Energy conversion I

Lecture 24:

Topic 6: DC Machines (S. Chapman   ch. 8 &9)

- A Simple Rotating Loop between Curved Pole Faces
- Commutation Problems in Real Machine
- The Construction of DC Machine
- The Internal Voltage and Torque Equations of Real DC Machine
- The Equivalent Circuit of a DC Motor
- Power Flow and Losses in DC Machines
- Separately Excited, Shunt, **Permanent-Magnet and Series DC Motors**
- **DC Motor Starter**
- Introduction to DC Generators

DC Series Motors

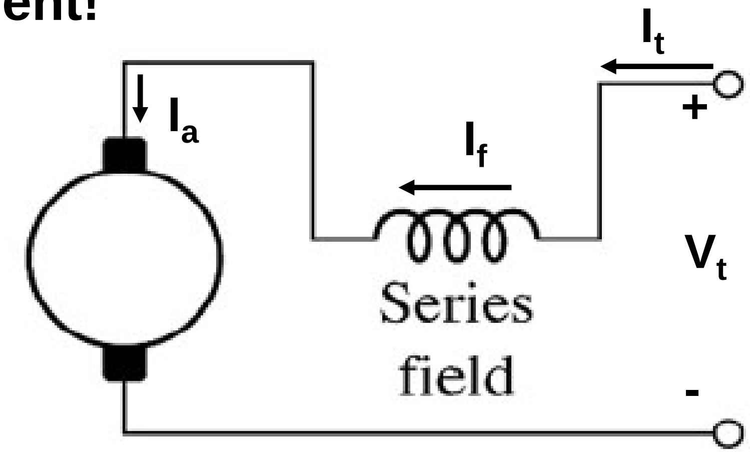
Field current is the same as Armature current!

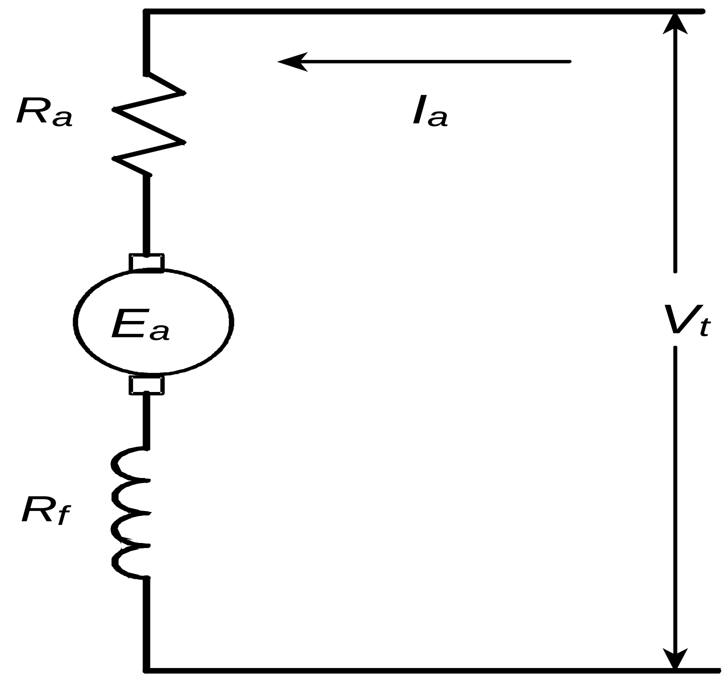
$$V_t - (R_a + R_f)I_a = E_A$$

$$I_t = I_a = I_f$$

- $T_A = K\,\phi\,I_a$
- $E_A = K\,\phi\,\omega$

$$\boxed{\omega = \frac{V_t}{K\varphi} - \frac{R_a + R_f}{(K\varphi)^2} T_A}$$





In Series machines: $I_f = I_a$ Therefore:

$$k\,\varphi = k_{sr} I_a$$

$$E_a = k_{sr} I_a \omega_m$$

$$T_A = k_a\,\varphi I_a = k_{sr} I_a^2 \text{ !!!}$$

DC Series Motors

$$T_A = k\varphi I_a = k_{sr} I_a^2$$

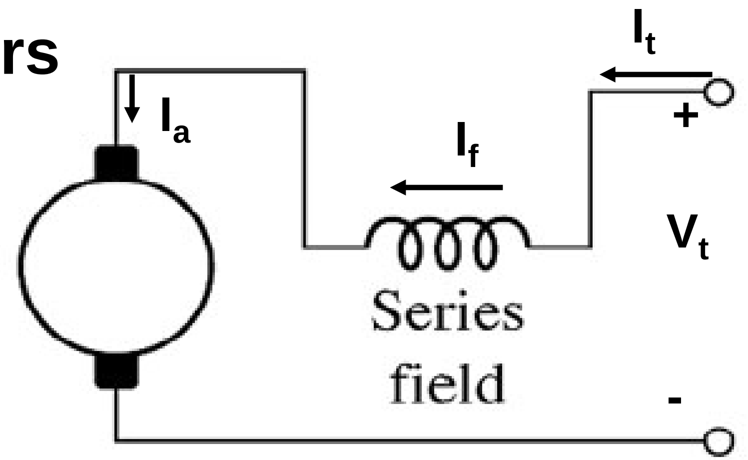
Current sign does not affect Torque!!

