DC Generator

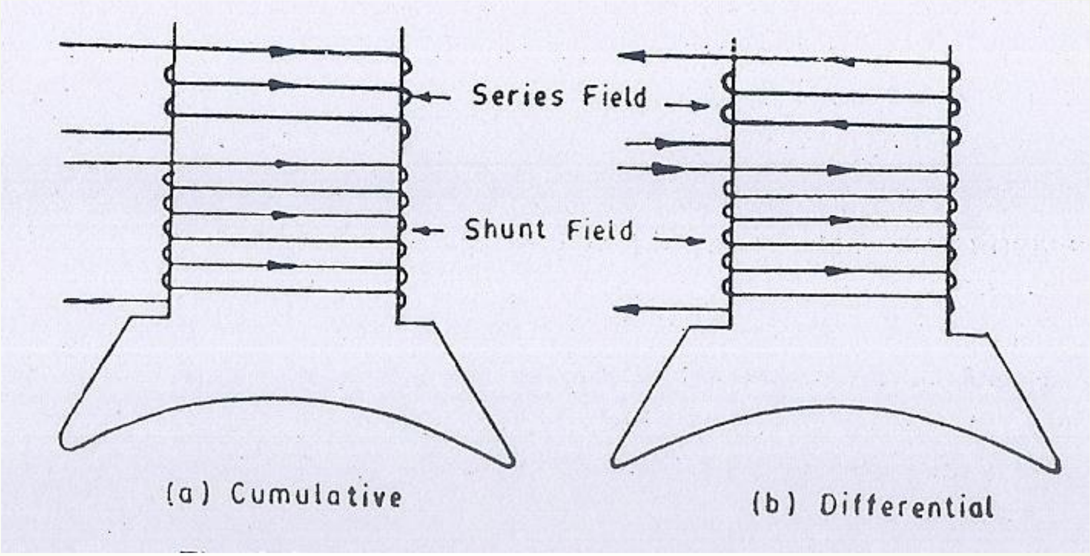
Edit by Shaheen

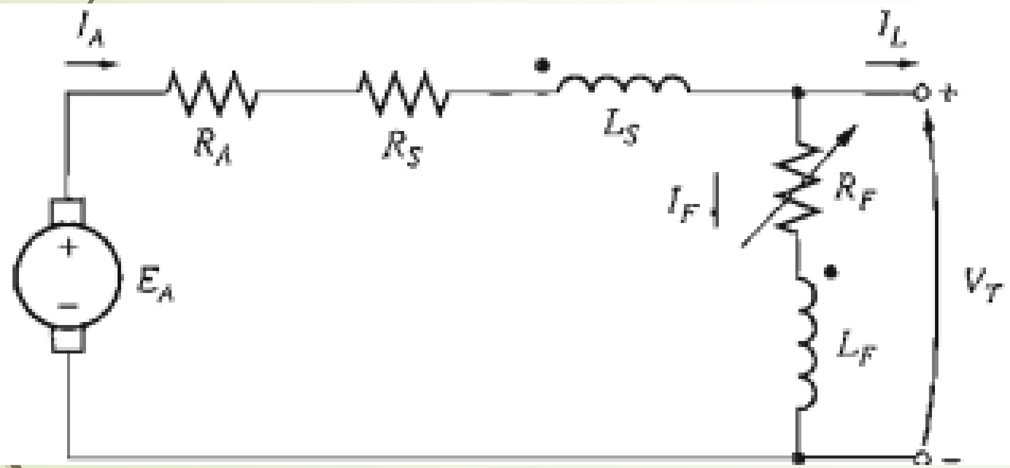
Types of DC Generator

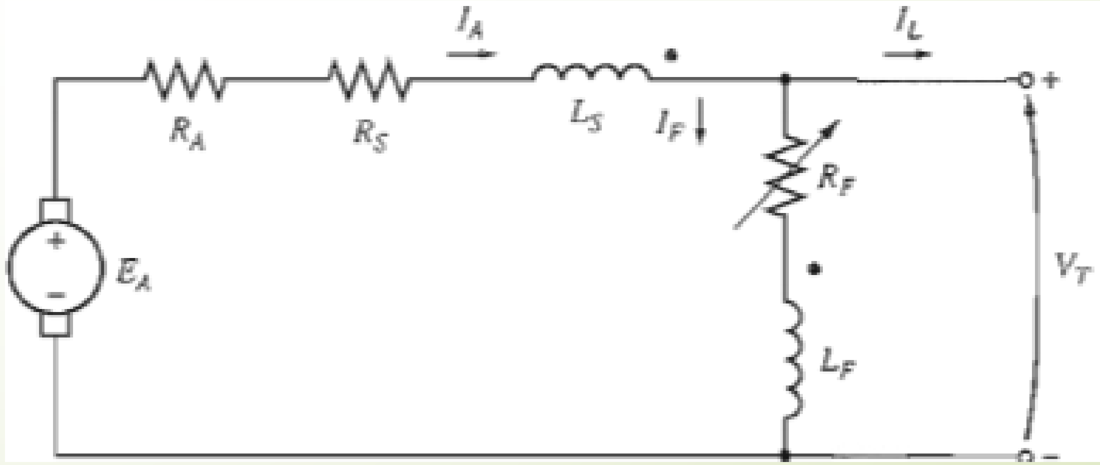
DC generators are dc machines used as generators. As previously noted, there is no real difference between a generator and a motor except for the direction of power flow. There are five major types of dc generators, classified according to the manner in which their field flux is produced:

1. *Separately excited generator.* In a separately excited generator, the field flux is derived from a separate power source independent of the generator itself.
2. *Shunt generator.* In a shunt generator, the field flux is derived by connecting the field circuit directly across the terminals of the generator.
3. *Series generator.* In a series generator, the field flux is produced by connecting the field circuit in series with the armature of the generator.
4. *Cumulatively compounded generator.* In a cumulatively compounded generator, both a shunt and a series field are present, and their effects are additive.
5. *Differentially compounded generator.* In a differentially compounded generator, both a shunt and a series field are present, but their effects are subtractive.

