CAN102
Electromagnetism and Electromechanics

2023/24-S2

Lecture 18 DC Generators

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Major Types of DC Generators

The major types of DC generators in general use:

- Separately excited DC generators (他励直流发电机)
- Self-excited DC generators (自励直流发电机)

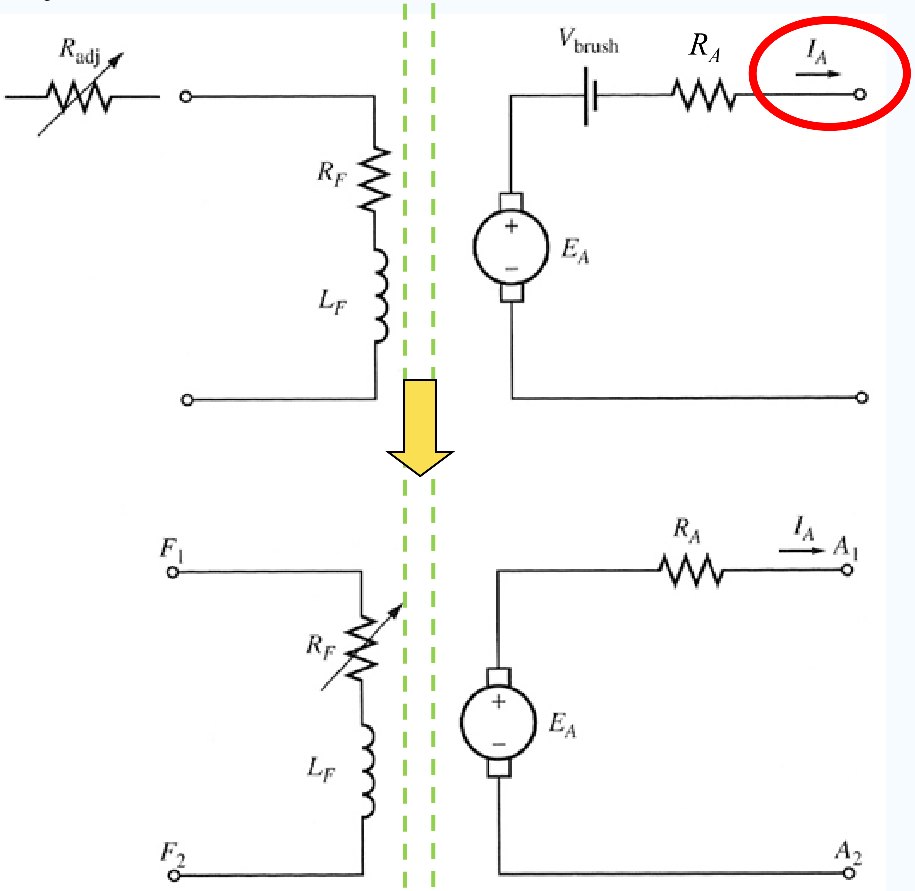
The shunt DC generators : the armature coils are connected in parallel with the field coils

The series DC generators : the armature coils are connected in series with the field coils

The compounded DC generators : the armature coils are connected in series/parallel with the field coils

General Equivalent Circuit

adjustable resistor



Field Circuit

Armature Circuit

For any DC machines:

armature circuit

E_A :an ideal voltage source (internal generated voltage)

R_A : a resistor of armature windings

I_A: armature current

V_{brush}: the brush voltage drop opposing the direction of the current flow in the machine

field circuit

L_F : an inductor produces the magnetic flux in the generator

R_F: a resistor of field windings

R_{adj} :an external variable resistor used to control the amount of current in the field circuit.

Separately Excited DC Generators

The field current is supplied by a separate external DC voltage source V_F,

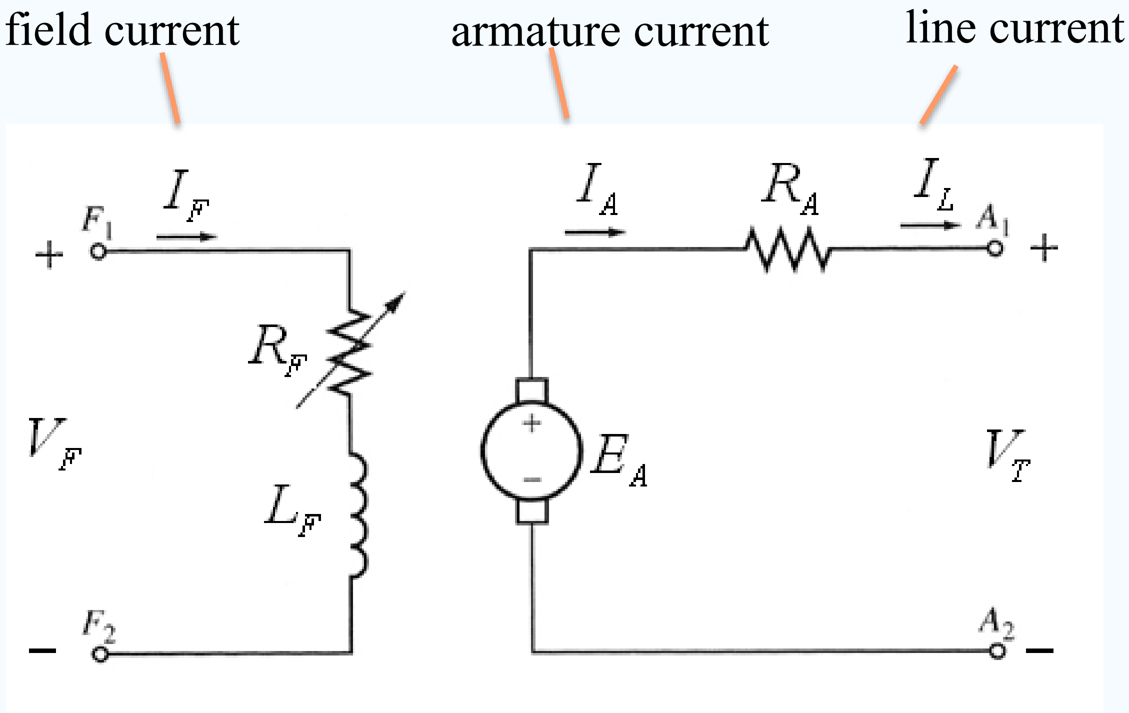
V_T is the output voltage measured at the terminals of generators

