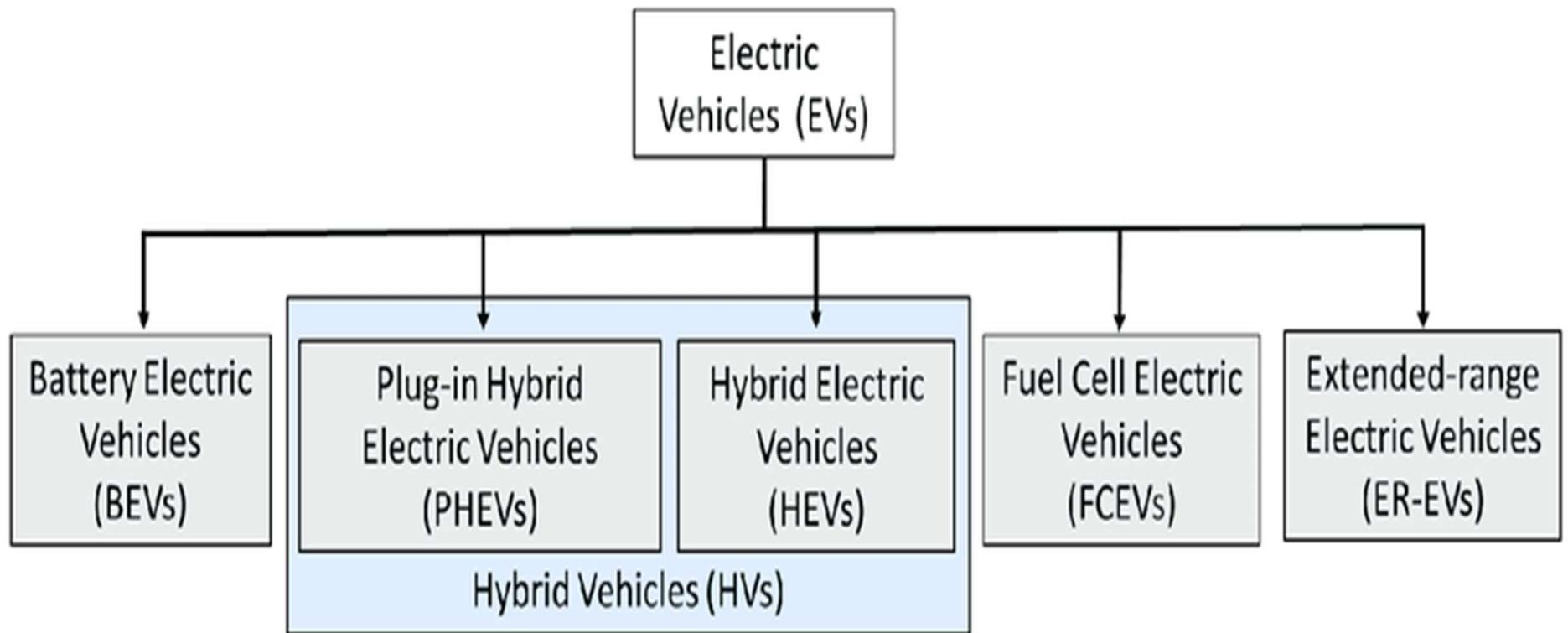


MOTORS AND DRIVES

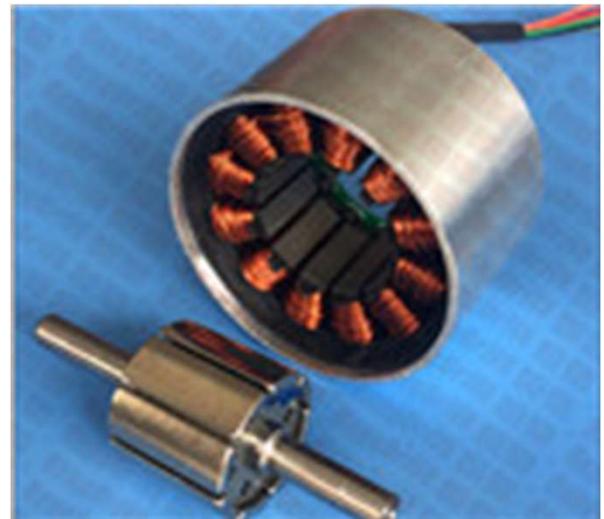
Unit - 3





INTRODUCTION

1. Electrical Machines are Electromechanical energy conversion devices.
2. Electrical motor converts electrical energy into mechanical energy and electrical generators are vice versa.
3. Electric motors play an essential role in almost every industry.
4. Using the right type of motor with high-quality parts and regular servicing keeps your facility running smoothly and prevents damage to the endpoint equipment due to wear or power surges.
5. Most of the Industrial load are inductive.



MAIN MOTOR COMPONENTS

While electric motors may differ from one design or type to another, many of them contain these parts and assemblies (located from the center working outward):

1. Central motor shaft
2. Windings
3. Bearings (to reduce friction and wear)
4. Armature (located on the rotor, the rotating part, or the stator, the stationary part)
5. Brushes (in DC motors)
6. Terminals
7. Frame and end shields

HOW ELECTRIC MOTORS WORK

- Both AC and DC motors use electrical current to produce rotating magnetic fields that, in turn, generate rotational mechanical force in the armature—located on the rotor or stator—around the shaft.
- The various motor designs use this same basic concept to convert electric energy into powerful bursts of force and provide dynamic levels of speed or power

Why Electric Motors?

- Controlled
- Simple Construction
- Efficiency is high compared to Mechanical motor
- Mechanical vibration and noise pollution is very less compared to an ICE



Selecting the Right Motor for Your Needs

Assess Your Priorities



Compare Motor Types

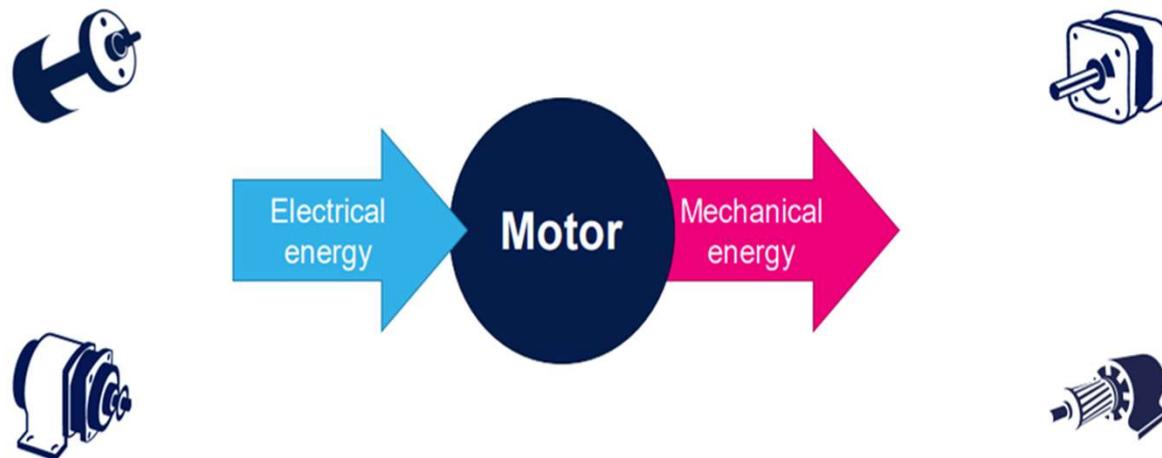


Consult Experts &
Online Resources

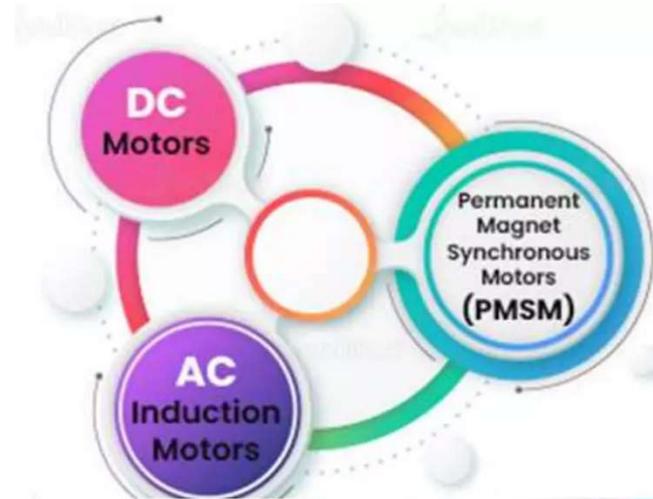


What an electric motor

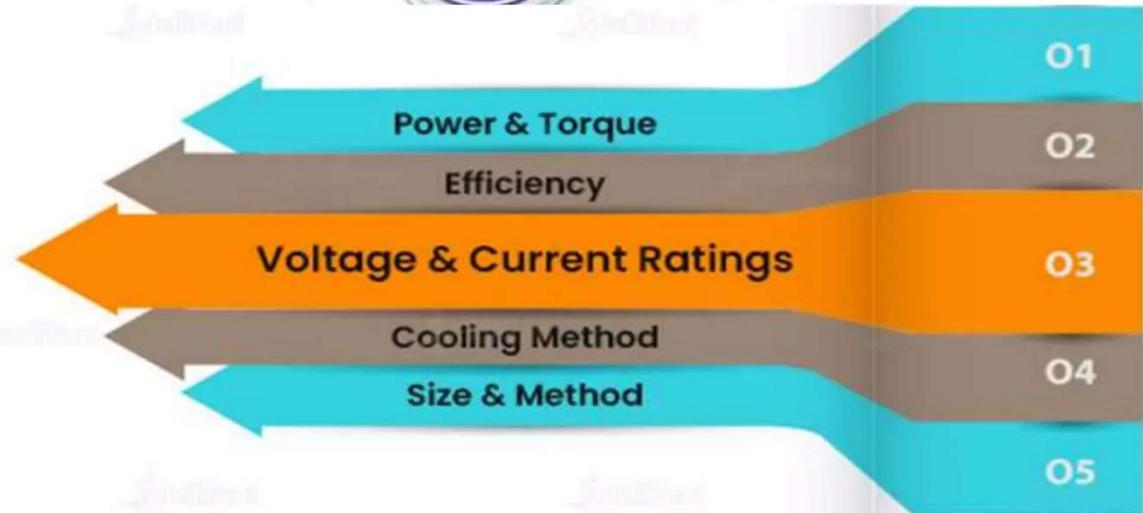
1. An electric motor is a device converting electrical energy into mechanical energy (generally a **torque**).
2. This conversion is usually obtained through the generation of a magnetic field by means of a current flowing into one or more coils.
3. Electric motors can be powered by **direct current** (DC) sources, such as batteries or **rectifiers**. Or by alternating current (AC) sources, such as inverters, **electric generators**, or a power grid.

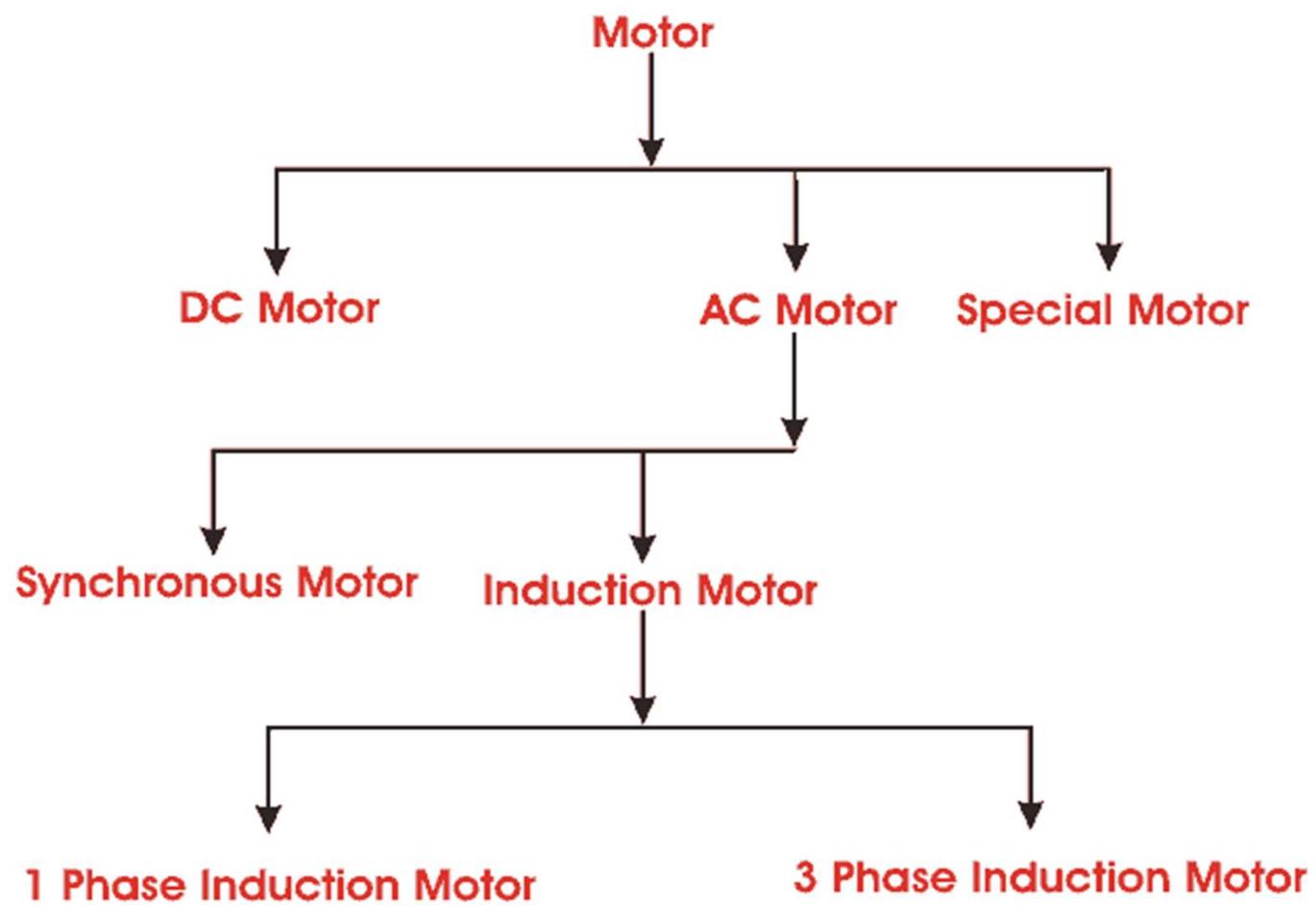


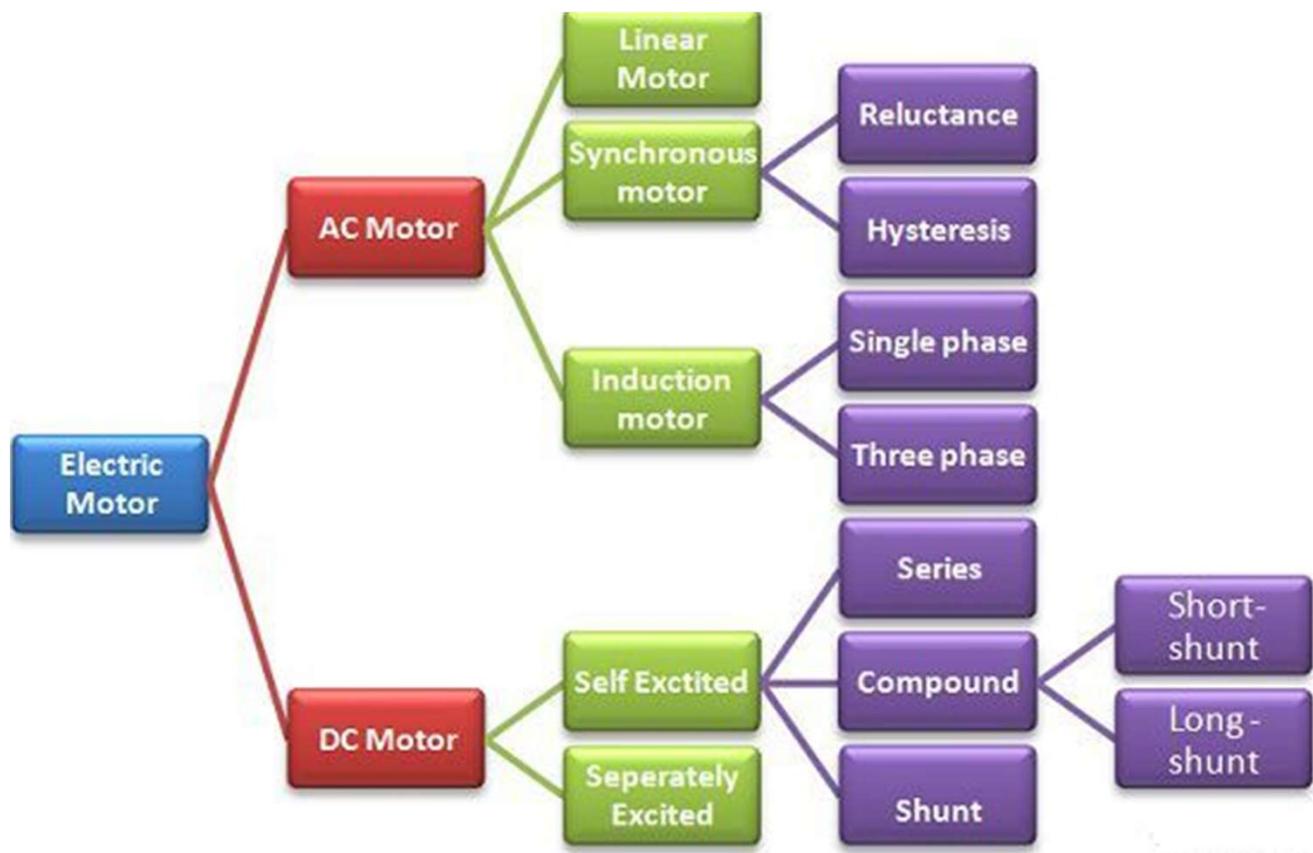
Types of Motors for Electric Vehicle



Electric Vehicle Motor Specifications







AC MOTOR Vs. DC MOTOR ADVANTAGES

Each motor type has different advantages that make them best suited for different commercial and industrial applications.

AC motors, for example, are flexible and easy to control.

- ❖ Some of their other advantages include:
 - Low startup power demands that also protect components on the receiving end
 - Controllable starting current levels and acceleration
 - VFD or VSD add-ons that can control speed and torque at different stages of use
 - High durability and longer life spans
 - Capabilities for multi-phase configurations

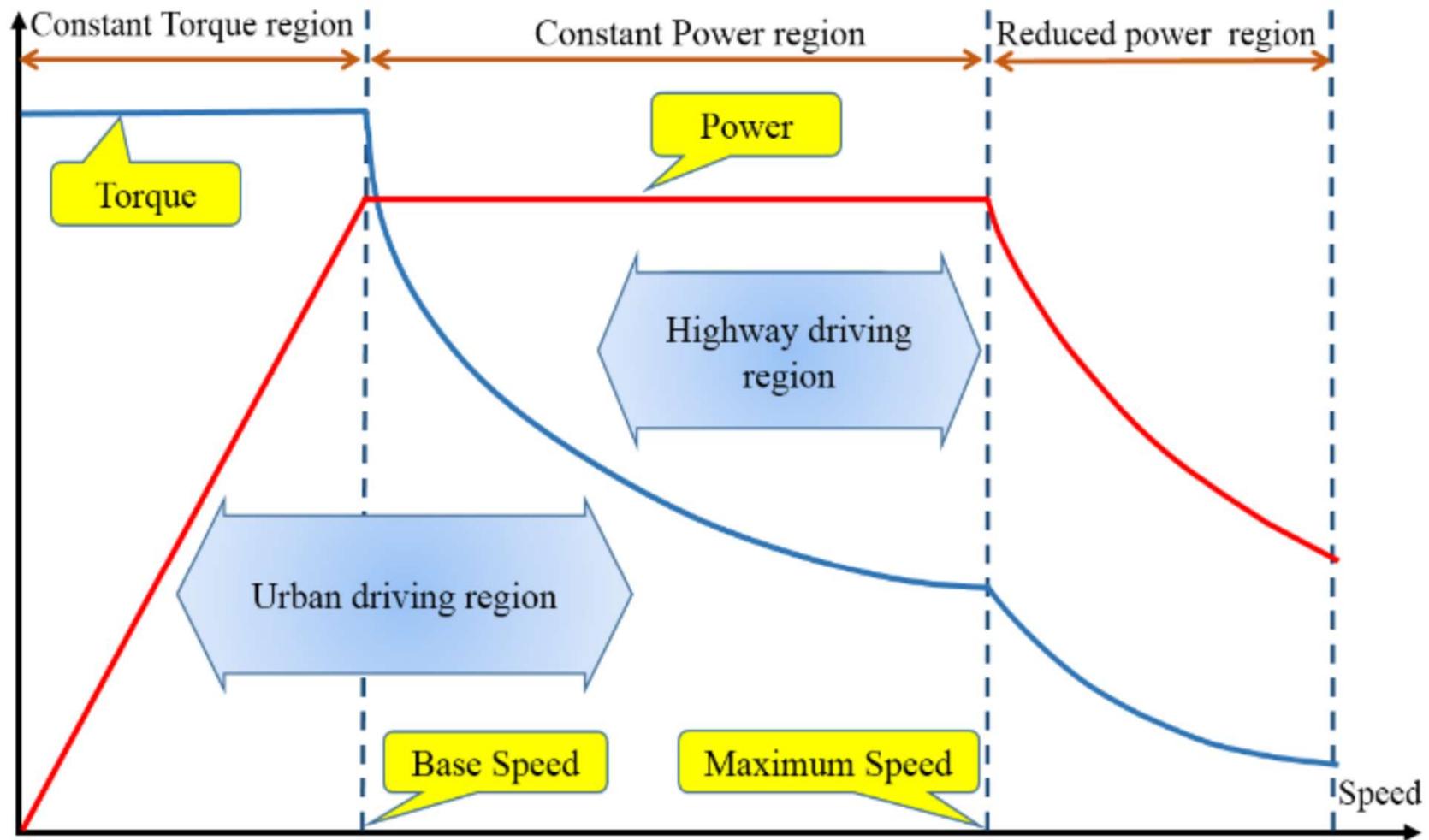
DC MOTORS

1. Simpler installation and maintenance
2. High startup power and torque
3. Fast response times to starting, stopping, and acceleration
4. Availability in several standard voltages

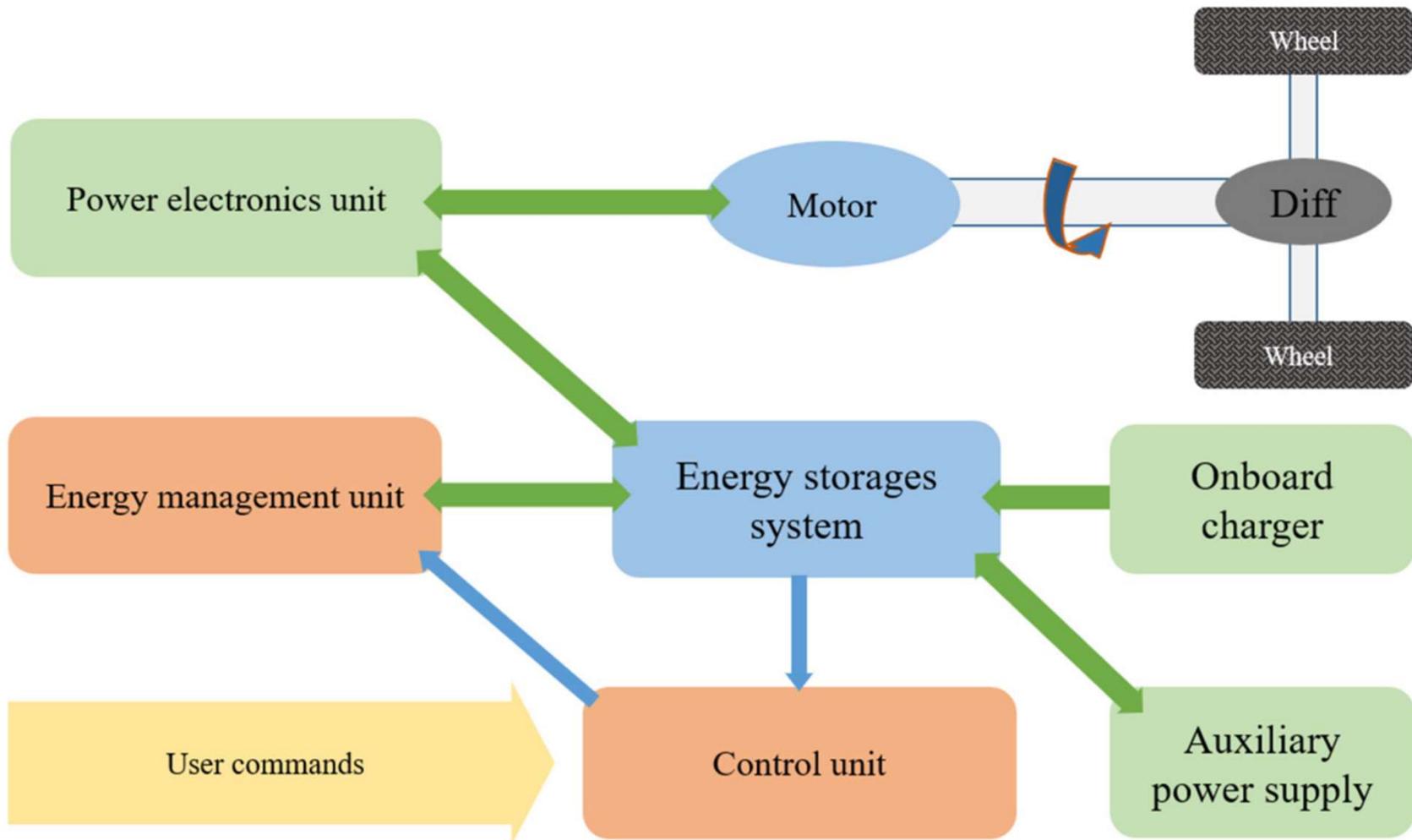
MOTOR CHARACTERISTICS

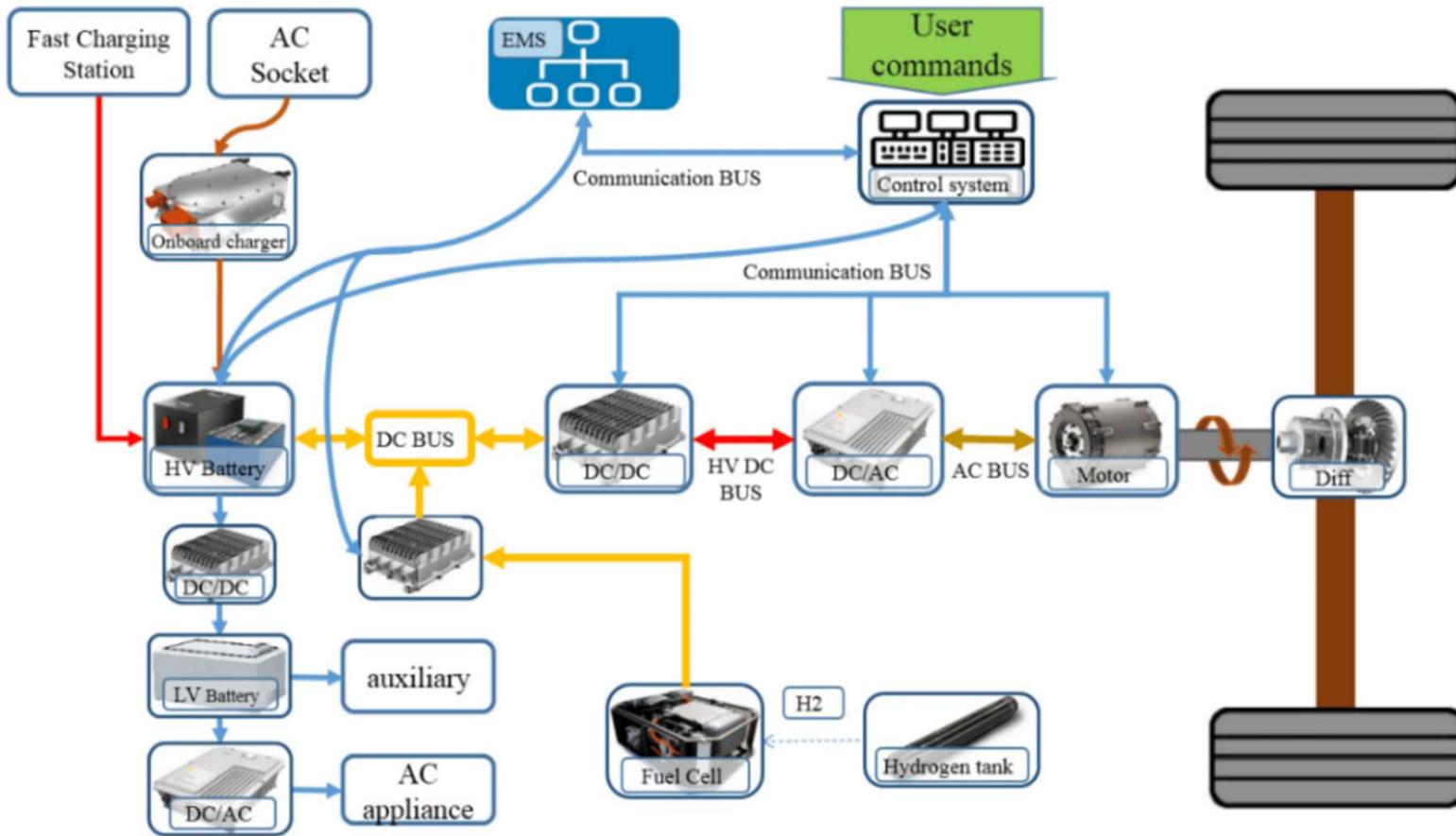
The major requirements of an electric vehicle propulsion system

1. High instant power and high power density.
2. A high torque at low speeds for starting and climbing, as well as high power at high speed for cruising.
3. A very wide speed range, including constant torque and constant power regions.
4. A fast torque response.
5. A high efficiency over wide speed and torque ranges.
6. A high efficiency for regenerative braking.
7. A high reliability and robustness for various vehicle operating conditions and
8. A reasonable cost.



