Energy conversion I

Lecture 23:

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

- A Simple Rotating Loop between Curved Pole Faces.
- Structure of DC machines
- Commutation Problems in Real 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

Power Flow and Losses in DC Machines

$$\text{Efficiency} = \frac{P_{out}}{P_{in}} = \frac{P_{in} - P_{loss}}{P_{in}} \times 100\%$$

Origin of losses:

Electrical or Copper Losses (RI^2 Loss)

in both rotor and stator

Armature loss: $P_A = I_A^2 R_A$

Field loss: $P_F = I_F^2 R_F$

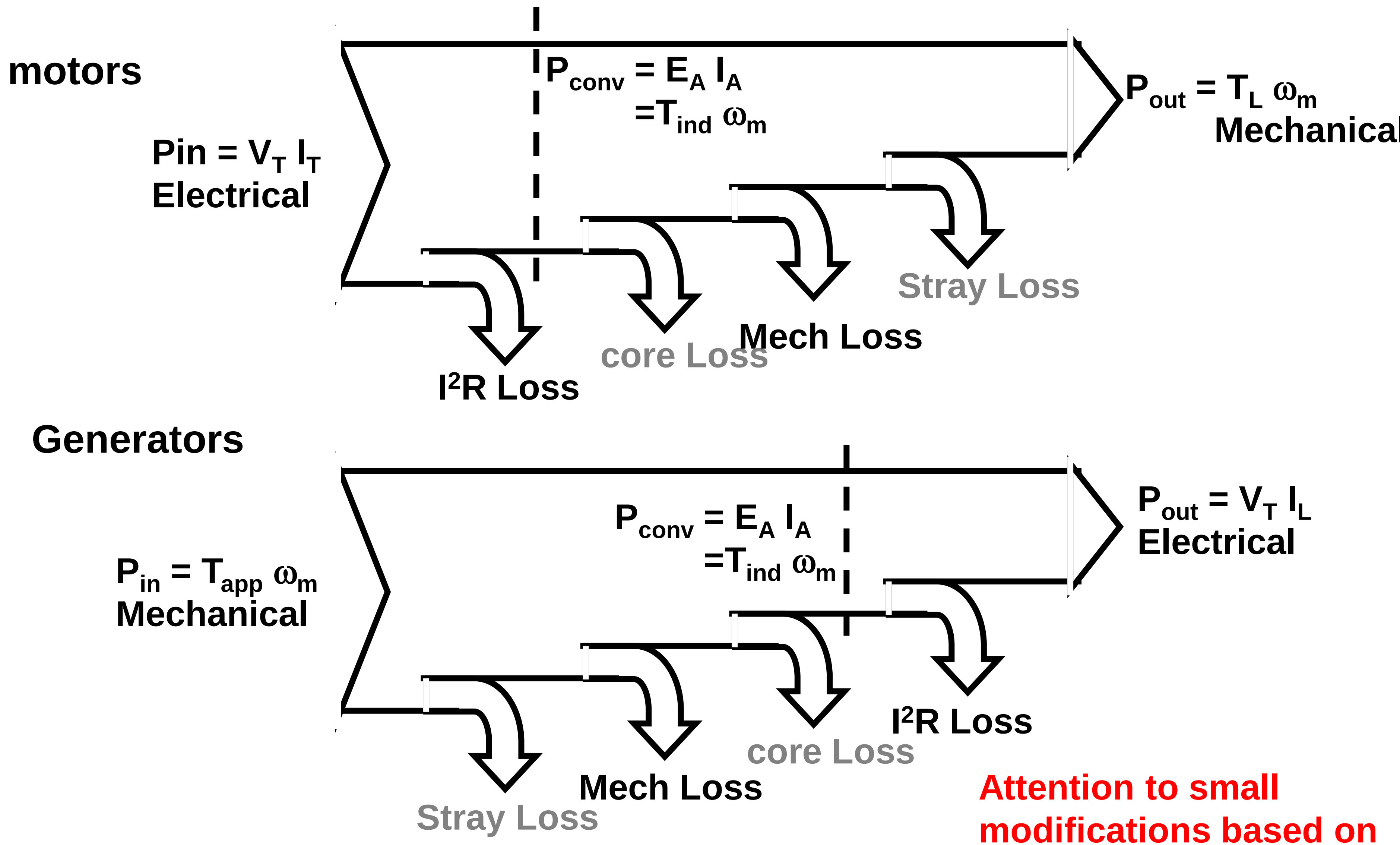
Brush Losses : $P_{BD} = V_{BD} \times I_A$

Core Losses : Hysteresis and Eddy current loss

Mechanical Losses : Friction and windage loss

Stray Loss

Power Flow and Losses in DC Machines



Attention to small modifications based on machine connections

Example:

A DC machine (12 kW, 100V, 1000 rpm, Ra = 0.1 Ω) is connected to 100 V. At no-load condition, the motor runs at 1000 rpm and the armature takes 6 amperes while the field current is 0.99 amperes.

when rated current flows in the armature, find:

A: the speed

B: electromagnetic torque

C: efficiency

Solution:

Speed can be calculated comparing induced voltage in two cases(no-load and rated current.