AC current can generate DC torque:

$$T = k_{sr} I_a^2 = k_{sr} I_m^2 \cos^2 \omega t$$

$$= \frac{k_{sr} I_m^2}{2} (1 + \cos 2\omega t)$$

$\boxed{\textbf{Universal motor}}$

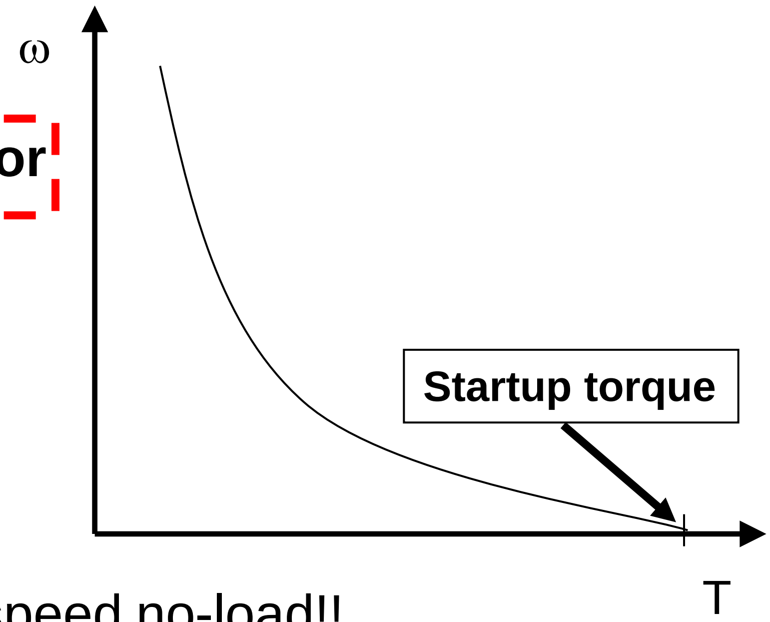


In addition:

$$\omega = \frac{V_t}{k\varphi} - \frac{R_a + R_f}{(k\varphi)^2} T_A$$

$$k\varphi = k_{sr} I_a \qquad I_a = \sqrt{\frac{T}{k_{sr}}}$$

$$\boxed{\omega = \frac{V_t}{\sqrt{k_{sr} T}} - \frac{R_a + R_f}{k_{sr}}}$$



High-speed no-load!!

High Start-up torque

Used when large starting torque is required:

Subway cars, traction systems, Automobile starter, Blender

Example

A 220V, 7 Hp series motor is mechanically coupled to a fan and draws 25 A, and runs at 300 RPM when connected to 220V. The torque required by the fan is proportional to the square of speed. Neglect armature reaction and rotational loss and determine the power delivered to the fan and the torque.

R_a=0.6 Ω, R_{sr}=0.4 Ω

Solution :

$$E_a = V_t - (R_a + R_{sr}) I_a = 220 - 25(0.4+0.6) = 195\ V$$

$$P = E_a I_a = 195 * 25 = 4880\ W$$

$$T = P / \omega = 4880 / (300*(2\pi/60))\ Nm$$

Example

The speed is to be reduced to 200 RPM by armature voltage variation.

Determine the voltage.

Solution:

Speed reduction leads torque reduction:

$$\text{load}: \frac{T_1}{T_2} = \frac{\omega_1^2}{\omega_2^2} \Rightarrow T_2 = T_1 \frac{\omega_2^2}{\omega_1^2} = (\frac{2}{3})^2 T_1 = 68.9Nm$$

$$\text{Motor}: \frac{T_1}{T_2} = \frac{I_1^2}{I_2^2} \Rightarrow I_2 = I_1 \sqrt{\frac{T_2}{T_1}} = \frac{\omega_2}{\omega_1} I_1 = \frac{200}{300} \times 25 = 16.7A$$

$$T_2 \omega_2 = E_{a2} I_2 \Rightarrow E_{a2} = \frac{68.9 \times \frac{200 \times 2\pi}{60}}{16.7} = 86.4V$$

$$V_t = E_a + (R_a + R_f) I_a = 86.4 + (0.4 + 0.6) \times 16.7 = 103.1V$$

DC Motor Starting

At Starting, ω = 0, then E_a = 0

$$I_a = \frac{V_t - E_a}{R_a}$$

$$T = K_a \phi \frac{V_t - E_a}{R_a}$$

$$I_{st} = \frac{V_t}{R_a}$$

$$T = K_a \phi \frac{V_t - K_a \phi \omega_m}{R_a}$$

$$T_{st} = K_a \phi \frac{V_t}{R_a}$$

Very high startup current!!