- An EV traction motor must meet different types of operating criteria than those used in industries. In industries, most loads are constant and classified, while on the road, the EV may need to change speed, increase torque on slopes, and abruptly apply brakes.
- **Figure** shows a typical load profile that is intended for a traction motor .
- It is imperative to note that the motor exceptionally or rarely follows the torque–speed curve during operation.
- These curves can be viewed as circling all load points.
- The full load cycle can be divided into three sections depending on the speed, as shown in the graph of **Figure**
- The main characteristics required for electrical machines for traction purposes include quick and rapid torque response with important power density at low speeds for starting and scaling, as well as consistent power at higher speed, high efficiency over the wide range of speeds with constant torque and constant power, overload capacity, usually twice the rated engine torque for short durations, small size, reduced weight, a lower moment of inertia, acceptable cost, as well as high reliability and robustness.
- For different operating conditions of the vehicle, the fault tolerance ability has to be considered





Power electronics of an EV.

Power to Weight

Ratio

Higher Power to Weight ratio provides higher speed and acceleration

Power Density

Higher Power density helps minimize space utilisation (compactness) for highest possible power output

Efficiency

Higher motor efficiency means less energy losses and more usable mechanical energy

Peak Power
Output

The maximum power that the Motor can sustain for short duration

AC Motor	DC Motor
An electrical machine that converts AC electrical energy into mechanical energy.	An electrical machine that converts DC electrical energy into Mechanical energy.
It is powered by alternating current (AC).	It is powered by a unidirectional direct current (DC).
There are two main types of AC motors; Asynchronous (Induction) motor & Synchronous motor.	There are two main types of DC motor; Brushed DC motor & Brushless DC (BLDC) motor.
AC motors can be single phase (phase and neutral as input) or three phase (3 lines of live wires as input).	DC Motors are single phase having two lines as input (positive and negative).
The input supply to the armature is AC, so it does not need commutation.	The input supply is DC, so it needs Commutation the DC input into AC.
The armature is always stationary known as Stator.	The armature in brushed DC motor rotates also known as the rotor.
The input is supplied to stator thus no need for carbon brushes.	The input is supplied to the rotor thus it needs Carbon brushes & commutator.
It does not generate any noise & operate smoothly.	The brushes slide along armature generates noise & sparks.

It offers increased output power.	It offers a wide range of speed control.
The input supplies can be Single-phase or three-phase.	The input supply is a DC source such as batteries, cell & solar panel, etc.
It uses the AC mains as its input supply.	It uses stored backup power from batteries.
Its direction can be reversed by changing the polarity of starter winding in a single phase & swapping any two terminals in a 3-phase motor.	Its direction can be easily reversed by changing the polarity of input DC supply.
Its speed is controlled by varying the input frequency. It uses VFD for controlling their speed.	It speed is controlled by varying armature current. It is easier to control externally through PWM.
It requires less maintenance & is cost-effective.	It requires frequent & costly maintenance. thus they are costlier than AC.
The magnetic field rotates while the armature is stationary.	The magnetic field is stationary while the armature rotates.
The torque decreases with an increase in speed.	It provides a constant torque over a wide range of speed.
AC motor has relatively low efficiency due to the induction current losses.	DC Motor has high efficiency because the magnetic field is generated by a permanent magnet.

<p>Not all AC motors are self-starting & require external equipment to start.</p>	<p>All dc motors are self-starting motors.</p>
<p>The AC induction motor is the most used electrical motor in the domestic & industrial sectors such as in drill machines, water pumps, fans, washing machines, blowers, etc.</p>	<p>Used in application requiring precise position control & high torque such as lifts, cranes, conveyor belts, etc. also small motors in embedded electronics, small toys.</p>

APPLICATIONS

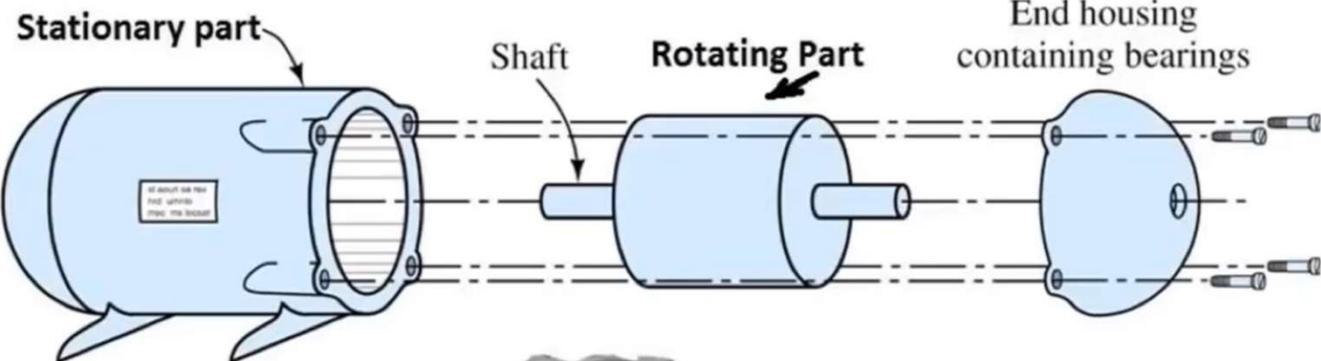
- AC motors include:

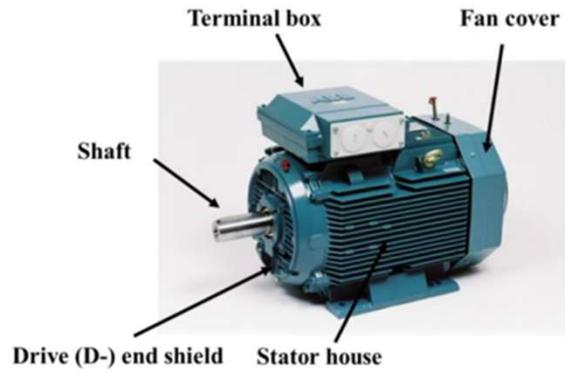
1. Appliances
2. Compressor drives and systems
3. Computers
4. Conveyor systems
5. Fans and air conditioners
6. Hydraulic and irrigation pumps
7. Transportation equipment

- DC motors include:

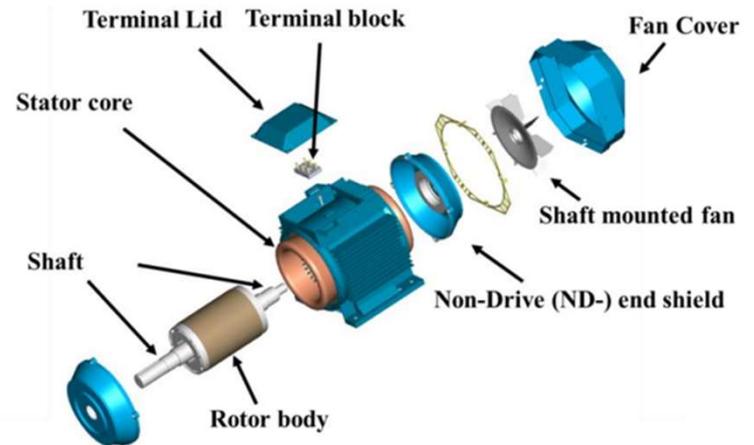
1. Fabrication and production units
2. Machinery that demands constant power such as vacuums, elevators, and sewing machines
3. Warehouse sorting equipment

Basics





Outer parts of a motor



Inner parts of a motor

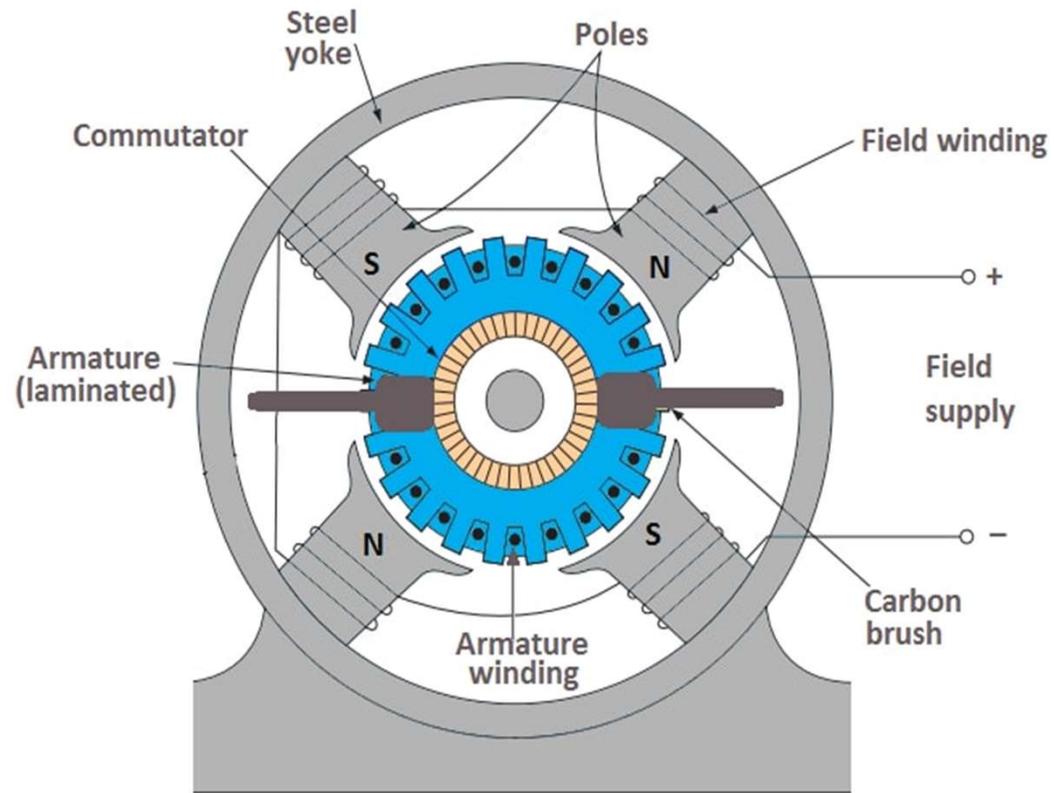
DC MOTOR

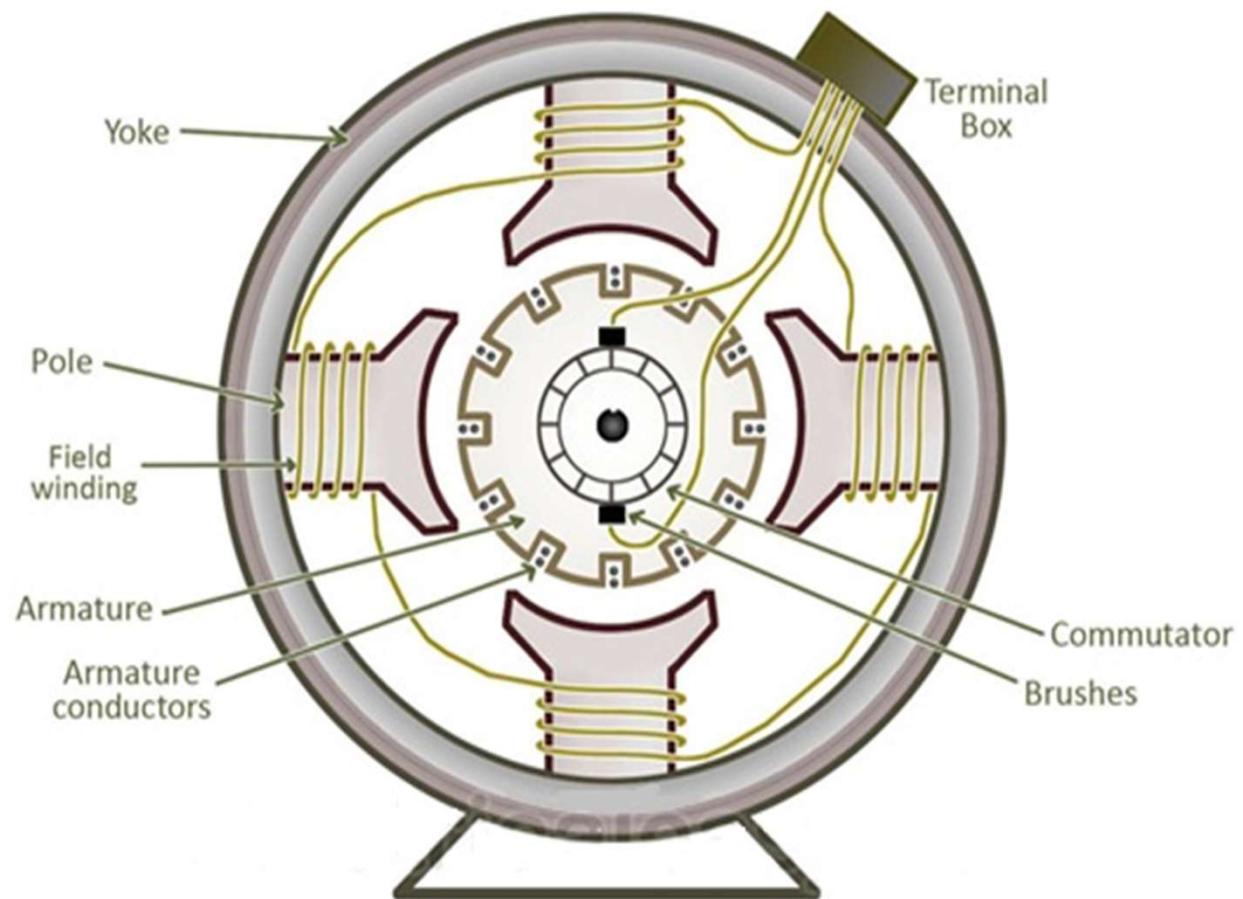
DC Motor



1. A machine that converts dc power into mechanical energy is known as dc motor.
2. Its operation is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.
3. The direction of the force is given by Fleming's left hand rule

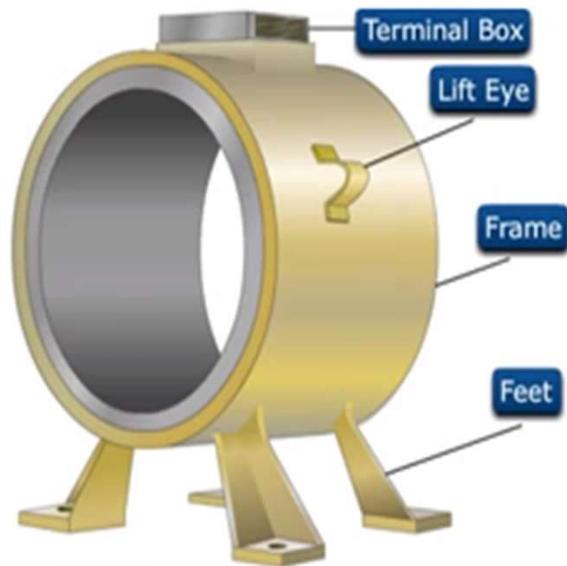
Construction





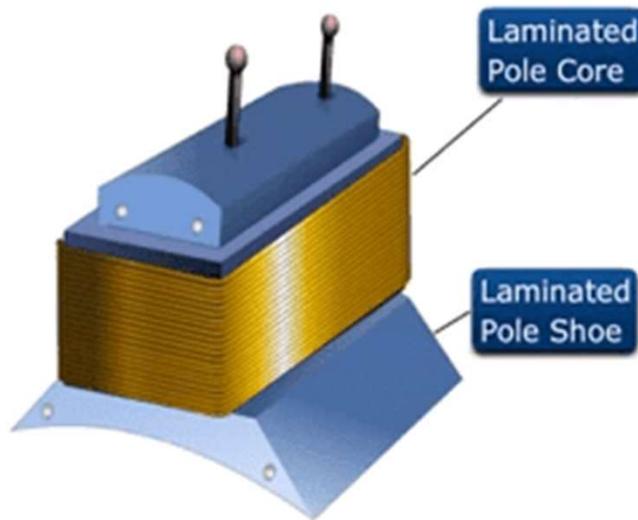
Yoke

(Magnetic Frame)



- The outer frame or yoke serves a double purpose :
 - i. It provides **mechanical support** for the poles and acts as a protecting cover for the whole machine.
 - ii. It **carries the magnetic flux** produced by the poles.
- In small machines yokes are made of **cast iron**. But, for large machines usually cast steel or rolled steel is employed.

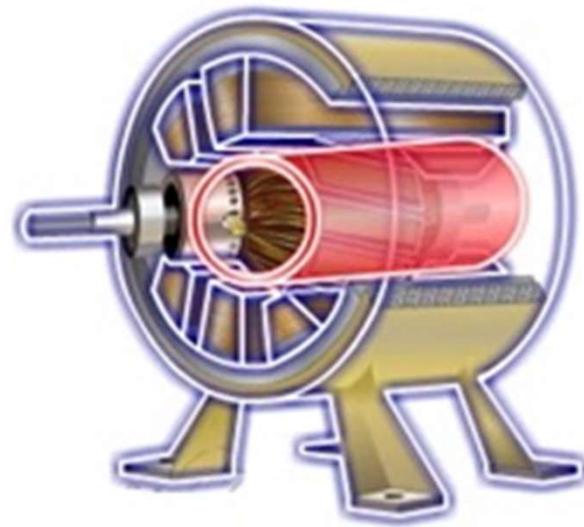
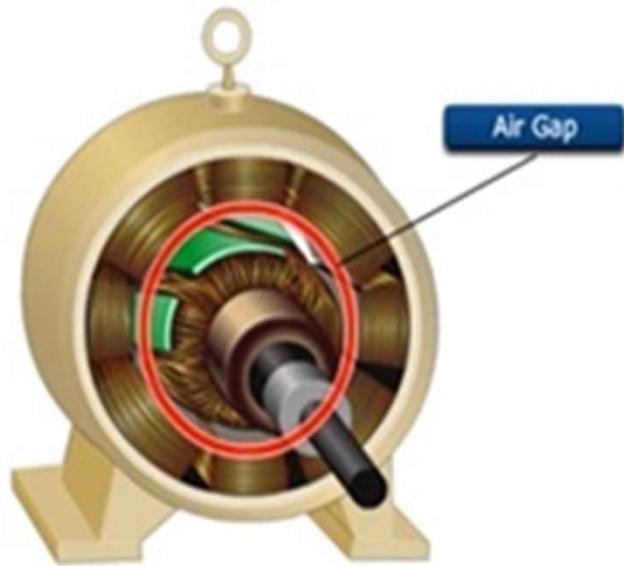
Pole Cores & Pole Shoes



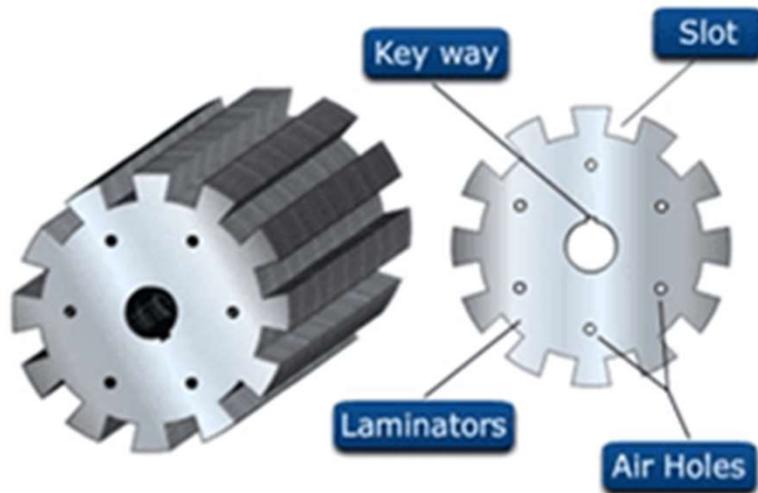
- They spread out the **flux** in the air gap and also, being of larger cross-section, reduce the reluctance of the magnetic path
- They support the **exciting coils** (or field coils)
- **Cast iron or cast steel**, modern design, thin laminations of **annealed steel** which are riveted together under hydraulic pressure.

Field System

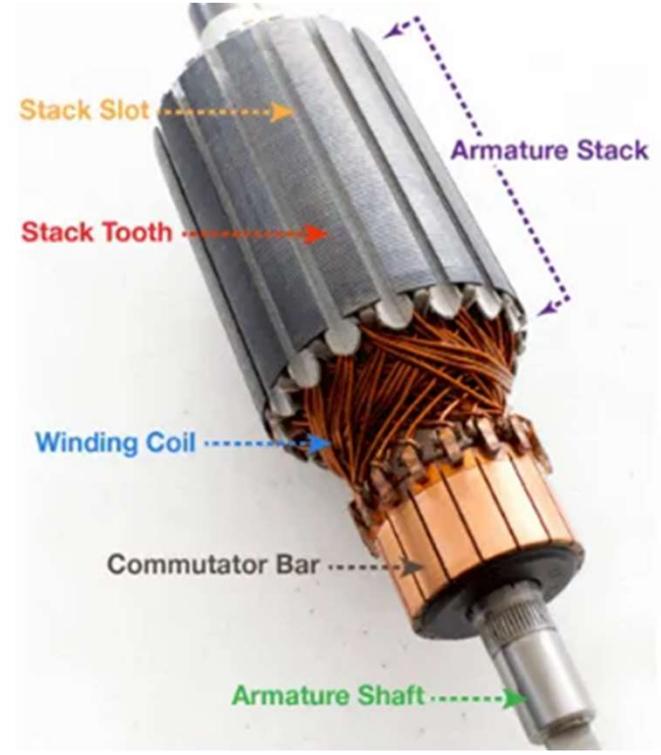
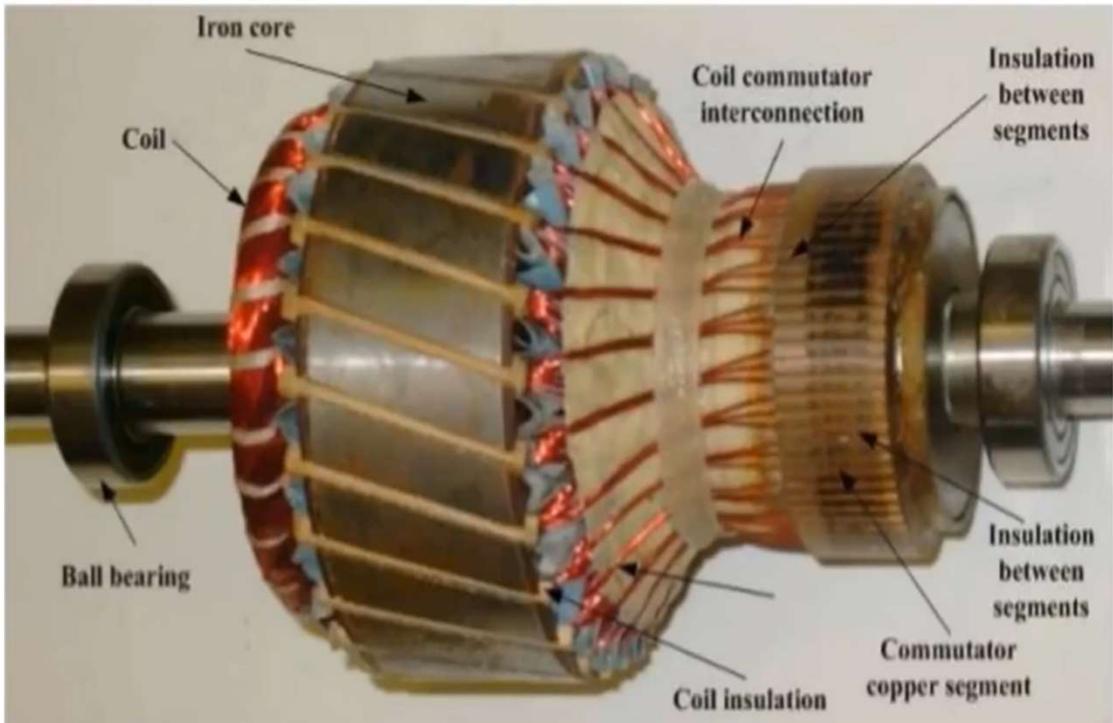
- The function of the field system is to produce a **uniform magnetic field** within which the armature rotates.
- **Field coils** are mounted on the poles and carry the dc exciting current.
- The field coils are connected in such a way that adjacent poles have **opposite polarity**.