$E_a = V_t - R_a \times I_a$

$E_{a,nl} = 100 - 0.1 \times 6 = 99.4$ V

$Ea_{fl} = 100 - 0.1 \times 120 = 88$ V

$$\frac{E_{a,nl}}{E_{a,fl}} = \frac{K\,\varphi\,\omega_{nl}}{K\,\varphi\,\omega_{fl}} = \frac{\omega_{nl}}{\omega_{fl}} = \frac{n_{nl}}{n_{fl}} \Rightarrow n_{fl} = \frac{E_{a,fl}}{E_{a,nl}} n_{nl}$$

$$n_{fl} = \frac{Ea_{fl}}{Ea_{nl}} n_{nl} \Rightarrow n_{fl} = \frac{88}{99.4} 1000 = 885.3\ \text{rpm}$$

Torque can be calculated using output power

$P_{conv} = E_a \times I_a = T_{ind}\omega_m$

$T_{ind} = E_a \times I_a / \omega_m = 88 \times 120 / (2\ \pi \times 885.4 / 60)$

$T_{ind} = 113.9$ N.m

To calculate the efficiency, rotational loss should be calculated. This one can be calculated based on no-load behavior

$P_{rotat} = E_{a,nl} \times I_{a,nl} = 99.4 \times 6 = 596.4$ W (assumed to be constant)

$P_{out} = P_{conv} - P_{rotat} = 88 \times 120 – 596.4 = 9963.6$ W

η= Pout / Pin = 9963.6 / [(120 +0.99) × 100)] = 82.35%

Separately Excited DC Motors

Field voltage can be different from Armature voltage!

$\mathbf{Va - R_a\, I_a = E_A}$

$\mathbf{I_f = V_f / R_f}$ (**how adjusted**)

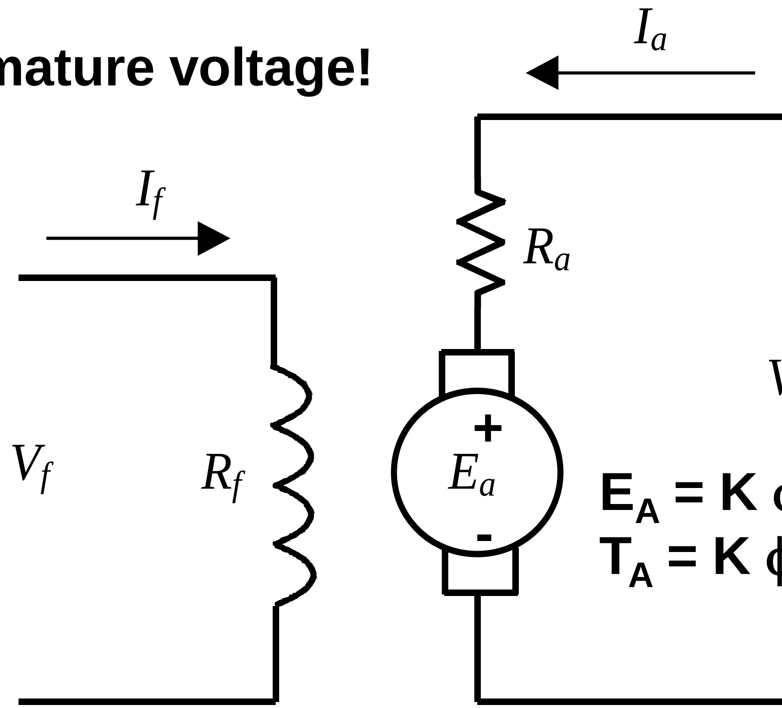
- $\mathbf{T_A = K\, \phi\, I_a}$
- $\mathbf{E_A = K\, \phi\, \omega}$