◆ **Equivalent Circuit**

$$I_F = V_F / R_F$$

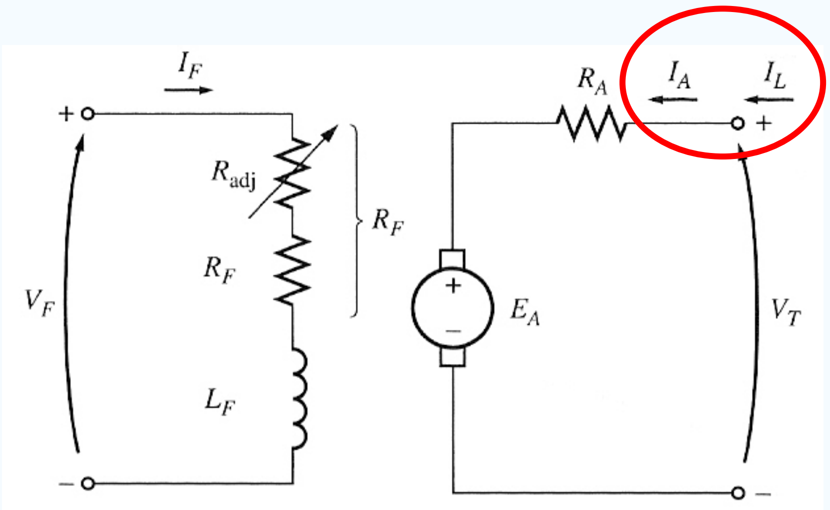
$$V_T = E_A - I_A R_A$$

$$I_L = I_A$$



Comparison

Separately excited DC **motors**

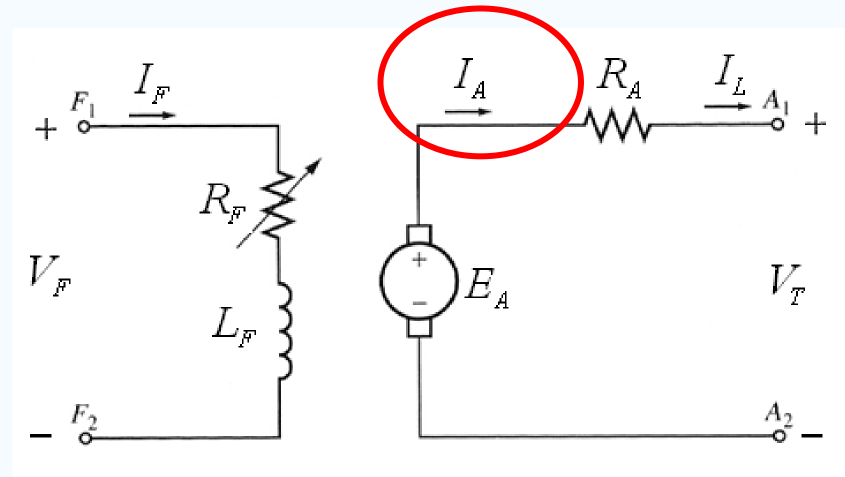


$$I_F = V_F/R_F$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A$$

Separately excited DC **generators**



$$I_F = V_F/R_F$$

$$V_T = E_A - I_A R_A$$

$$I_L = I_A$$

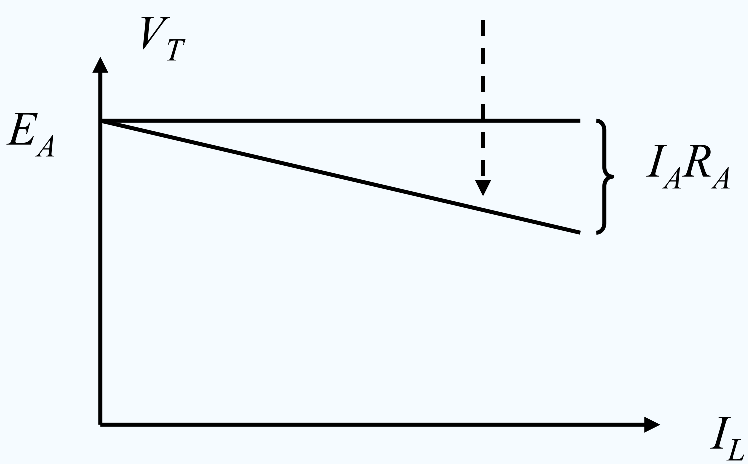
Separately Excited DC Generators

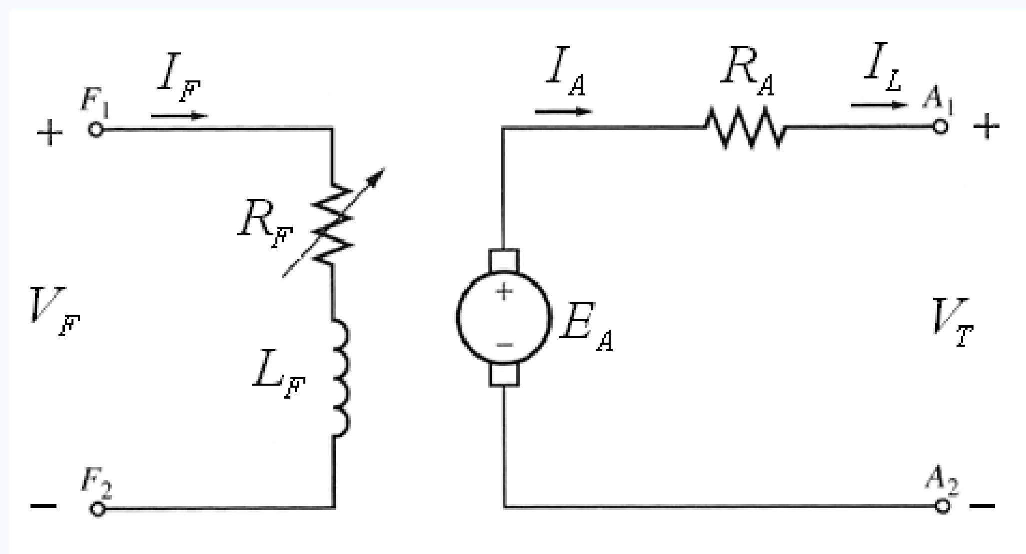
◆ Terminal Characteristic

The terminal characteristic of a separately excited generator is a plot of V_T versus I_L for a constant speed ω.

