Electrical Technology

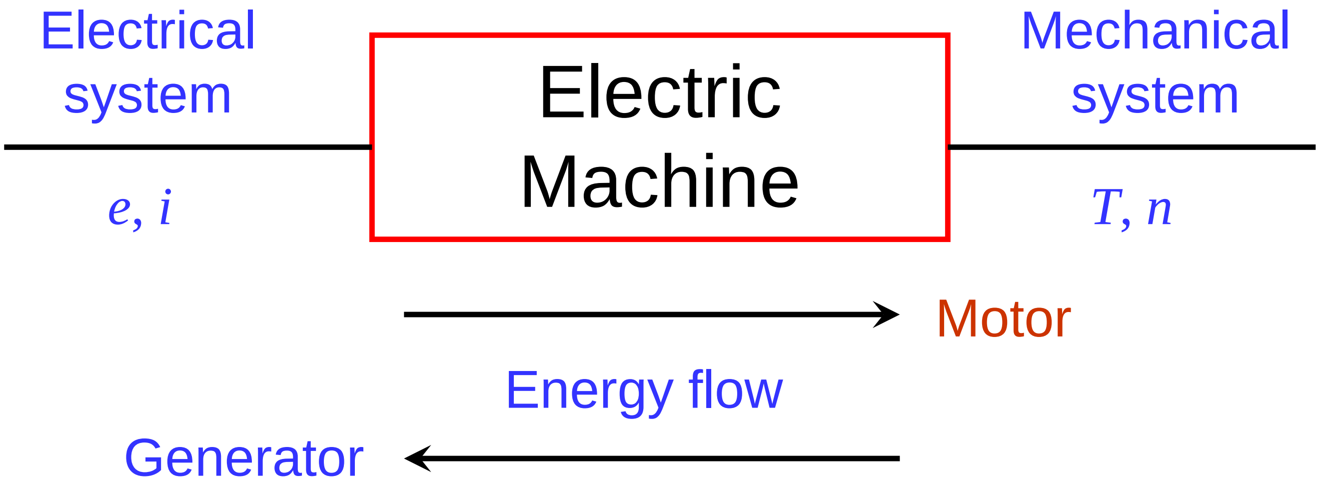
(EE-101-F)

Contents

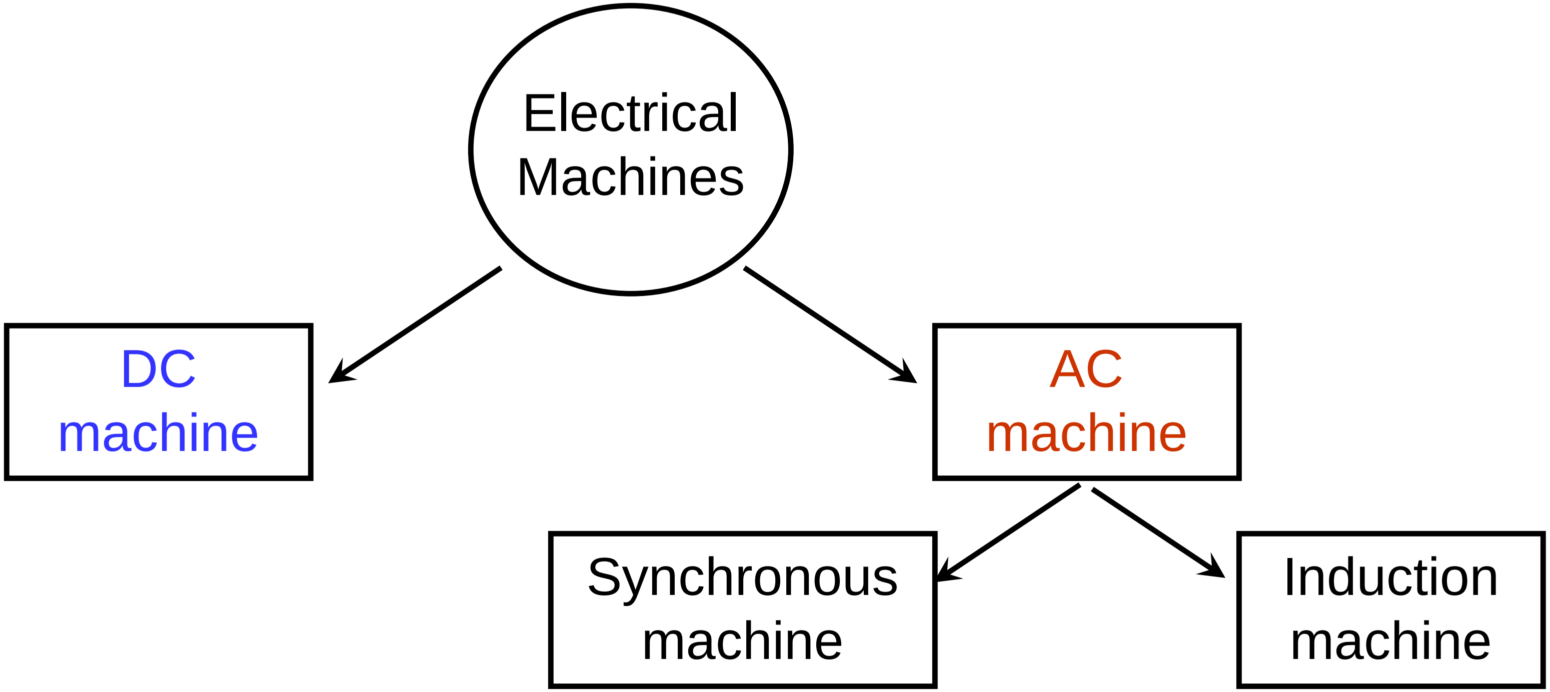
Introduction to Machines

One of energy can be obtained from the other form with the help of converters. Converters that are used to continuously translate electrical input to mechanical output or vice versa are called electric machines.

