# ELEC 342
# Electromechanical Energy Conversion and Transmission

2025-26 Winter Term 2

Lecture 10

February 5, 2026

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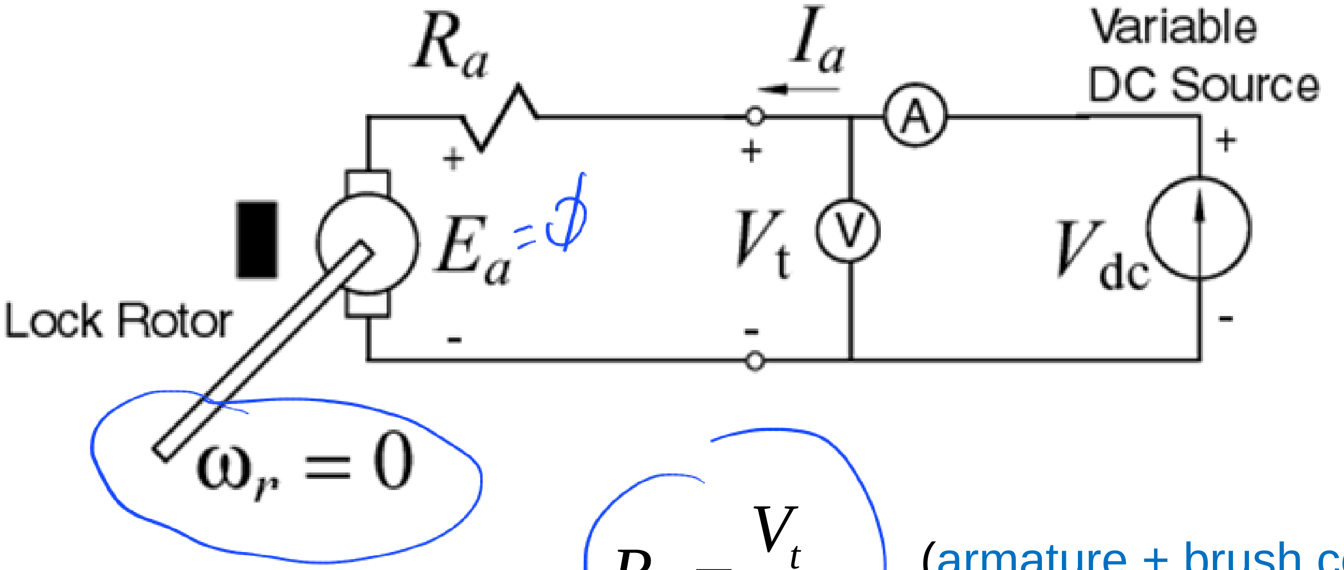
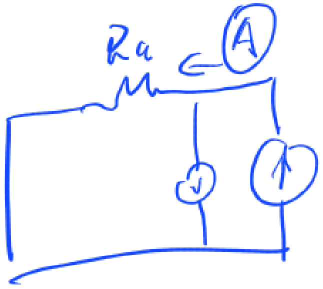
# Parameters of PM DC Machine

- **Blocked-Rotor Test** (DC Measurements)

**Slowly ramp up DC voltage and measure DC current up to nominal value**
**Determine resistance of armature winding:**




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

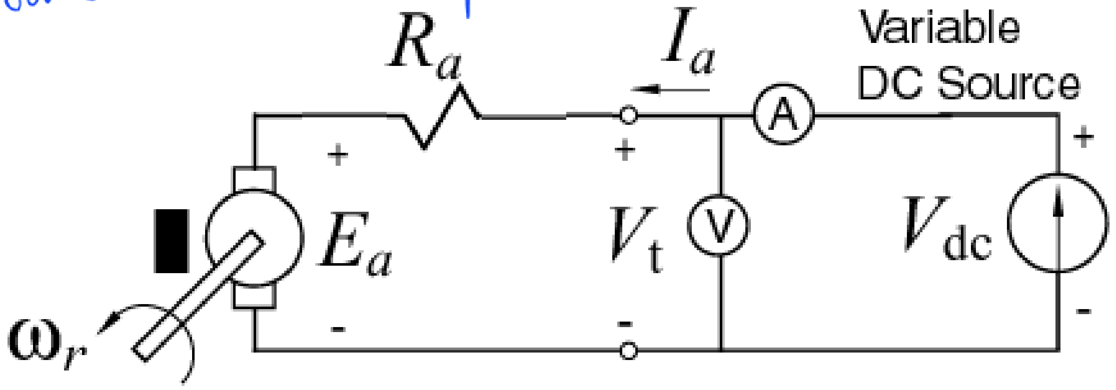
(armature + brush combined resistance at no speed!)

**Use similar measurement for field winding to estimate its resistance for field-wound DC machines**


$$R_f = \frac{V_f}{I_f}$$

# Parameters of PM DC Machine

- **No Load Test** (Friction vs. Speed) → rotate ~ nominal speed, no load




Assume you know $R_a$

Measure $I_a, V_t, \omega_r$

$$E_a = k_v \omega_r$$

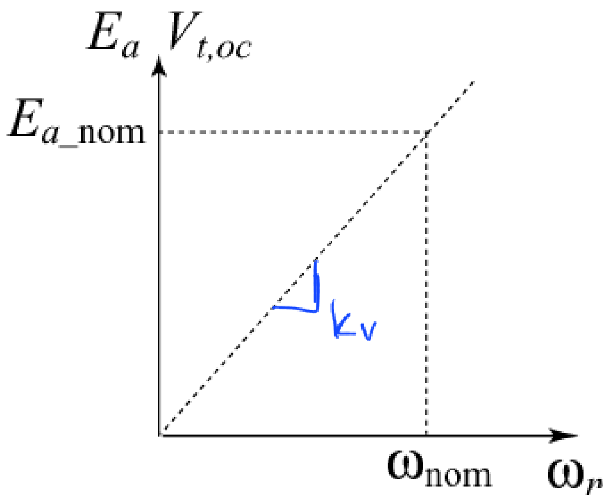
$$V_t = R_a I_a + E_a = k_v \omega_r + R_a I_a$$

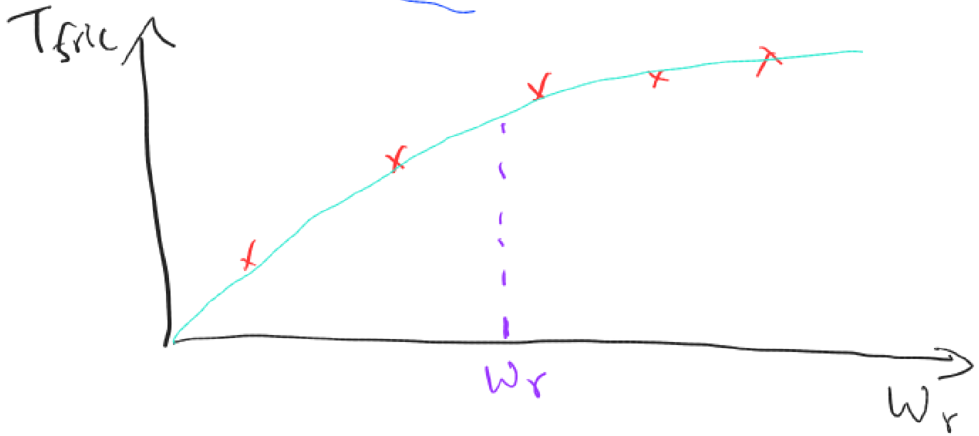
Torque / voltage machine constant $\quad k_t = k_v \Rightarrow \dfrac{V_t - R_a I_a}{\omega_r}$