When load ↑

$$V_T \downarrow = E_A - I_A R_A \uparrow$$

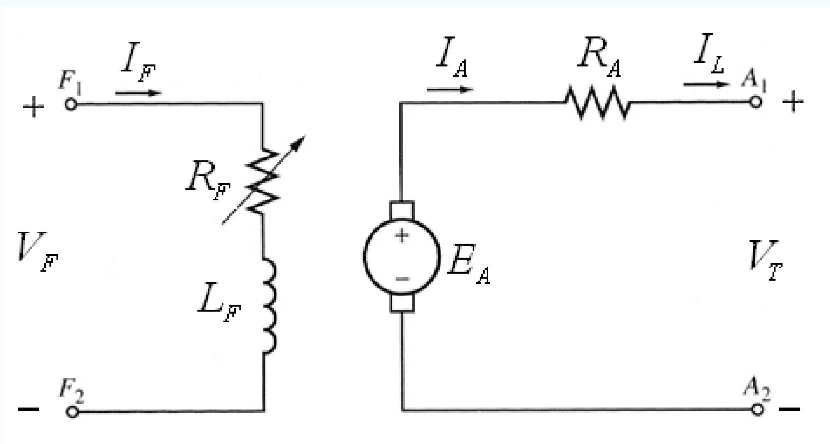




Separately Excited DC Generators

◆ Control of Terminal Voltage V_T

In many applications, the speed range of the prime mover is quite limited, so the terminal voltage is most commonly controlled by changing the field current (by changing the resistance of the field windings).



1. Change the speed of rotation: when $\omega \uparrow$

$$V_T \uparrow = E_A \uparrow - I_A R_A$$

$$E_A \uparrow = K\Phi\omega \uparrow$$

2. Change the field current: when $R_F \downarrow$

$$I_F \uparrow = V_F / R_F \downarrow$$

$$\Phi \uparrow \dashrightarrow E_A \uparrow \dashrightarrow V_T \uparrow$$

Separately Excited DC Generators

◆ Nonlinear Analysis

The internal generated voltage E_A of a generator is a nonlinear function of its magnetomotive force and field current I_F

The nonlinearity is represented by the magnetization curve.

If a machine has armature reaction, its flux will be reduced with each increase in load, causing E_A to decrease.

The equivalent actual field current is given by $I_F^{*} = I_F - \dfrac{F_{AR}}{N_F}$

It is often easy to calculate I_F in a separately excited DC generator, then we can find E_A in the magnetization curve.

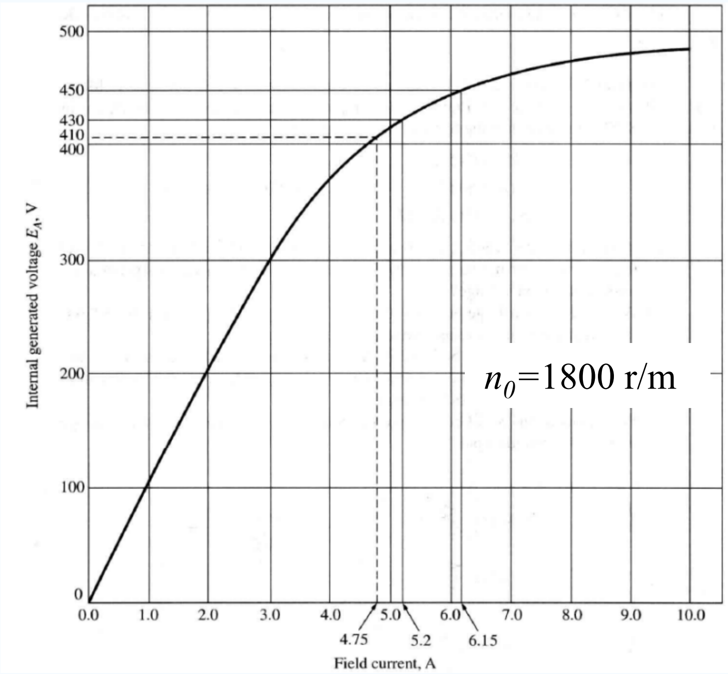
Separately Excited DC Generators

◆ Nonlinear Analysis

The difference between the speed of the magnetization curve and the real speed of the generator must be taken into account

$$\boxed{\frac{E_A}{E_{A0}} = \frac{\omega_m}{\omega_0} = \frac{n_m}{n_0}}$$

Where E_{A0} and n_0 represent the reference values of voltage and speed, respectively



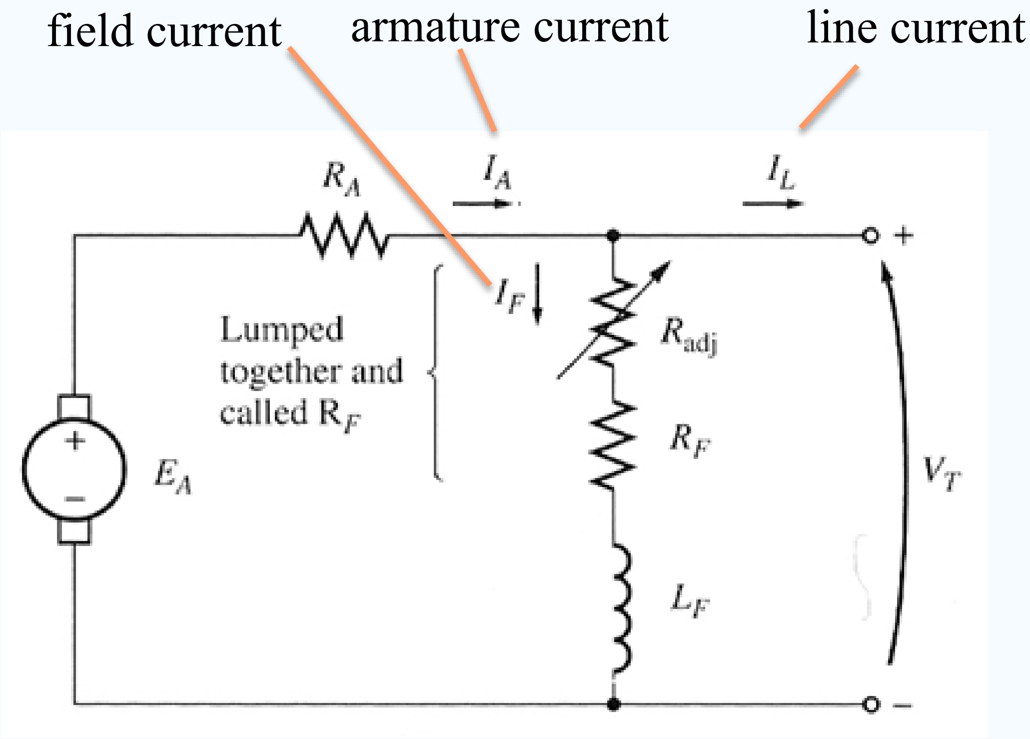
Shunt DC Generators

the armature coils are connected in parallel with the field coils. (no external power supply is required for the field circuit)