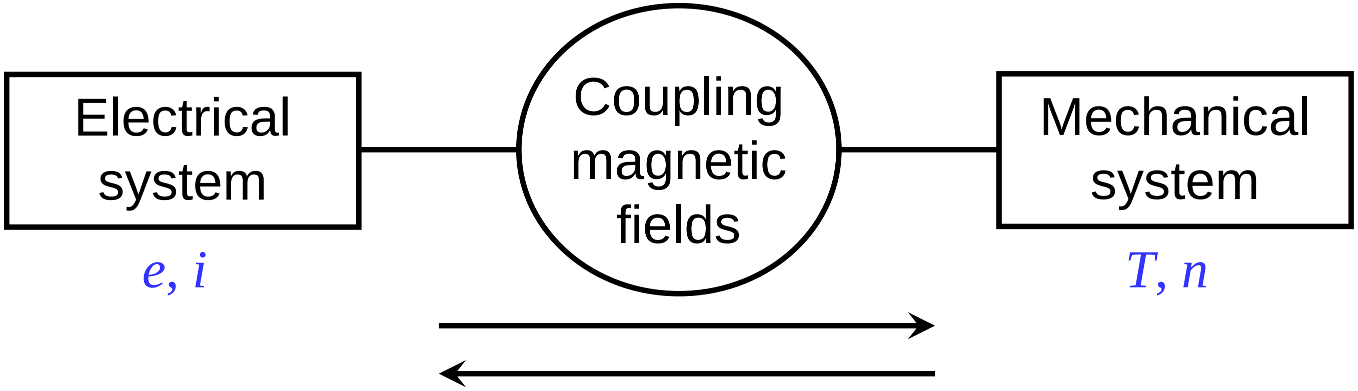
The process of translation is known as electromechanical energy conversion.



- An electrical machine is link between an electrical system and a mechanical system.
- Conversion from mechanical to electrical: generator
- Conversion from electrical to mechanical: motor



- Machines are called AC machines (generators or motors) if the electrical system is AC.
- DC machines (generators or motors) if the electrical system is DC.

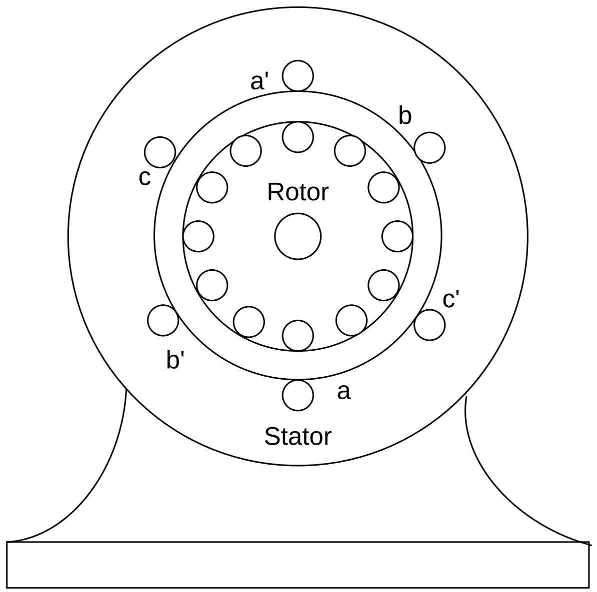


Two electromagnetic phenomena in the electric machines:

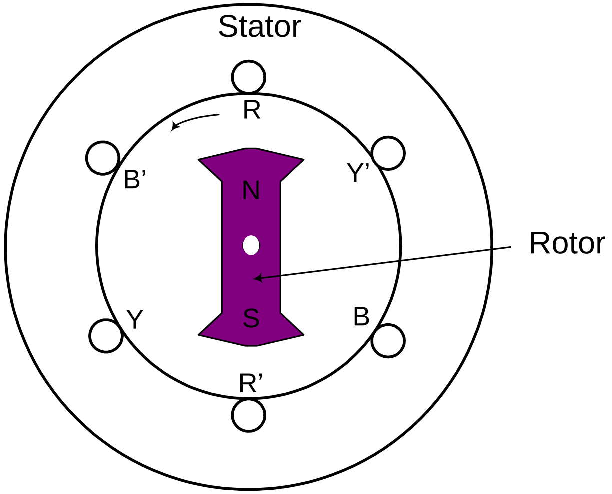
•When a conductor moves in a magnetic field, voltage is induced in the conductor.

•When a current-carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.

Electric Machines
Basic Structure



•The structure of an electric machine has two major components, stator and rotor, separated by the air gap.



• Stator:

Does not move and normally is the outer frame of the machine.

• Rotor:

Is free to move and normally is the inner part of the machine.

•Both rotor and stator are made of ferromagnetic materials.

Direct Current (DC) Machines Fundamentals

- **Generator action:** An EMF (voltage) is induced in a conductor if it moves through a magnetic field.

- **Motor action:** A force is induced in a conductor that has a current going through it and placed in a magnetic field

- Any DC machine can act either as a generator or as a motor.

- **DC Machine is most often used for a motor.**
- **The major advantages of DC machines are the easy speed and torque regulation.**
- **However, their application is limited to mills, mines and trains. As examples, trolleys and underground subway cars may use dc motors.**
- **In the past, automobiles were equipped with DC dynamos to charge their batteries.**

- **Even today the starter is a series dc motor .**

- **However, the recent development of power electronics has reduced the use of dc motors and generators.**

- **The electronically controlled ac drives are gradually replacing the dc motor drives in factories.**

- **Nevertheless, a large number of dc motors are still used by industry and several thousand are sold annually.**