**Obtain Friction Torque-Speed Characteristic**

$$T_e = k_t I_a$$

$$T_e = T_{fric}(\omega_r) = \omega_r K_{fric}$$



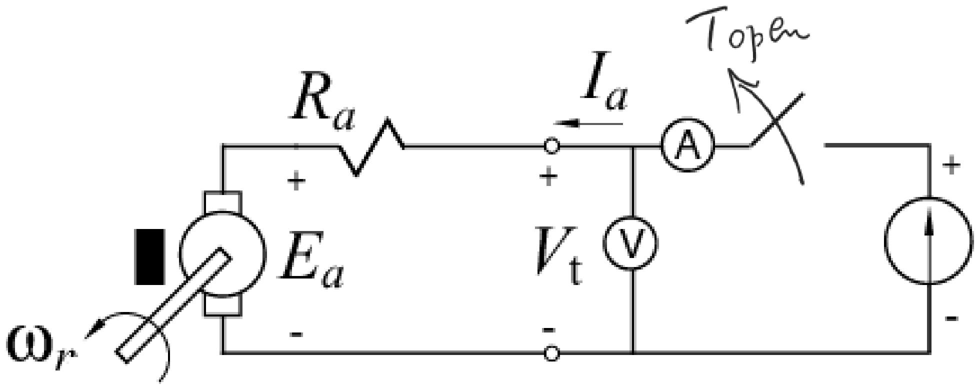



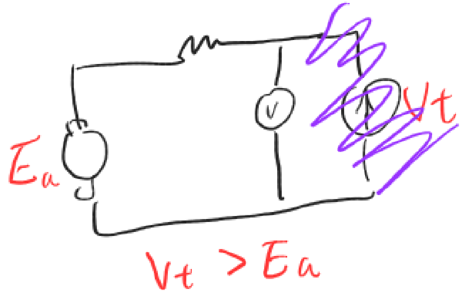
# Parameters of DC Machine

- **Stopping Transient** (for Determining Inertia)

Assume you know $T_{fric}(\omega_r)$

Measure & Record $I_a, V_t, \omega_r$



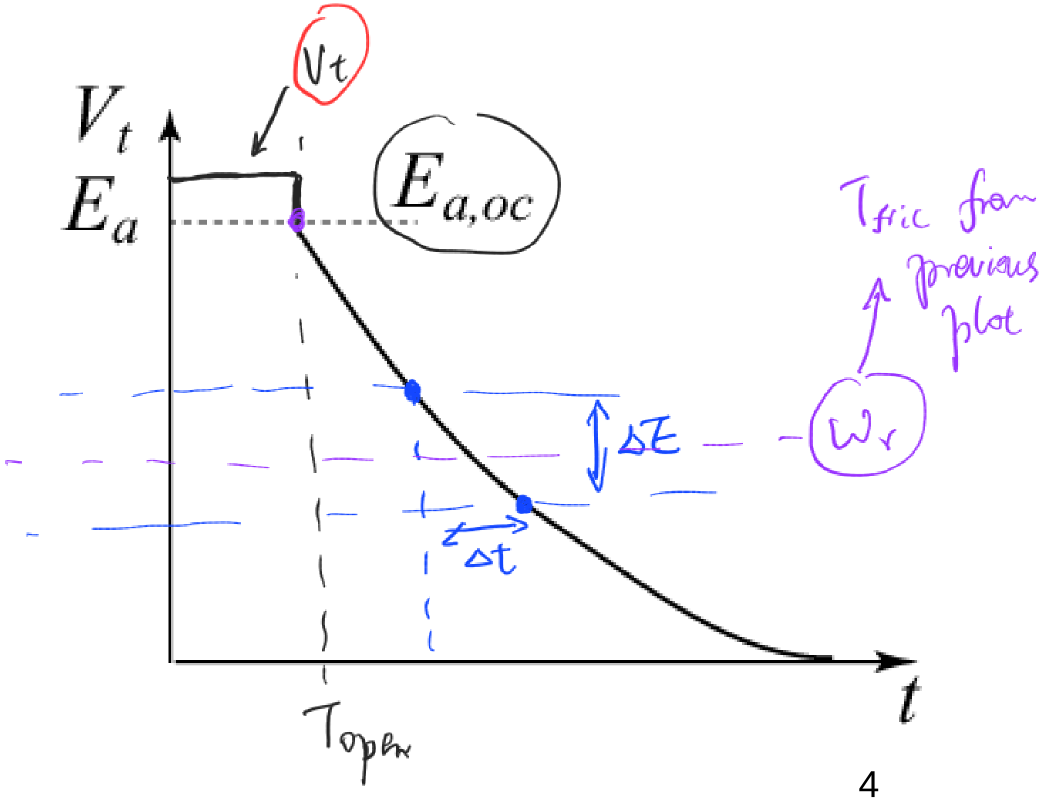




$$T_e = T_m + T_{fric}(\omega_r) + J\frac{d\omega_r}{dt}$$

$$E_a = K_a \Phi_p \omega_r = K_v \omega_r$$

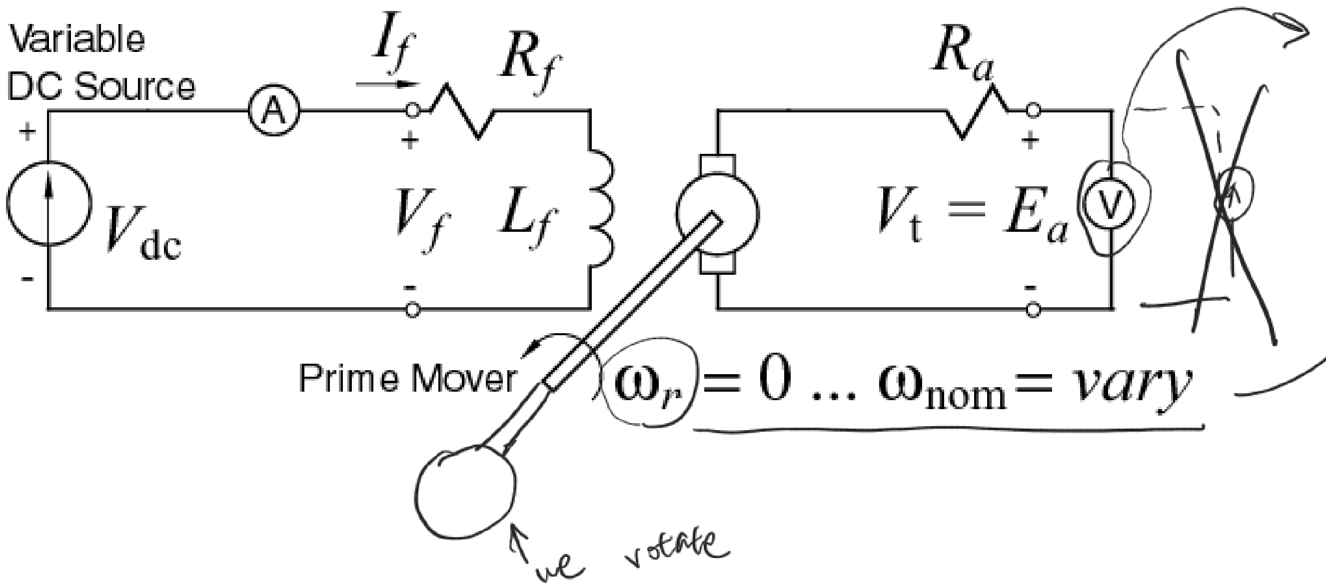
$$\to T_{fric}(\omega_r) = -J\frac{\Delta\omega_r}{\Delta t} = -J\frac{\Delta E_a}{K_v \Delta t}$$