V_T is the output voltage measured at the terminals of generators

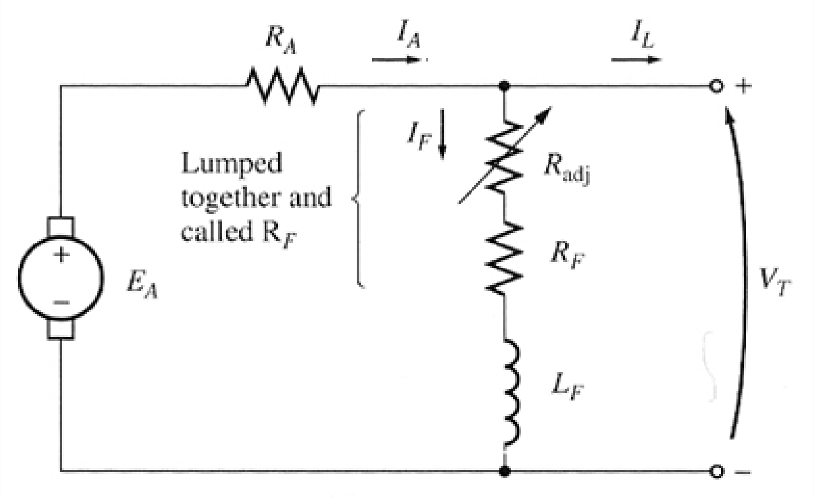
- **Equivalent Circuit**

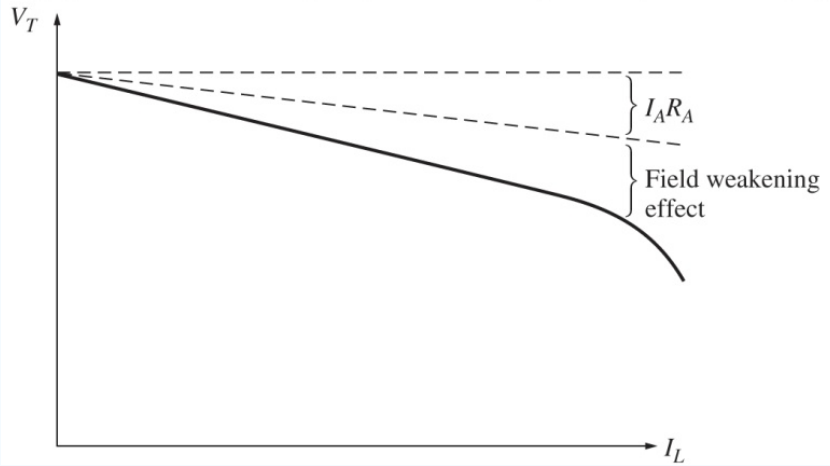
$$I_A = I_F + I_L$$
$$V_T = E_A - I_A R_A$$
$$I_F = V_T / R_F$$



Shunt DC Generators

◆ Terminal Characteristic





$I_A = I_F + I_L$

$V_T = E_A - I_A R_A$

$I_F = V_T / R_F$

When load $\uparrow$, then $I_L \uparrow \quad \Rightarrow I_A \uparrow (= I_F + I_L)$

causing $V_T \downarrow (= E_A - I_A \uparrow R_A)$

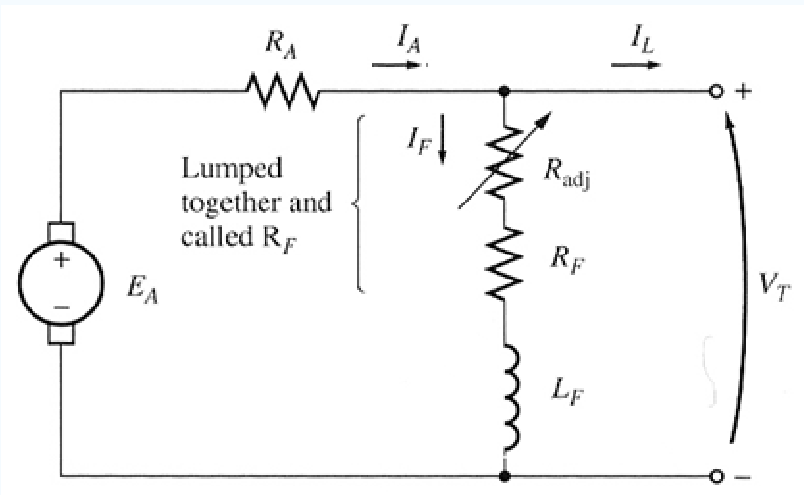
$V_T \downarrow \quad \Rightarrow \quad I_F \downarrow (= V_T / R_F) \quad \Rightarrow \quad \Phi \downarrow \quad \Rightarrow \quad E_\mathrm{A} \downarrow (= K\Phi\omega)$

$E_\mathrm{A} \downarrow$ also $\Rightarrow \quad V_T \downarrow (= E_A - I_A R_A)$

The voltage regulation of a shunt generator is worse than that of a separately excited generator.