Types of DC Generator

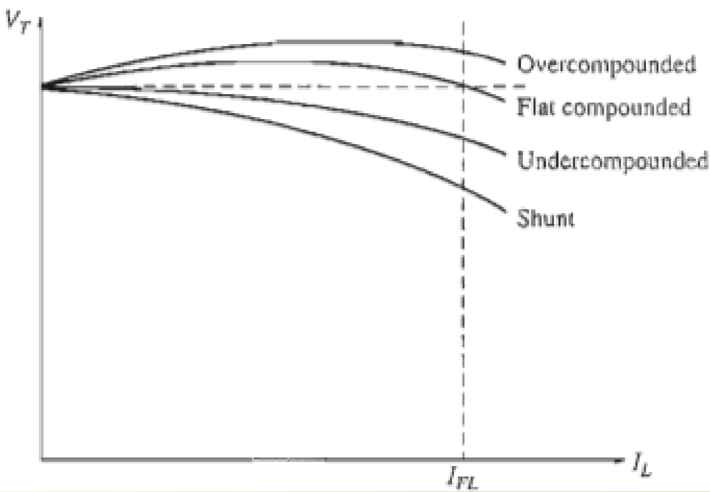




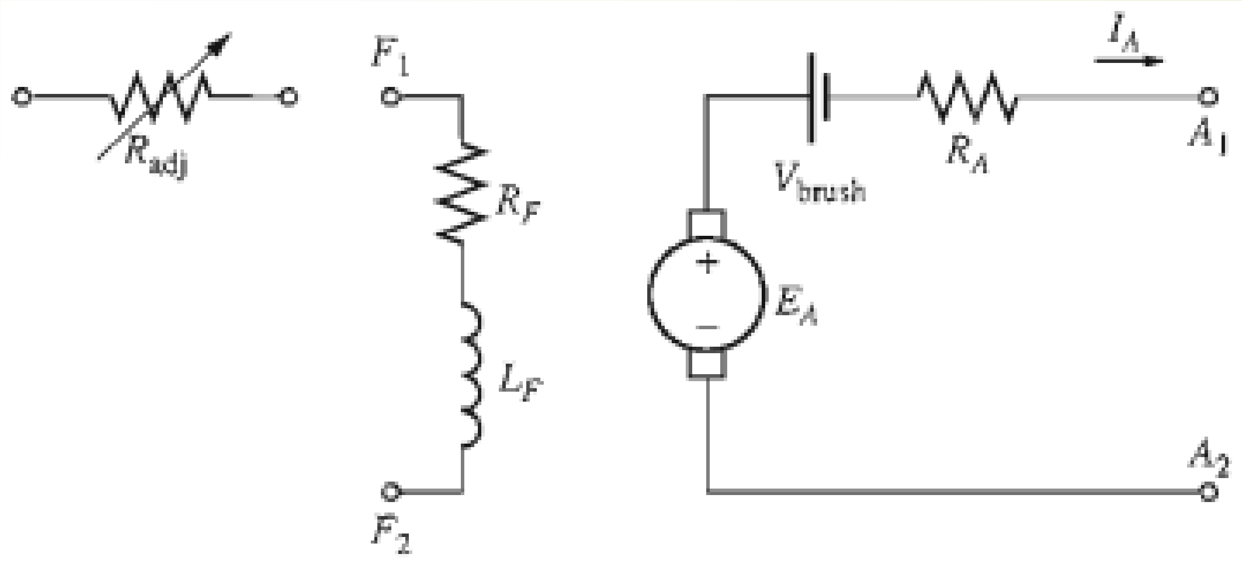


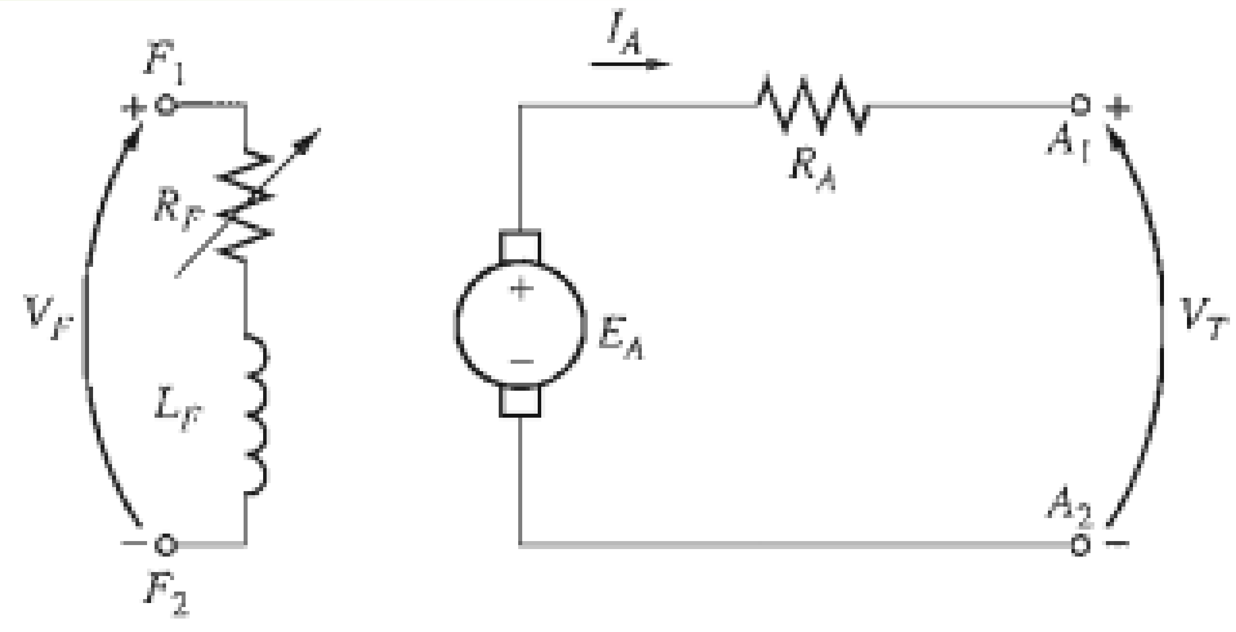
Types of DC Generator

1. *Few series turns (N_{SE} small).* If there are only a few series turns, the resistive voltage drop effect wins hands down. The voltage falls off just as in a shunt generator, but not quite as steeply (Figure 8–61). This type of construction, where the full-load terminal voltage is less than the no-load terminal voltage, is called *undercompounded.*
2. *More series turns (N_{SE} larger).* If there are a few more series turns of wire on the poles, then at first the flux-strengthening effect wins, and the terminal voltage rises with the load. However, as the load continues to increase, magnetic saturation sets in, and the resistive drop becomes stronger than the flux increase effect. In such a machine, *the terminal voltage first rises and then falls as the load increases.* If V_T at no load is equal to V_T at full load, the generator is called *flat-compounded.*
3. *Even more series turns are added (N_{SE} large).* If even more series turns are added to the generator, the flux-strengthening effect predominates for a longer time before the resistive drop takes over. The result is a characteristic with the full-load terminal voltage actually higher than the no-load terminal voltage. If V_T at a full load exceeds V_T at no load, the generator is called *overcompounded.*