Armature Core and Laminations



- The armature core is keyed to the machine shaft and rotates between the field poles.
- It consists of **slotted soft-iron laminations**
- The purpose of laminating the core is to reduce the *eddy current loss*.

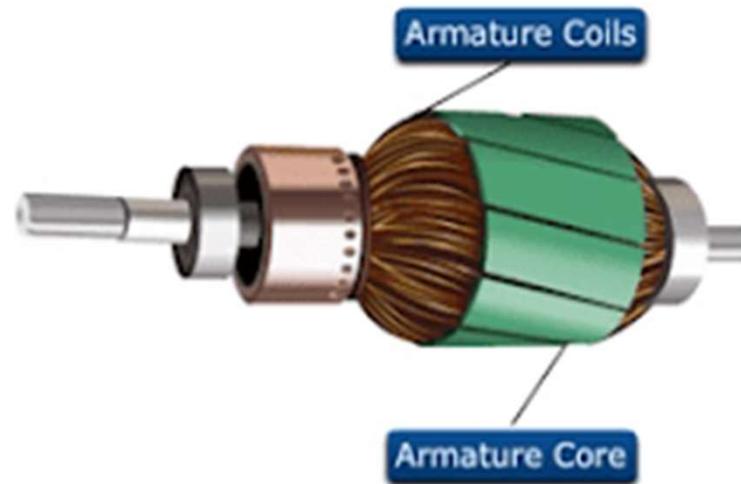


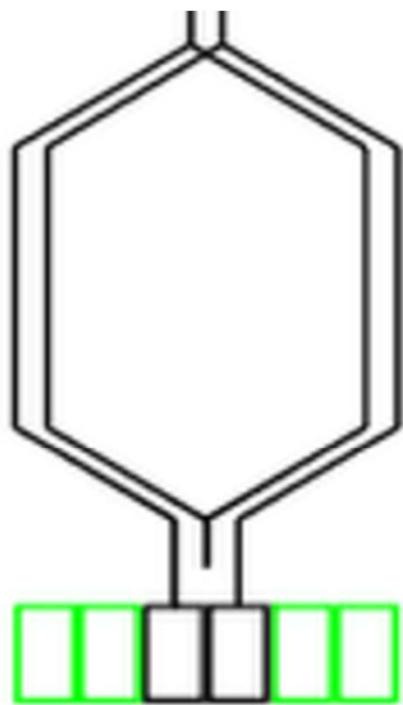
Armature Winding

- The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as **armature winding**.
- This is the winding in which “working” e.m.f. is induced.
- The armature conductors are connected in series/parallel; the conductors being connected in series so as to increase the *voltage* and in parallel paths so as to increase the *current*.

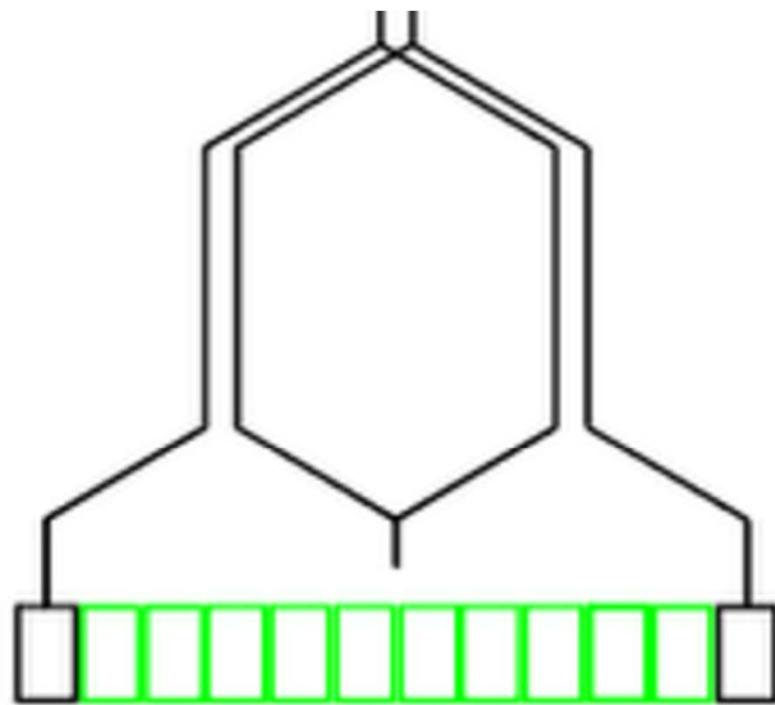
(a) lap winding

(b) wave winding



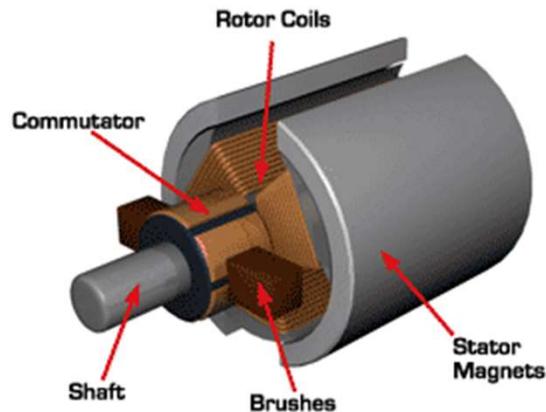


Lap winding

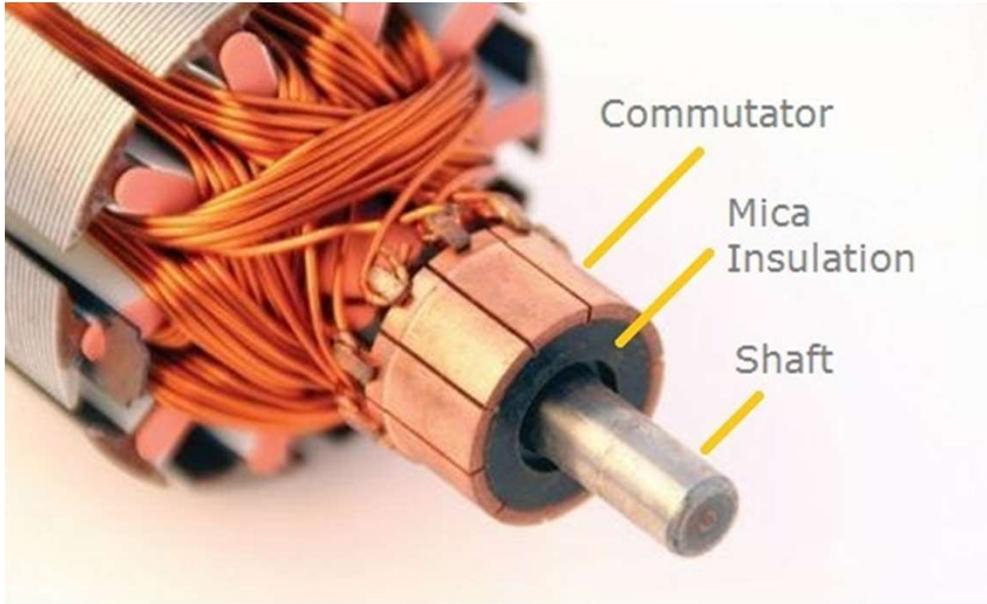


Wave winding

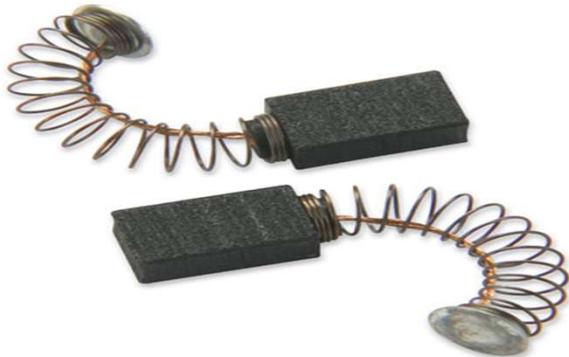
Commutator



- The commutator of DC motor is a cylindrical structure made up of **copper segments** stacked together, but insulated from each other by **mica**.
- Its main function as far as the DC motor is concerned is to commute or relay the supply current from the mains to the armature winding housed over a rotating structure through the brushes of DC motor.



Brushes

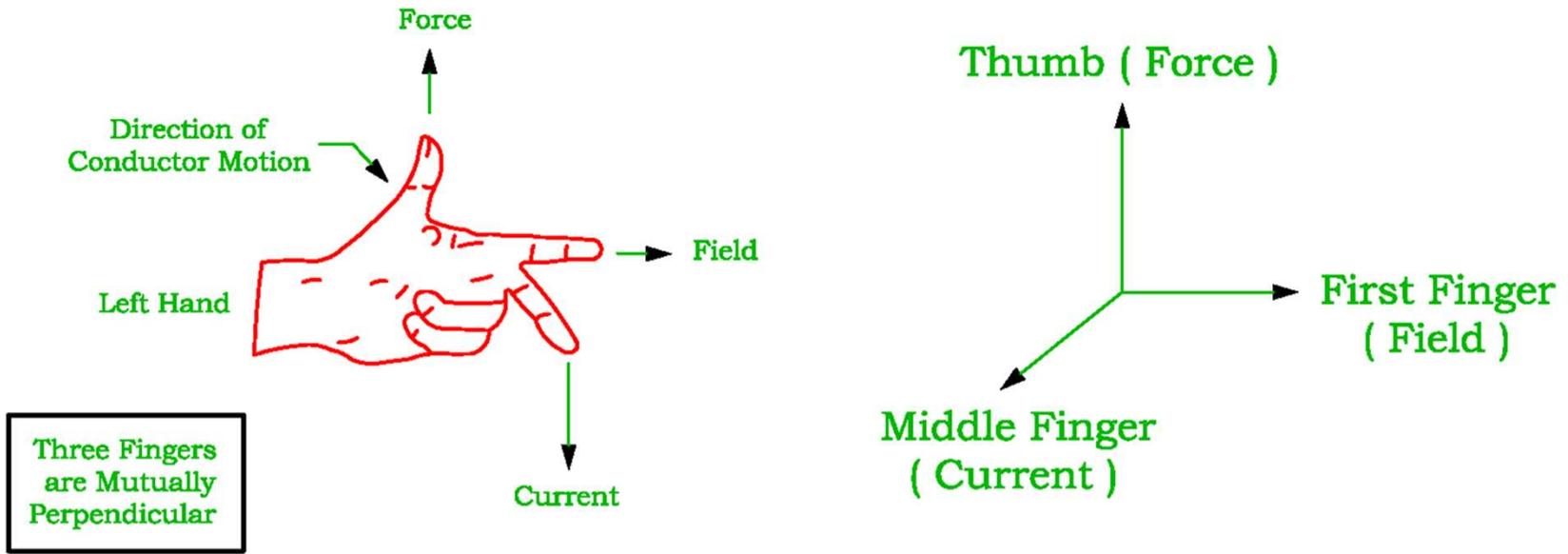


- The brushes of a DC motor are made with **graphite** and **carbon** structure.
- These brushes conduct electric current from the external circuit to the rotating commutator.
- Hence, we come to understand that the commutator and the brush unit are concerned with *transmitting the power* from the static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

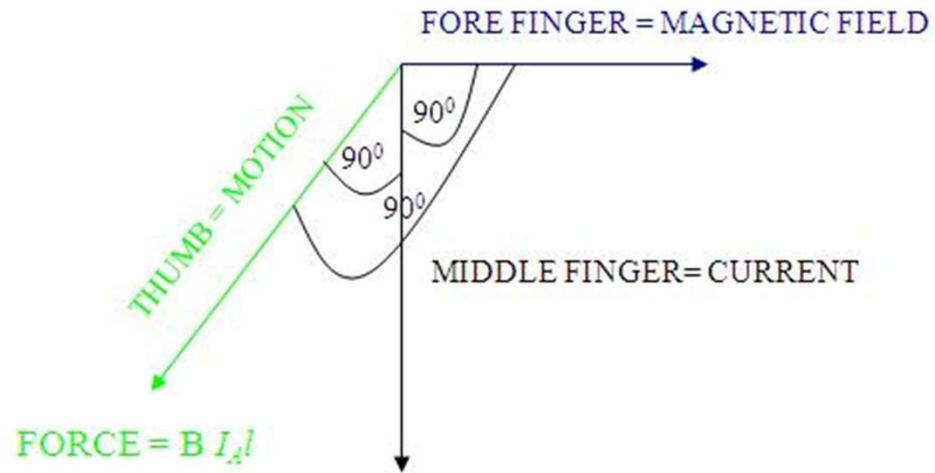
Bearings



- **Smooth movement** between the different components.
- The main function of bearings is to minimize the *friction* between the rotating and stationary parts of the machine
- High carbon steel , hard material that can be constantly greased and protected from the dust intrusion.



Fleming's left hand rule



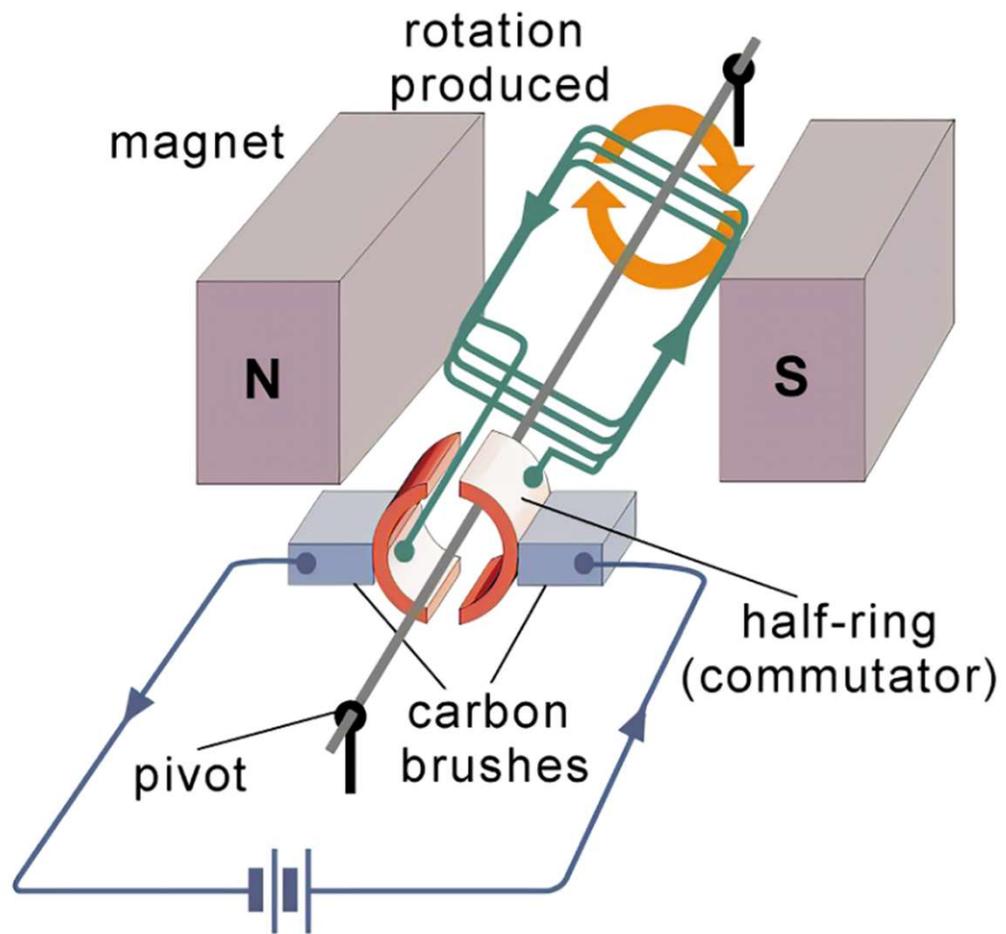
$$F = BIl$$

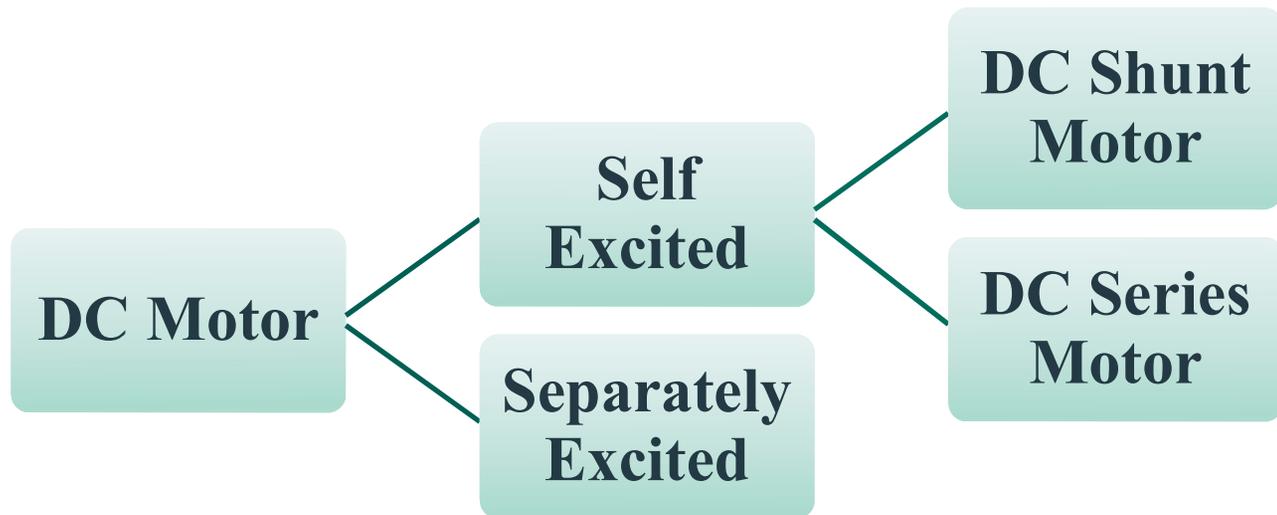
Where:

B = Flux Density

I = Current

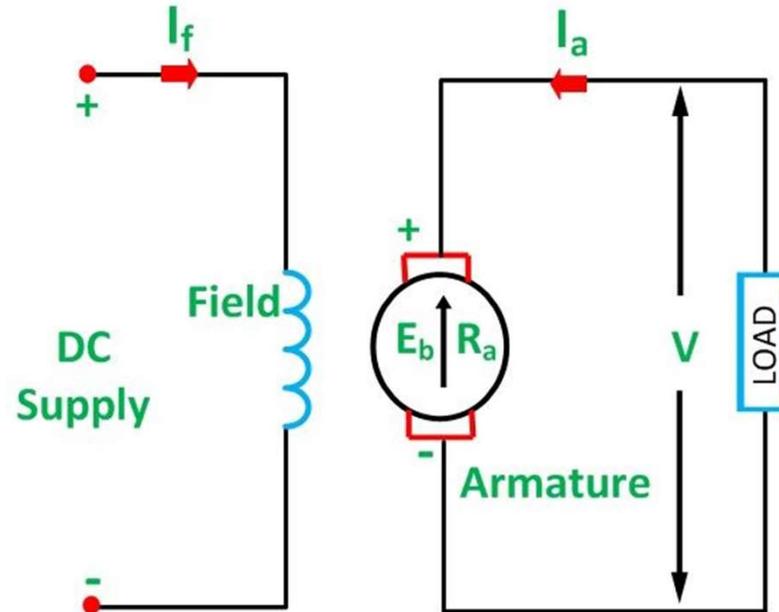
l = Length





Separately Excited DC Motor

- As the name signifies, the field coils or field windings are energised by a separate DC source .

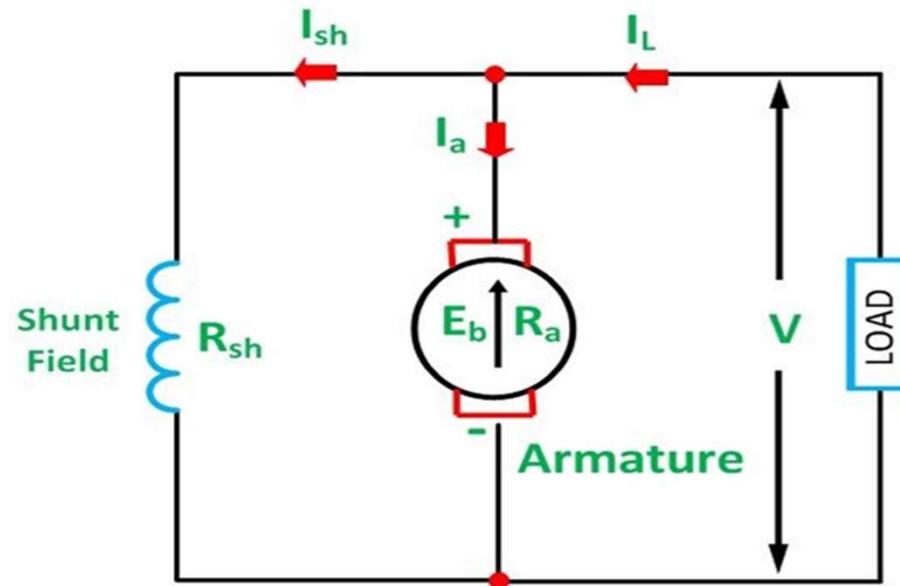


Self Excited DC Motor

- As the name implies self-excited, hence, in this type of motor, the current in the windings is supplied by the machine or motor itself.
- Self-excited DC Motor is further divided into shunt wound, and series wound motor.
 1. Shunt Motor
 2. Series Motor

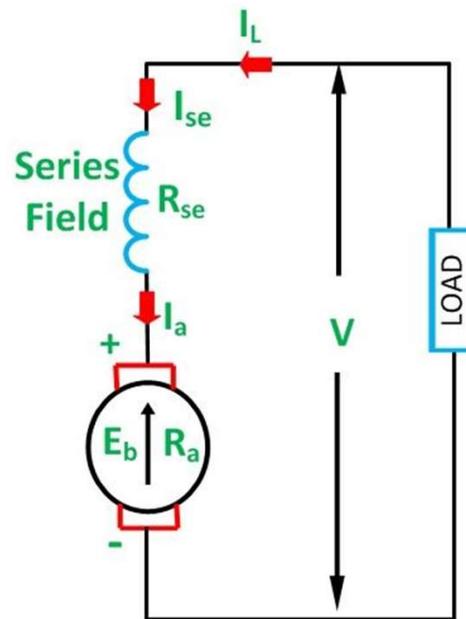
1. Shunt Motor

- This is the most common types of DC Motor.
- Here the field winding is connected in parallel with the armature



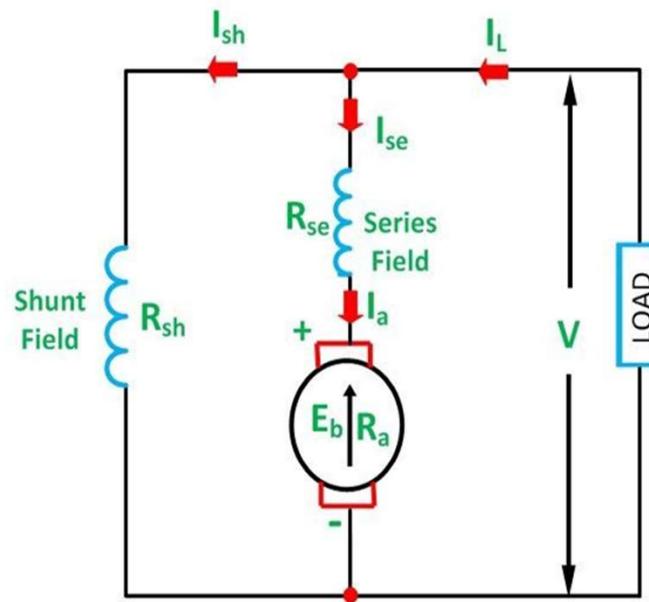
2. Series Motor

In the series motor, the field winding is connected in series with the armature winding. The connection diagram is shown below.



Compound Wound Motor

A DC Motor having **both** shunt and series field windings is called a Compound Motor.

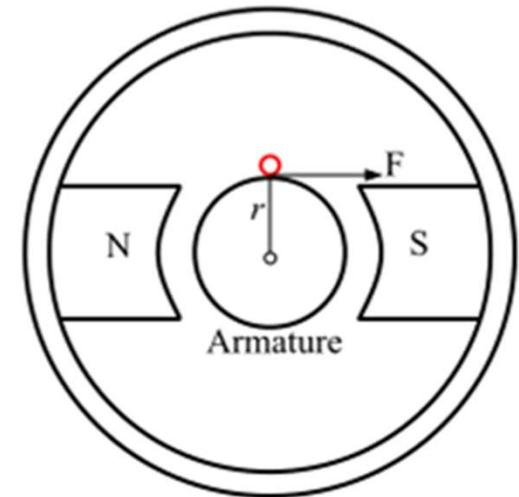


Torque

- ❑ **Torque** is defined as the turning moment of a force about an axis.
- ❑ It is measure by the product of the force (F) and perpendicular distance (r) of the line of action of force from the axis of rotation, i.e.,

$$\text{Torque, } \tau = F \times r$$

- ❑ Measured in *Newton-meters (Nm)*



Advantages Of DC Motor

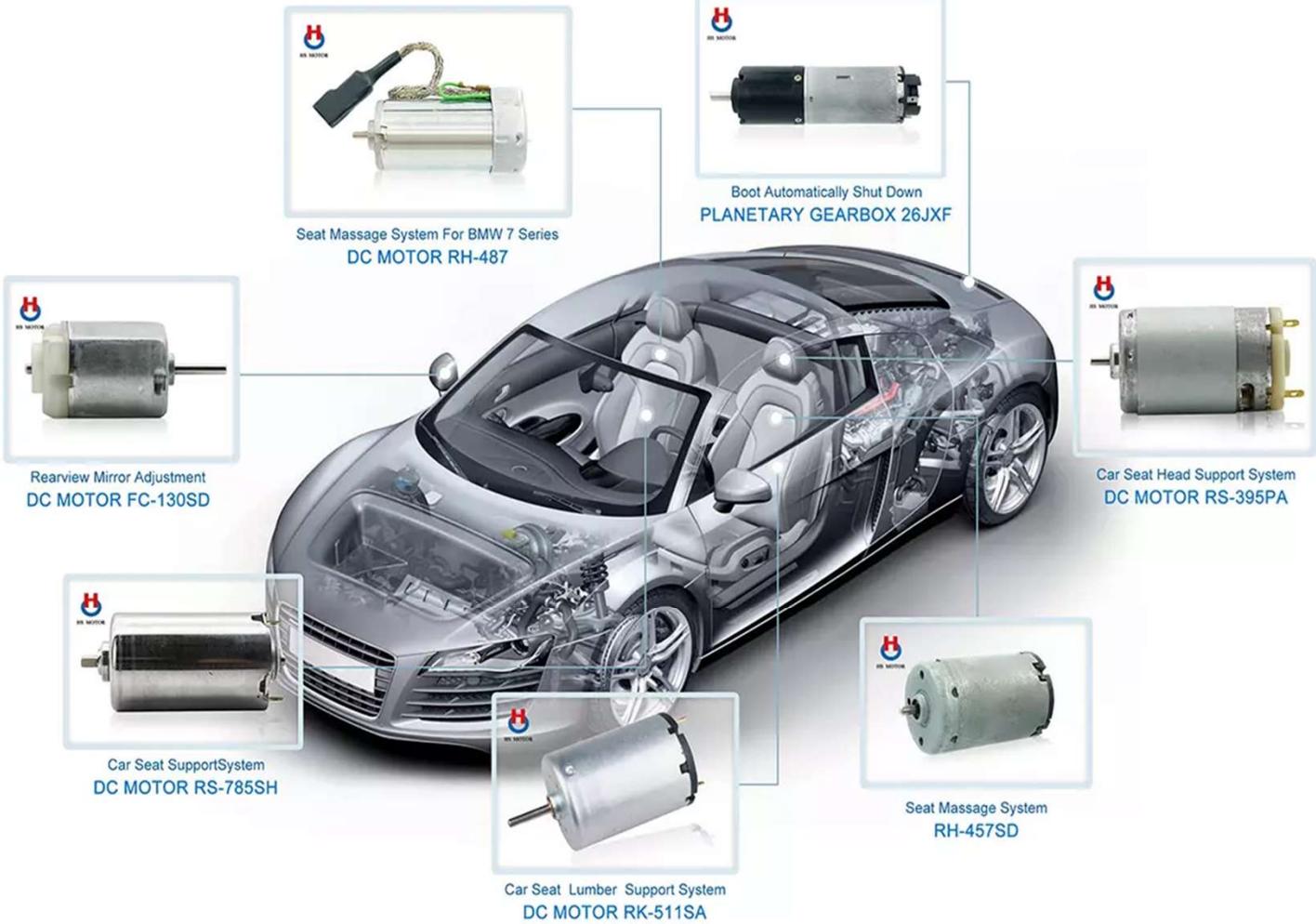
- DC motors are smaller in size.
- These motors operate on DC supply then they can be used in electronics devices.
- DC motors are suitable for traction systems for driving heavy loads.
- DC series motors have will high starting torque.
- **Wide range of speed control.**
- DC Shunt motors are best suited for armature control and field control.
- DC motors have quick starting, stopping, reversing, and fast acceleration.
- DC motors are free from harmonics.