Very high start up torque!

Think about the problems with:

High start-up current !

High start-up torque !

Example:

A 10kW, 100V, 1000rpm, separately excited DC motor has : *Ra* = 0.1 Ω

Calculate the rated current and torque, and starting current and torque at full voltage .

$$I_{rated} = \frac{P_{rated}}{V_a} = \frac{10000}{100} = 100\ A$$

$$T_{rated} = \frac{p_{rated}}{\omega_{rated}} = \frac{10000}{1000 \times \frac{2\pi}{60}} = 95.5 N.m$$

$$I_{start} = \frac{V_a}{R_a} = 1000 A$$

$$\frac{T_{start}}{T_{rated}} = \frac{I_{start}}{I_{rated}} = \frac{1000}{10} \Rightarrow T_{start} = 10 T_{rated} = 955 N.m$$

Starting of DC motor

$$E_a = V_t - R_a I_a$$

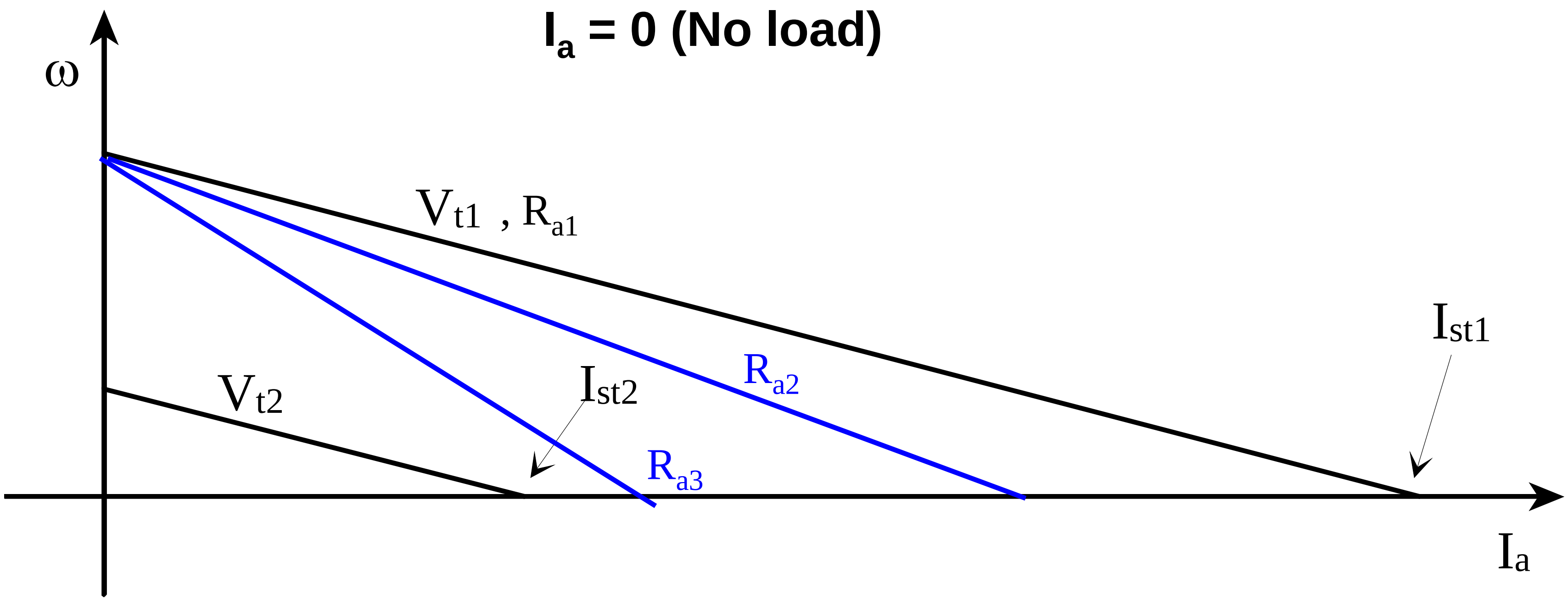
$$\omega = \frac{V_t}{k\varphi} - \frac{R_a \; I_a}{k\varphi}$$

Current speed characteristics

$$I_{st} = \frac{V_t}{R_a}$$

ω = 0 (Start up)

I_a = 0 (No load)



Example:

How can you reduce the starting current to 2 times the rated current?