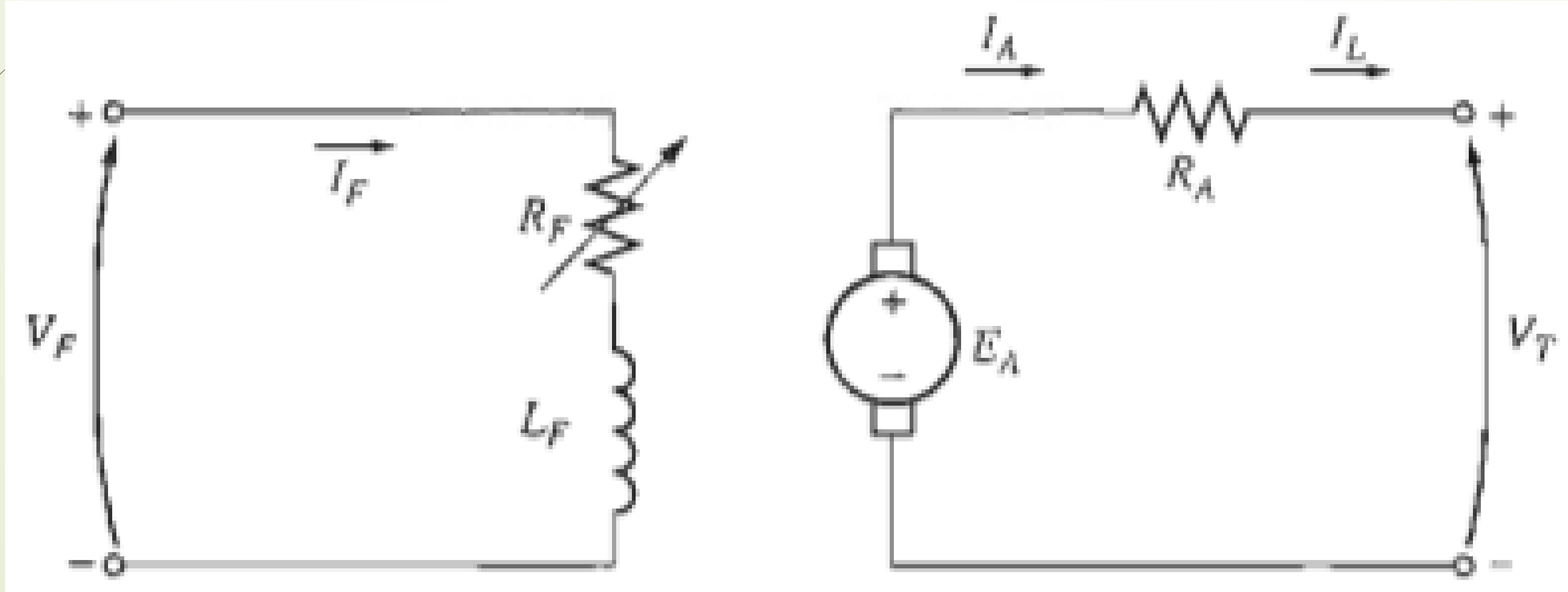
Equivalent circuit of a DC Generator





Separately Excited DC Generator

- A separately excited de generator is a generator whose field current is supplied by a separate external de voltage source.



Equivalent circuit of Separately Excited DC Generator

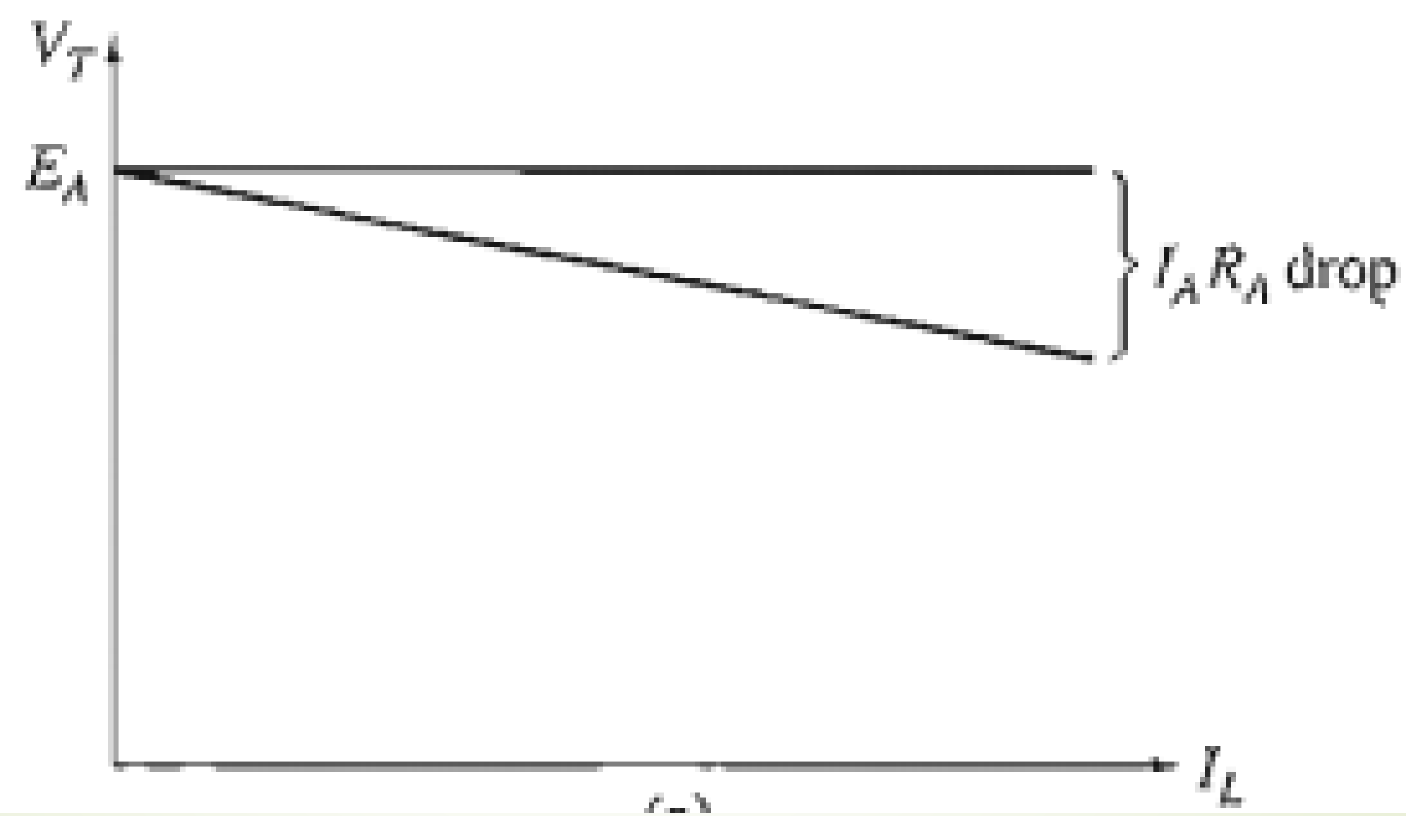
- In this circuit, the voltage V_T represents the actual voltage measured at the terminals of the generator, and the current I_L represents the current flowing in the lines connected to the terminals.
- The internal generated voltage is E_A , and the armature current is I_A.
- It is clear that the armature current is equal to the line current in a separately excited generator:

$$I_A = I_L$$

$$V_T = E_A - I_A R_A$$

$$I_F = V_F / R_F$$

Terminal Characteristics of Separately Excited DC Generator



Terminal Characteristics of Separately Excited DC Generator

- The terminal characteristic of a device is a plot of the output quantities of the device versus each other.
- For a dc generator, the output quantities are its terminal voltage and line current.
- The terminal characteristic of a separately excited generator is thus a plot of V_T versus I_L for a constant speed ω. By Kirchhoff's voltage law, the terminal voltage is;

$$V_T = E_A - I_A R_A$$

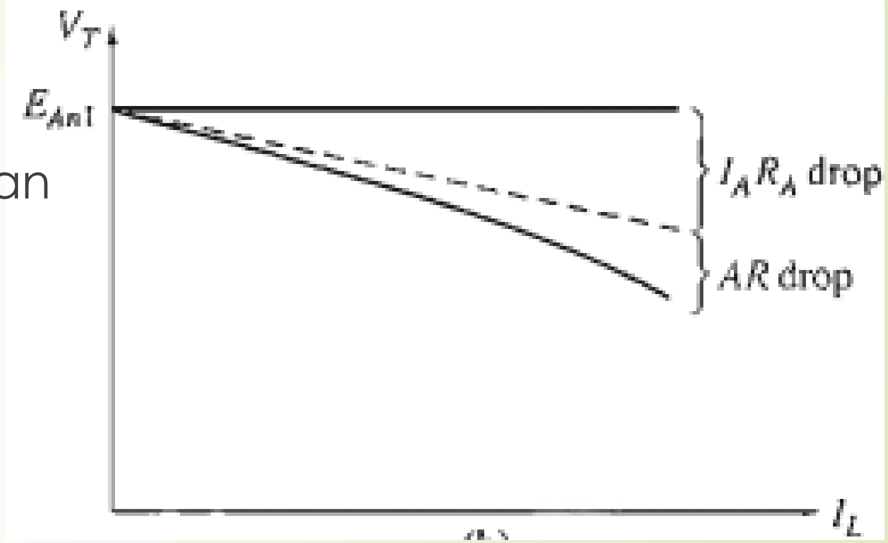
- Since the internal generated voltage is independent of I_A, the terminal characteristic of the separately excited generator is a straight line.
- When the load supplied by the generator is increased, I_L (and therefore I_A) increases. As the armature current increases, the $I_A R_A$ drop increases, so the terminal vo1tage of the generator falls.

Terminal Characteristics of Separately Excited DC Generator

- This terminal characteristic is not always entirely accurate.
- In generators without compensating windings, an increase in I_A causes an increase in armature reaction, and armature reaction causes flux weakening.
- This flux weakening causes a decrease in E_A.

$$E_A = K\phi\downarrow\omega_m$$

- Which further decreases the terminal voltage of the generator.



Control of Terminal Voltage of Separately Excited DC Generator

- The terminal voltage of a separately excited dc generator can be controlled by changing the internal generated voltage E_A of the machine.
- By Kirchhoff's voltage law $\mathbf{V_T = E_A - I_AR_A}$' so if $\mathbf{E_A}$ increases, $\mathbf{V_T}$ will increase, and if $\mathbf{E_A}$ decreases, $\mathbf{V_T}$ will decrease. Since the internal generated voltage $\mathbf{E_A}$ is given by the equation

$$E_A = K\phi\omega_m$$

- there are two possible ways to control the voltage of this generator:
  1. *Change the speed of rotation*. If ω increases, then E_A increases, so $V_T = E_A – I_AR_A$ increases as well.
  2. *Change the field current*. If R_F is decreased, then the field current increases $I_F = V_F / R_F \downarrow$ Therefore, the flux "**Φ**", in the machine increases. As the flux rises, $E_A = K\phi\uparrow\omega_m$ must rise too, so $V_T = E_A\uparrow - I_AR_A$ increases.

Practice Example 8.9

DC Shunt Generator

- A shunt dc generator is a dc generator that supplies its own field current by having its field connected directly across the terminals of the machine.
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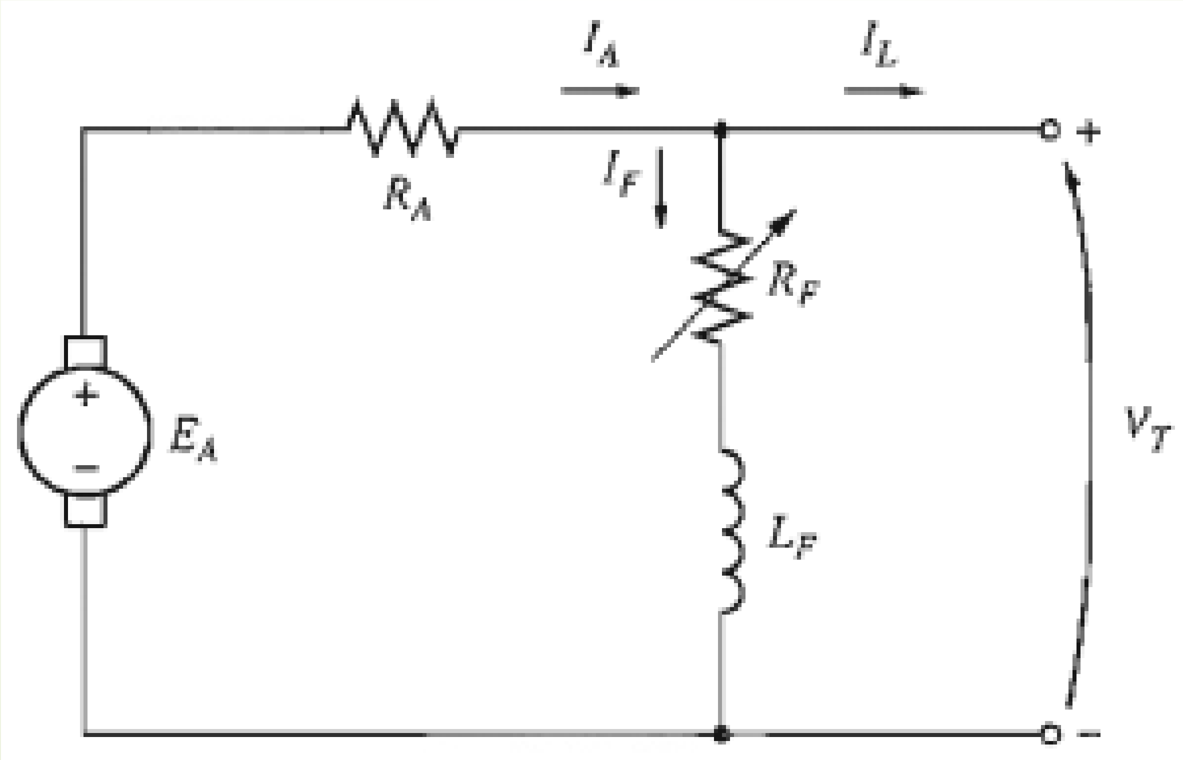