Shunt DC Generators

◆ Control of Terminal Voltage V_T



1. Change the speed of rotation: when $\omega \uparrow$

$$V_T \uparrow = E_A \uparrow - I_A R_A$$

$$E_A \uparrow = K\Phi\omega \uparrow$$

2. Principal method-Change the field resistor (field current): when $R_F \downarrow$

$$I_F \uparrow = V_F / R_F \downarrow$$

$$\Phi \uparrow \dashrightarrow E_A \uparrow \dashrightarrow V_T \uparrow$$

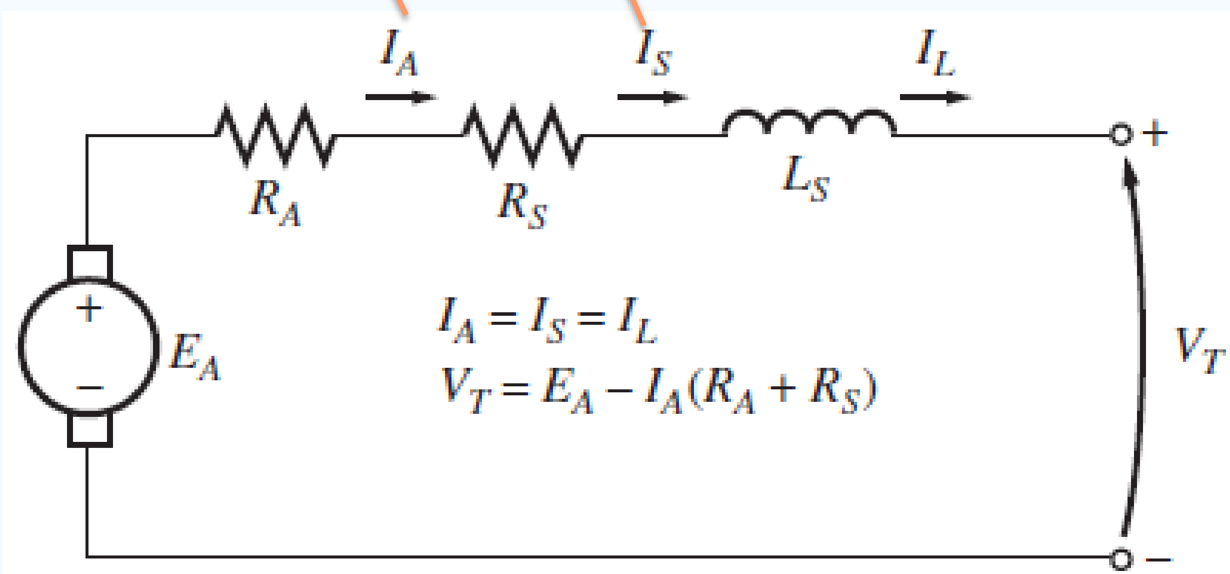
Series DC Generators

the armature coils are connected in series with the field coils. (no external power supply is required for the field circuit)

V_T is the output voltage measured at the terminals of generators

- **Equivalent Circuit**

armature current field current line current



Series DC Generators

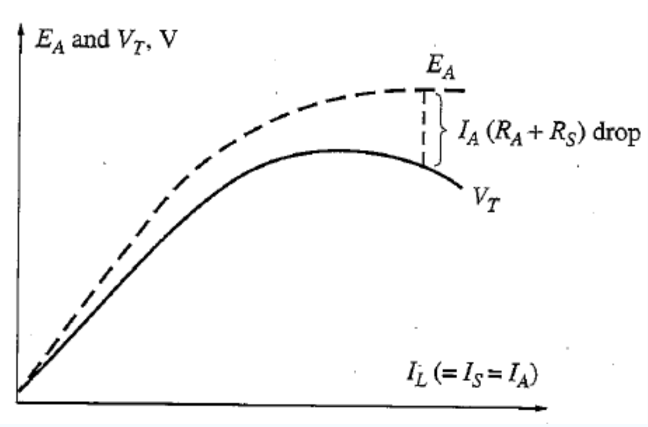
◆ Terminal Characteristic

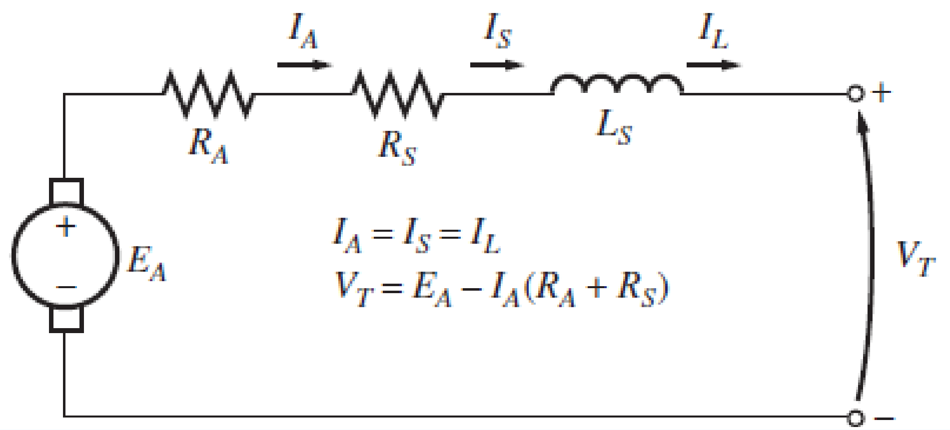
When load $\uparrow$, then $I_F \uparrow \Rightarrow E_{\mathrm{A}} \uparrow$ and $I_A(R_A + R_S) \uparrow$

From no load, at first the $E_{\mathrm{A}} \uparrow$ more rapidly than $I_A(R_A + R_S) \uparrow$,

so $V_T \uparrow$, after a while, the machine approaches saturation, and E_{A}

becomes almost constant, then $I_A(R_A + R_S) \uparrow$ is predomiant effect $\Rightarrow V_T \downarrow$.





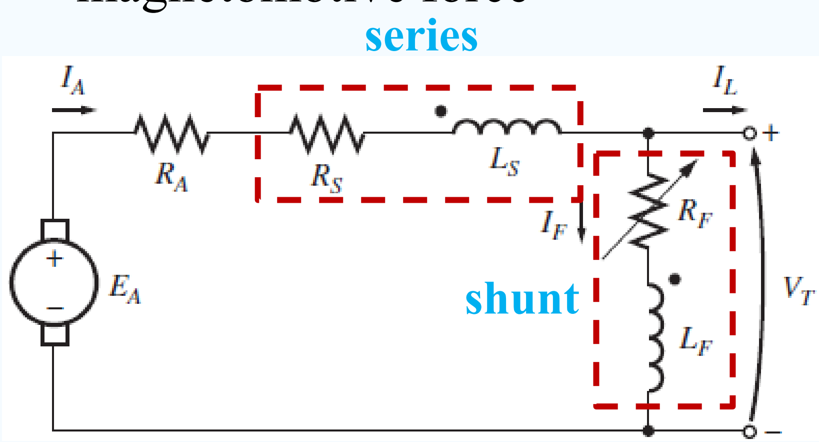
A series generator would make a bad constant-voltage source.

Compounded DC Generators

◆ Equivalent Circuit

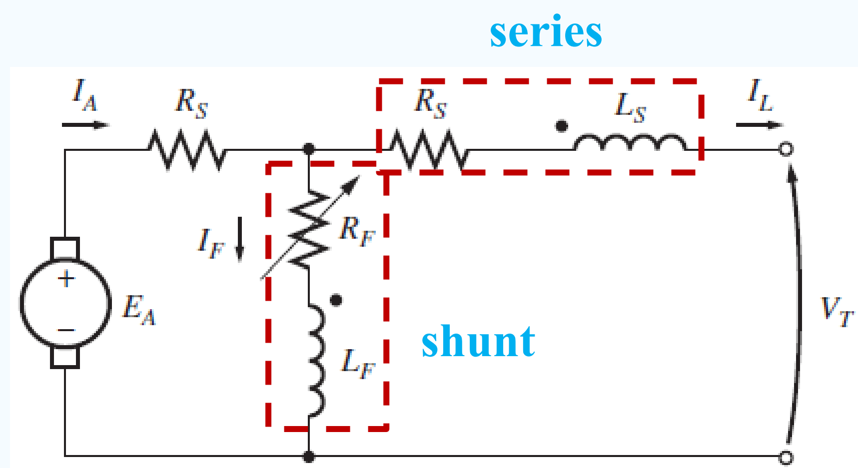
A compounded DC generator: the armature coils are connected in series/parallel with the field coils.