Disadvantages Of DC Motor

- DC motors have a high initial cost.
- Maintenance cost is high and increased operation due to the presence of brushes and commutator.
- Due to sparking at brush DC motors cannot operate in explosive and hazardous conditions.
- As the speed increases, the shaft gets vibrated and the armature gets damaged.
- We need converters to supply power to the motor.

Applications

1. DC series motors are used where **high starting torque** is required and variation of speed is possible. Series motors are used in traction systems, cranes, air compressors, vacuum compressors, sewing machines, etc.
2. Shunt motors are a special type of motor used where **constant speed** is required. These motors are used in blowers, weaving machines, spinning machines, lifts, etc.



Seat Massage System For BMW 7 Series
DC MOTOR RH-487



Boot Automatically Shut Down
PLANETARY GEARBOX 26JXF



Rearview Mirror Adjustment
DC MOTOR FC-130SD



Car Seat Head Support System
DC MOTOR RS-395PA



Car Seat Support System
DC MOTOR RS-785SH



Car Seat Lumber Support System
DC MOTOR RK-511SA



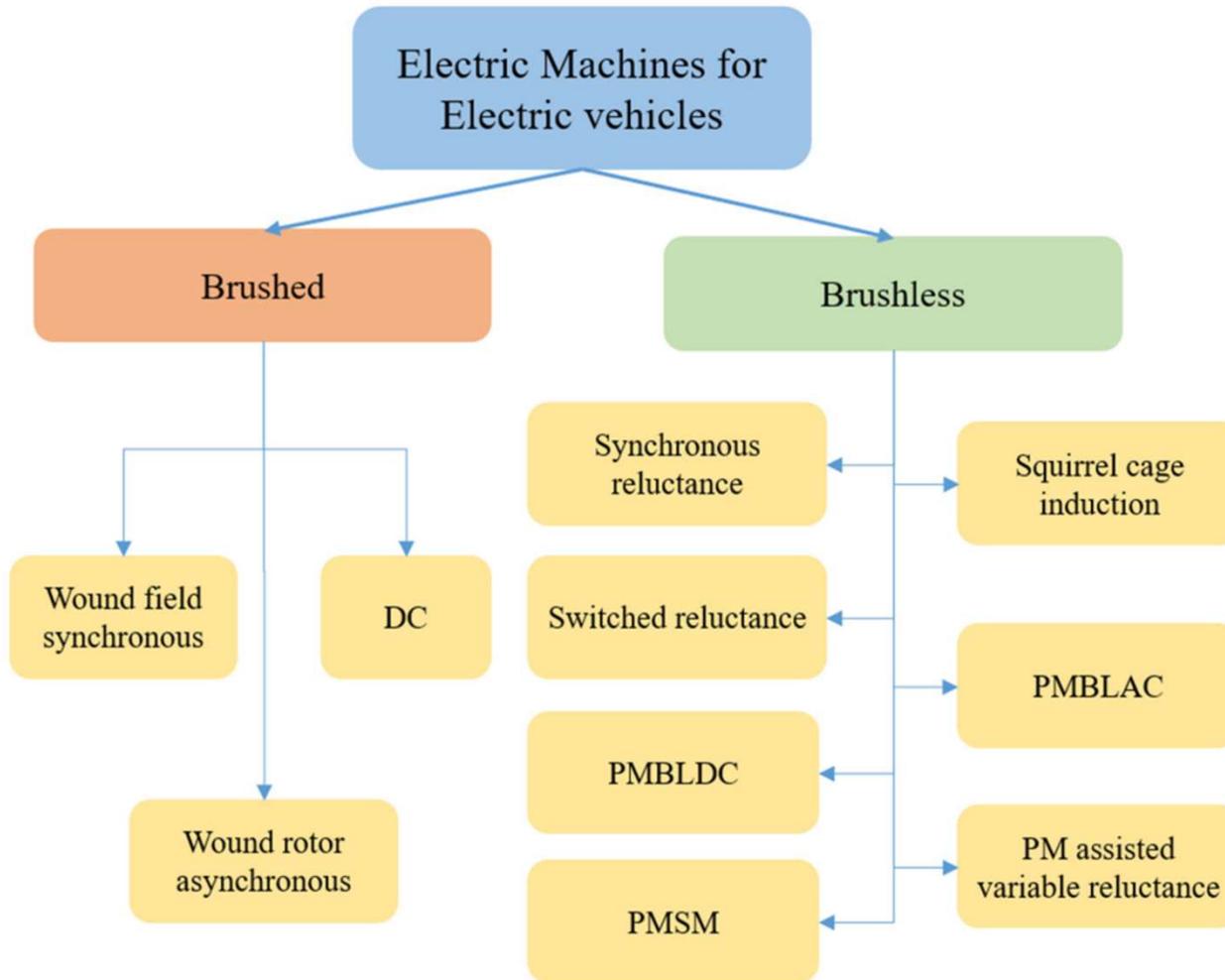
Seat Massage System
RH-457SD



Drives

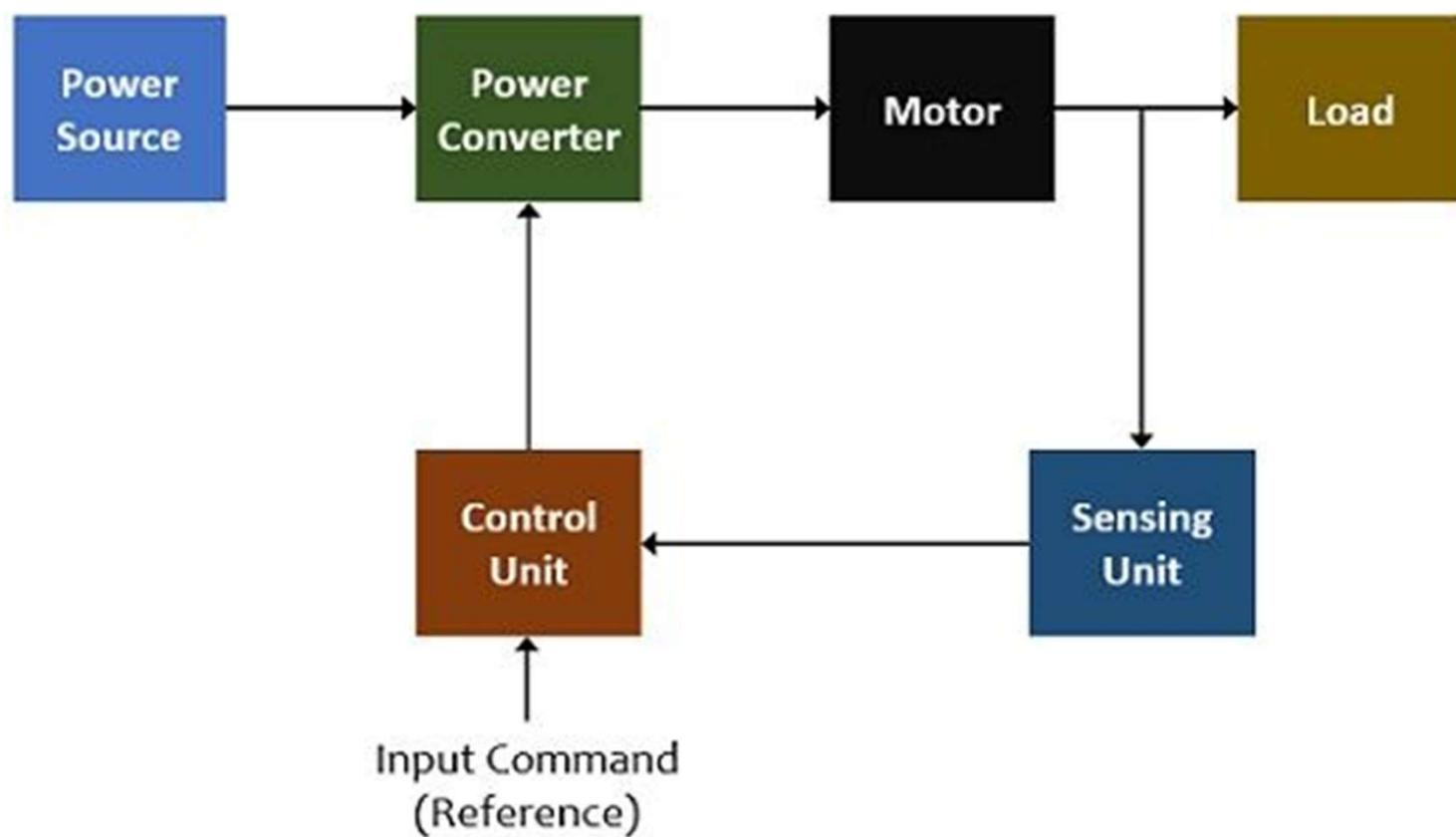
The major requirements of EVs' propulsion drives

1. High instant power and high power density.
2. High torque at low speeds for starting and climbing, and high power at high speed for cruising.
3. Very wide speed range including constant-torque and constant-power regions
4. Fast torque response
5. High efficiency over wide speed and torque ranges
6. Regenerative braking capacity
7. High reliability and robustness for various vehicle operating conditions
8. High fault-tolerance
9. Power converter technology
10. Low total cost



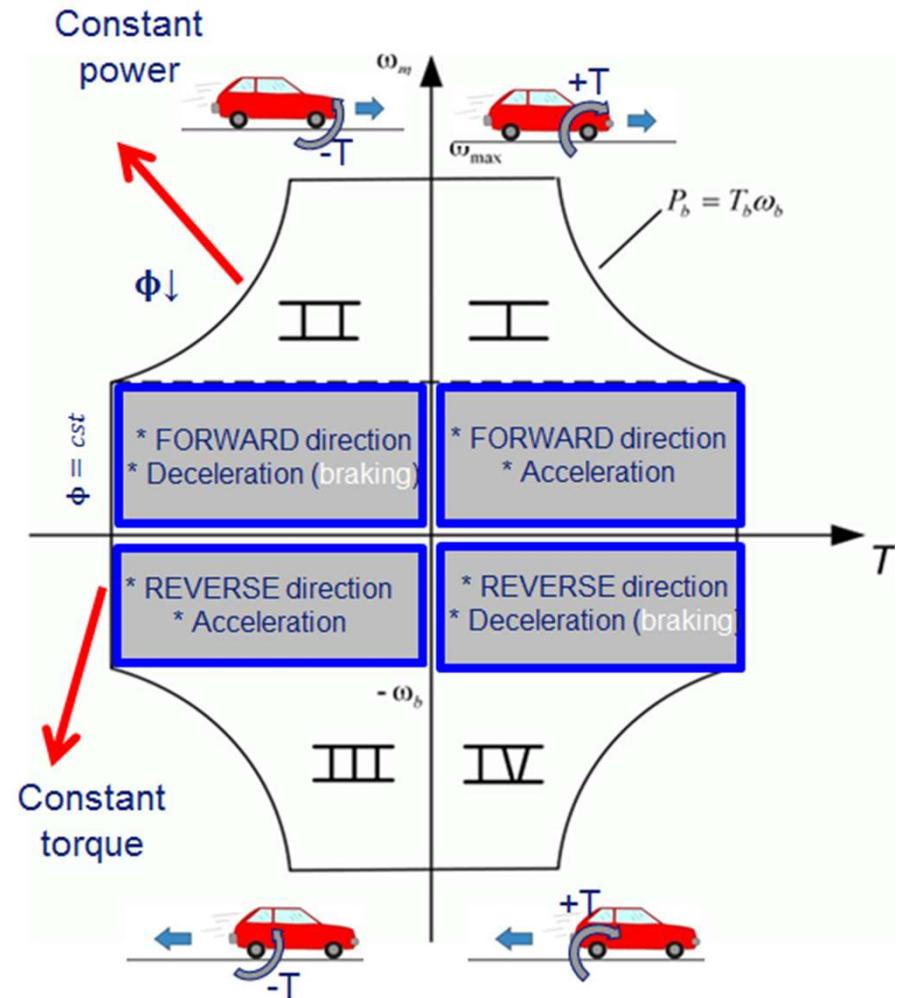
Various types of Electric Motors used in Electric Vehicles

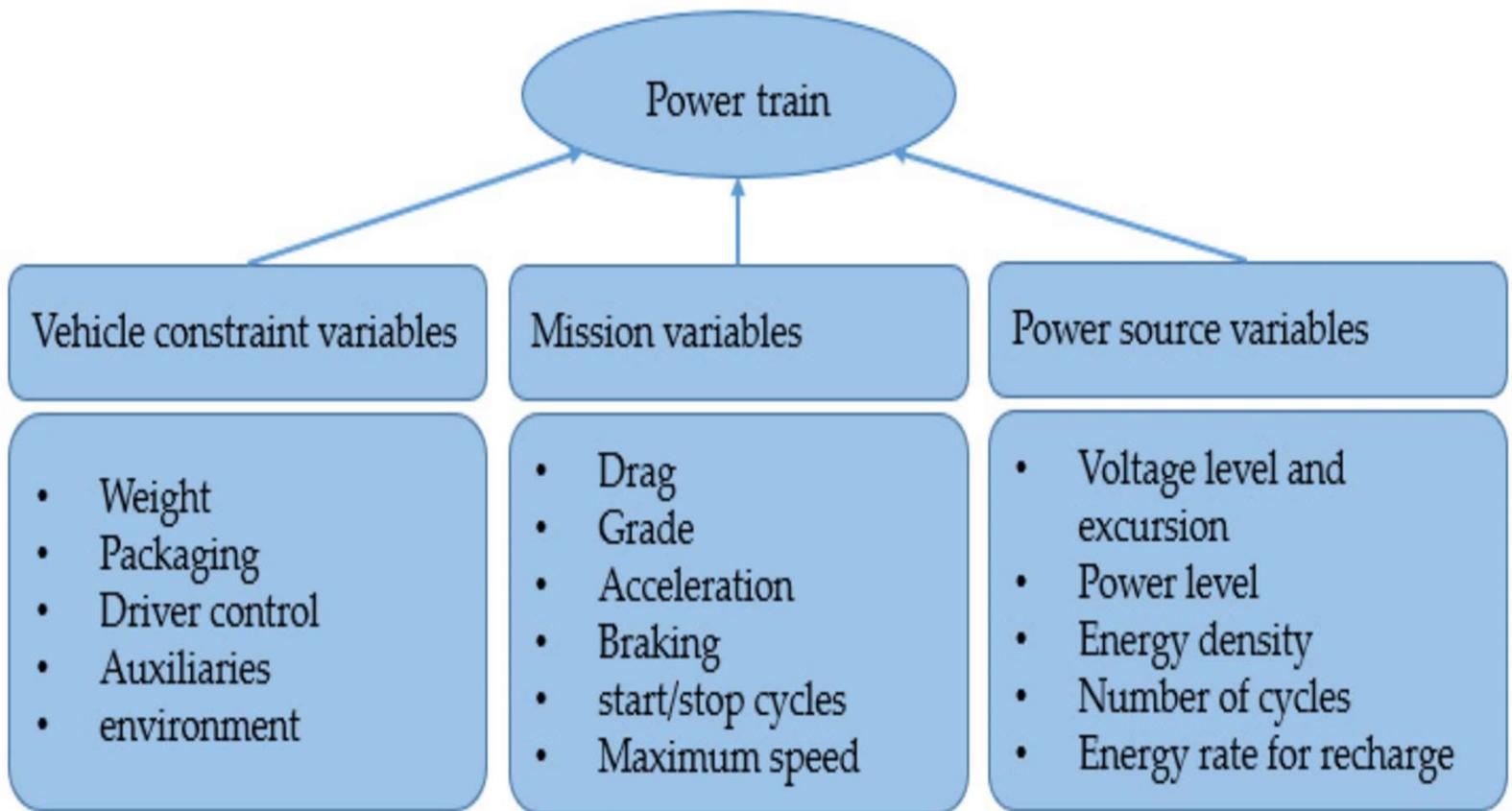
- DC Series Motor
- Brushless DC Motor
- Permanent Magnet Synchronous Motor (PMSM)
- Three Phase AC Induction Motors
- Switched Reluctance Motors (SRM)



Block Diagram of Electric Drive

Torque-Speed characteristics





- There are 3 methods of speed control:
 - Field Control
 - Armature control
 - Supply Voltage Control
- Field control can be done by:-
 - Field Divertor
 - Tapped field Control
 - Parallel field control
- Armature control can be achieved by:-
 - Armature Resistance control
 - Shunted Armature control
 - Armature terminal Voltage control
- Supply voltage can be achieved by:-
 - Ward Leonard Method
 - Power Electronics converter
 - Controlled Rectifier

Power Electronics Converter Based speed control methods of DC Motor

- DC to DC Converter
 - Non isolated
 - Buck, Boost, Buck-boost, Cuk, Sepic, Zeta converter
 - Isolated
 - Flyback, Forward, Push-pull, Half-bridge, Full-bridge converter
- AC to DC Converter
 - Half wave Rectifier
 - Full wave Rectifier
 - Three phase Rectifier

SPEED CONTROL OF D.C MOTORS

$$N = \frac{V - I_a R_a}{k\phi}$$

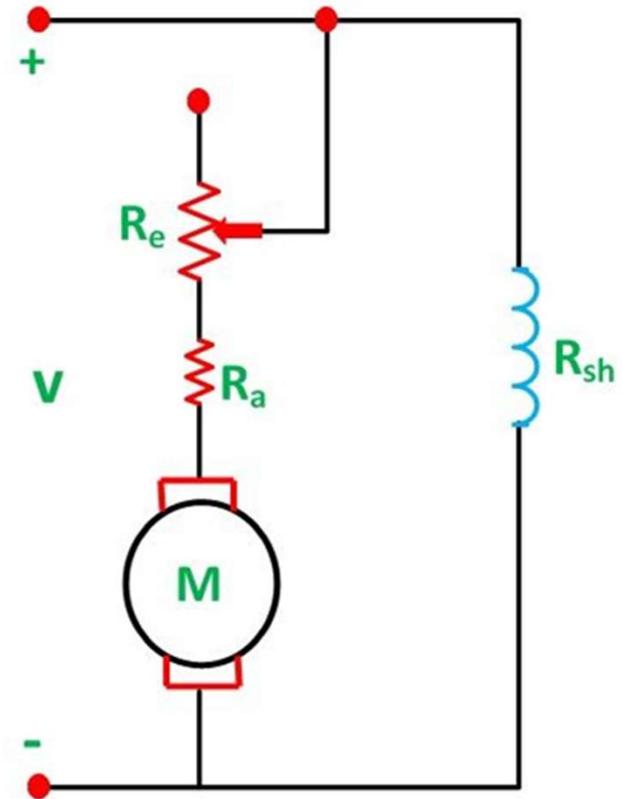
Methods of speed control of d.c. motors

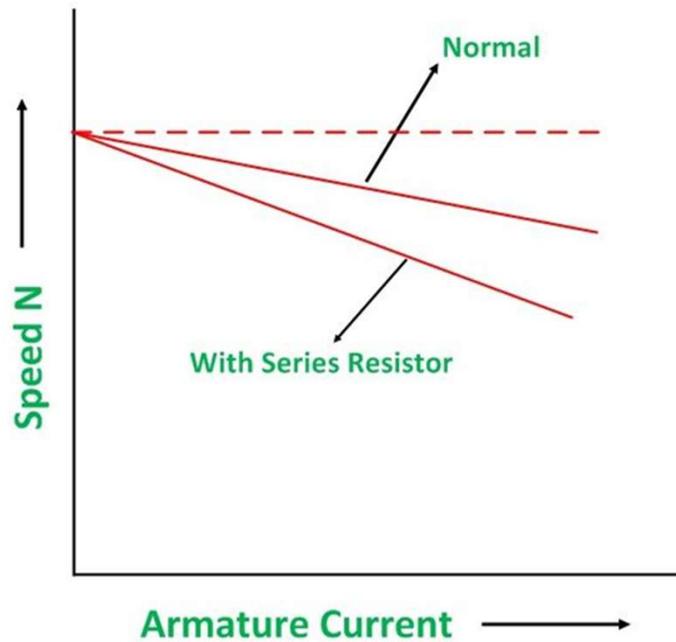
- 1} Variation of resistance in the armature circuit, This method is called **armature resistance control (RHEOSTATIC CONTROL)**

- 2} Variation of field flux ϕ
This method is called **field flux control.**

Armature Resistance Control [Rheostatic Control]

- Variable Series resistor R_e is put in armature circuit.
- In this field is directly connected to across the supply and therefore flux ϕ is not affected by variation of R_e .





- When the controller resistance is increased, the voltage drop takes place in it and the armature does not receive full supply voltage.
- Consequently, the back e.m.f. is less than when the armature is subjected to full voltage. Therefore armature speed reduces since $N \propto E_b$.

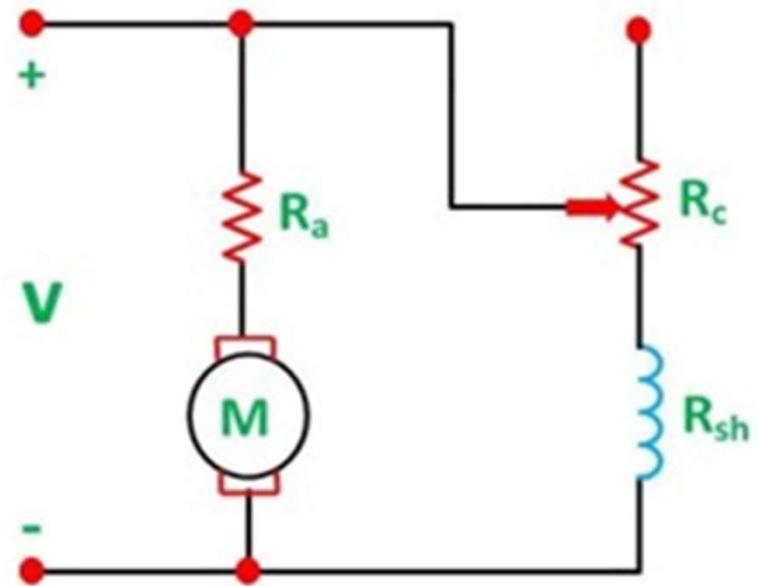
Disadvantages

1. A large amount of power is **wasted** in the external resistance R_e .
2. Armature resistance control is **restricted** to keep the speed below the normal speed of the motor and increase in the speed above normal level is not possible by this method.
3. For a given value of variable resistance, the speed reduction is **not constant** but varies with the motor load.
4. This speed control method is used only for **small motors**.

- i. We can control the speed by controlling the armature resistance by controlling the voltage drop across the **armature**, and we also use a variable resistor in series with the armature.
- ii. When we keep the resistance to its minimum value we have a normal **armature voltage drop**.
- iii. And when we gradually increase the resistance the voltage across the armature decreases.
- iv. And in turn the speed of the motor decreases and here we can reach a speed below the normal range.
- v. We usually use this method in the printing press, cranes, hoists and so on where we use a speed lower than the normal.

Variation of Field Flux [Field flux Control]

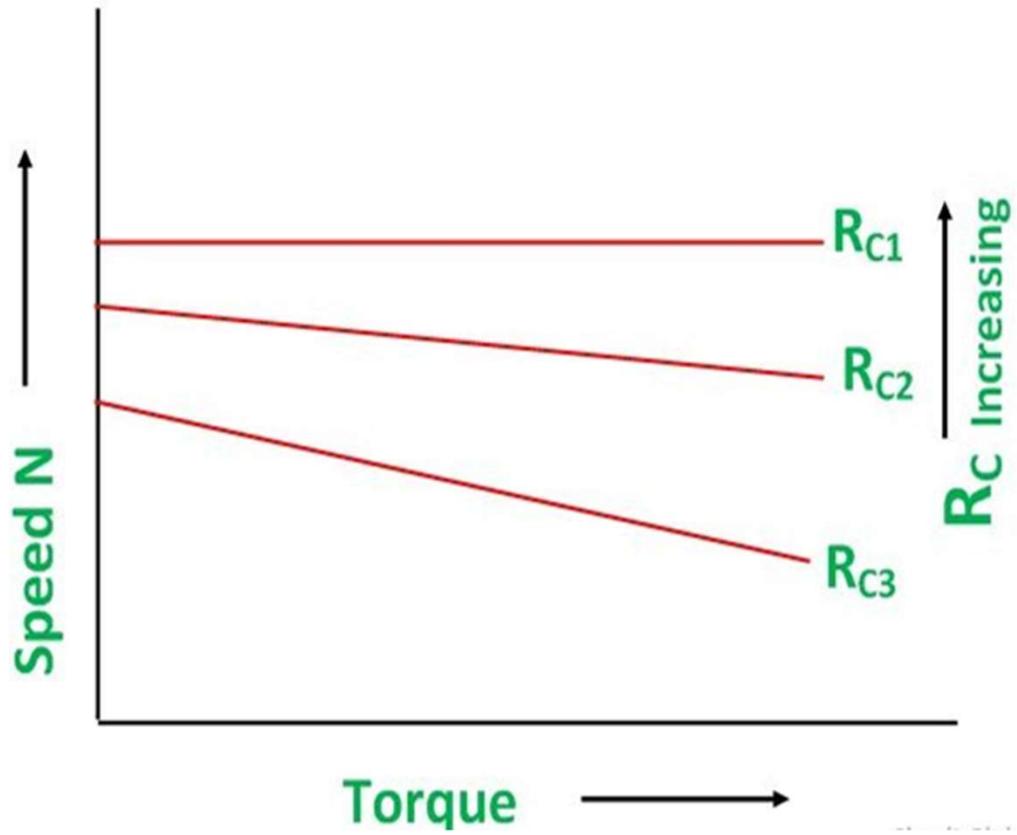
1. In a Shunt Motor, the variable resistor R_C is connected in series with the shunt field windings.
2. This resistor R_C is known as a Shunt Field Regulator.