Equivalent circuit of DC Shunt Generator

- Armature current is divided into load current and field current;

$$I_A = I_L + I_F$$

- The Kirchhoff's voltage law equation for the armature circuit of this machine is;

$$V_T = E_A - I_A R_A$$

and

$$I_F = V_T / R_F$$

- This type of generator has a distinct advantage over the separately excited DC generator in that no external power supply is required for the field circuit.
- But, that leaves an important question unanswered: If the generator supplies its own field current, how does it get the initial field flux to start when it is first turned on?

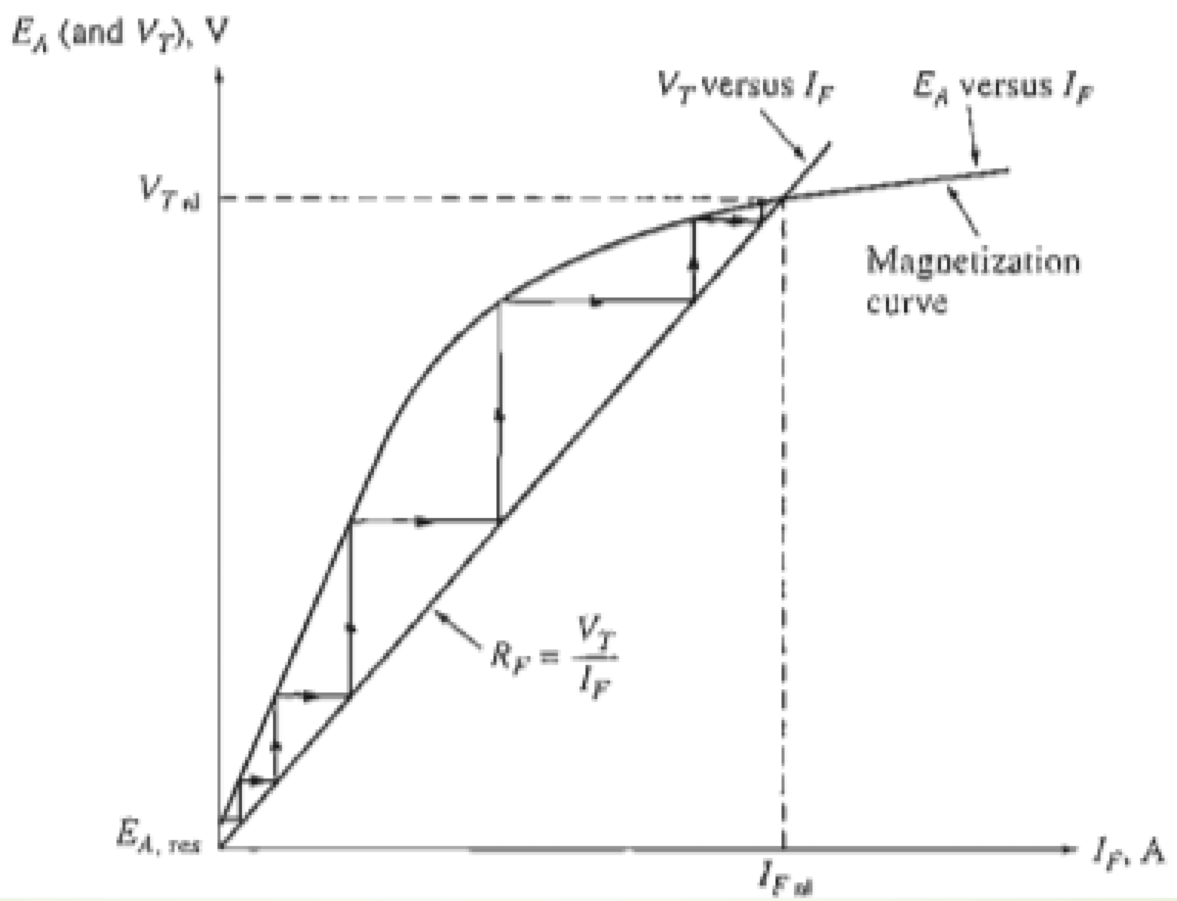
Voltage Buildup in DC Shunt Generator

- The voltage buildup in a de generator depends on the presence of a residual flux in the poles of the generator. When a generator first starts to turn, an internal voltage will be generated, which is given by

$$E_A = K\phi_{res}\omega_m$$

- This voltage appears at the terminals of the generator (it may only be a volt or two). But when that voltage appears at the terminals, it causes a current to flow in the generator's field coil $I_F = V_T\uparrow/R_F$
- This field current produces a magnetomotive force in the poles. which increases the flux in them. The increase in flux causes an increase in $E_A = K\phi\uparrow\omega_m$ which increases the terminal voltage V_T .
- When V_T rises, I_F increases further, increasing the flux **Φ** more, which increases E_A. etc.