The dot means current flowing into a dot produces a positive magnetomotive force



Long-shunt connection

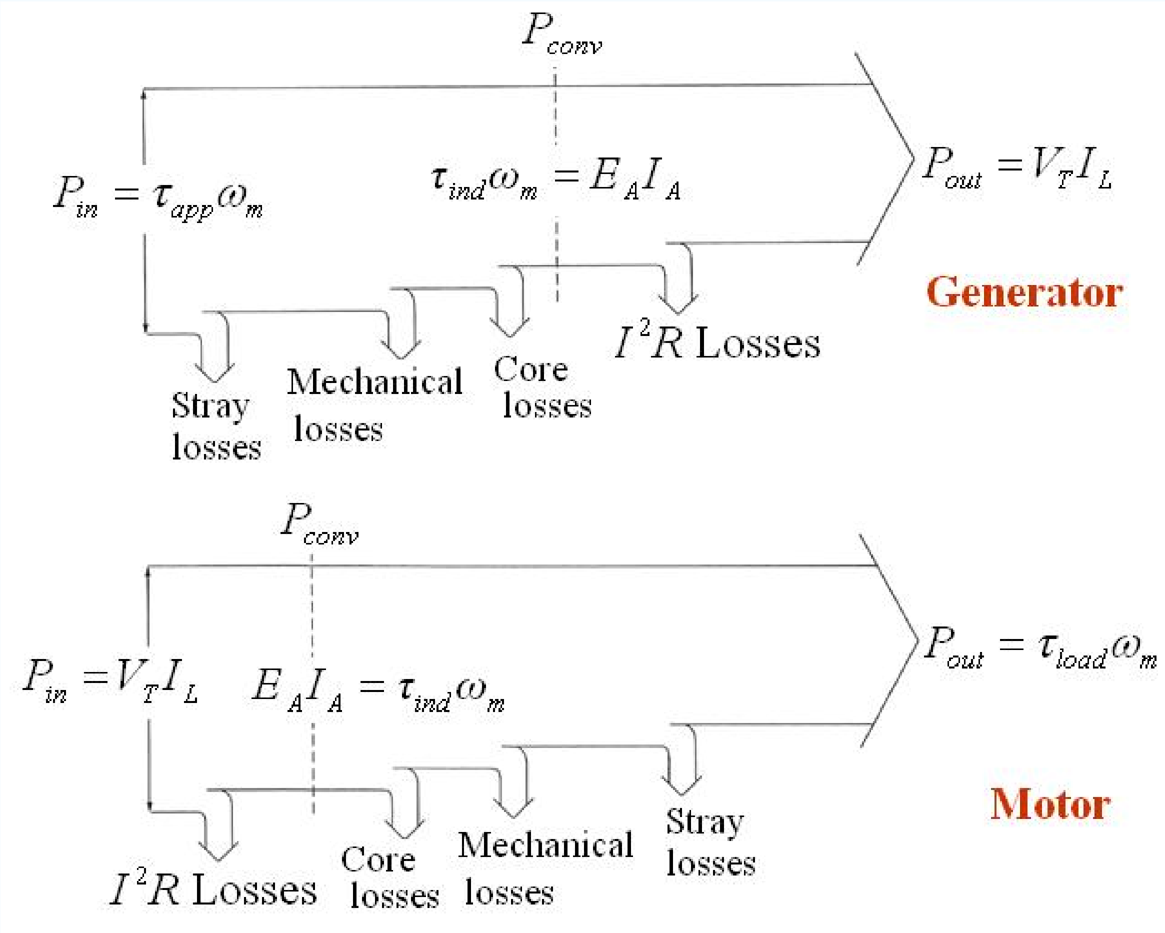
$$I_A = I_F + I_L$$
$$V_T = E_A - I_A(R_A + R_S)$$
$$I_F = V_T / R_F$$



Short-shunt connection

$$I_A = I_F + I_L$$
$$V_T = E_A - I_A R_A - (I_A - I_F) R_S$$
$$\cancel{I_F = V_T / R_F}$$

Power Flow in DC Machines



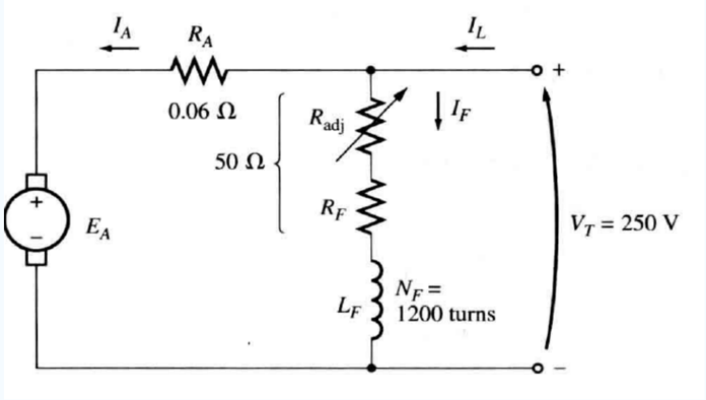
DC generators convert mechanical energy to DC electric energy.

DC motors convert DC electric energy to mechanical energy.

There is no real difference between a generator and a motor except for the direction of power flow.

Example 1

One 250 V, 1200 r/min dc shunt motor with compensating windings has an armature resistance of 0.06 Ω, as shown in the figure. Its field circuit has a total resistance $R_{adj}+R_F$ of 50 Ω, which produces a no-load speed of 1200 r/min.