3. The shunt field current is given by the equation shown below.

$$I_{sh} = \frac{V}{R_{sh} + R_C}$$

4. The connection of RC in the field reduces the field current, and hence the flux is also reduced.
4. This reduction in flux increases the speed, and thus, the motor runs at speed higher than the normal speed.
4. Therefore, this method is used to give motor speed above normal or to correct the fall of speed because of the load.



Advantages of Field Flux Control

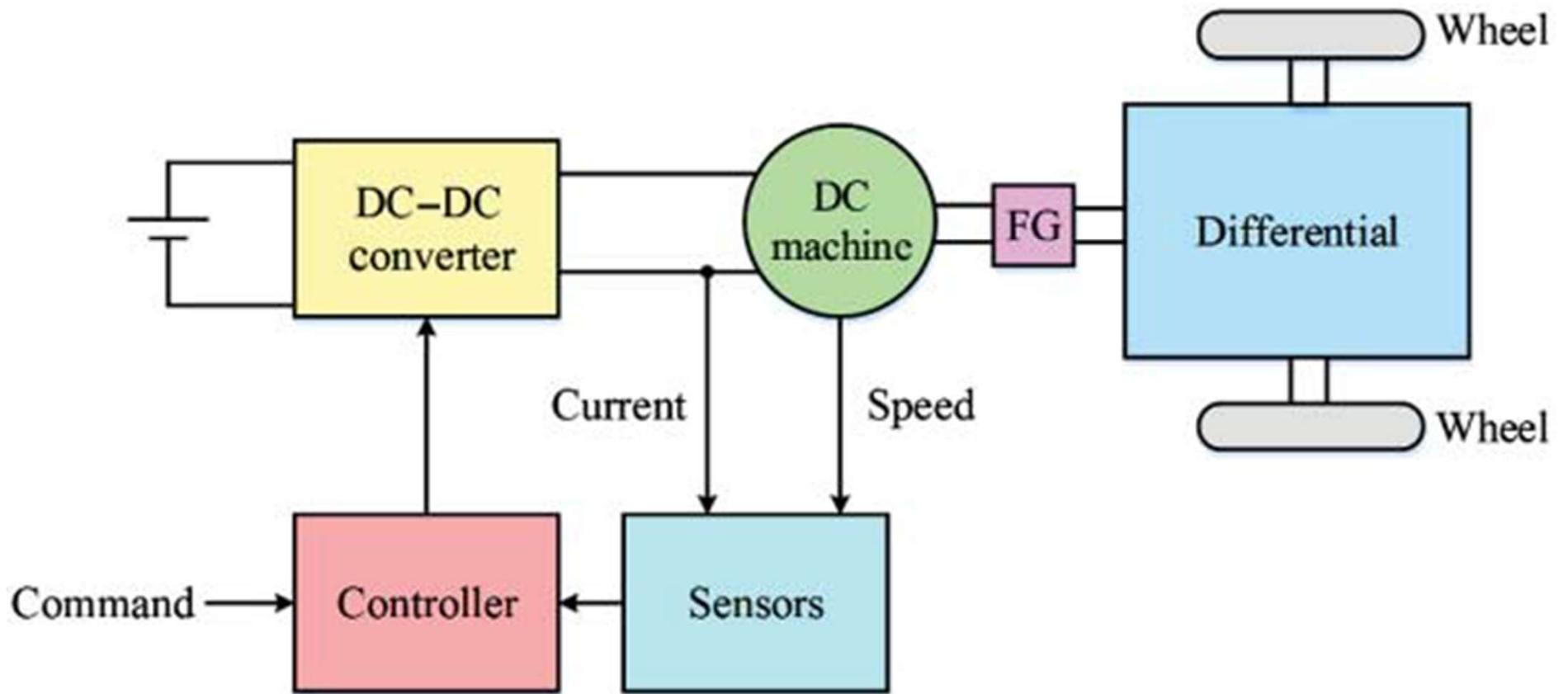
1. The following are the advantages of the field flux control method.
 1. This method is easy and convenient.
 2. As the shunt field is very small, the power loss in the shunt field is also small.
2. The flux cannot usually be increased beyond its normal values because of the saturation of the iron.
3. Therefore, speed control by flux is limited to the weakening of the field, which gives an increase in speed.
4. This method is applicable over only to a limited range because if the field is weakened too much, there is a loss of stability.

Advantages :

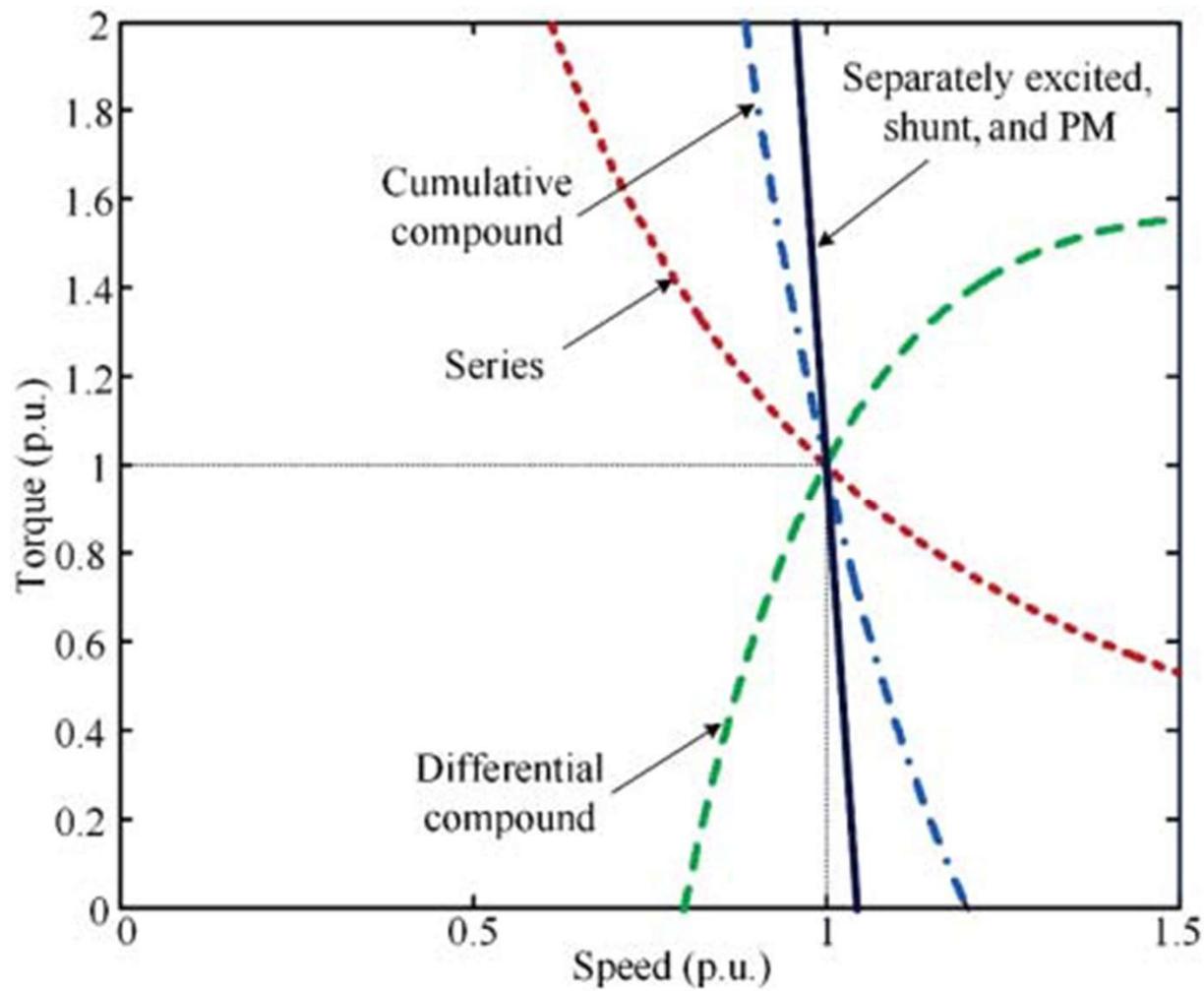
1. It is economical since very little power is wasted due to relatively small I_{sh}
2. The speed control is independent of load on the machine.

Dis-advantages :

1. Above the rated speed only can be obtained since R_{sh} cannot be reduced.
2. If flux is reduced too much commutation becomes poorer.

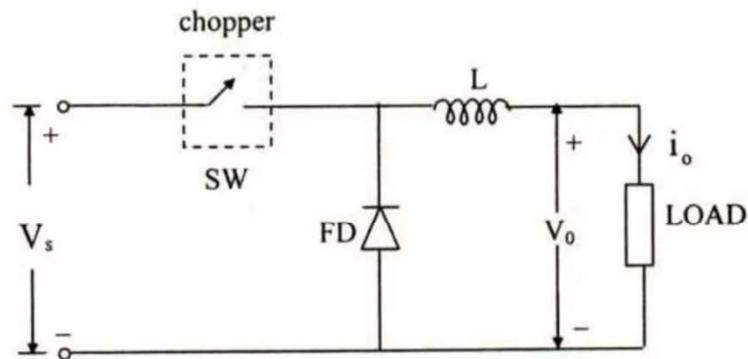


Basic configuration of DC motor drives

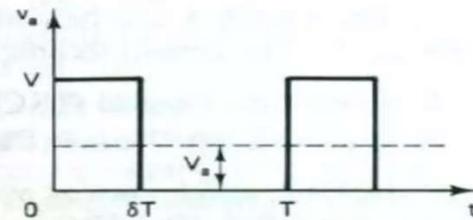


Torque-speed characteristics of DC machines

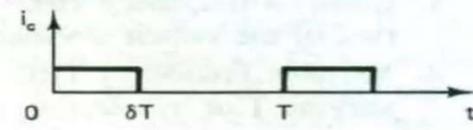
Basic Step-down chopper



$$V_o = \frac{1}{T} \int_0^T V_s dt = \frac{1}{T} \int_0^{\delta T} V_s dt = \delta V$$



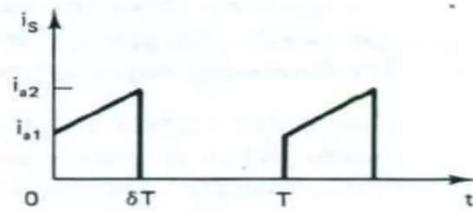
(b)



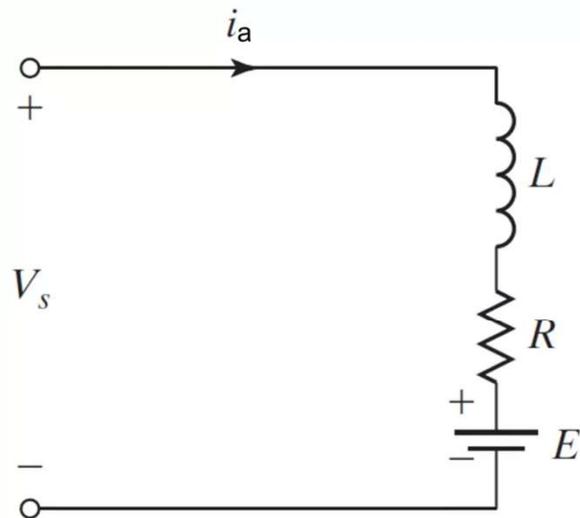
(c)



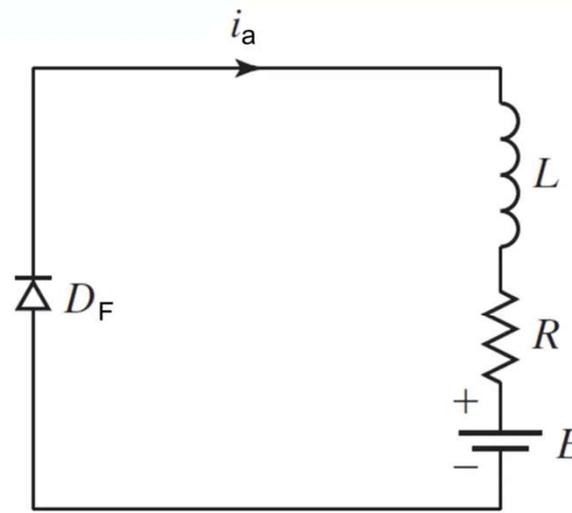
(d)



Modes of Operation



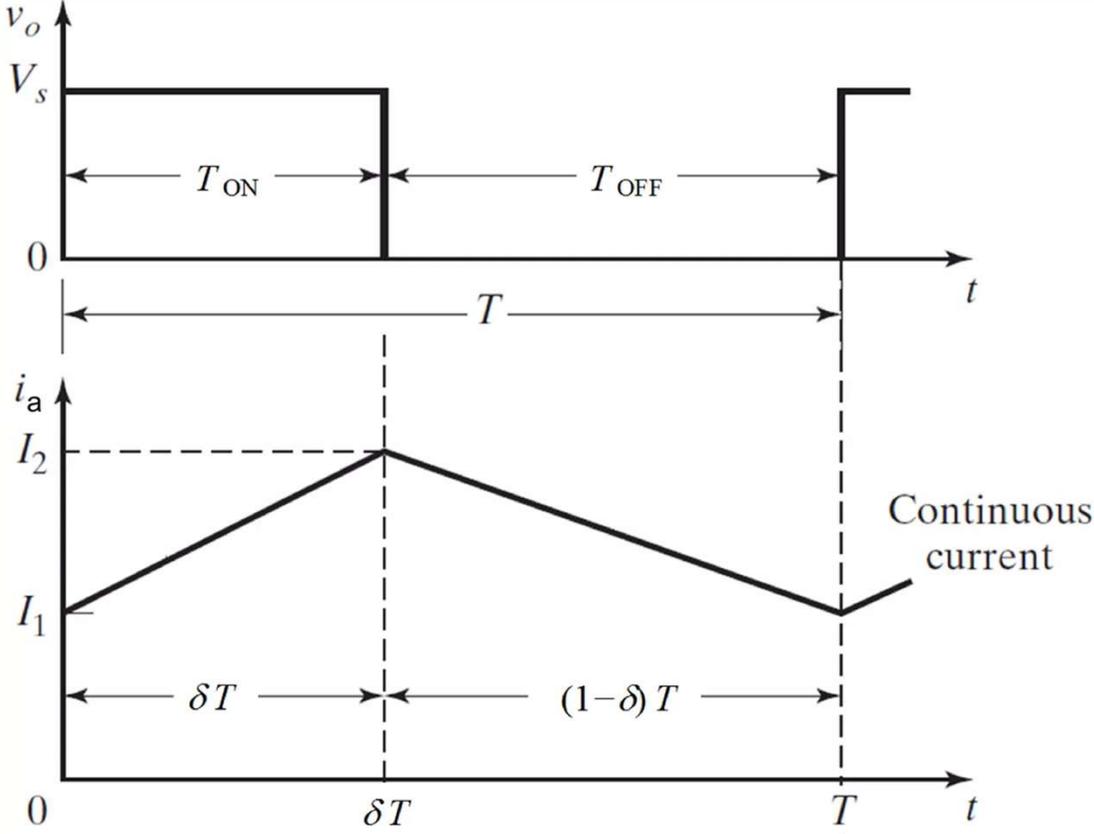
Mode 1



Mode 2

Mode 1: S is ON, Mode 2: S is OFF

Waveform



Motoring Control

- Motoring Control is achieved using a step-down chopper as shown in the above fig.
- The fully controlled switch S (MOSFET/BJT/IGBT) is operated at high frequencies (~kHz)
- If T is the time period of the chopper & T_{ON} is the ON period of the switch, then duty ratio is defined as: $\delta = T_{ON}/T$
- When S is closed, armature current i_a increases and when S is open, i_a decreases. In steady state, i_a fluctuates between two extremes I_1 & I_2
- Average output voltage is given by: $V_0 = \delta V_s$
- Motor attains a constant speed ω_m with back EMF $E = K \omega_m$
- Speed-torque equation:

$$\omega_m = \frac{\delta V}{K} - \frac{R}{K^2} T$$

Regenerative Braking with chopper

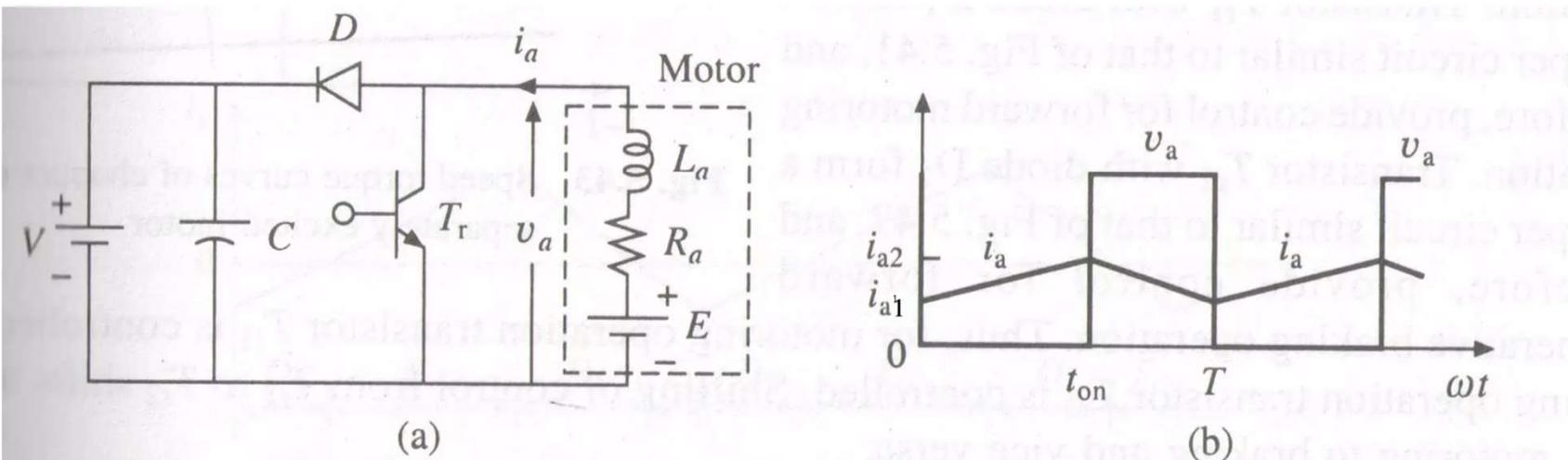


Fig.

Regenerative braking of separately excited motor by chopper control

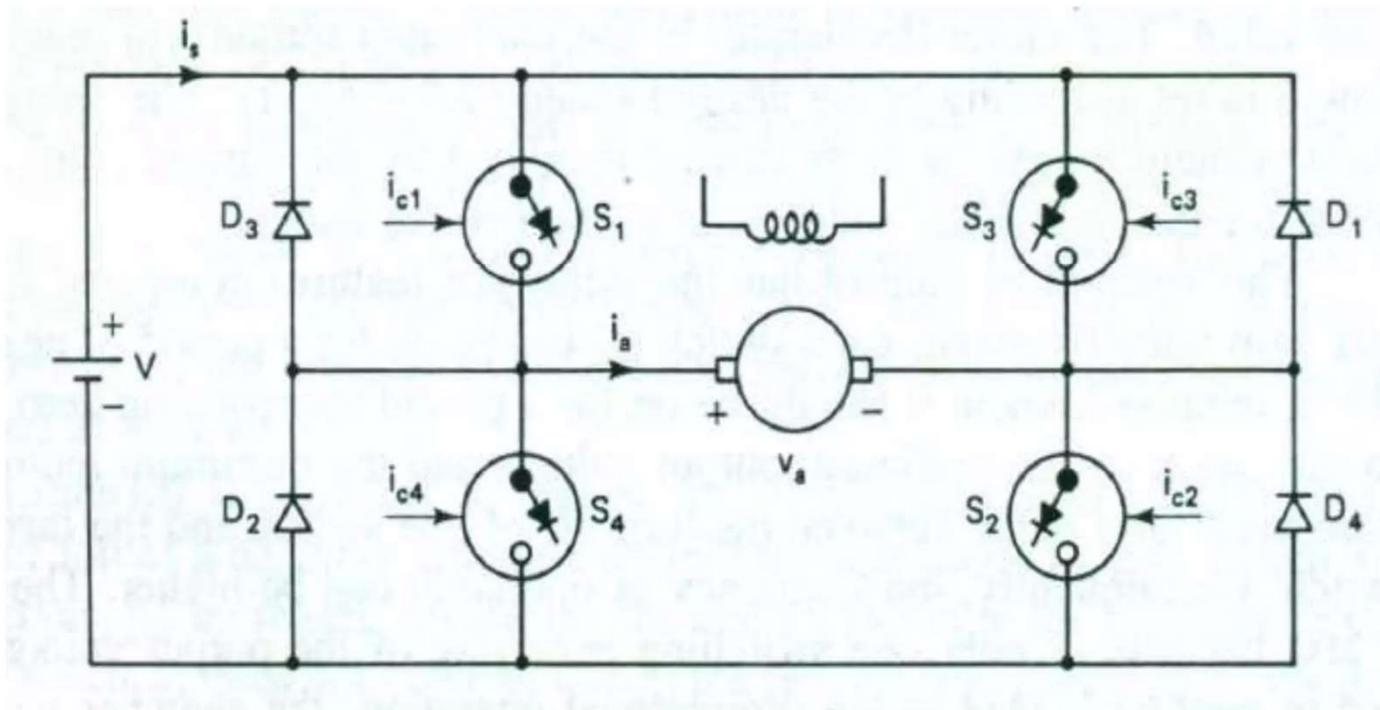
1. Energy Storage Interval ($0 < t < T_{\text{ON}}$)

- Transistor switch is ON during the interval.
- Diode D is reverse biased.
- The energy released by the motor is partly absorbed by the inductor, partly dissipated as heat in the resistor and switch.
- The current increases from i_{a1} to i_{a2} , and $v_a = 0$

2. Energy Transfer Interval ($T_{ON} < t < T$)

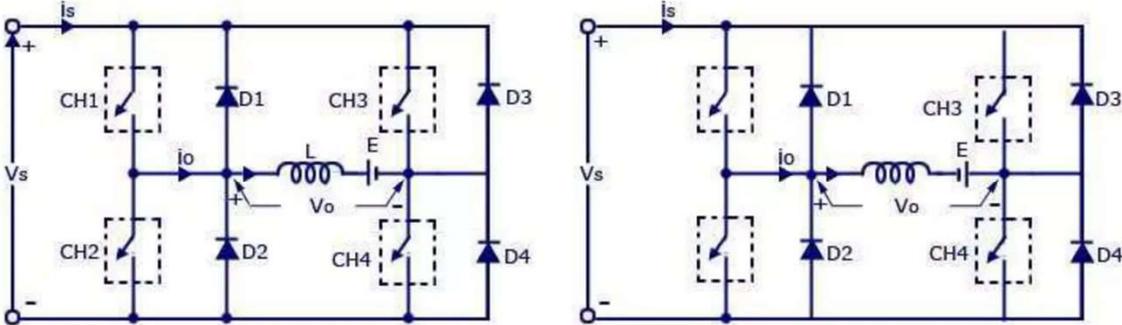
- Transistor switch is opened at $t = T_{ON}$
- Armature current starts decreasing and flows through diode D and source V, and reduces from i_{a2} to i_{a1} . Armature voltage $v_a = V$
- The polarity of the inductor is reversed, and D becomes forward biased.

4 Quadrant control of Chopper fed DCM



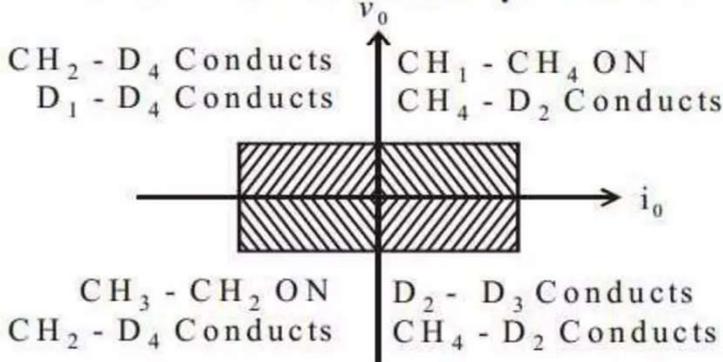
Type-E chopper or the Fourth-Quadrant Chopper

E-type Chopper Circuit Diagram With Load emf E and E Reversed



www.CircuitsToday.com

Four Quadrant Operation



Induction Motor

4. ACI Motors (ACIM)

Types of Motors used in EVs – AC Induction Motor
AC Induction Motor (ACIM) is also being used by some EV Manufacturers in 2 Wheeler and 4 Wheeler.

For example in 2 Wheeler:

- Emflux Motors-Emflux One

For example in 4 Wheeler:

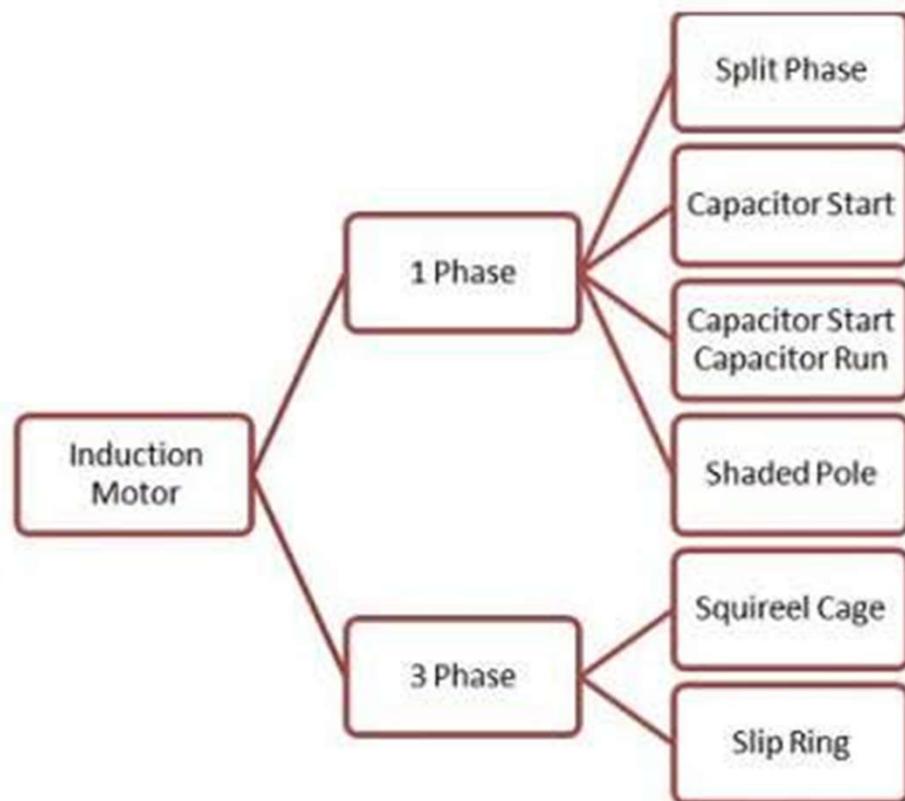
- Tesla Roadster 2008,
- Tesla Model S,
- Tesla Model X,
- Mahindra e-Verito,
- Mahindra e2o,
- Mahindra e-Supro,
- TATA Tigor,
- TATA Tiago.