DC Generator Fundamentals

$e = (\boldsymbol{B} \times \boldsymbol{v}) . l$

$e = \mathrm{B}\, l\, v \sin\alpha \cos\beta$

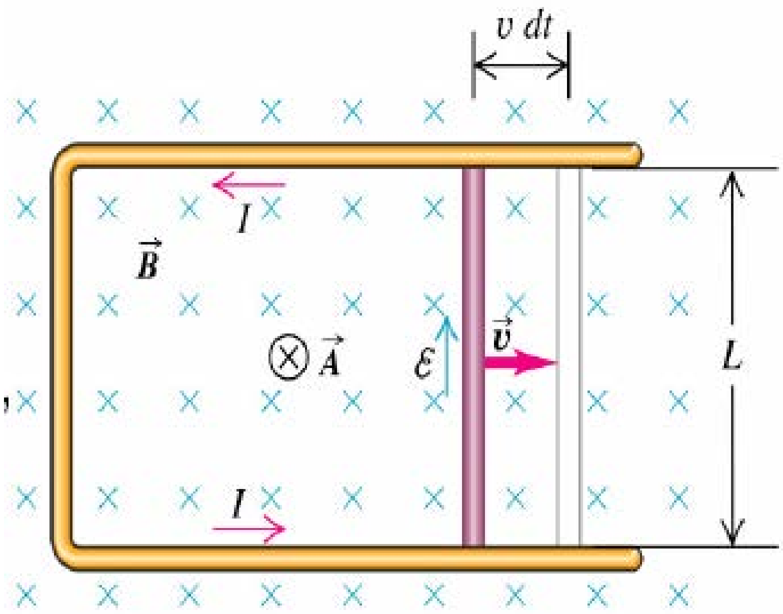
e = induced voltage, v = velocity of the conductor, B = flux density and *l* is the length of the conductor

〈 - angle between the direction in which the conductor is moving and the flux is acting.

β - smallest possible angle the conductor makes with the direction of, the vector product, ($v \times \boldsymbol{B}$) and for maximum induction,

β = 0. Hence, $e = Blv$ for most cases.

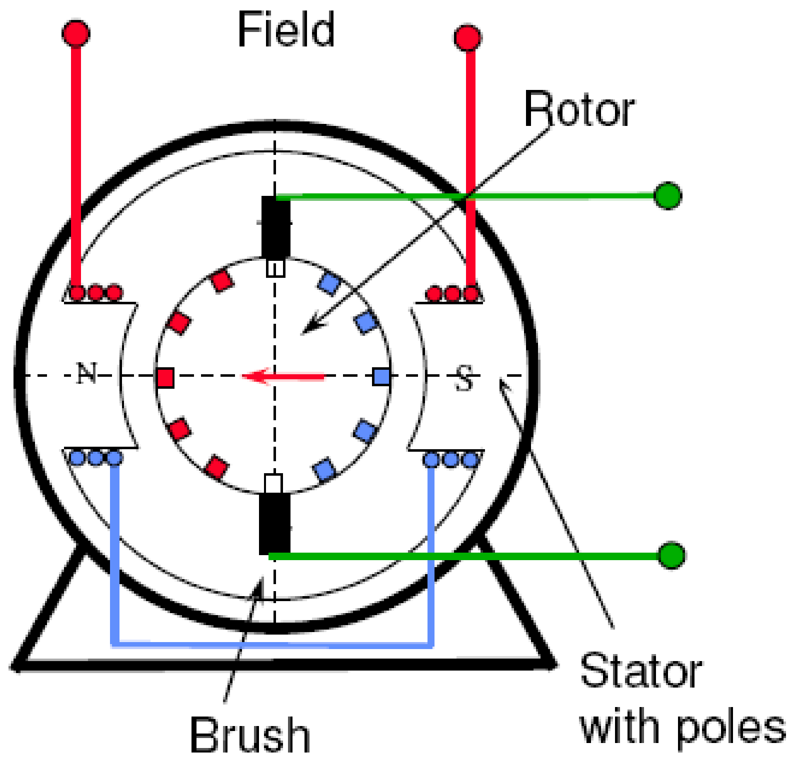
($v \times \boldsymbol{B}$) indicates the direction of the current flow in the conductor, or the polarity of the emf.



DC machine Construction

- **Stator:** Stationary part of the machine. The stator carries a field winding that is used to produce the required magnetic field by DC excitation. Often know as the field.

- **Rotor:** The rotor is the rotating part of the machine. The rotor carries a distributed winding, and is the winding where the emf is induced. Also known as the armature.



DC Motors Equivalent circuit

The equivalent circuit of DC Motors (and Generators) has two components:

- **Armature circuit:** it can be represented by a voltage source and a resistance connected in series (the armature resistance). The armature winding has a resistance, Ra.

- **The field circuit:** It is represented by a winding that generates the magnetic field and a resistance connected in series. The field winding has resistance Rf.

Classification of DC Motors

- **Separately Excited and Shunt Motors**

Field and armature windings are either connected separate or in parallel.

- **Series Motors**

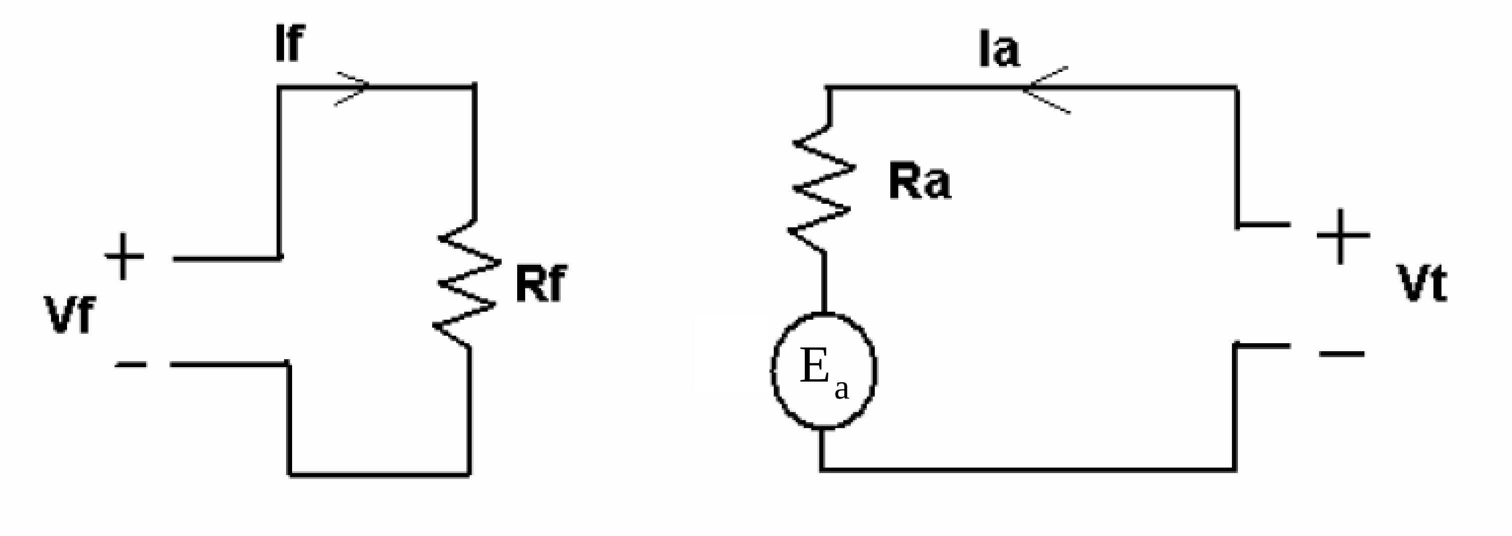
Field and armature windings are connected in series.