$$J = \frac{T_{fric}(\omega_r) \cdot K_v \cdot \Delta t}{\Delta E}$$

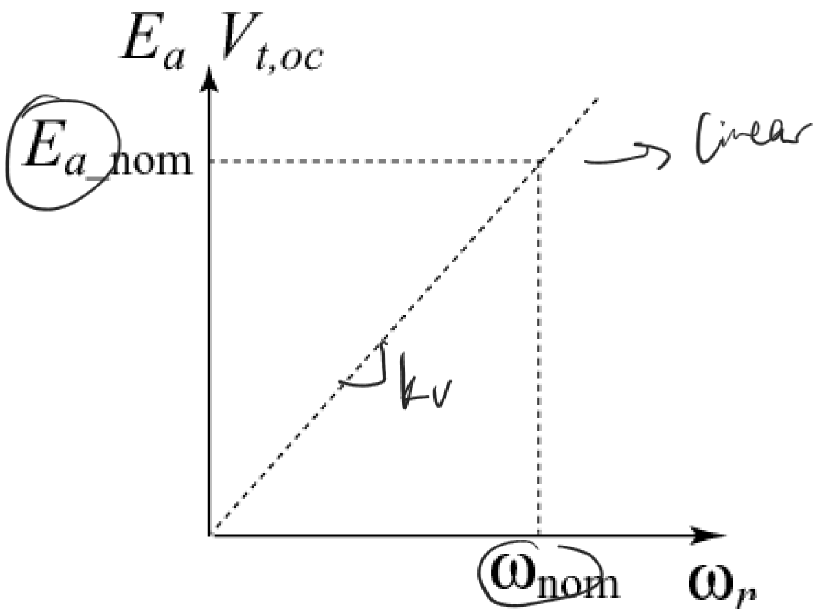


# Parameters of DC Machine

- **Open-Circuit Test** (Generated Voltage vs. Speed)




change speed by using another prime mover



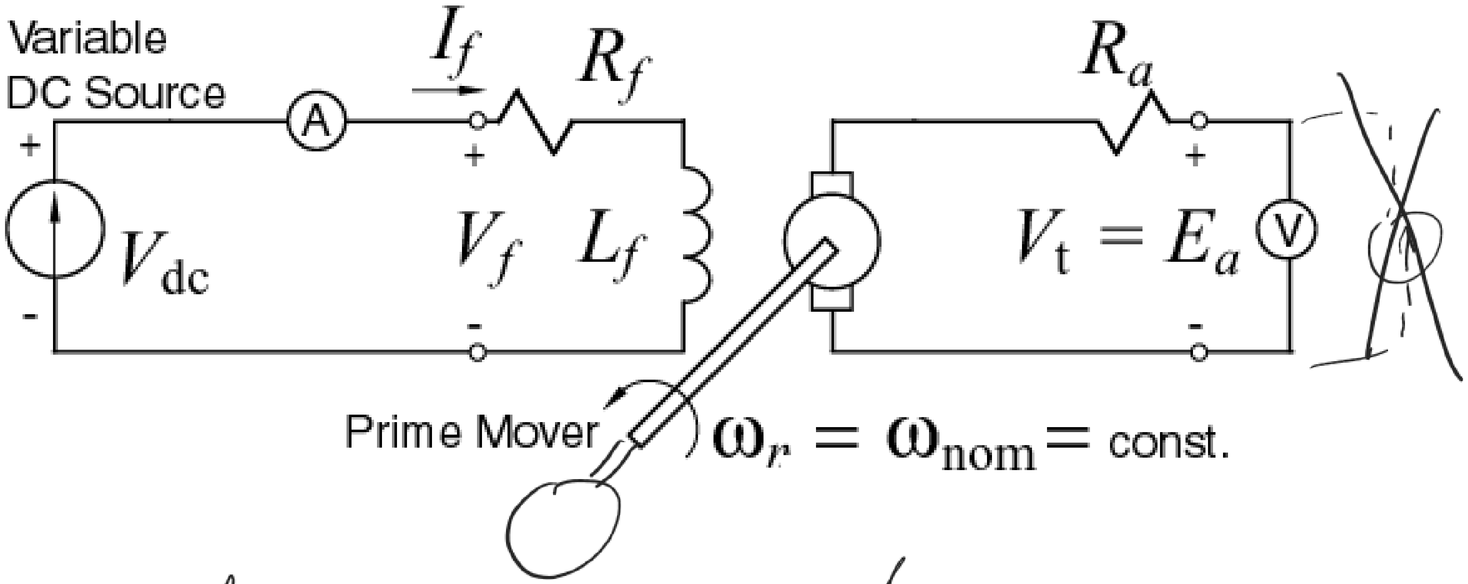

$$E_a = K_a \Phi_p \omega_r = K_a \frac{L_f}{N_f} I_f \omega_r$$

$$= L_{af} I_f \omega_r$$ Separately excited

$$= K_v \omega_r$$ PM

# Parameters of DC Machine

- **Open-Circuit Test** (Generated Voltage vs. Field Currents)