$$V_a = K\varphi\omega + R_a \frac{T_A}{K\varphi}$$

$$\omega = \frac{V_a}{K\varphi} - \frac{R_a}{(K\varphi)^2} T_A$$

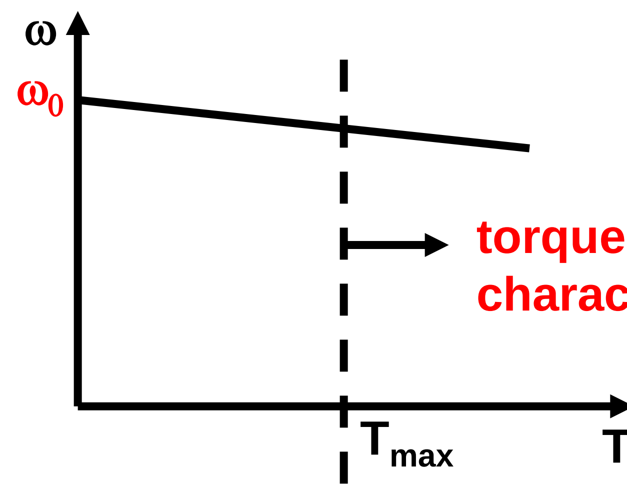
No-load speed

Speed reduction slop



$\mathbf{E_A = K\, \phi\, \omega}$

$\mathbf{T_A = K\, \phi\, I_A}$



torque speed characteristics!

Think about effect of different parameters on torque speed characteristics!

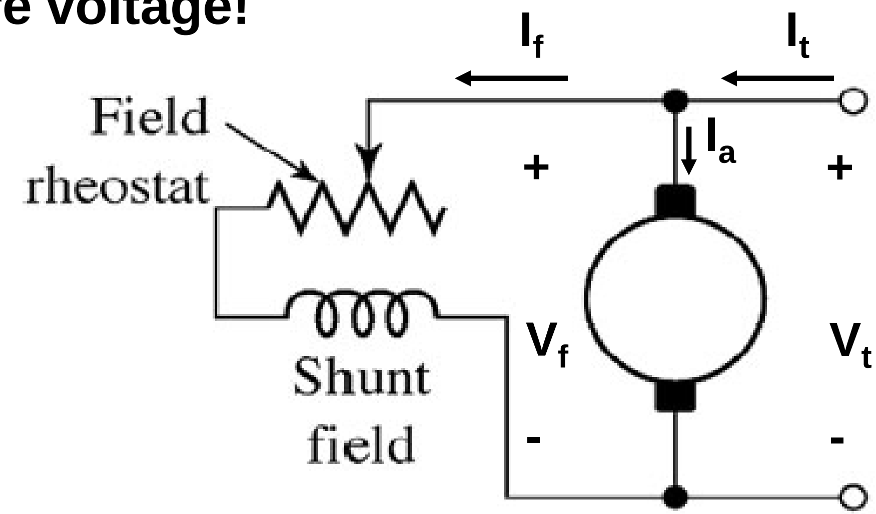
DC Shunt Motors

Field voltage is the same as Armature voltage!

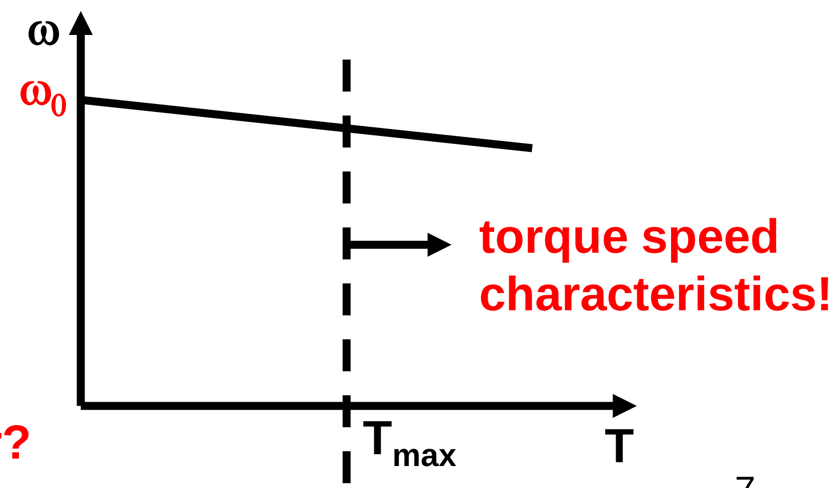
$Va - R_a I_a = E_A$

$I_f = V_f / R_f$

- $V_t = V_f = V_a$
- $I_t = I_a + I_f$
- $T_A = K \phi I_a$
- $E_A = K \phi \omega$



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



Think about effect of different parameters on torque speed characteristics.

How V_t can be changed?

How it affects the characteristics?

Is it a good choice for a variable speed motor?