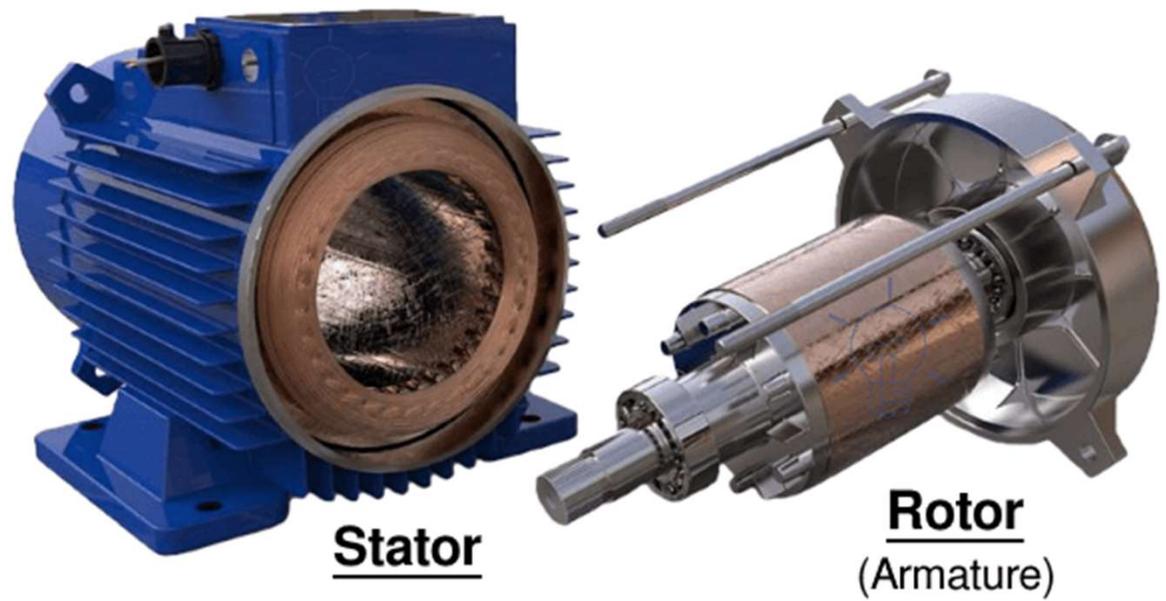
WHAT IS AN INDUCTION MOTOR?

- An induction motor (also known as an asynchronous motor) is a commonly used **AC electric motor**.
- In an induction motor, the electric current in the rotor needed to produce torque is obtained via electromagnetic induction from the rotating magnetic field of the stator winding.
- The rotor of an induction motor can be a squirrel cage rotor or wound type rotor.
- Induction motors are referred to as '**asynchronous motors**' because they operate at a speed less than their synchronous speed.





- Stator
- Rotor
- Other parts



Stator :- It is the stationary part of the motor, A stator winding is placed in the stator of induction motor and the three phase supply is given to it.

Rotor :- It is a rotating part of the motor. It is mounted on the shaft. It consists of hollow laminated core having slots on its outer periphery. The windings placed in these slots (rotor winding).The rotor is connected to the mechanical load through the shaft.

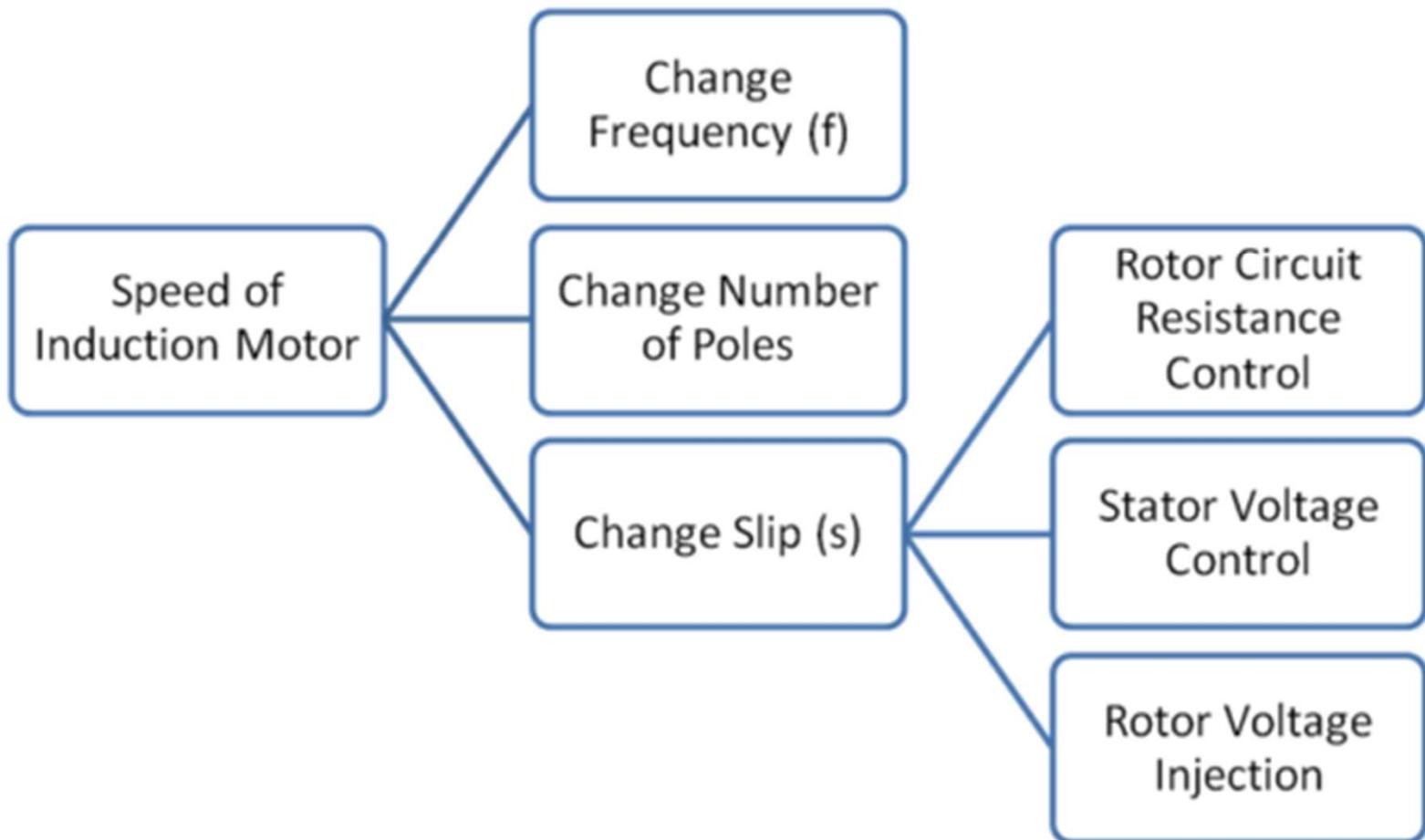
STATOR

- Stator Frame
- Stator Core
- Stator Winding



Types of AC Motor Drives

- Vector Control
 - Direct Torque Control
 - Field Oriented Control
 - Airgap flux oriented control
 - Direct
 - Indirect
 - Stator flux oriented control
 - Rotor flux oriented control
 - Predictive Control
 - Nonlinear Control
- Scalar Control
 - V/f Control
 - Frequency control
 - Pole changing method



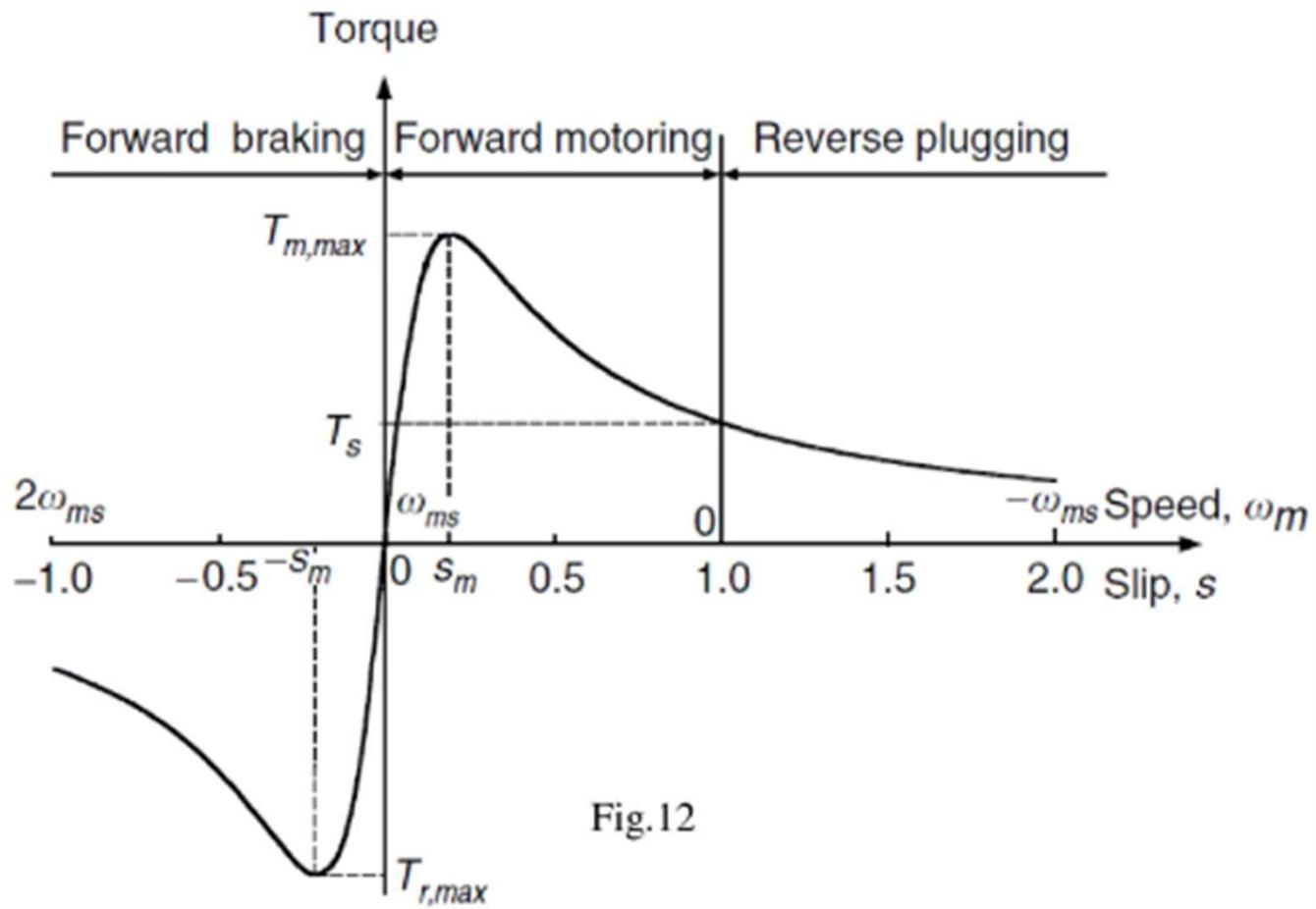
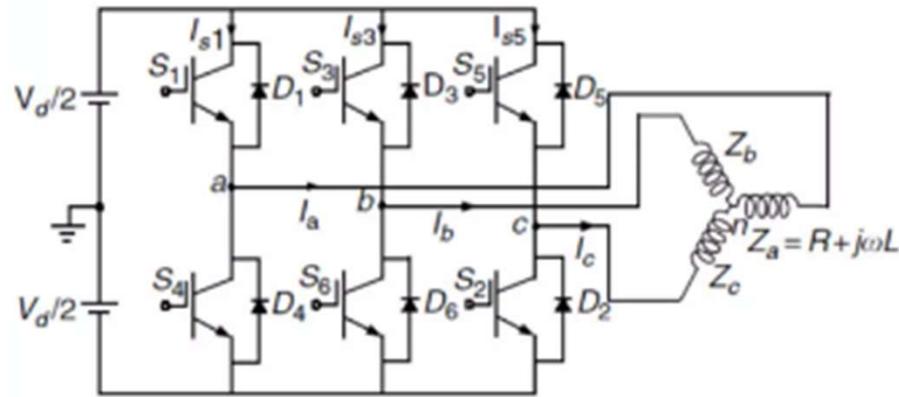
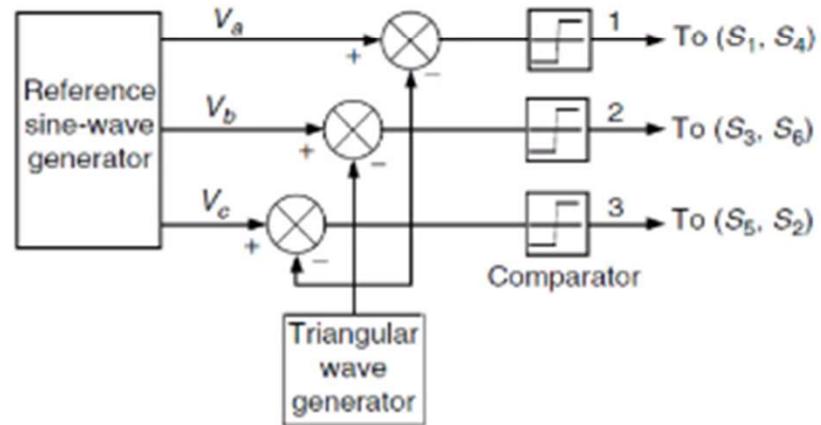


Fig.12

PWM Control of 3 phase inverter in Induction Motor Drive



(a) inverter topology



(b) control signals

Power Electronic Control

- A variable frequency and variable voltage DC/AC inverter is needed to feed the induction motor.
- The general DC/AC inverter is constituted by power electronic switches and power diodes.
- The commonly used topology of a DC/AC inverter is shown in Fig.13 which has three legs and six switches (S1 and S4, S3 and S6, and S5 and S2), feeding phases a, b, and c of Induction motor.
- The inverter can be broadly classified as a voltage source inverter or a current source inverter.

Field Oriented Control of Induction Motor Drive

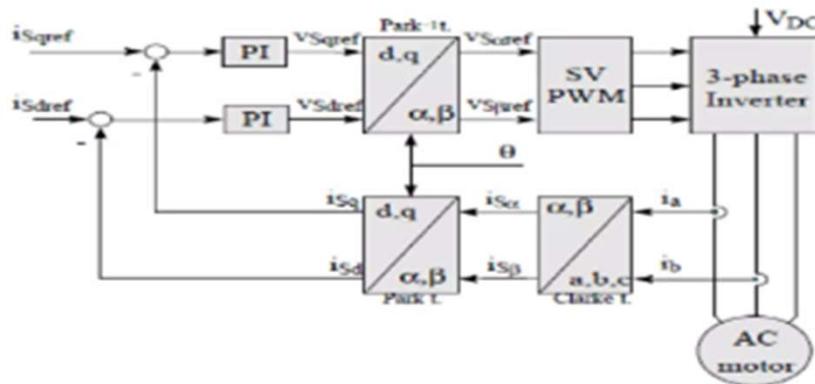
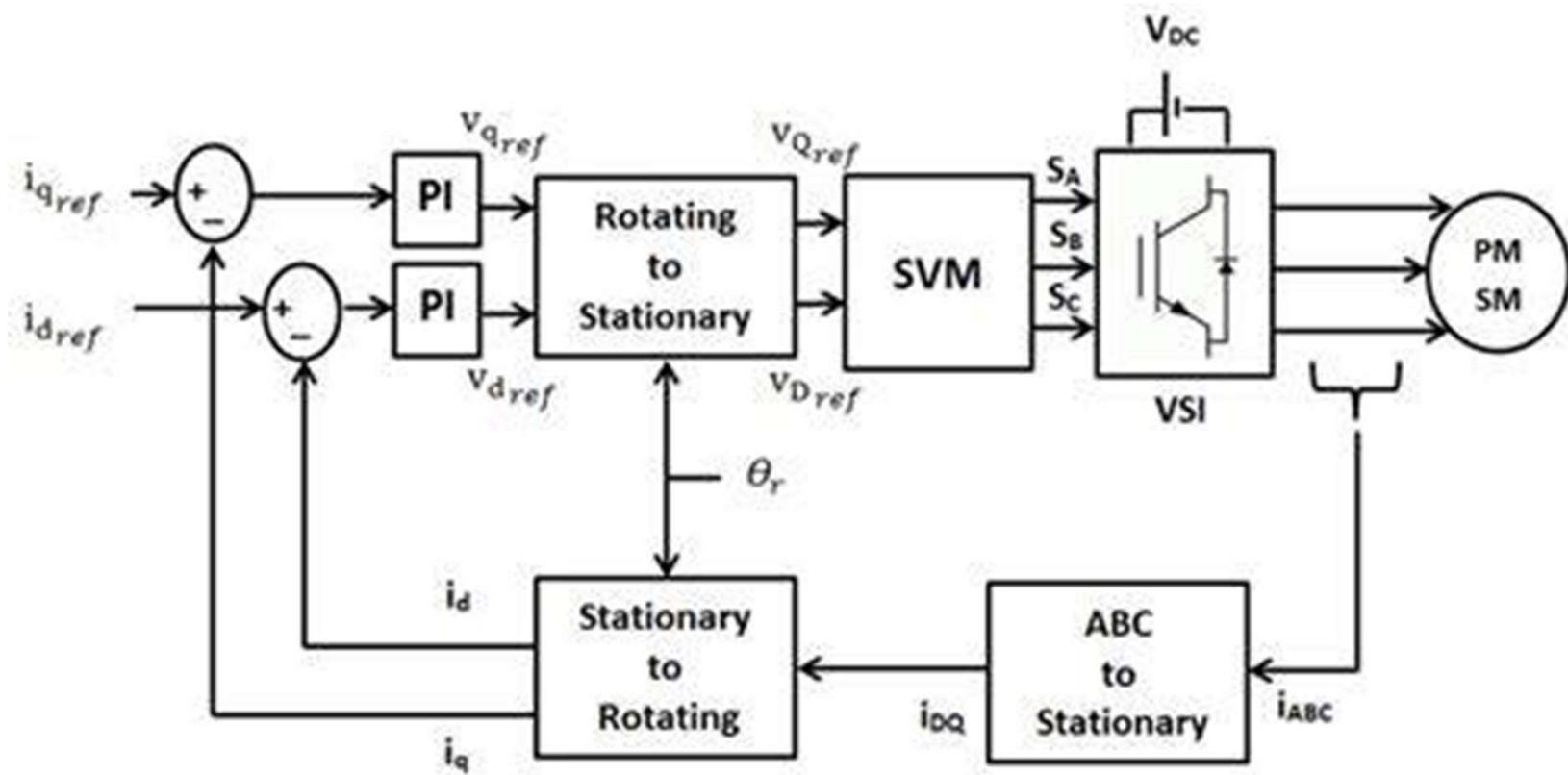
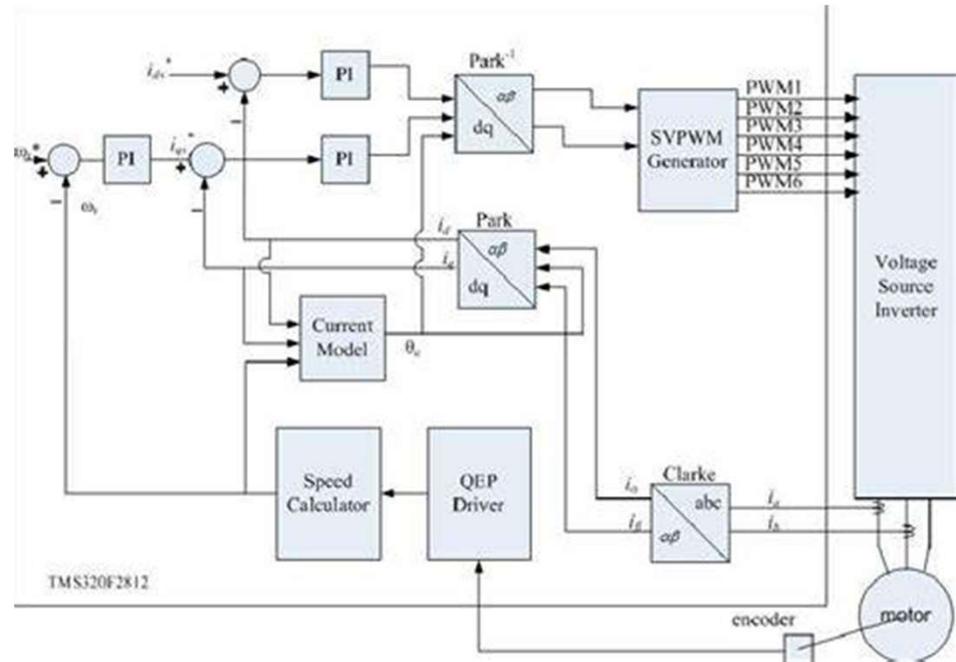


Fig.14 : Basic scheme of FOC for AC-motor

- Two motor phase currents are measured. These measurements feed the Clarke transformation module. The outputs of this projection are designated $i_{S\alpha}$ and $i_{S\beta}$.
- These two components of the current are the inputs of the Park transformation that gives the current in the d,q rotating reference frame.
- The i_{Sd} and i_{Sq} components are compared to the references i_{Sdref} (the flux reference) and i_{Sqref} (the torque reference).





- The magnetic field is controlled indirectly by regulating the stator current in the d-axis, while the torque is controlled by regulating the stator current in the q-axis . Indirect FOC is simpler to implement than direct FOC and is commonly used in low-to-medium performance applications. Direct FOC provides faster and more accurate torque control, but requires more complex algorithms and hardware, while indirect FOC is simpler to implement but may not be as precise in some high-performance applications.
- FOC is renowned for its excellent transient response.
- **Figure** shows the operating principle of FOC for speed control in PMSM. The principles for FOC are the same whether the PMSM has an inner rotor or outer rotor. FOC for AFPM is implemented using space vector modulation (SVM) technique in for both no-load and with load torque conditions.

Permanent Magnet Synchronous Motor(PMSM)

Types of Motors used in EVs – PMSMs Motor

Permanent Magnet Synchronous Motor (PMSM) is also being used by many EV Manufacturers for their High-Performance Electric Motorcycle, Electric Cars and Electric Buses.

For example in Electric Motorcycle:

- Energica Motors,
- Brammo Empulse R

For example in Electric Cars:

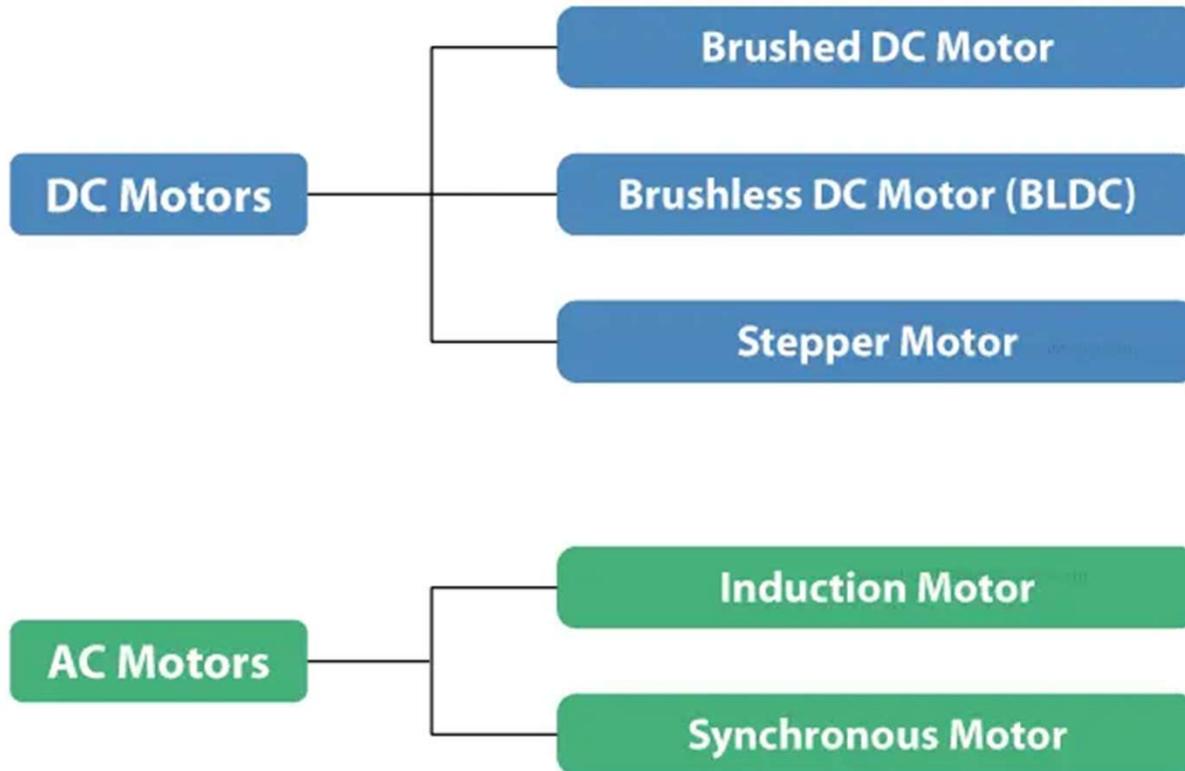
- Chevy Bolt EV,
- Nissan Leaf EV,
- Upcoming Hypercar Pininfarina Battista 0-100kmph in <2Sec

For example in Electric Buses

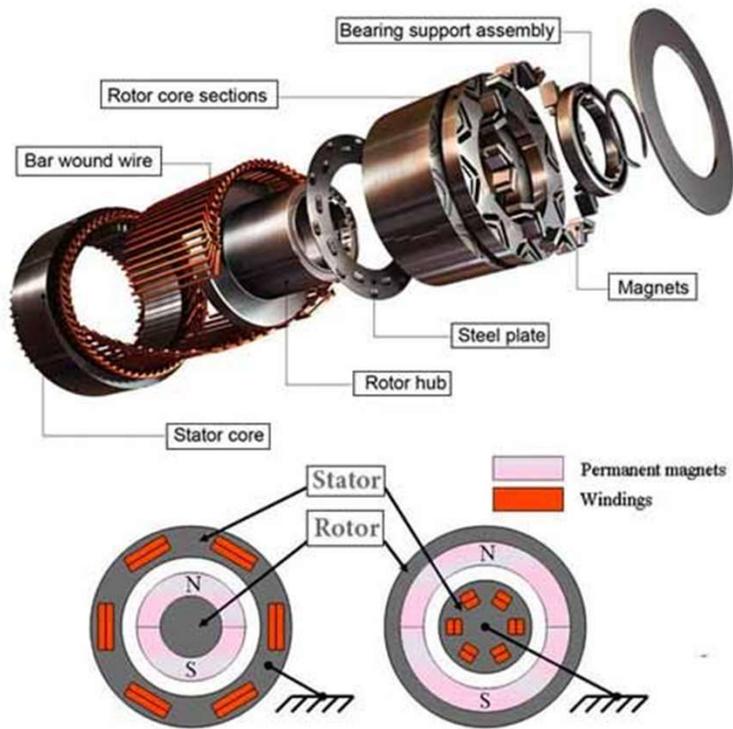
- TATA Ultra Urban 6/9 & 6/12

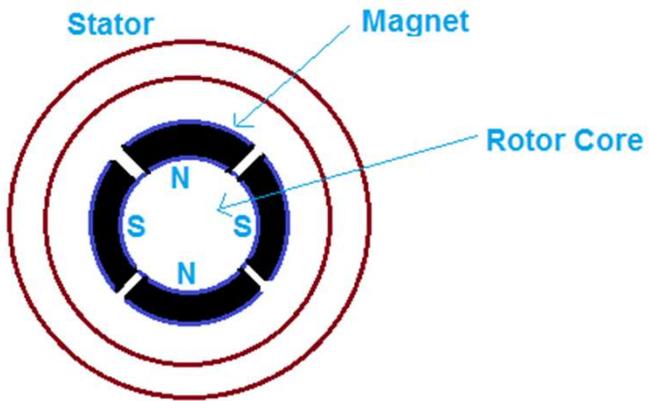


Common Motor Types

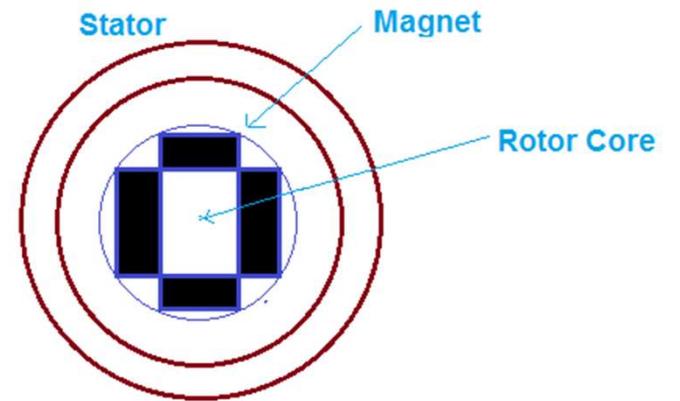


Permanent magnet synchronous motor construction





Surface Mounted PMSM



Interior or Buried PMSM



Working Principle

The working principle of permanent magnet synchronous motor is same as that of synchronous motor. When three phase winding of stator is energized from 3 phase supply, rotating magnetic field is set up in the air gap. At **synchronous speed**, the rotor field poles locks with the rotating magnetic field to produce torque and hence rotor continues to rotate.