Voltage Buildup in DC Shunt Generator

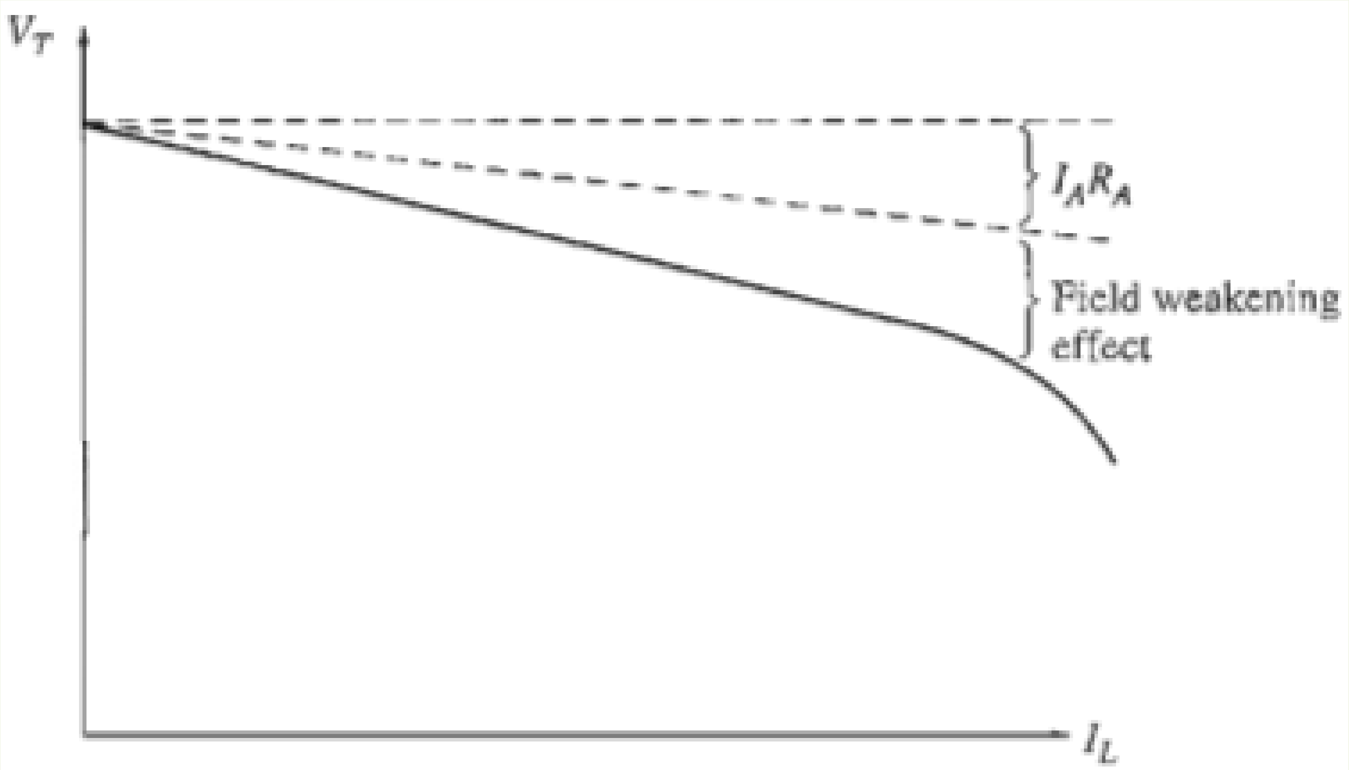


Voltage Buildup in DC Shunt Generator

There are several possible causes for the voltage to fail to build up during starting. Among them are;

- There may be no residual magnetic flux in the generator to start the process going. If the residual flux Φ= 0, then E_A = 0, and the voltage never builds up.
  - If this problem occurs, disconnect the field from the armature circuit and connect it directly to an external dc source, such as a battery. The current flow from this external dc source will leave a residual flux in the poles, which will then allow normal starting. This procedure is known as "flashing the field."
- The direction of rotation of the generator may have been reversed, or the connections of the field may have been reversed. In either case, the residual flux produces an internal generated voltage E_G ,The voltage E_A produces a field current which produces a flux opposing the residual flux, instead of adding to it. Under these circumstances, the flux actually decreases below Φres and no voltage can ever build up.
  - It can be fixed by reversing the direction of rotation, by reversing the field connections, or by flashing the field with the opposite magnetic polarity.
- The field resistance may be adjusted to a value greater than the critical resistance. Point, the voltage of the generator can fluctuate very widely with only tiny changes in R_F or 1_A. This value of the resistance is called the critical resistance. If R_F exceeds the critical resistance, then the steady-state operating voltage is essentially at the residual level, and it never builds up.
  - The solution to this problem is to reduce R_F .

Terminal Characteristics of DC Shunt Generator



Terminal Characteristics of DC Shunt Generator

- The terminal characteristic of a shunt dc generator differs from that of a separately excited dc generator, because the amount of field current in the machine depends on its terminal Voltage.
- As the load on the generator is increased, I_L increases and so $\mathbf{I_A = I_L + I_F}$
- An increase in I_A increases the armature resistance voltage drop $I_A R_A$ causing $\mathbf{V_T = E_A - I_A{\uparrow}R_A}$ to decrease.
- When V_T decreases, the field current in the machine decreases with it. This causes the flux in the machine to decrease, decreasing E_A.
- Decreasing E_A causes a further decrease in the terminal voltage $\mathbf{V_T = E_A{\downarrow} - I_A R_A}$

Voltage Control of DC Shunt Generator

There are two ways to control the voltage of a shunt generator:

1. Change the shaft speed ω_m of the generator.
2. Change the field resistor of the generator, thus changing the field current.

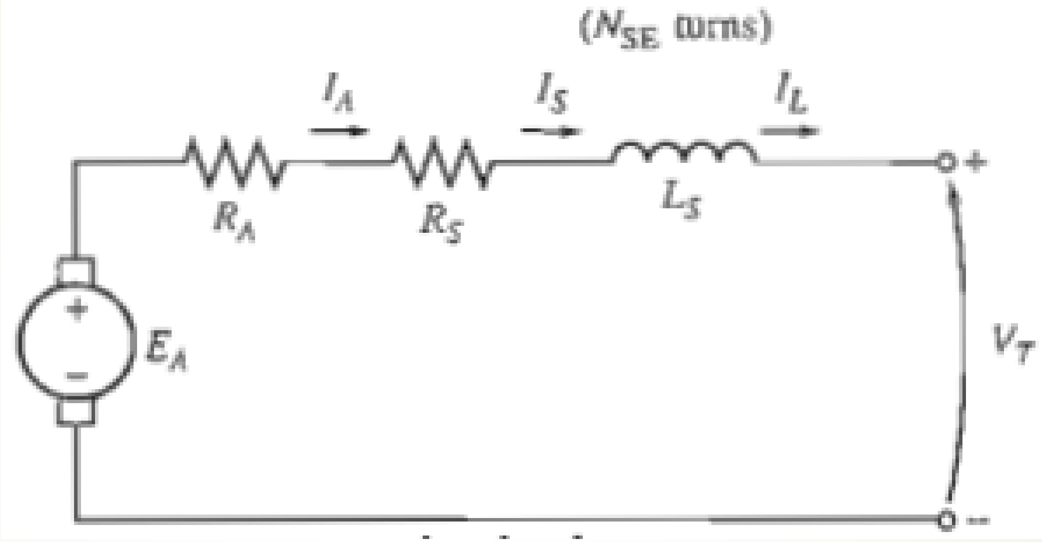
- Changing the field resistor is the principal method used to control terminal voltage in real shunt generators. If the field resistor Rr is decreased, then the field current $\mathbf{I_F = V_T/R_F\downarrow}$ increases. When I_F increases, the machine's flux Φ increases, causing the internal generated voltage E_A to increase. The increase in E_A causes the terminal voltage of the generator to increase as well.