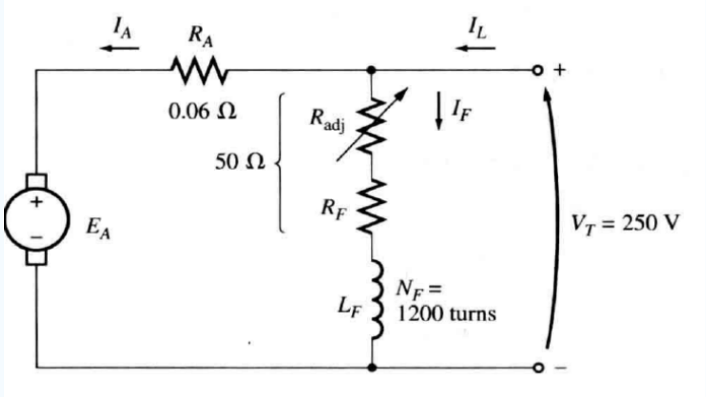
a) Find the speed of this motor when I_L=100 A

b) Find the speed of this motor when I_L =200 A

c) Find the speed of this motor when I_L =300 A

d) Find the induced torque of this motor when I_L =300 A

Example 1



$$I_F = V_T/R_F$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A + I_F$$

a) Find the speed of this motor when I_L=100 A

$$I_F = \frac{V_T}{R_F} = \frac{250}{50} = 5 \text{ A}$$

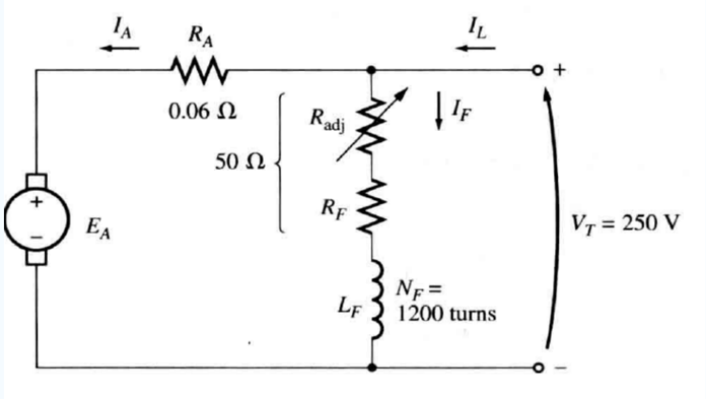
$$\boxed{\frac{E_A}{E_{A0}} = \frac{\omega_m}{\omega_0} = \frac{n_m}{n_0}}$$

$$I_A = I_L - I_F = 100 - 5 = 95 \text{ A}$$

$$E_A = V_T - I_A R_A = 250 - 95 \times 0.06 = 244.3 \text{ V}$$

$$n_m = n_0 \frac{E_A}{E_{A0}} = n_0 \frac{E_A}{V_T} = 1200 \frac{244.3}{250} = 1173 \text{ r/min}$$

Example 1



$$I_F = V_T/R_F$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A + I_F$$

b) Find the speed of this motor when I_L=200 A

$$I_F = \frac{V_T}{R_F} = \frac{250}{50} = 5 \text{ A}$$

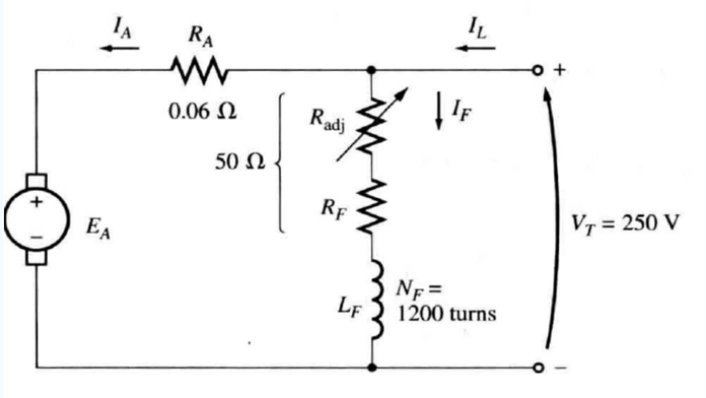
$$\boxed{\frac{E_A}{E_{A0}} = \frac{\omega_m}{\omega_0} = \frac{n_m}{n_0}}$$

$$I_A = I_L - I_F = 200 - 5 = 195 \text{ A}$$

$$E_A = V_T - I_A R_A = 250 - 195 \times 0.06 = 238.3 \text{ V}$$

$$n_m = n_0 \frac{E_A}{E_{A0}} = n_0 \frac{E_A}{V_T} = 1200 \frac{238.3}{250} = 1144 \text{ r/min}$$

Example 1



$$I_F = V_T/R_F$$

$$V_T = E_A + I_A R_A$$

$$I_L = I_A + I_F$$

c) Find the speed of this motor when I_L=300 A

$$\boxed{\frac{E_A}{E_{A0}} = \frac{\omega_m}{\omega_0} = \frac{n_m}{n_0}}$$

$$I_F = \frac{V_T}{R_F} = \frac{250}{50} = 5 \text{ A}$$

$$I_A = I_L - I_F = 300 - 5 = 295 \text{ A}$$

$$E_A = V_T - I_A R_A = 250 - 295 \times 0.06 = 232.3 \text{ V}$$

$$n_m = n_0 \frac{E_A}{E_{A0}} = n_0 \frac{E_A}{V_T} = 1200 \frac{232.3}{250} = 1115 \text{ r/ min}$$

Example 1

d) Find the induced torque of this motor when I_L =300 A

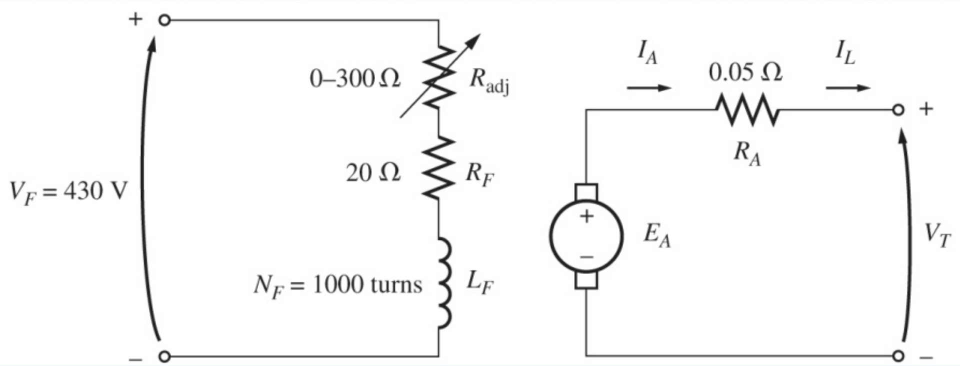
$$P_{conv} = E_A I_A = \tau_{ind}\omega_m$$