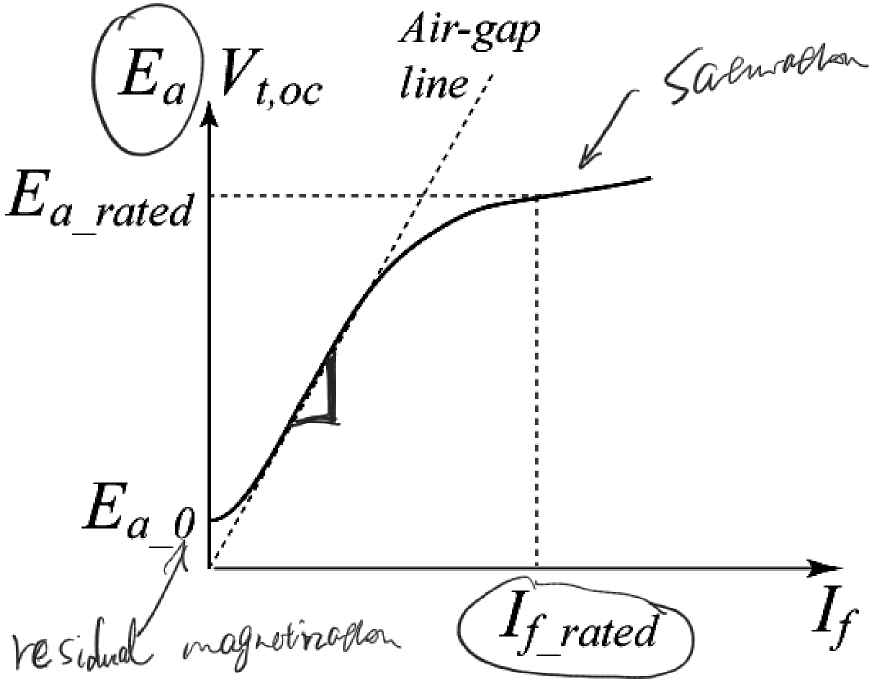



measured measured

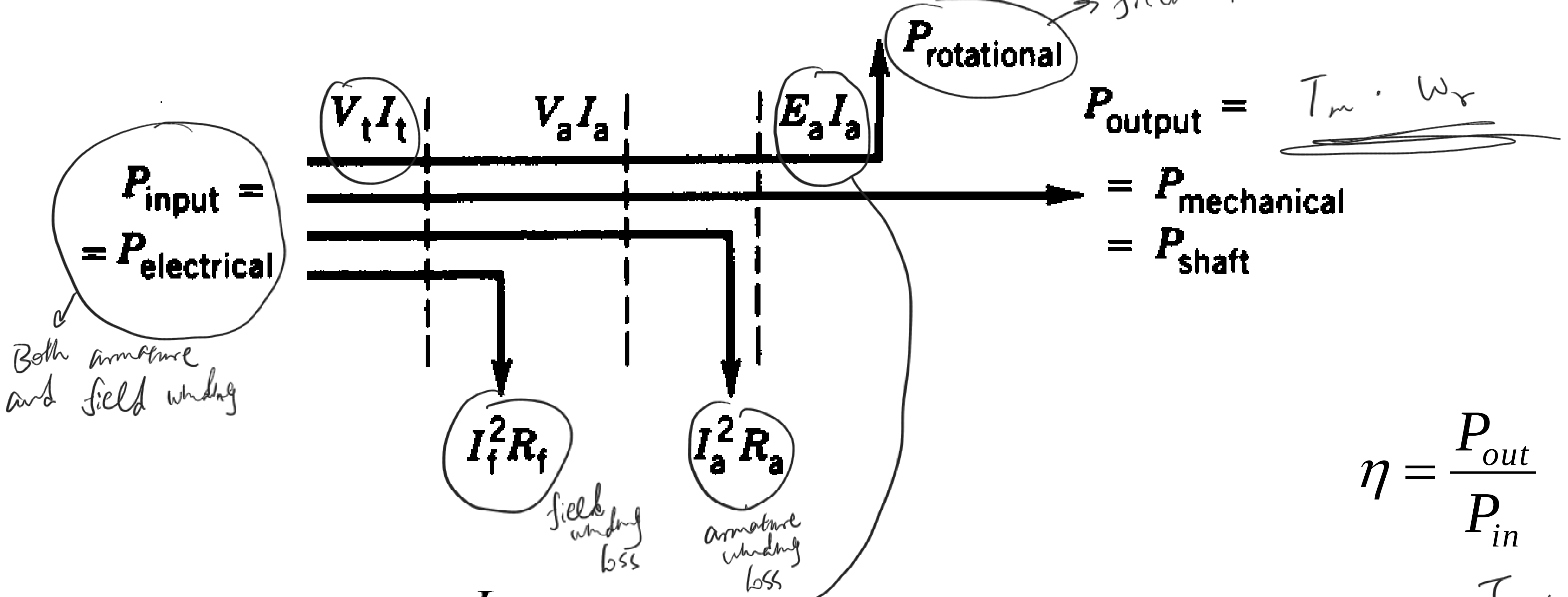
we set

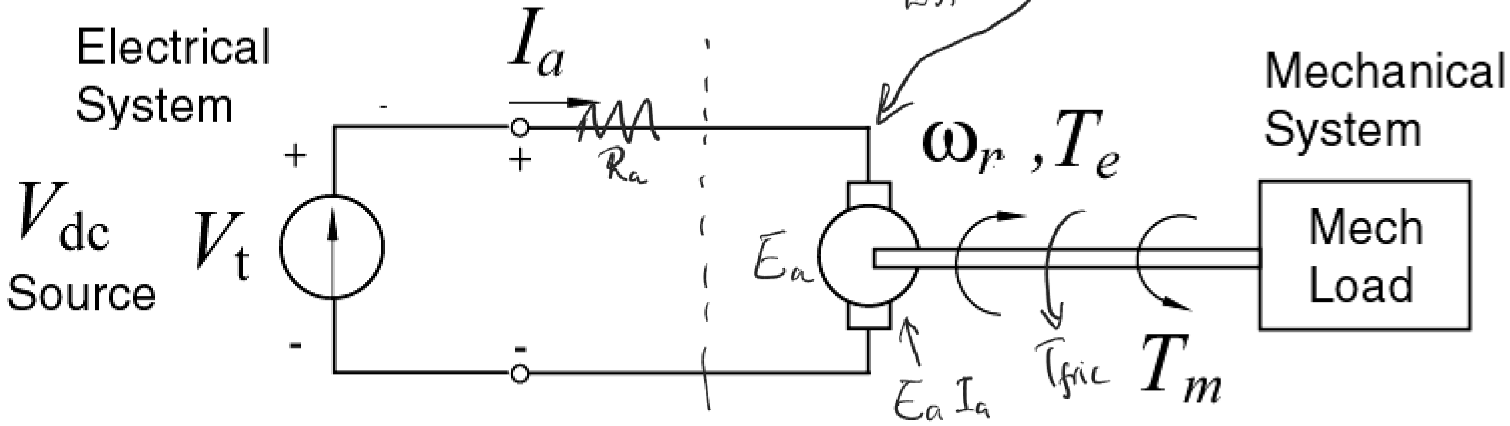
$$E_a = K_a \Phi_p \omega_r = K_a \frac{L_f}{N_f} I_f \omega_r$$

$$= \boxed{L_{af} I_f \omega_r} \Rightarrow \boxed{L_{af} = \frac{E_a}{I_f \omega_r}}$$



# Power Flow & Efficiency for DC Motor



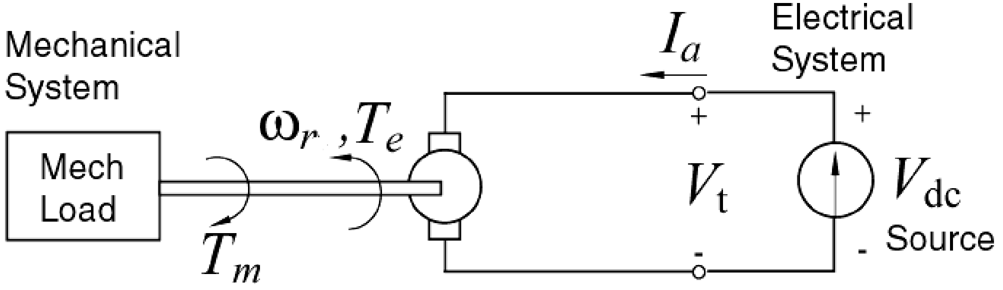




$$\eta = \frac{P_{out}}{P_{in}}$$

$$= \frac{T_m \cdot \omega_r}{\underbrace{V_t I_t}_{\text{power into stator + rotor}}}$$