DC Series Generator

- A series dc generator is a generator whose field is connected in series with its armature. Since the armature has a much higher current than a shunt field, the series field in a generator of this sort will have only a very few turns of wire, and the wire used will be much thicker than the wire in a shunt field.

- Because magnetomotive force is given by the equation mmf = NI, exactly the same magnetomotive force can be produced from a few turns with high current as can be produced from many turns with low current. Since the full-load current flows through it, a series field is designed to have the lowest possible resistance.

Equivalent circuit of DC Series Generator



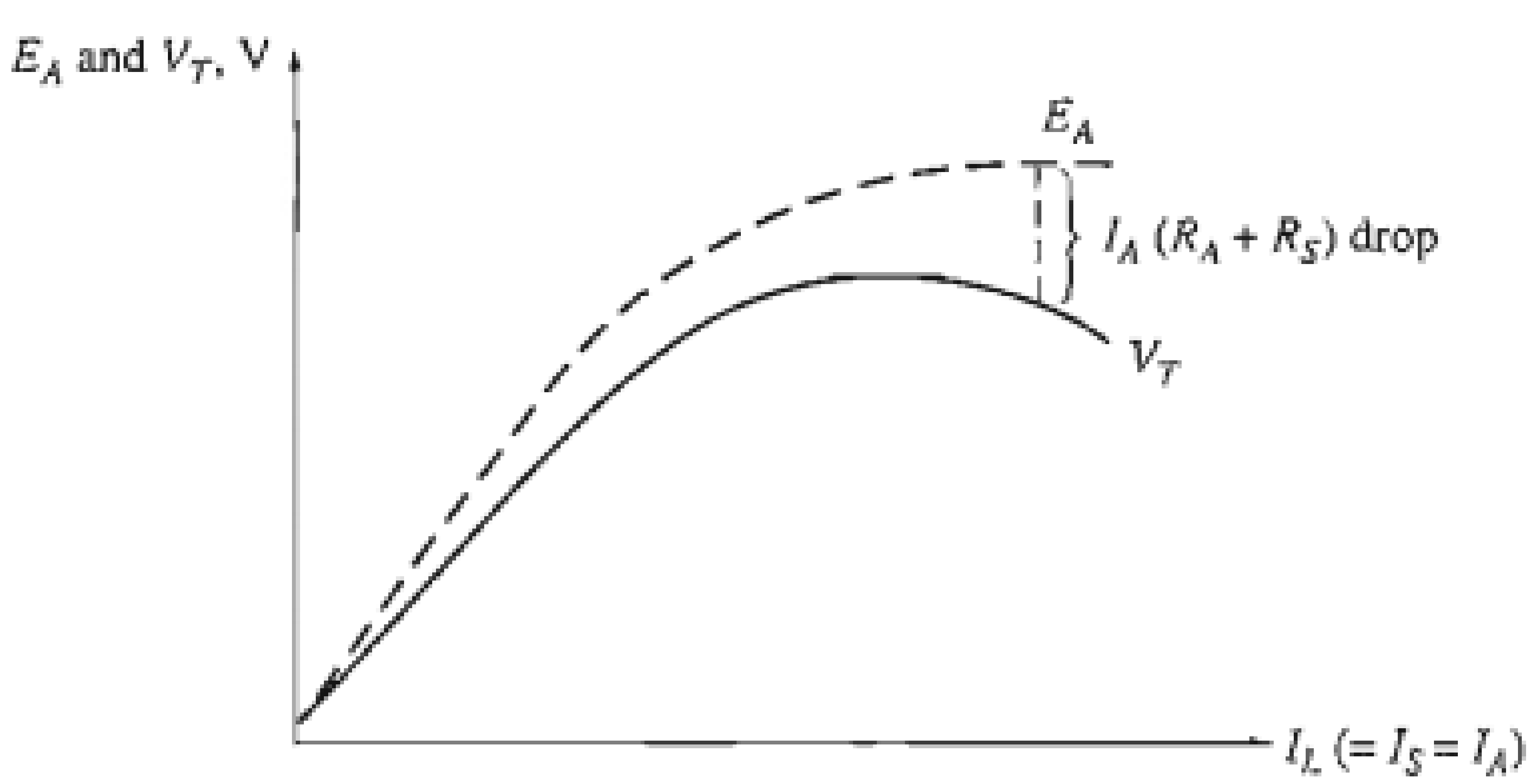
- The armature current, field current, and line current all have the same value.

$$I_A = I_S = I_L$$

- The Kirchhoff's voltage law equation for this machine is

$$V_T = E_A - I_A (R_A + R_S)$$

Terminal Characteristics of DC Series Generator



Terminal Characteristics of DC Series Generator

- At no load, however, there is no field current, so VT is reduced to a small level given by the residual flux in the machine.
- As the load increases, the field current rises, so E_A rises rapidly. The $I_A(R_A + R_S)$ drop goes up too, but at first the increase in EA goes up more rapidly than the $I_A(R_A + R_S)$ drop rises, so V_T increases.
- After a while, the machine approaches saturation, and E_A becomes almost constant.
- At that point, the resistive drop is the predominant effect, and V_T Starts to fall.
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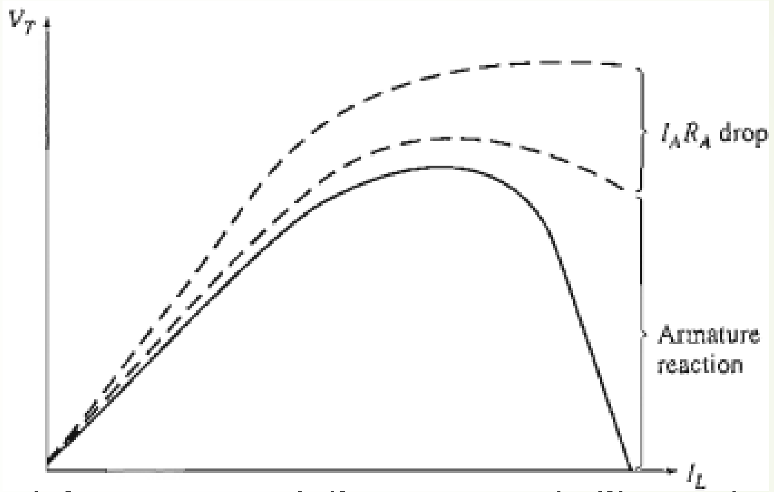
Terminal Characteristics of DC Series Generator for Arc Welding



- Series generators used in arc welding are deliberately designed to have a large armature reaction
- when the welding electrodes make contact with each other before welding commences, a very large current flows. As the operator separates the welding electrodes, there is a very steep rise in the generator's voltage while the current remains high. This voltage ensures that a welding arc is maintained through the air between the electrodes.