- **Compound Motors**

Has both shunt and series field so it combines features of series and shunt motors.

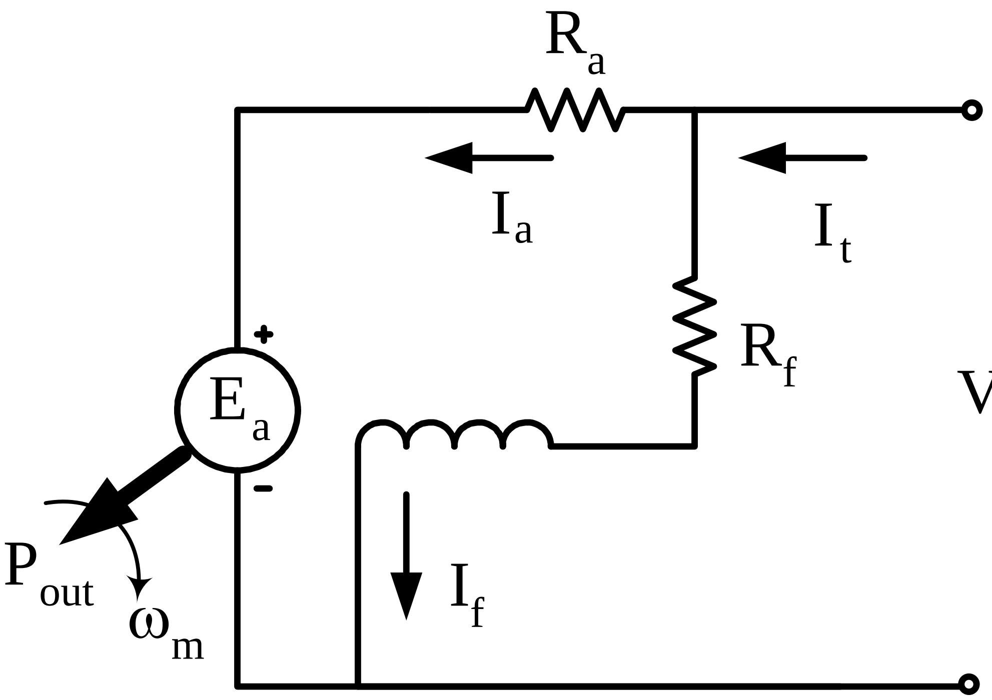
Separately Excited DC Motors

– The armature winding supplies the load.
– The field winding is supplied by a separate DC source whose voltage is variable.
– Good speed control.



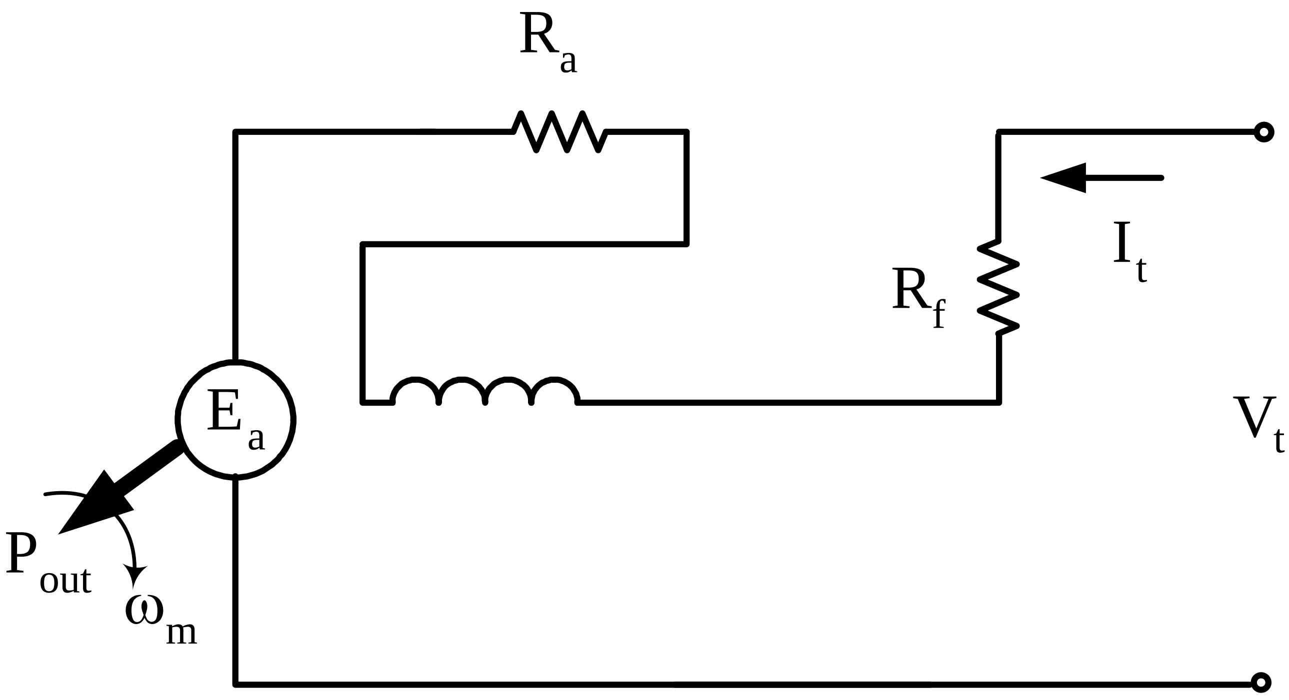
Shunt DC Motors

– The armature and field windings are connected in parallel.
– Constant speed operation.