Example:

A 50HP, 250V, 1200 r/min DC shunt motor with compensating windings has an armature resistance (including the brushes, compensating windings, and interpoles) of 0.06 Ω. Its field circuit has a total resistance of 50 Ω, which produces a no-load speed of 1200r/min.

Find the speed of this motor when its input current is:

A: 100A.

B: 200A.

C: 300A.

Solution:

@No-load, $I_a = 0$ and therefore $V_t = E_a = 250$ V

If field current is constant (If = 250 /50 = 5 A), then E_a is proportional to n:

$$\frac{n}{n_{nl}} = \frac{E_a}{E_{a,nl}}$$

$$E_a = V_t - R_a I_a = \begin{cases} 250 - 0.06 \times (100 - 5) = 244.3 \\ 250 - 0.06 \times (200 - 5) = 238.3 \\ 250 - 0.06 \times (300 - 5) = 232.3 \end{cases}$$

$$n = n_{nl} \times \frac{E_a}{E_{a,nl}} = \begin{cases} 1200 \times \frac{244.3}{250} = 1173 \\ 1200 \times \frac{238.3}{250} = 1144 \\ 1200 \times \frac{232.3}{250} = 1115 \end{cases} \quad \text{rpm}$$

Speed Control of DC SE/Shunt Motors

For speed control, torque-speed characteristics should be modified

$$\omega = \frac{V_a}{K\varphi} - \frac{R_a}{(K\varphi)^2} T_A$$

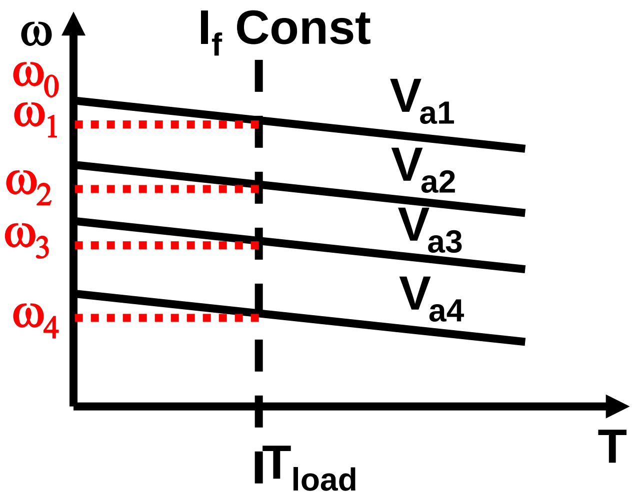
Parameters affecting: V_a, ϕ ($/I_f$), R_a

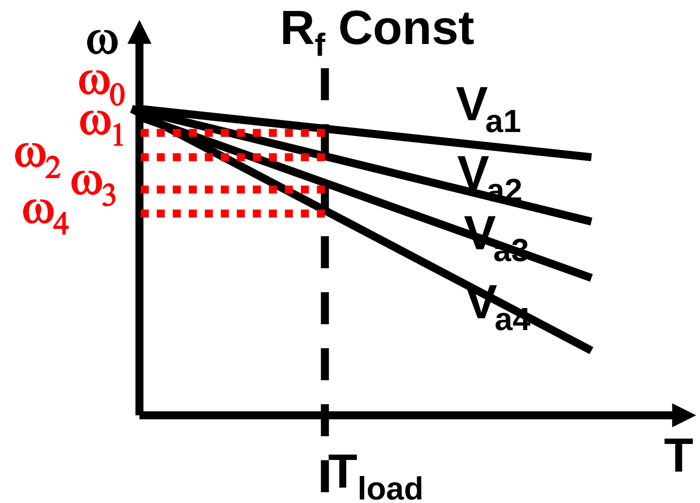
A: V_a,

Needs controlled DC power supply

Changes no-load speed (if I_f can be controlled to be constant)

Changes the slop while no load speed is almost constant (neglecting saturation) (Compare it with Separately excited motors)





Speed Control of DC SE/Shunt Motors

B: ϕ (/ If),

$$\omega = \frac{V_a}{K\varphi} - \frac{R_a}{(K\varphi)^2} T_A$$

Can be controlled adding a rheostat

Decreasing flux increases no-load speed while increasing the slope (increasing the speed in normal operating point)

for the same torque, increases I_a (Why?, What is the problem? What happens if field is open?)