As we know that **synchronous motors are not self starting**, PMSM needs to be started somehow. Since there is no winding on the rotor, induction windings for starting is not applicable for such motors and therefore variable frequency power supply for this purpose.

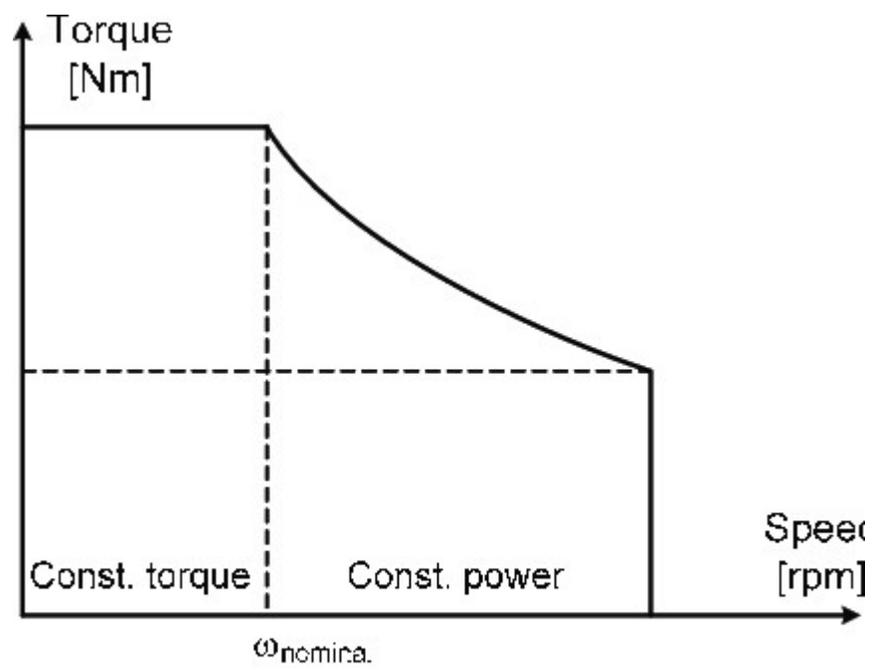
Control

Sinusoidal Category

- Scalar
- Vector: Field oriented control (FOC) (with and without position sensor)
- Direct torque control

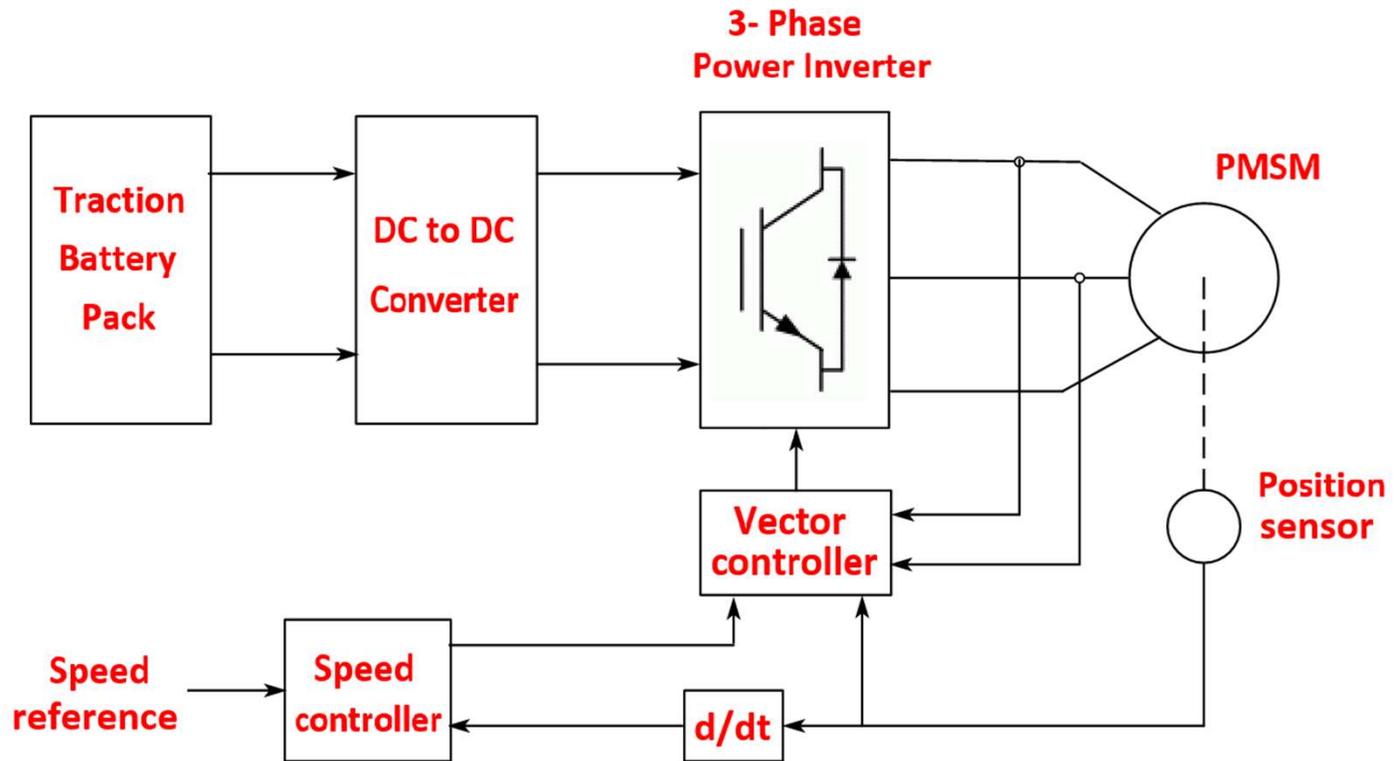
Trapezoidal Category

- Open-loop
- Closed-loop (with and without position sensor)



Applications:

Permanent Magnet Synchronous Motor can be used as an alternative for servo drives. It is widely used in various industrial application viz. robotics, traction, aerospace etc.

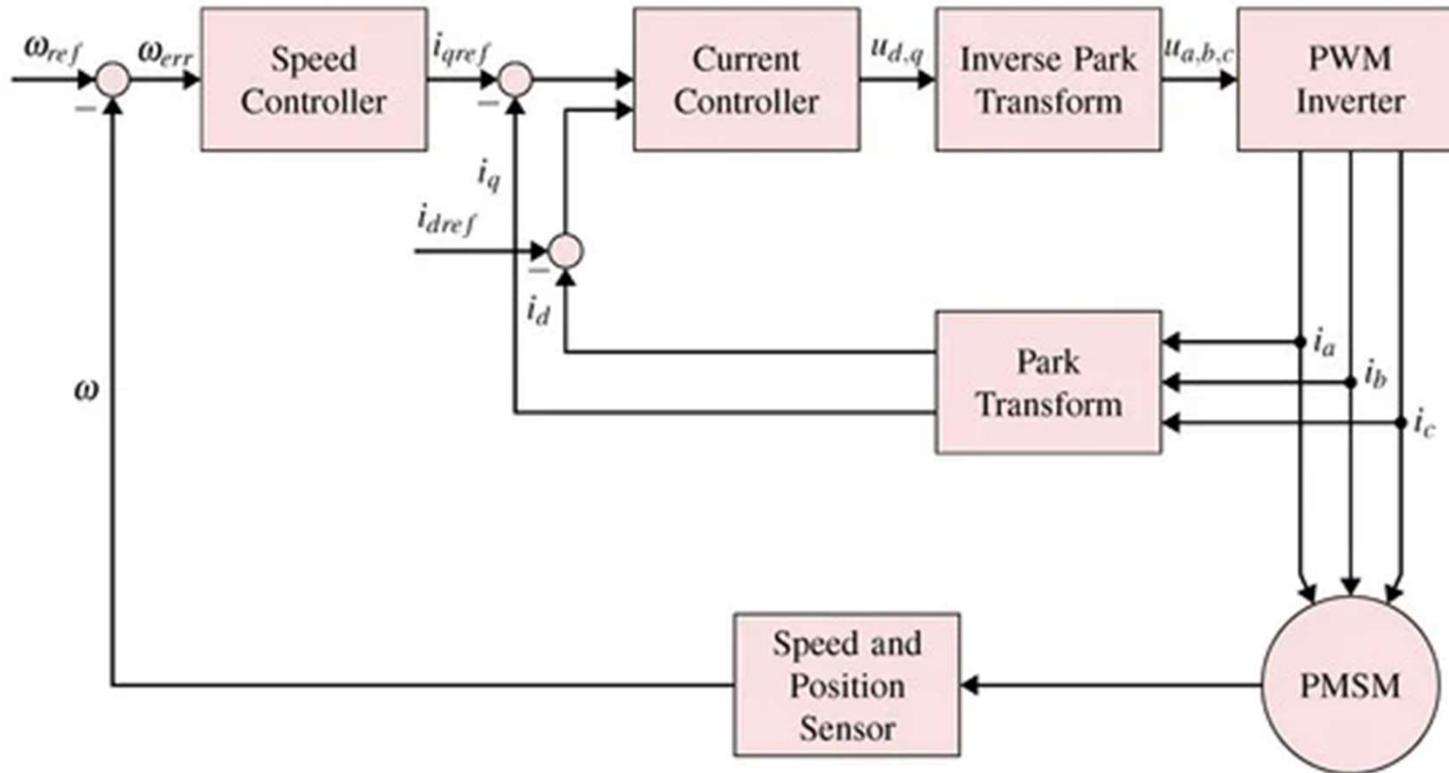


Vector Controlled PMSM-Drive Operation in an E V:

1. The PMSM Drive is a classical vector control drive for Permanent Magnet Synchronous Motors.
2. This drive features a closed-loop speed control based on the vector control method.
3. Closed-loop configuration provided with speed feedback.
4. Feedback allows the drive to track the exact rotor position to provide a true infinite speed range, including full torque at zero speed.
5. The operation of PMSM motors requires position sensors in the rotor shaft when operated without damper winding.
6. The ones most commonly used for motors are encoders and resolvers.
7. The speed control loop outputs the reference electromagnetic torque of the machine taken from an external source can be an analog signal and encoder feedback, or a serial command from a feedback device.
8. These PM drives use motor data and current measurements to calculate rotor position; the digital signal processor (DSP) calculations are quite accurate.
9. During every sampling interval, the three-phase AC system dependent on time and speed is transformed into a rotating two-coordinate system in which every current is expressed and controlled as the sum of two vectors.

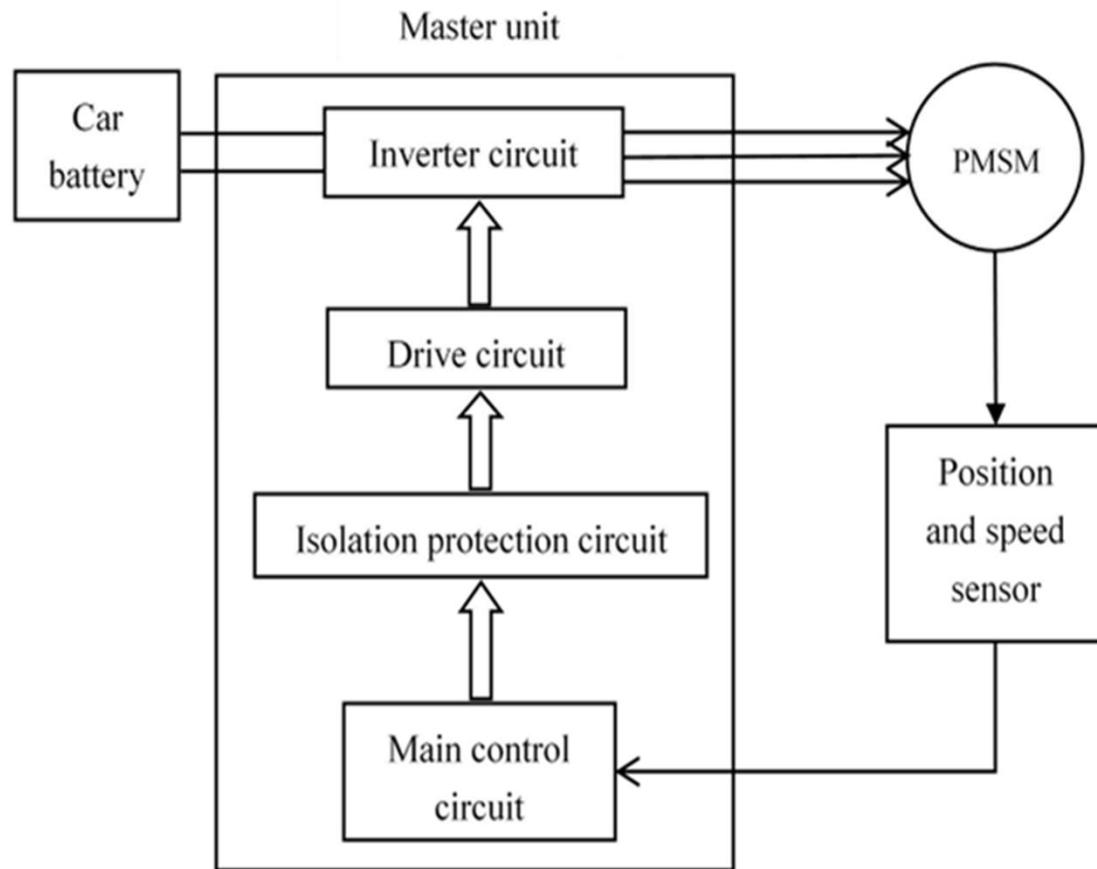
Vector Controlled PMSM-Drive Operation in an E V:

- The reference direct and quadrature (dq) components of the stator current corresponding to the commanded torque are derived based on vector control strategy.
- The reference dq components of the stator current are then used to obtain the required gate signals for the inverter through a hysteresis-band current controller.
- The main advantage of this drive compared to scalar-controlled drives is its fast dynamic response.
- The inherent coupling effect between the torque and flux in the machine is managed through decoupling (stator flux orientation) control, which allows the torque and flux to be controlled independently.
- However, due to its computation complexity, the implementation of this drive requires fast computing processors or DSPs.



Field oriented control block diagram for speed control in PMSM.

- FOC is a popular vector-control technique that is commonly used for electric motor drives, particularly for PMSMs.
- Direct and indirect field-oriented control (DFOC/IFOC) are two approaches to implement FOC for electric motor drives.
- The main difference between these two methods lies in how the motor current and voltage signals are controlled. In direct FOC, the stator current components in the d-q reference frame are directly controlled by the voltage components in the same reference frame.
- This is achieved by using a PI controller to regulate the error between the desired and actual stator current and voltage components. Direct FOC is often used in high-performance applications where fast and accurate torque control is required.
- In contrast, indirect FOC separates the control of the motor's magnetic field and torque by using a separate controller for each component.



PMSM Drive and Control System Architecture

Basis of Difference	BLDC Motor	PMSM Motor
Full form	BLDC Motor is the abbreviated name for Brushless Direct Current Motor.	PMSM stands for Permanent Magnet Synchronous Motor.
Definition	A BLDC motor is an electronically commutated DC motor which does not have carbon brushes and commutator assembly.	A PMSM motor is an AC synchronous motor that uses permanent magnets to provide the necessary field excitation.
Type of motor	BLDC motor is a direct current (DC) motor.	PMSM motor is an alternating current (AC) motor.
Waveform of back emf	The waveform of back emf of a BLDC motor is trapezoidal shaped.	The waveform of back emf of a PMSM motor is sinusoidal shaped.
Torque	The torque produced by a BLDC motor is comparatively lower.	A PMSM motor produces higher torque as compared to BLDC motor.
Efficiency	The efficiency of a BLDC motor is less, around 85% to 90%.	PMSM motors are comparatively more efficient. The typical efficiency is about 92% to 97%

Basis of Difference	BLDC Motor	PMSM Motor
Switching losses	At same switching frequency, a BLDC motor has less switching losses.	The switching losses in a PMSM motor are high.
Core losses	BLDC motor has high core losses because of harmonics.	The core losses are less in a PMSM motor due to less harmonic content.
Torque ripple	In BLDC motors, the torque ripples present at the commutation.	There is no torque ripple at the commutation in case of PMSM motor.
Control	BLDC motor uses comparatively	The control algorithms used in PMSM
algorithm	simple control algorithms.	motors are complex and mathematically intensive.
Cost	The BLDC motor is comparatively less expensive.	The cost of PMSM motor is high.
Applications	BLDC motors are used in hard drives, CD/DVD drives, washing machines, fans, pumps, robotics, etc.	PMSM motors are used in servo drives, traction control, robotics, aerospace, power factor improvement, machine tools, etc

Brushless DC Motor

Brushless DC Motor(BLDCM) are being used in most of the lightweight 2 Wheeler & 3 Wheeler EVs like Electric Scooters and Electric Motorcycles.

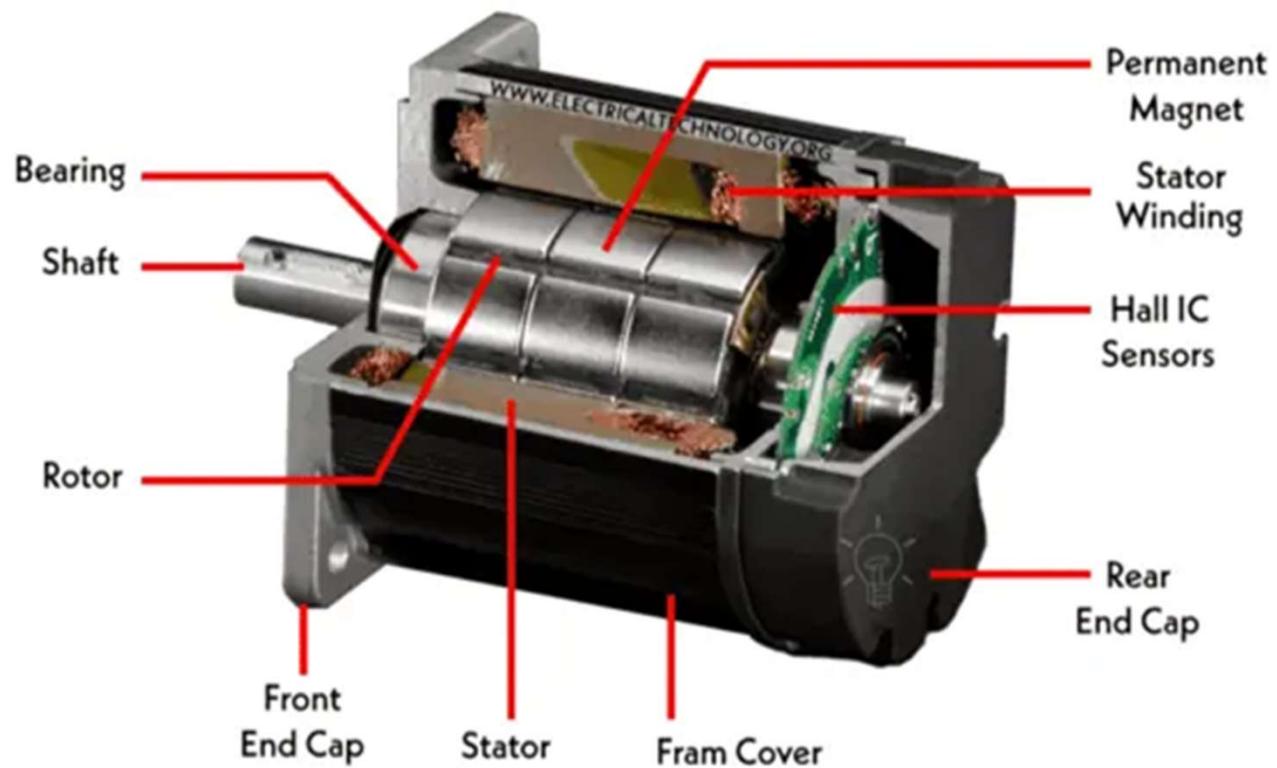
For example in Electric Scooters:

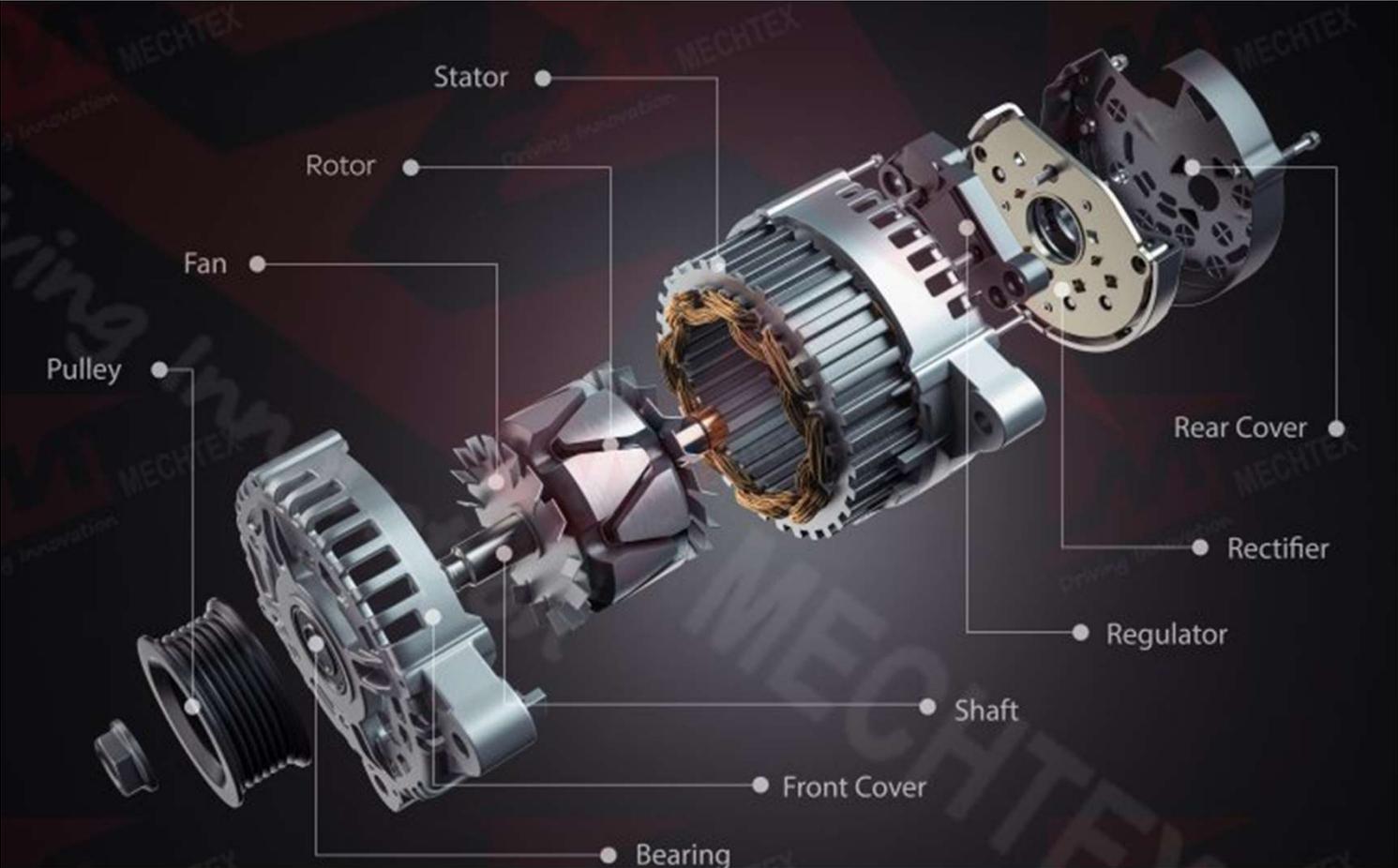
- Ather Energy Scooters,
- Upcoming TVS Creon,
- 22Motors, Hero Electric,
- Niu Electric Scooters,
- Yamaha EC-03, etc.