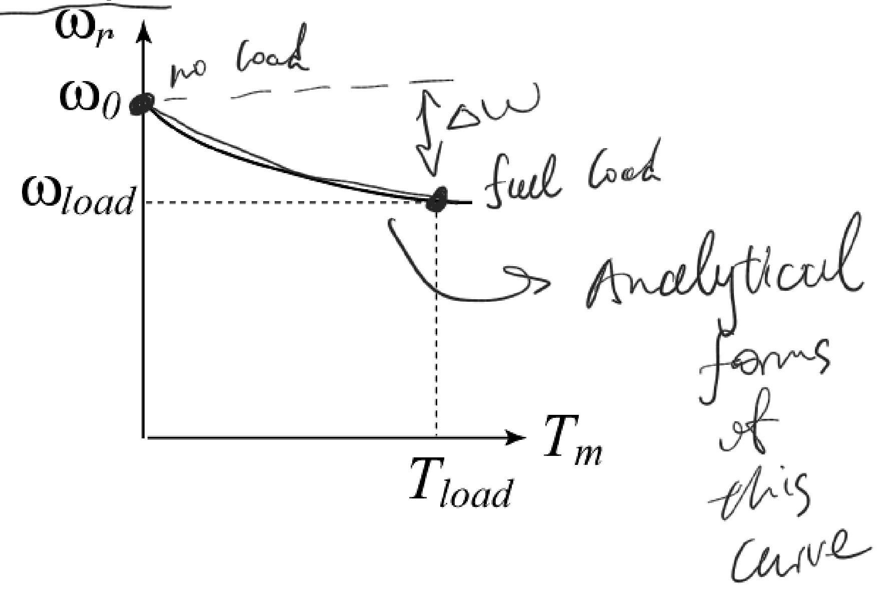
# DC Machines Characteristics:

## Speed Regulation (for Motors)

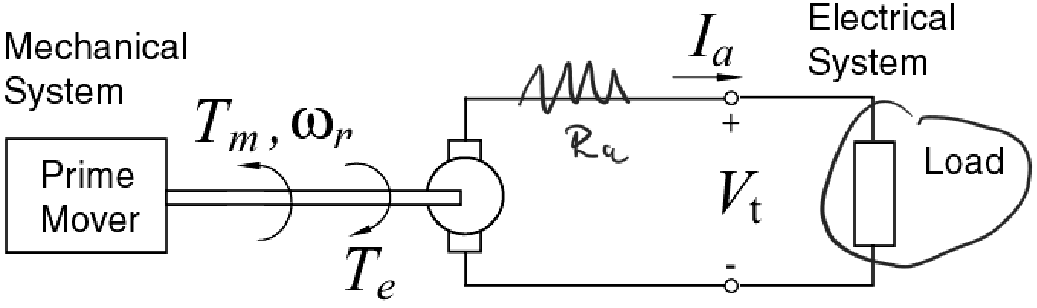



$$SR = \frac{\omega_{r,no\_load} - \omega_{r,load}}{\omega_{r,load}} 100\% = \frac{n_{no\_load} - n_{load}}{n_{load}} 100\%$$

Speed-Torque Characteristic

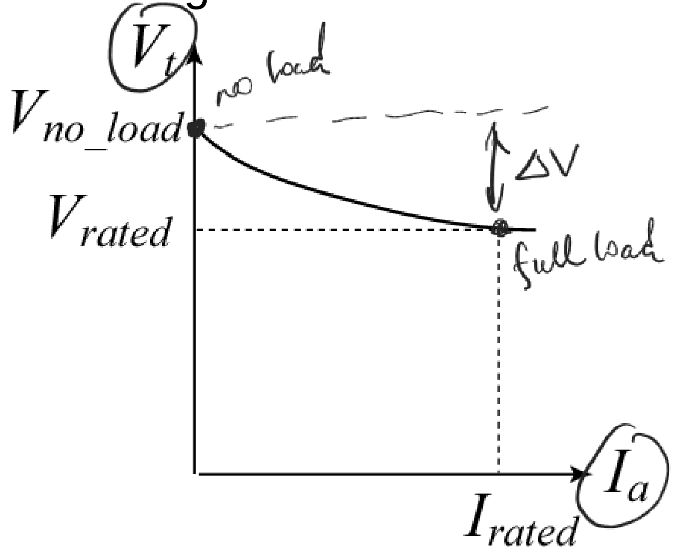



## Voltage Regulation (for Generators)



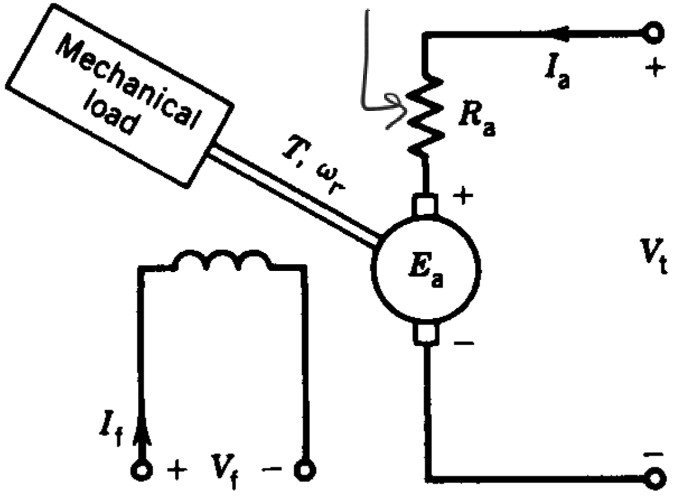

$$VR = \frac{V_{t,oc} - V_{t,load}}{V_{t,load}} 100\% = \frac{V_{no\_load} - V_{nom}}{V_{nom}} 100\%$$