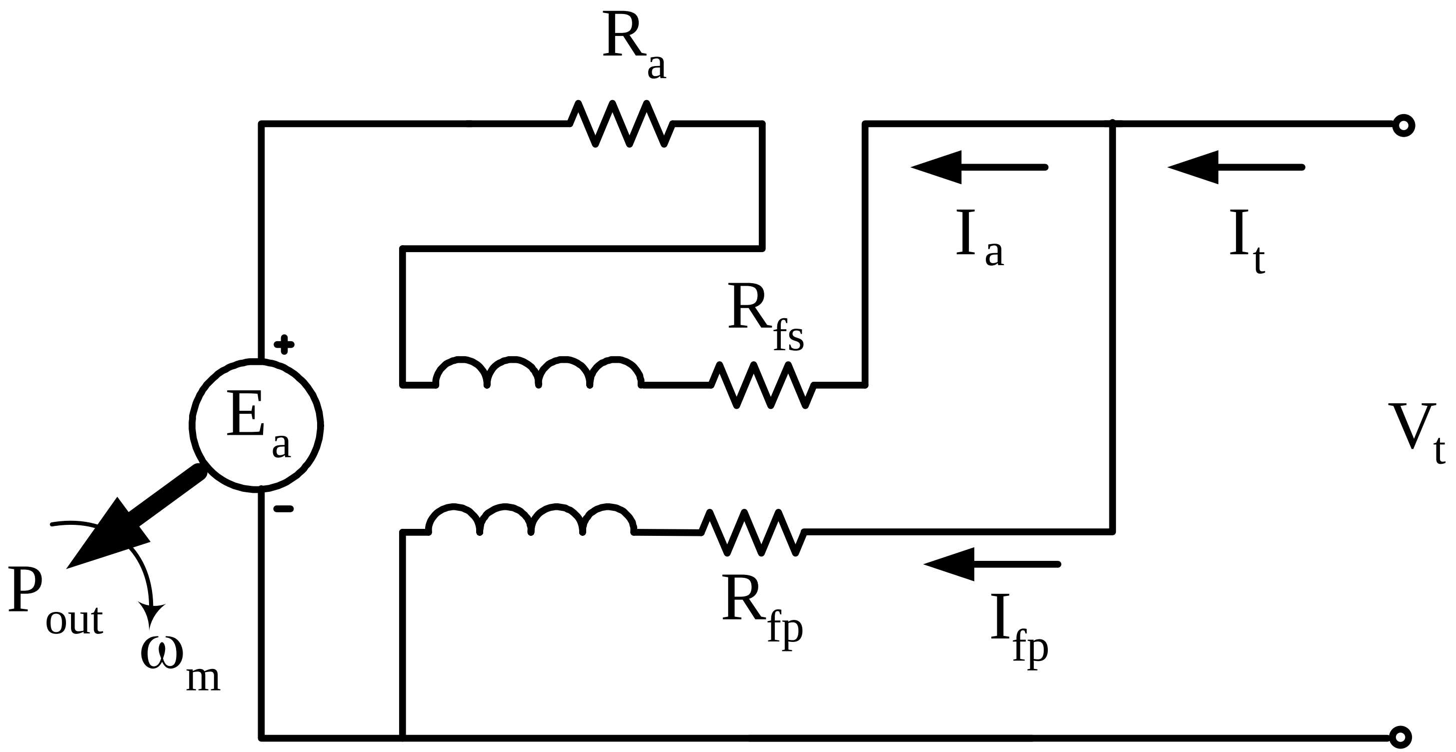


Series DC Motors

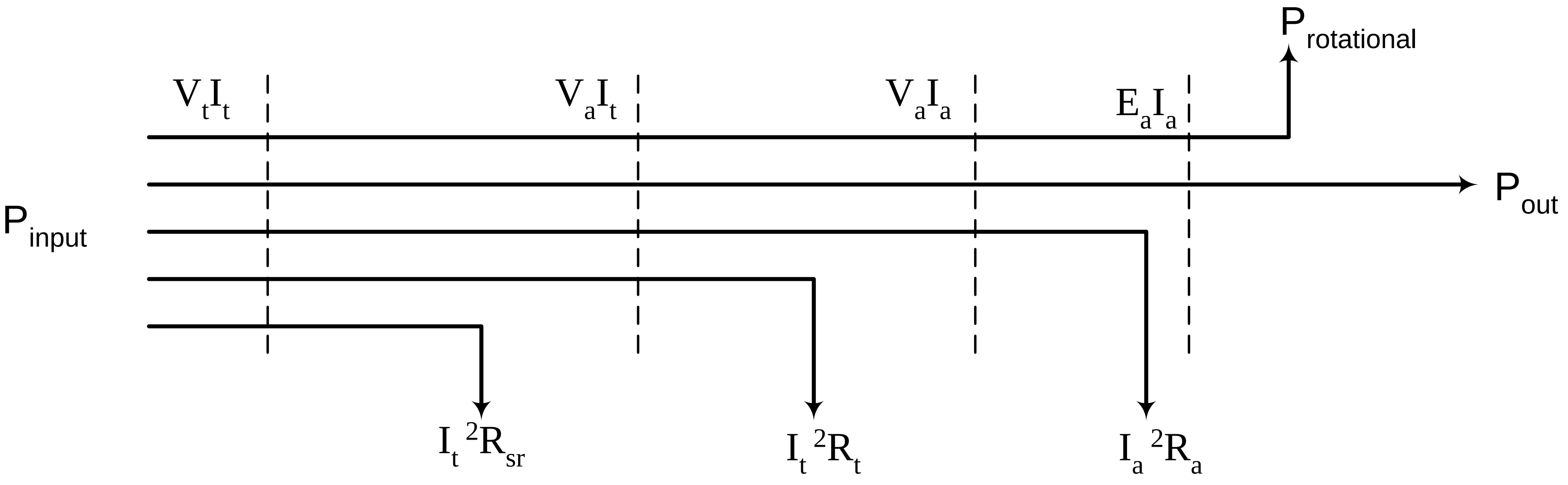
– The armature and field winding are connected in series.
– High starting torque.