A- using external resistance:

B- Using reduced armature voltage:

Solution:

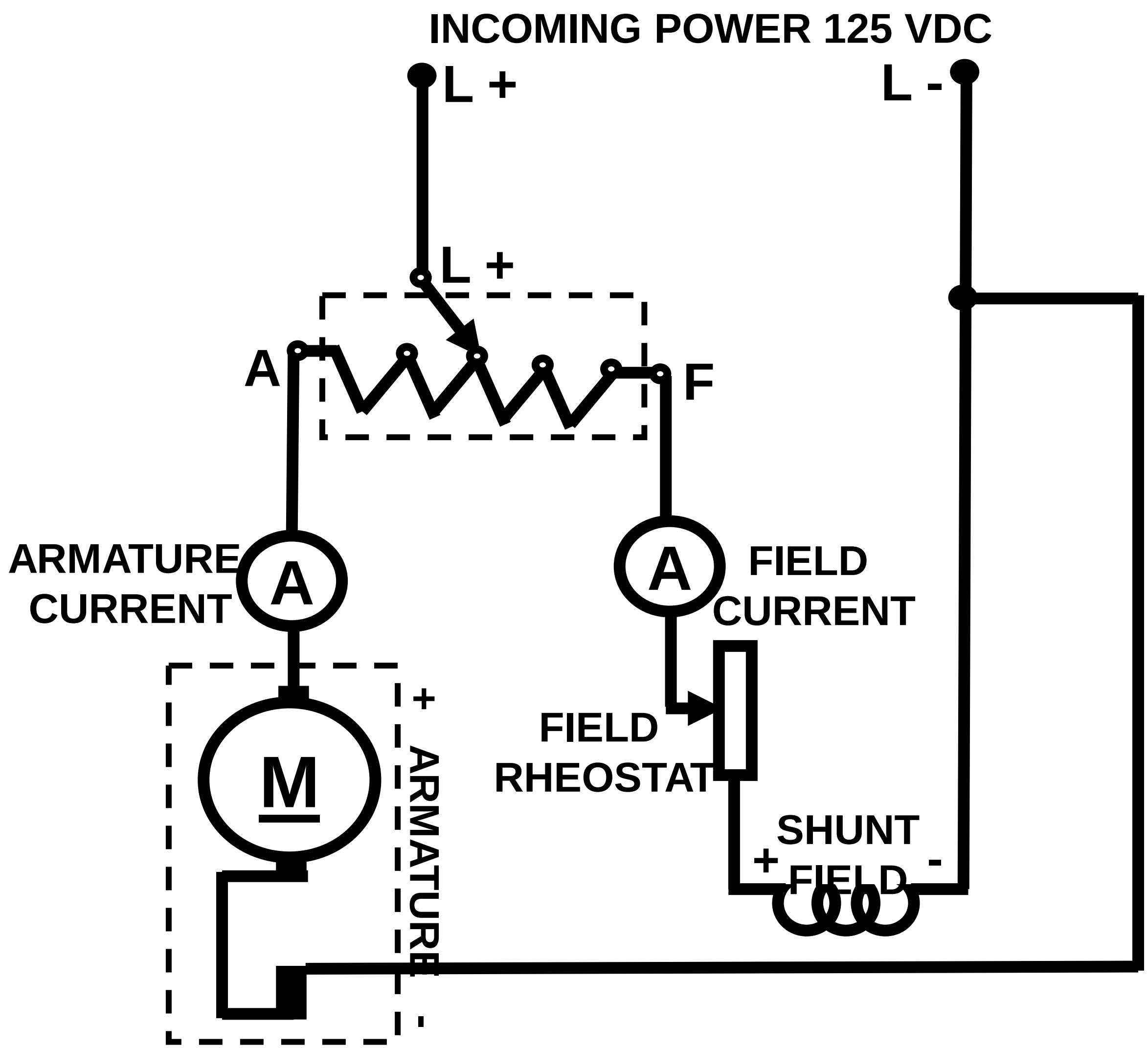
A:
$$R_{st} + R_a = \frac{V_t}{I_{st}}$$

$$R_{st} = \frac{V_t}{I_{st}} - R_a = \frac{100}{2 \times 100} - 0.1 = 0.4\,\Omega$$

External resistance can be gradually taken out

B:
$$V_{st} = I_{st}\ R_a = 2 \times 100 \times\ 0.1 = 20\ \ V$$

DC motor starter



DC motor name plate

- **Horse power at Base Speed**
- **Base Speed at Rated Load**
- **Rated Armature Voltage**
- **Rated Field Voltage**
- **Armature Rated Current**
- **Power Supply Code**
- **Maximum Ambient Temperature**
- **Insulation Class (A, B, H, F)**
- **Winding Type (shunt, Series, Compound, PM)**
- **Manufacturer's Type and frame Designation**
- **Enclosure**