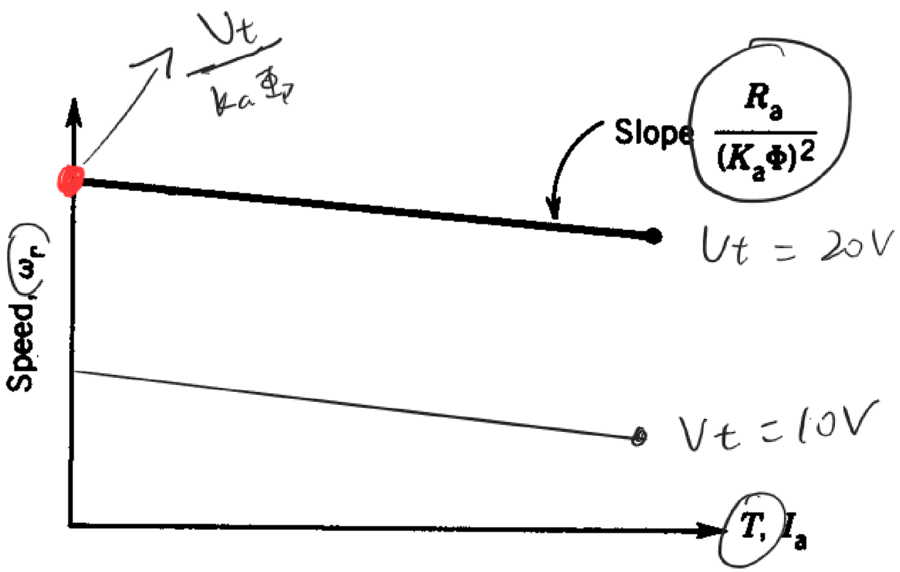
Load-Voltage Characteristic



# Separately-Excited DC Motor

or PM DC motor




$$
\begin{cases}
V_t = E_a + R_a I_a \quad \Rightarrow E_a = V_t - R_a I_a \\
E_a = K_a \Phi_p \omega_r = L_{af} I_f \omega_r \\
T = K_a \Phi_p I_a = L_{af} I_f I_a
\end{cases}
$$

$\boxed{\text{Control } V_t,\ R_a,\ I_f}$

Speed-Torque Characteristic

$$\omega_r = \frac{V_t - I_a R_a}{K_a \Phi_p} = \frac{V_t - I_a R_a}{L_{af} I_f}$$

→ $E_a$

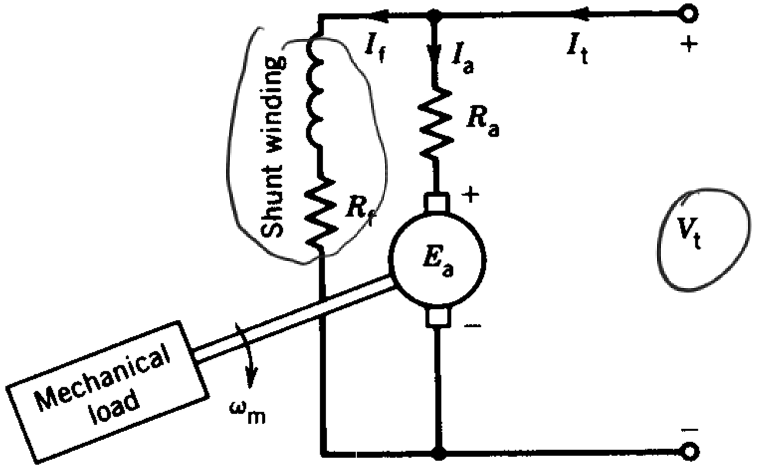
→ Sub. in $T_e$

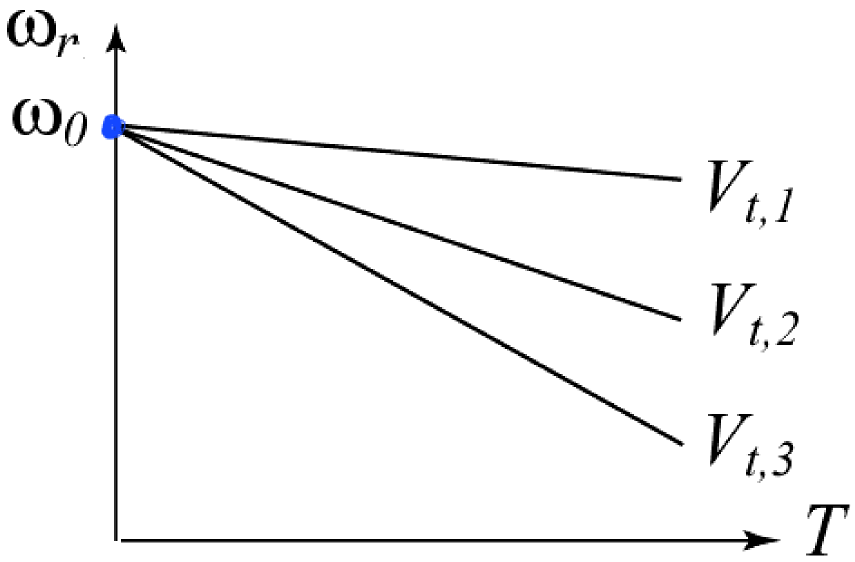
$$\Rightarrow \omega_r = \frac{V_t}{K_a \Phi_p} - \frac{R_a}{(K_a \Phi_p)^2} T = \frac{V_t}{L_{af} I_f} - \frac{R_a}{(L_{af} I_f)^2} T$$

→ Slope not dependent on $V_t$

$\omega_r = f(T)$

# Shunt DC Motor




$$\omega_r = \frac{V_t}{L_{af} I_f} - \frac{R_a}{\left(L_{af} I_f\right)^2} T$$

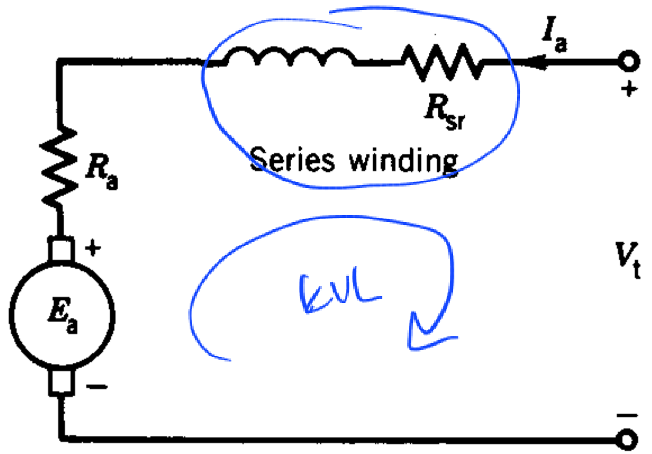
$$L_{af} I_f = \frac{L_{af} V_t}{R_f}$$

Speed-Torque Characteristic

$$\boxed{\omega_r = \frac{R_f}{L_{af}} - \frac{R_a R_f^2}{\left(L_{af} V_t\right)^2} T}$$