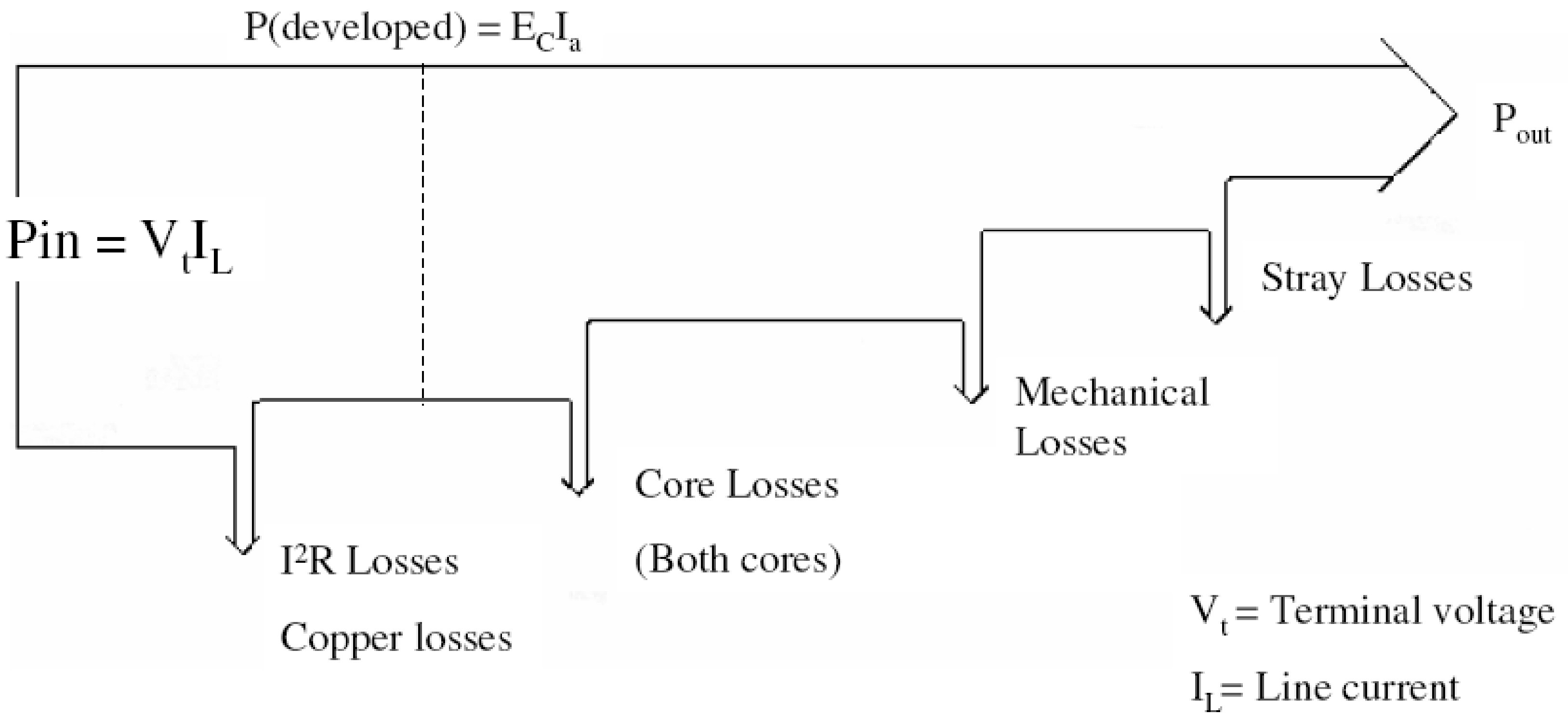


Compound dc motors



Power Flow and Losses in DC Motors





P(developed) = $E_C I_a$
P_{out}
Pin = $V_t I_L$
Stray Losses
Mechanical Losses
Core Losses
(Both cores)
I^2R Losses
Copper losses
V_t = Terminal voltage
I_L = Line current

Speed Control of DC Motors

Speed can be controlled by varying:

1) Armature circuit resistance using an external resistance $R_{a\ Ext}$.
2) *IF* can be varied by using an external resistance R_{adj} in series with R_f to control the flux, hence the speed.
3) The applied voltage to the armature circuit resistance, if the motor is separately excited

Comparison of DC Motors

Shunt Motors: "Constant speed" motor (speed regulation is very good). Adjustable speed, medium starting torque.
Applications: centrifugal pump, machine tools, blowers fans, reciprocating pumps, etc.

Series Motors: Variable speed motor which changes speed drastically from one load condition to another. It has a high starting torque.
Applications: hoists, electric trains, conveyors, elevators, electric cars.

Compound motors: Variable speed motors. It has a high starting torque and the no-load speed is controllable unlike in series motors.
Applications: Rolling mills, sudden temporary loads, heavy machine tools, punches, etc

Classification of AC Rotating Machines

Synchronous Machines:

- **Synchronous Generators:** A primary source of electrical energy.
- **Synchronous Motors:** Used as motors as well as power factor compensators (synchronous condensers).

Asynchronous (Induction) Machines:

- **Induction Motors:** Most widely used electrical motors in both domestic and industrial applications.
- **Induction Generators:** Due to lack of a separate field excitation, these machines are rarely used as generators.