Losses in DC Machines

1. Electrical or Copper Losses (I^2R losses)
2. Brush Losses
3. Core Losses
4. Mechanical Losses
5. Stray Load Losses

Losses in DC Machines

ELECTRICAL OR COPPER LOSSES. Copper losses are the losses that occur in the armature and field windings of the machine. The copper losses for the armature and field windings are given by

$$\text{Armature loss:} \qquad P_A = I_A^2 R_A \tag{7–52}$$

$$\text{Field loss:} \qquad P_F = I_F^2 R_F \tag{7–53}$$

BRUSH LOSSES. The brush drop loss is the power lost across the contact potential at the brushes of the machine. It is given by the equation

$$P_{BD} = V_{BD} I_A \tag{7–54}$$

Losses in DC Machines

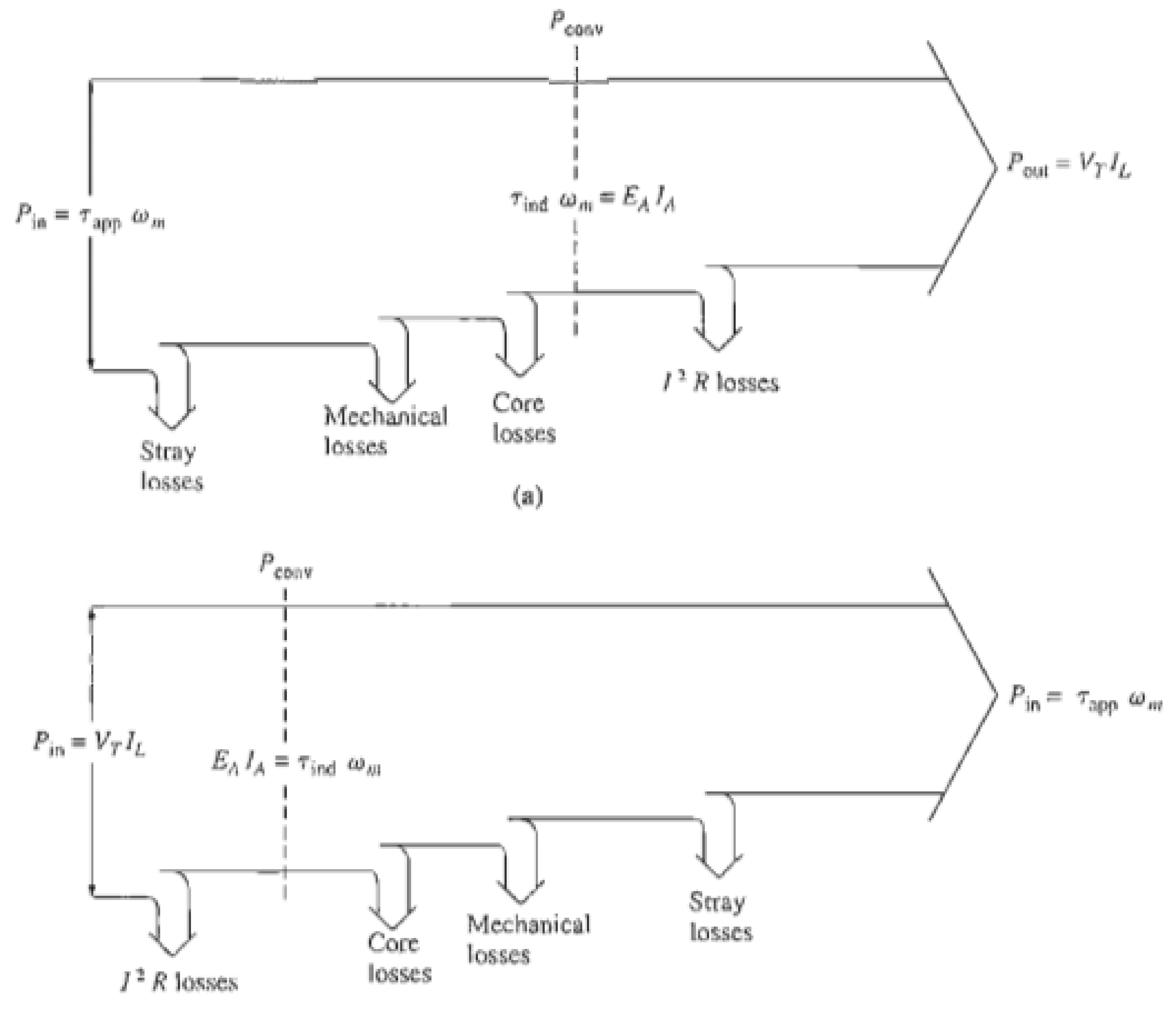
CORE LOSSES. The core losses are the hysteresis losses and eddy current losses occurring in the metal of the motor. These losses are described in Chapter 1. These losses vary as the square of the flux density (B^2) and, for the rotor, as the 1.5th power of the speed of rotation ($n^{1.5}$).

MECHANICAL LOSSES. The mechanical losses in a dc machine are the losses associated with mechanical effects. There are two basic types of mechanical losses: *friction* and *windage*. Friction losses are losses caused by the friction of the bearings in the machine, while windage losses are caused by the friction between the moving parts of the machine and the air inside the motor's casing. These losses vary as the cube of the speed of rotation of the machine.

Losses in DC Machines

STRAY LOSSES (OR MISCELLANEOUS LOSSES). Stray losses are losses that cannot be placed in one of the previous categories. No matter how carefully losses are accounted for, some always escape inclusion in one of the above categories. All such losses are lumped into stray losses. For most machines, stray losses are taken by convention to be 1 percent of full load.

Power Flow Diagram of DC Machines



Exercise Chapter 8

- Numericals /Practice Problems related to Motors and Generators.