slope dependent

# Series DC Motor



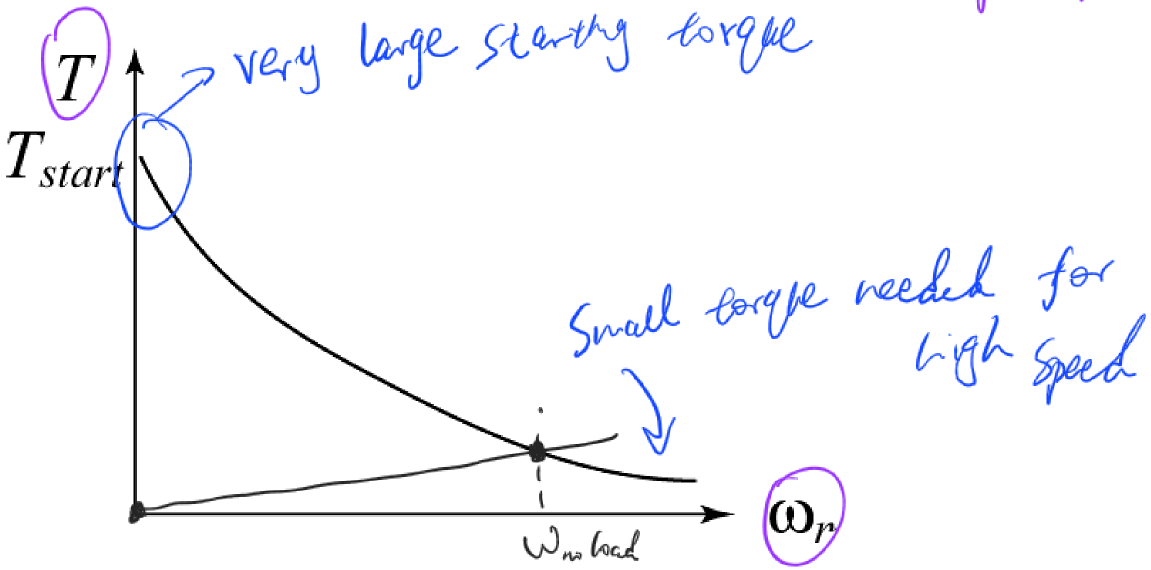

$$V_t = I_a\left(R_a + R_{sr}\right) + \underbrace{L_{af} I_a \omega_r}_{E_a}$$

$$I_a = \frac{V_t}{R_a + R_{sr} + L_{af}\,\omega_r}$$

$$T_e = L_{af} I_a^2 = L_{af} I_f I_a$$

equal

T- $\omega_r$ curve (more convenient to plot)

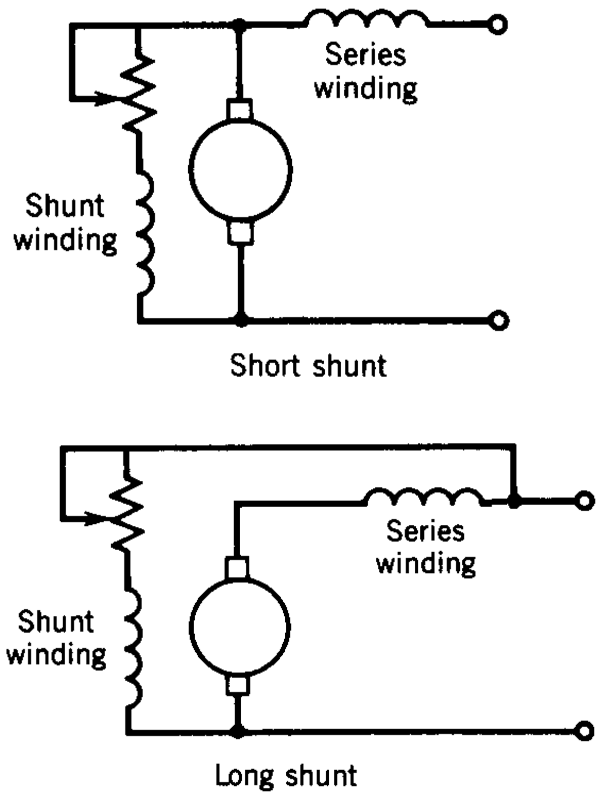



Torque-Speed Characteristic

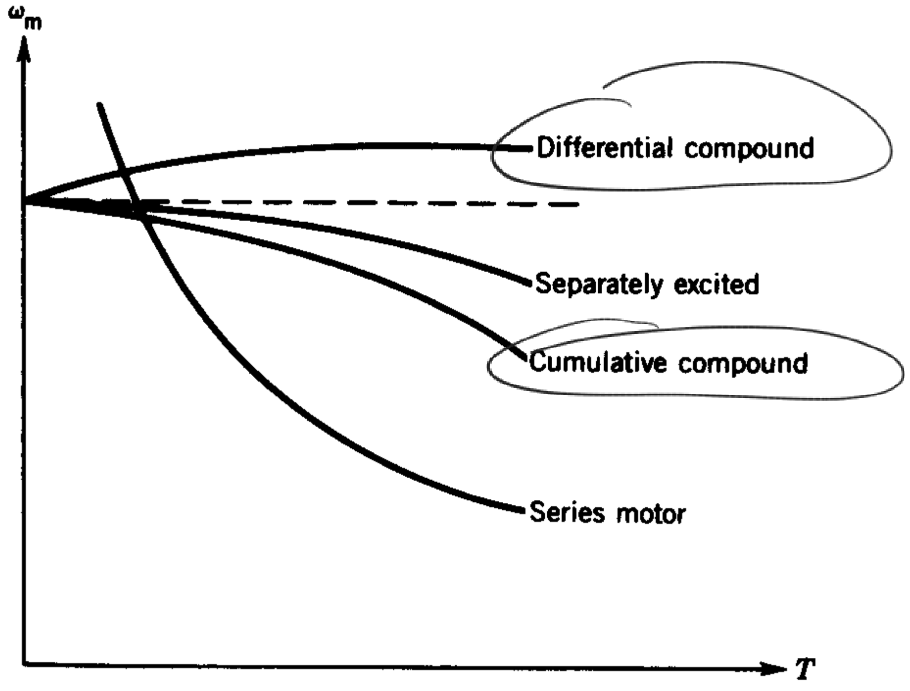
$$T = \frac{L_{af} V_t^2}{\left(R_a + R_{sr} + L_{af}\,\omega_r\right)^2}$$

# Compound DC Motor

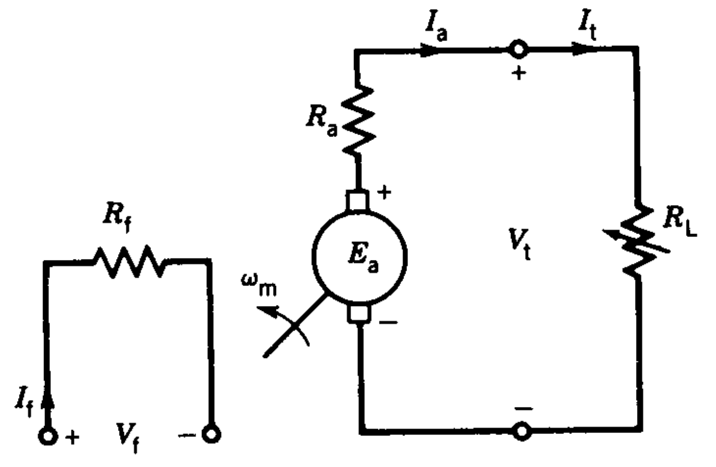
- Both Shunt and Series field windings are present
- Various connections are possible
- Field windings are designed/adjusted and connected to achieve a desirable torque/speed characteristic