Synchronous Machine

- **Unlike induction machines, the rotating air gap field and the rotor rotate at the same speed, called the synchronous speed.**

- **Synchronous machines are used primarily as generators of electrical power, called synchronous generators or alternators.**

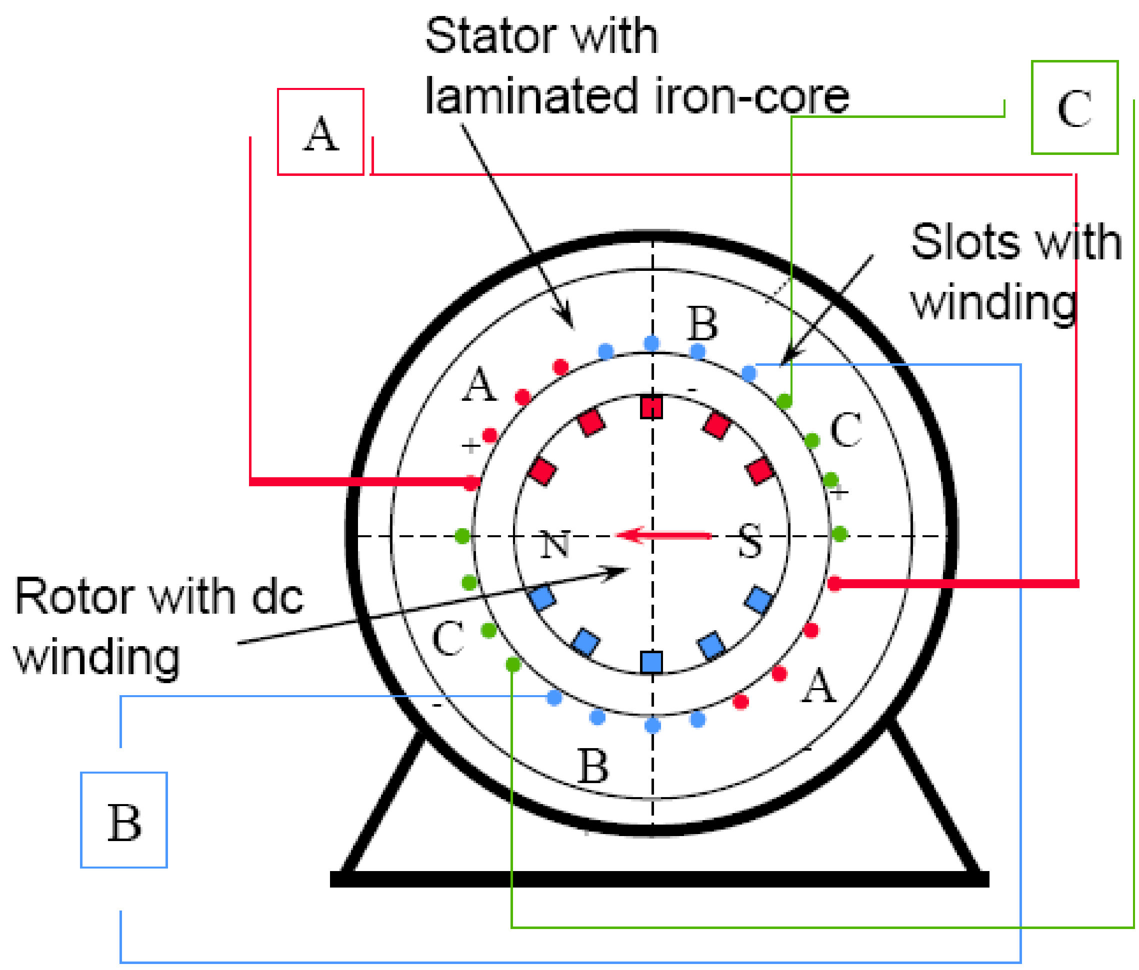
- **They are usually large machines generating electrical power at hydro, nuclear, or thermal power stations.**

- **Application as a motor: pumps in generating stations, electric clocks, timers, and so forth where constant speed is desired.**

Synchronous Machine

Round Rotor Machine

- The stator is a ring shaped laminated iron-core with slots.
- Three phase windings are placed in the slots.
- Round solid iron rotor with slots.
- A single winding is placed in the slots. DC current is supplied through slip rings.



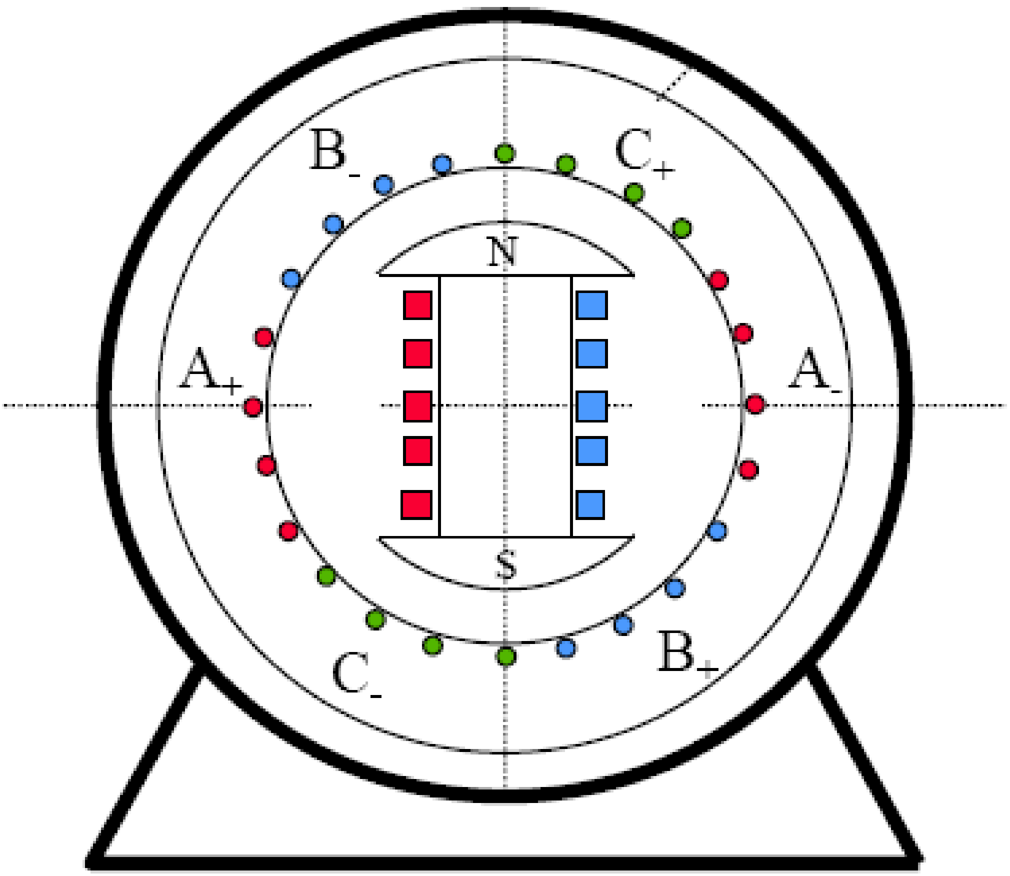
Synchronous Machine

Salient Rotor Machine

- **The stator has a laminated iron-core with slots and three phase windings placed in the slots.**