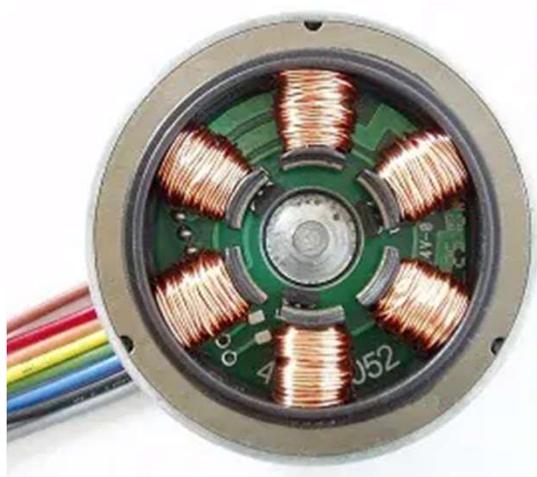
For example in Electric Motorcycles:

- Tork Motors,
- eMotion Motors,
- Menza Motors,
- Chinese Evoke Motorcycles etc. **In all e-Rickshaws & eAuto Rickshaws**



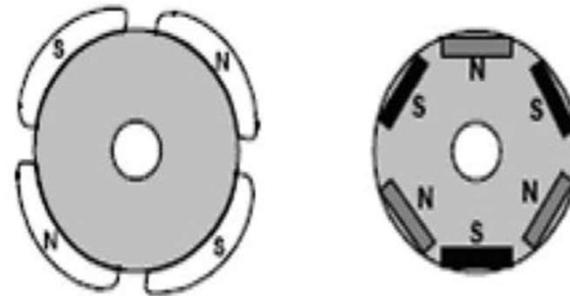






The Brushless DC (BLDC) Motor

- A modern, much improved, version of the traditional brushed DC motor.
- An inside out DC motor with electronic commutation
- Field- permanent magnets- is on the rotor.
- Armature- is on the stator which has good cooling.
- Two types of motor
 - sinusoidal
 - trapezoidal



- By using high-energy permanent magnets as the field excitation mechanism, a permanent magnet motor drive can be potentially designed with high power density, high speed, and high operation efficiency.
- These prominent advantages are quite attractive to the application on electric and hybrid electric vehicles. Of the family of permanent magnetic motors, the brush-less DC (BLDC) motor drive is the most promising candidate for EV and HEV application.

The major advantages of BLDC motor include

1. High Efficiency
2. Compactness:
3. Ease of control:
4. Ease of cooling:
5. Low maintenance, great longevity, and reliability:
6. Low noise emissions

The major disadvantages of BLDC motor include

1. Cost:
2. Limited constant power range:
3. Safety
4. Magnet demagnetization
5. High-speed capability
6. Inverter failures in BLDC motor drives

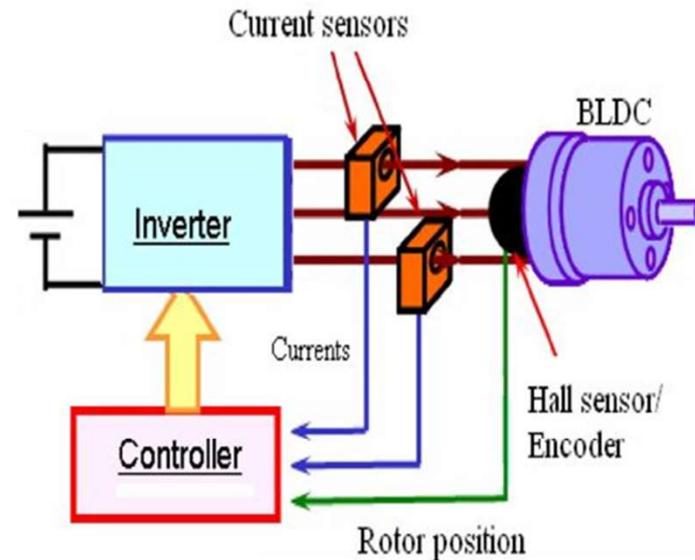
➤ **Sinusoidal motor**

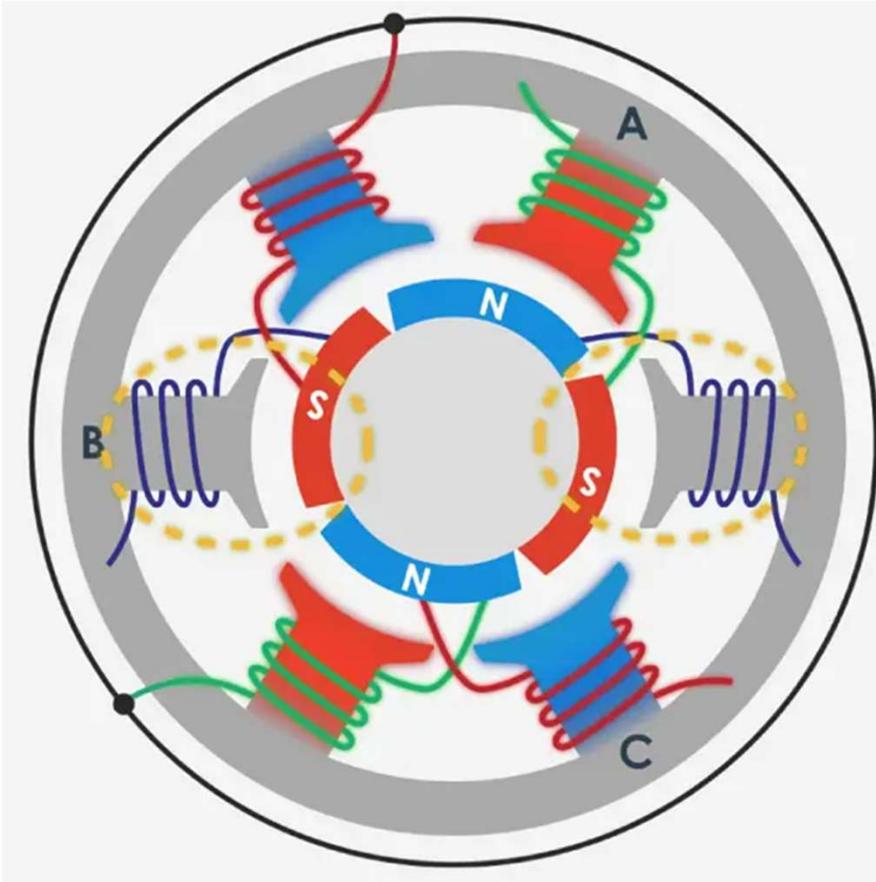
1. Sinusoidal distribution of magnetic flux
2. Sinusoidal current waveforms
3. Sinusoidal distribution of stator conductors.

➤ **Trapezoidal motor**

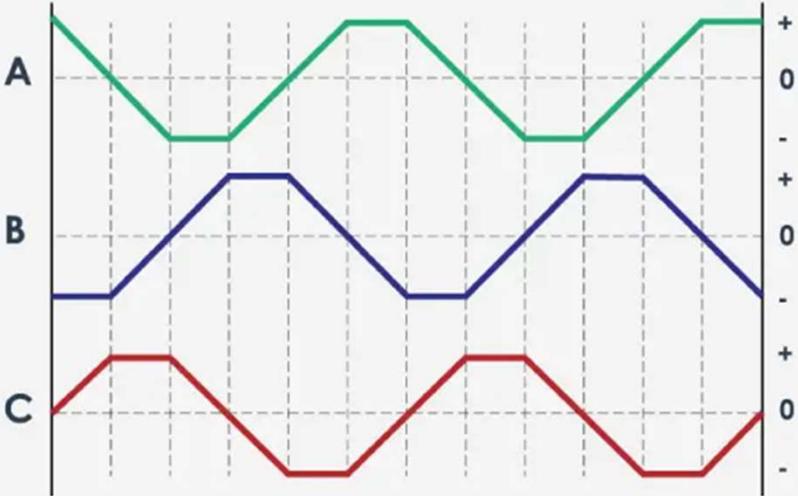
1. Rectangular distribution of magnetic flux
2. Rectangular current waveform
3. Concentrated stator windings.

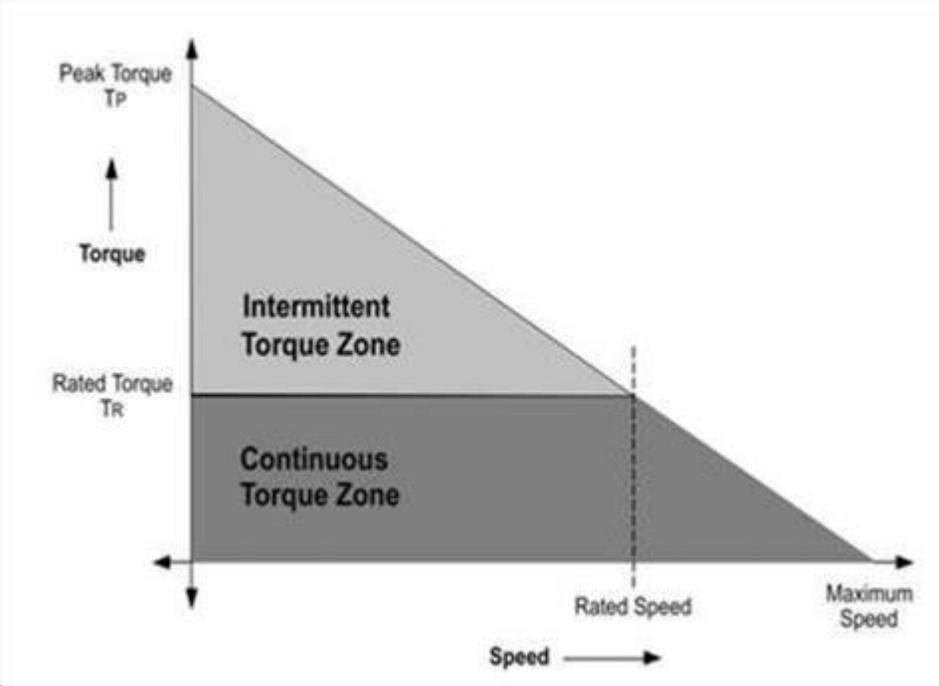
- Mechanical commutator of brushed motor replaced by electronic switching of the phases.
- Switching - synchronised to absolute rotor position – smooth torque production.





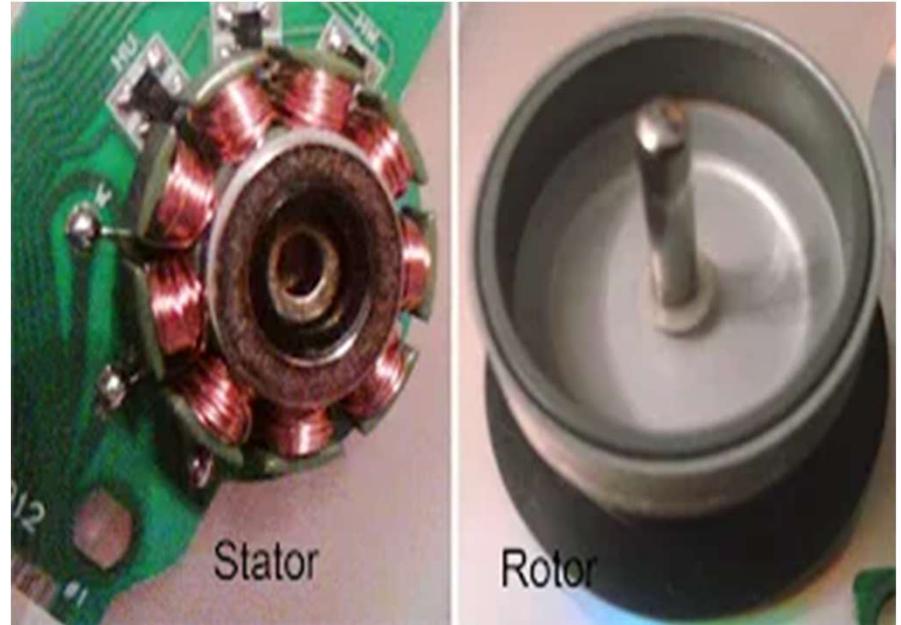
Back EMF



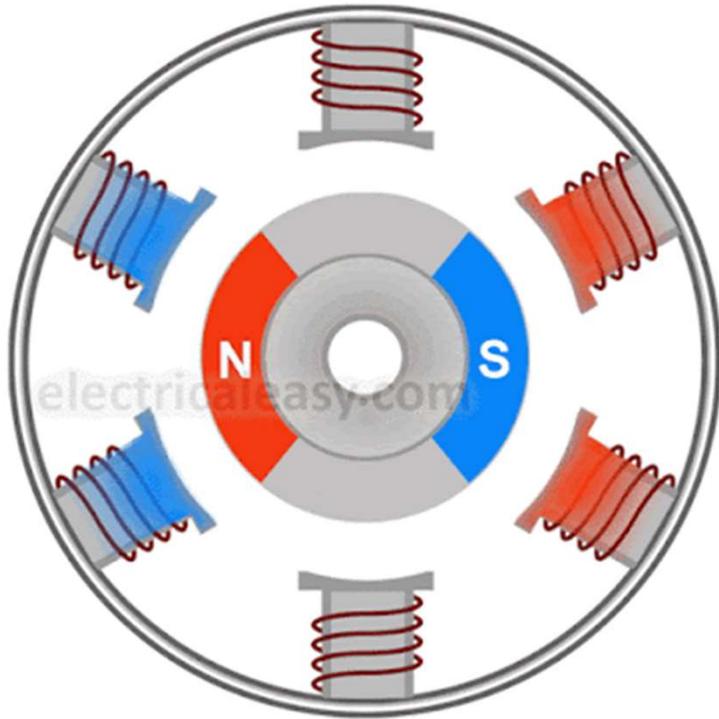




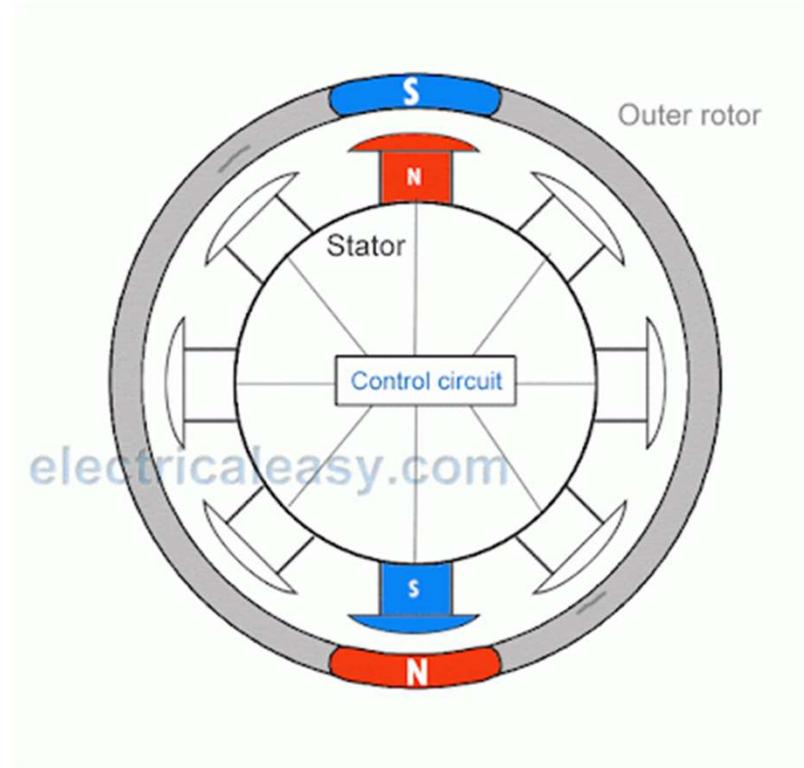
Inner-rotor BLDC motor



Outer rotor BLDC motor



Inner-rotor BLDC motor



Outer rotor BLDC motor

BLDC MOTOR CLASSIFICATION

ROTOR'S PLACEMENT

INRUNNER BLDC MOTOR

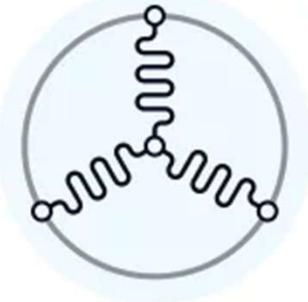
OUTRUNNER BLDC MOTOR



WINDING CONNECTION

WYE-WOUND BLDC MOTOR

DELTA-WOUND BLDC MOTOR



Sensors

- Hall-effect sensors;
- rotary encoders;
- variable reluctance sensors;
- resolvers;
- optical sensors.

BLDC MOTOR CONTROLLER TYPES

ROTOR'S POSITIONING METHOD

SENSOR BLDC MOTOR CONTROLLER
(USING POSITION SENSORS)



SENSORLESS BLDC MOTOR CONTROLLER
(MEASURING BACK EMF)



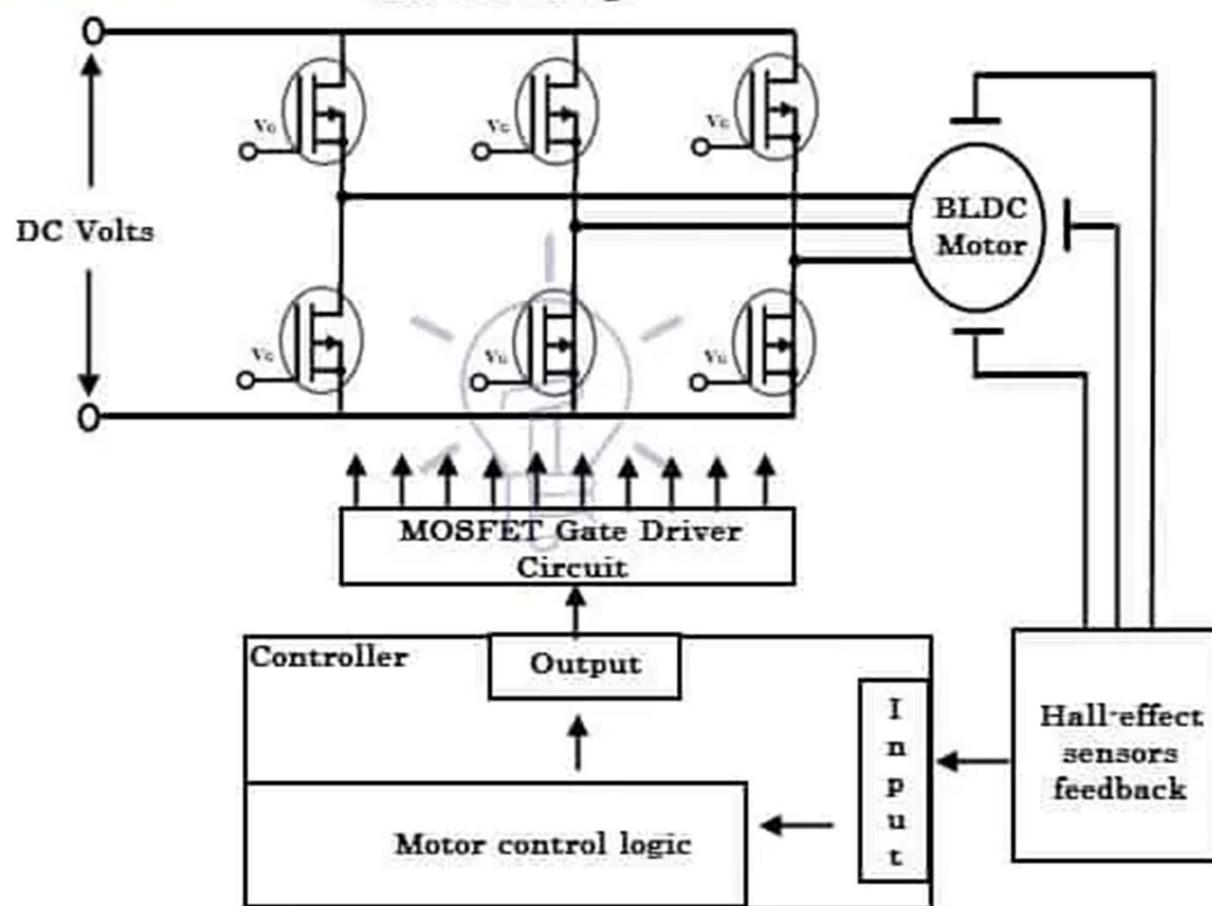
Comparison of BLDC Motor & Brushed Motor

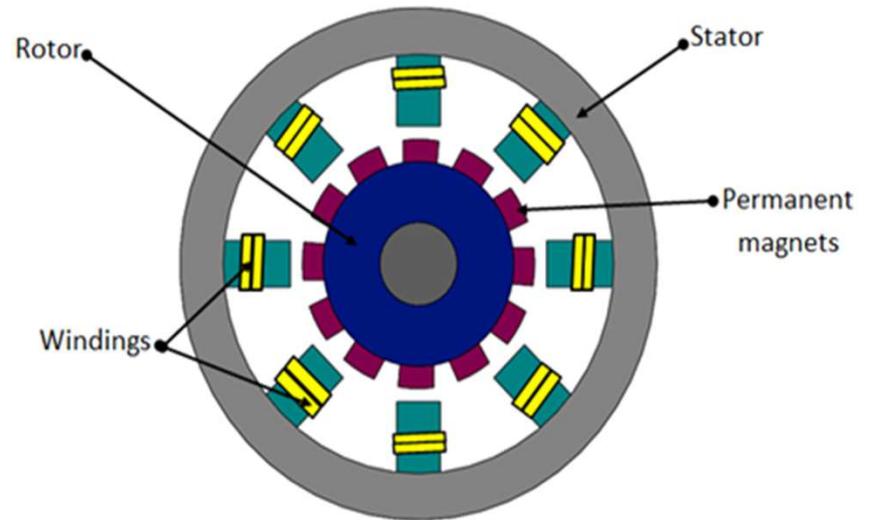
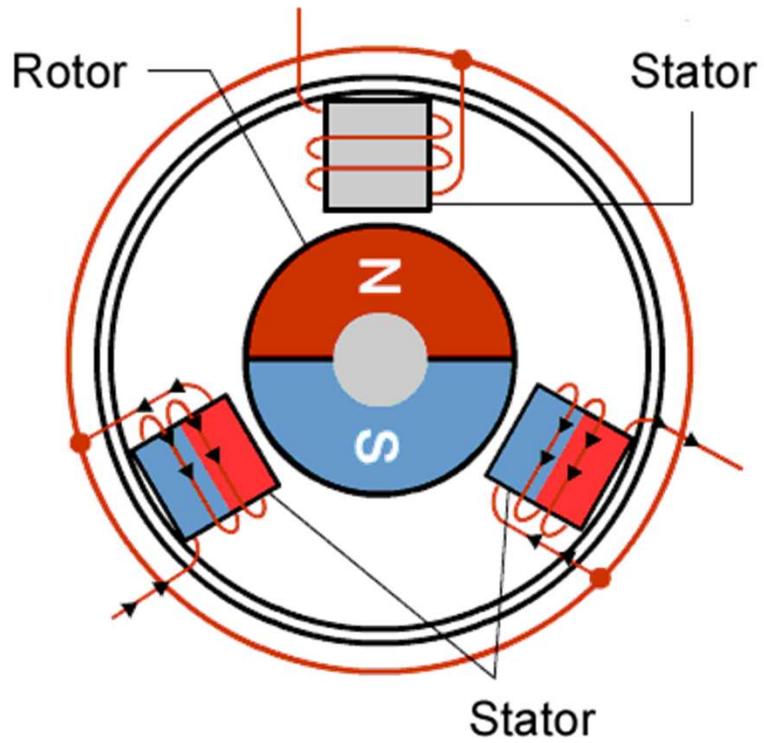
Feature	BLDC Motor	Brushed Motor
Commutation	Electronic Commutation based on Hall Sensors	Brushed Commutation
Maintenance	Less	Periodic
Life	Longer	Shorter
Speed/Torque Characteristics	Flat	Moderately Flat
Efficiency	High	Moderate
Output Power	High	Low
Rotor inertia	Low	Higher
Speed Range	Higher	Lower
Electric Noise	Low	Arcs in brushes-generate noise
Cost of Building	Higher	Low
Control	Complex & Expensive	Simple & inexpensive
Control Requirements	Controller is always required	No controller is required

Advantages of BLDC Motor

- Better speed versus torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Noiseless operation
- Higher speed ranges
- Ratio of torque to size of the motor is higher

MOSFET Bridge

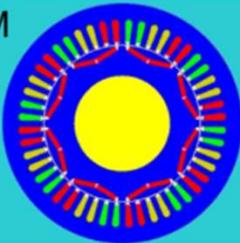
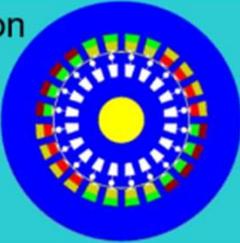




COMPARISONS BETWEEN FOUR TYPES OF ELECTRIC MOTOR DRIVES

Index	DC motor drives	IM drives	PM BLDC motor drives	SRM drives
Efficiency	2	4	5	4.5
Weight	2	4	4.5	5
Cost	5	4	3	4
Total	9	12	12.5	13.5

COMPARISON OF MOTOR PARAMETERS

Category (point of comparison)	Motor type		
	PMSM 	Induction 	SRM 
Power / torque density	+++	++	++
Efficiency	+++	++	+
Torque ripple	+	+	+++
Noise	++	+	+++
Motor cost	+++	++	+
Controller cost	++	++	+++
Fault tolerance	Poor	Excellent	Excellent
Winding locations	Stator	Stator and Rotor	Stator
Reliability	++	+++	+++

Machine Type	Max. output power (kW)	Max. speed with 45Nm Torque (rpm)
IM	59.4	7110
IPM	68.9	7350
SRM	55.6	6520
SFM	58.2	6730
AFPM	53.7	6460
DSDR-AFIM	85.5	8000

Table 1: Different models of electric vehicles.

Company	EV Model	EV Motor
Fiat	Fiat Panda Electra	Series dc motor
Fiat	Fiat Seicento Elettra	Induction motor
Honda	Honda EV Plus	PM brushless motor
Mazda	Mazda Bongo	Shunt dc motor
Nissan	Nissan Altra	PM brushless motor
Toyota	Toyota RAV 4	Pm brushless motor
General Motors	GM EV1	Induction motor
Ford	Ford Think City	Induction motor



Fig 2 Few electric vehicle models (photo courtesy Ford, Honda, Nissan, GM)

How the top electric vehicles stack up

CAR	RANGE (MILES)	HORSEPOWER	SPEED	COST*
Ford Focus Electric 	76	143	84 mph (top speed)	\$27,170
BMW i3 	81	170	0-70 mph in 7 seconds	\$42,400
Chevrolet Spark EV 	82	140	0-60 mph in 7.2 seconds	\$29,995
Volkswagen e-Golf 	83	115	0-62 mph in 10 seconds	\$28,995
Nissan Leaf 	84	107	0-60 mph in 9.9 seconds	\$29,010
Fiat 500e 	87	111	85 mph (top speed)	\$31,800
Mercedes B-class electric drive 	87	177	0-60 mph in > 8 seconds	\$41,450
Kia Soul EV 	93	109	0-60 mph in 11.5 seconds	\$31,950
Tesla Model X 	250	762	0-60 mph in 3.2 seconds	\$132,000
Tesla Model S 85D 	265	373	0-60 mph in 4.2 seconds	\$67,500

* Owners are eligible for up to \$7,500 in federal tax savings