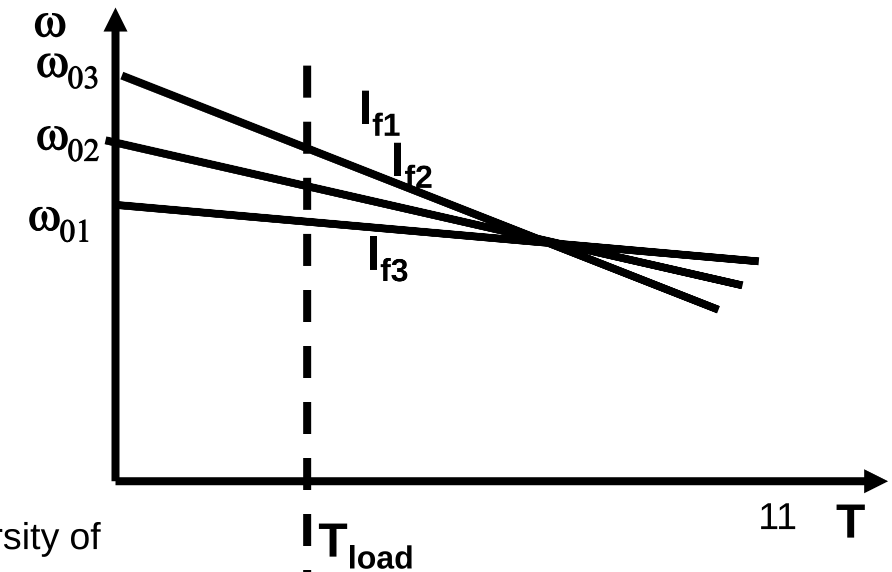
C: R_a

Can be increased using a rheostat

Increases the slop

Decreases the efficiency

Not in use in recent systems



Wide Range Speed Control of DC Shunt Motors

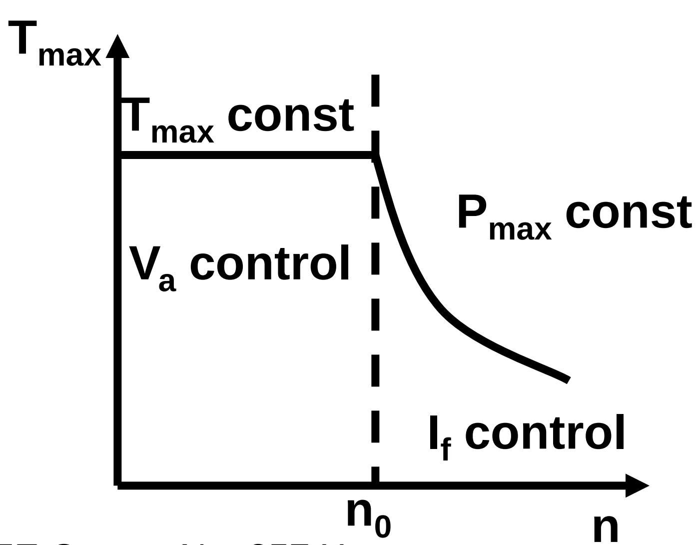
Less than rated speed: Armature voltage control

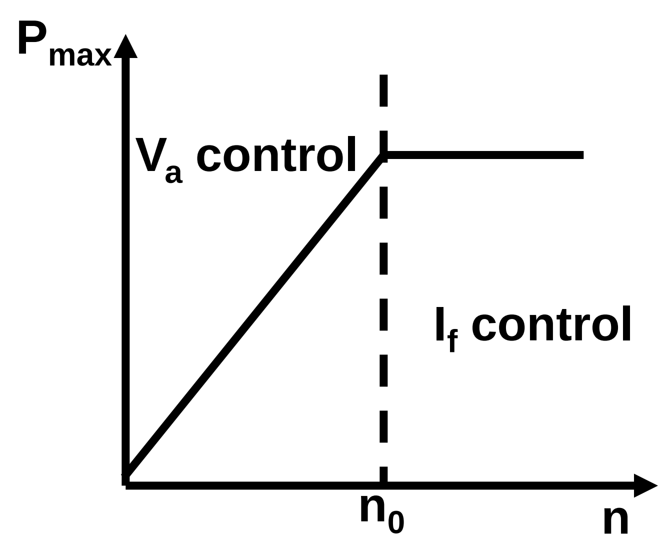
Constant stator field, maximum current **maximum torque**

power increases with speed

More than rated speed: Field current control, Constant armature voltage

maximum current **maximum power** **decreasing maximum torque**





Permanent Magnets DC Motors

Stator Magnetic field is generated by Permanent Magnets

No power loss in the field → High efficiency

Smaller magnetic field

!!

Higher armature current for the same torque!!

No control on the field

Speed control using armature voltage

Speed less than rated