- **The rotor has salient poles excited by dc current.**

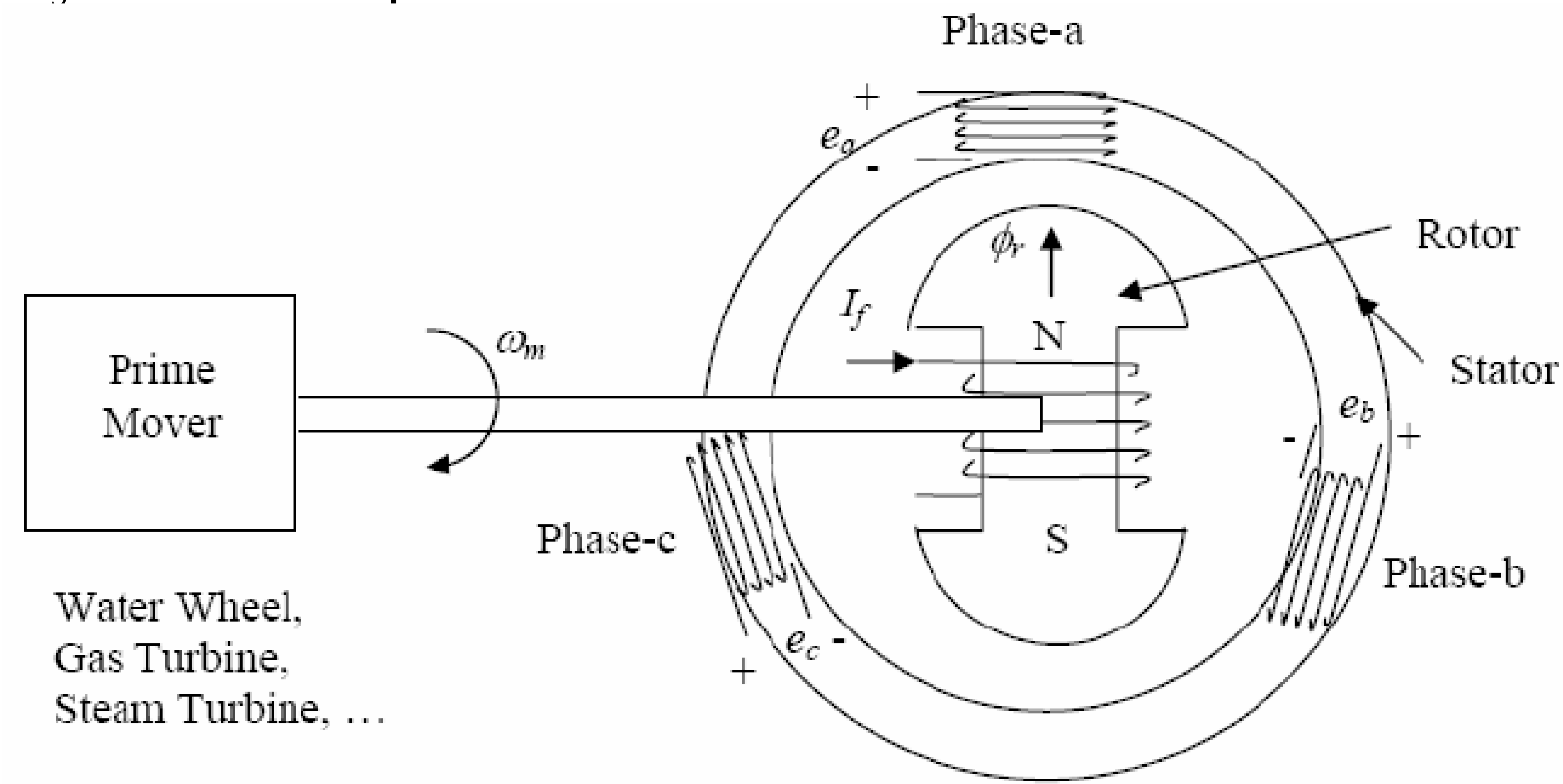
- **DC current is supplied to the rotor through slip-rings and brushes.**



Synchronous Generator

Principle of Operation

1) From an external source, the field winding is supplied with a DC current -> excitation.
2) Rotor (field) winding is mechanically turned (rotated) at synchronous speed.
3) The rotating magnetic field produced by the field current induces voltages in the outer stator (armature) winding. The frequency of these voltages is in synchronism with the rotor speed.



Parallel Operation of Synchronous Generator

Generators are rarely used in isolated situations. More commonly, generators are used in parallel, often massively in parallel, such as in the power grid. The following steps must be adhered to:

- when adding a generator to an existing power grid:

1) RMS line voltages of the two generators must be the same.
2) Phase sequence must be the same.
3) Phase angles of the corresponding phases must be the same.
4) Frequency must be the same.

Induction Machine

- **The induction machine is the most rugged and the most widely used machine in industry.**
- **Both stator and rotor winding carry alternating currents.**
- **The alternating current (ac) is supplied to the stator winding directly and to the rotor winding by induction – hence the name induction machine.**
- **Application (1ϕ): washing machines, refrigerators, blenders, juice mixers, stereo turntables, etc.**
- **2-ϕ induction motors are used primarily as servomotors in a control system.**
- **Application 3ϕ: pumps, fans, compressors, paper mills, textile mills, etc.**

Induction Motor

It is usually for large 3 phase induction motors.

- Rotor has a winding the same as stator and the end of each phase is connected to a slip ring.
- Three brushes contact the three slip-rings to three connected resistances (3-phase Y) for reduction of starting current and speed control.
- Compared to squirrel cage rotors, wound rotor motors are expensive and require maintenance of the slip rings and brushes, so it is not so common in industry applications.
- Wound rotor induction motor was the standard form for variable speed control before the advent of motor