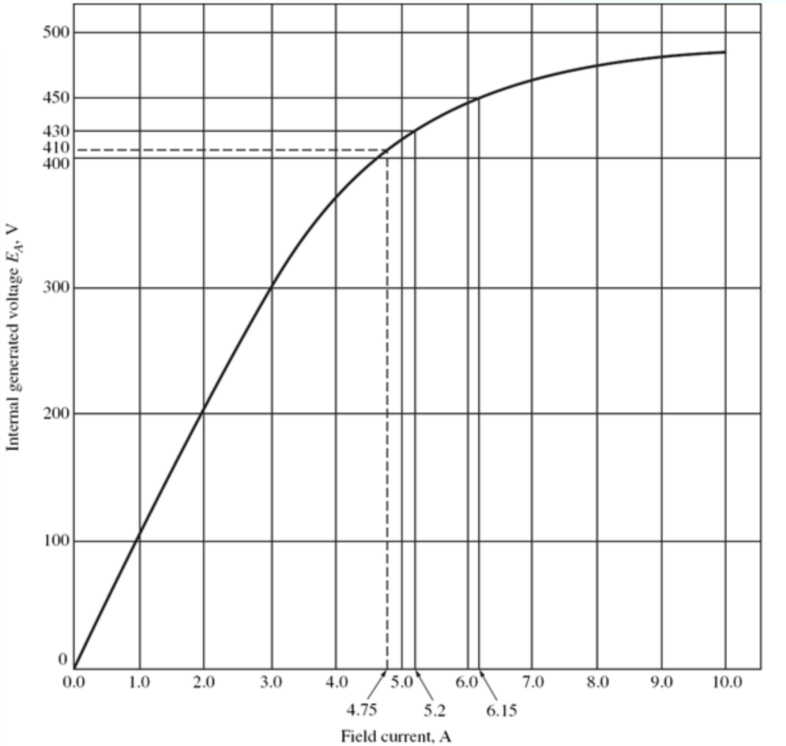
$$\tau_{ind} = \frac{E_A I_A}{\omega_m} = \frac{232.3 \times 295}{1115 \times 2\pi / 60} = 587 \ \text{N} \bullet \text{m}$$

Example 2

A separately excited dc generator is rated at 172 kW, 430 V, 400 A, and 1800 r/min. It is shown in Figure and its magnetization curve is shown in Figure This machine has the following characteristics:

$$R_A = 0.05\ \Omega \qquad V_F = 430\ \text{V}$$
$$R_F = 20\ \Omega \qquad N_F = 1000 \text{ turns per pole}$$
$$R_{\text{adj}} = 0 \text{ to } 300\ \Omega$$





Example 2

(a) If the variable resistor R_{adj} in this generator's field circuit is adjusted to 63 Ω and the generator's prime mover is driving it at 1600 r/min, what is this generator's no-load terminal voltage?

(b) What would its voltage be if a 360-A load were connected to its terminals? Assume that the generator has compensating windings.

(c) What would its voltage be if a 360-A load were connected to its terminals but the generator does not have compensating windings? Assume that its armature reaction at this load is 450 A • turns.

Example 2

Solution

(a) If the generator's total field circuit resistance is

$$R_F + R_{\text{adj}} = 83\ \Omega$$

then the field current in the machine is

$$I_F = \frac{V_F}{R_F} = \frac{430\ \text{V}}{83\ \Omega} = 5.2\ \text{A}$$

From the machine's magnetization curve, this much current would produce a voltage $E_{A0} = 430$ V at a speed of 1800 r/min. Since this generator is actually turning at $n_m = 1600$ r/min, its internal generated voltage E_A will be

$$\frac{E_A}{E_{A0}} = \frac{n_m}{n_0}$$

$$E_A = \frac{1600\ \text{r/min}}{1800\ \text{r/min}}\, 430\ \text{V} = 382\ \text{V}$$

Since $V_T = E_A$ at no-load conditions, the output voltage of the generator is $V_T = 382$ V.

Example 2

(*b*) If a 360-A load were connected to this generator's terminals, the terminal voltage of the generator would be

$$V_T = E_A - I_A R_A = 382 \text{ V} - (360 \text{ A})(0.05 \ \Omega) = 364 \text{ V}$$

(*c*) If a 360-A load were connected to this generator's terminals and the generator had 450 A • turns of armature reaction, the effective field current would be

$$I_F^* = I_F - \frac{\mathscr{F}_{AR}}{N_F} = 5.2 \text{ A} - \frac{450 \text{ A} \cdot \text{turns}}{1000 \text{ turns}} = 4.75 \text{ A}$$

From the magnetization curve, $E_{A0} = 410$ V, so the internal generated voltage at 1600 r/min would be

$$\frac{E_A}{E_{A0}} = \frac{n}{n_0} \qquad (8\text{–}13)$$

$$E_A = \frac{1600 \text{ r/min}}{1800 \text{ r/min}} 410 \text{ V} = 364 \text{ V}$$

Therefore, the terminal voltage of the generator would be

$$V_T = E_A - I_A R_A = 364 \text{ V} - (360 \text{ A})(0.05 \ \Omega) = 346 \text{ V}$$

It is lower than before due to the armature reaction.

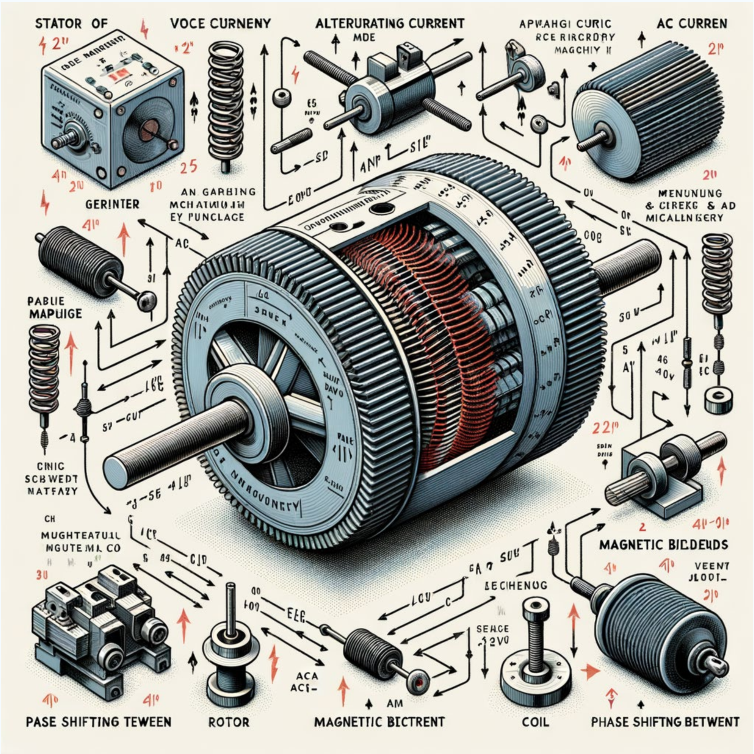
Summary

There are four types of DC generators:

separately excited （自励）, shunt （并励）, and series（串励）, and compounded（复励）.

- Equivalent Circuits
- Terminal Characteristic
- Methods of Terminal Voltage Control
- Non-linear Analysis

Next



AC Machinery Fundamentals

Thanks for your attention