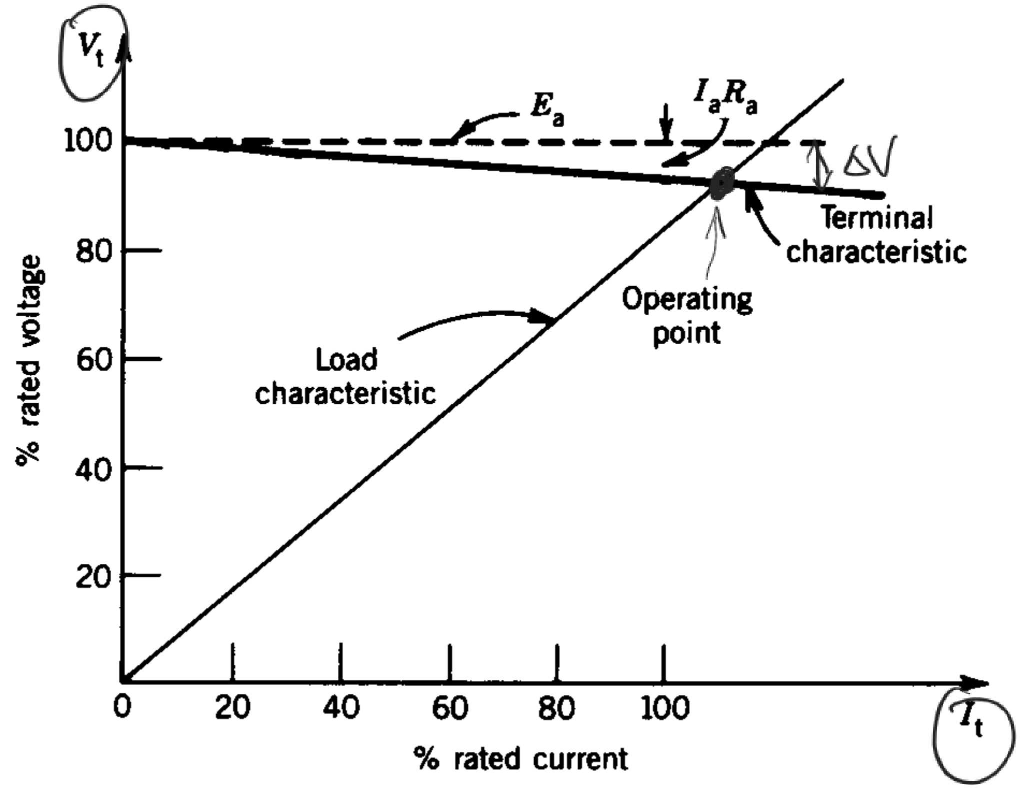



Speed-Torque Characteristic



# Separately-Excited DC Generator




$$V_f = R_f I_f$$

$$E_a = V_t + I_a R_a$$

$$E_a = K_a \Phi_p \omega_r = L_{af} I_f \omega_r$$

$$V_t = I_t R_{load} = I_a R_{load}$$

Load-Voltage Characteristic

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

# Starting DC machine: Issues and solutions

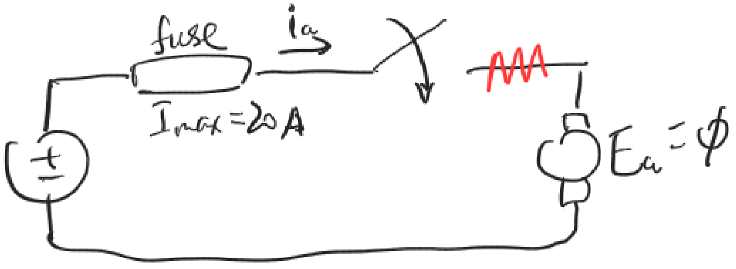
Consider a 1.2 kW, 120 V, Shunt DC Motor with Ra = 2 Ω, and Ia_max = 20 A

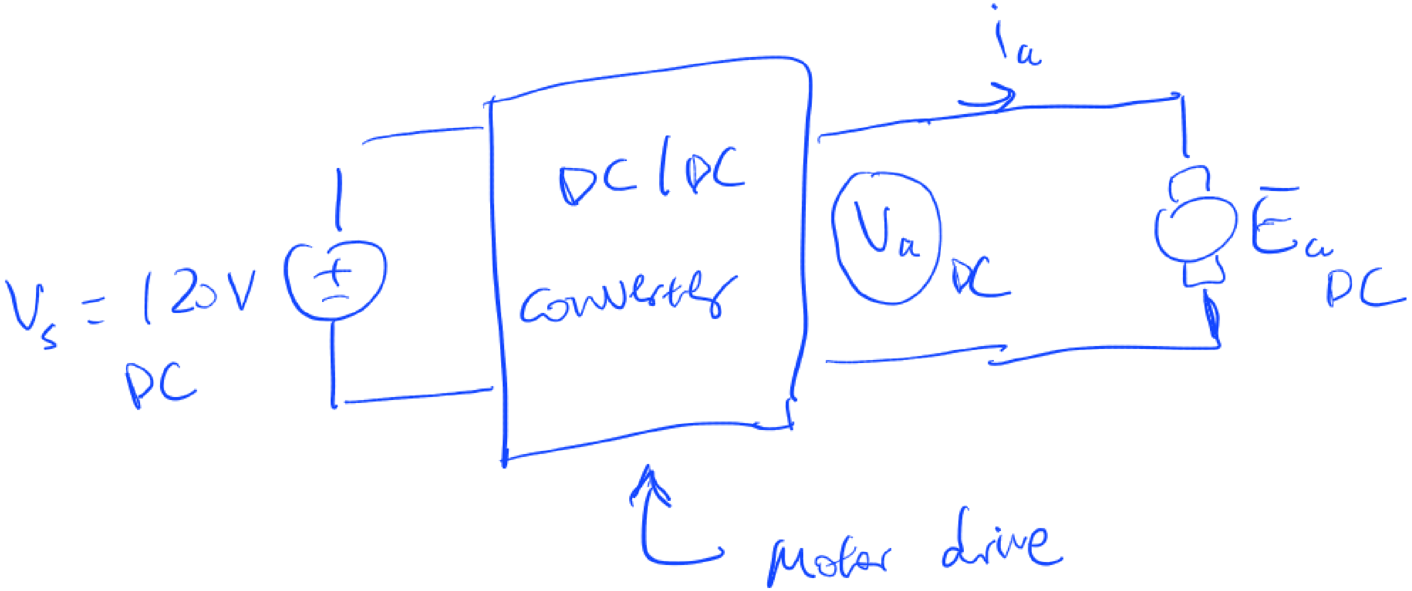
Rated current $I_{a,rated} = \dfrac{1200}{120} = 10\,\text{A}$ → $E_a \neq 0$

→ $E_a = 0$ at start up

Starting current $I_{a,start} = \dfrac{V_t - E_a}{R_a} = \dfrac{120 - 0}{2} = 60\,\text{A}$ Too high ! => It can burn the motor and cause damage!

1. Use additional starting resistor in series with armature
2. Use reduced voltage
3. Use Power Electronics Drive & Controller



# DC Motor Drives and Dynamics

↳ Use power electronic converter to control DC machine behaviour through feedback control

## Important Topics & Concepts

- Basic principles of controlling DC motors
- Four Quadrants of operation
- Power electronic converters

Lab 3

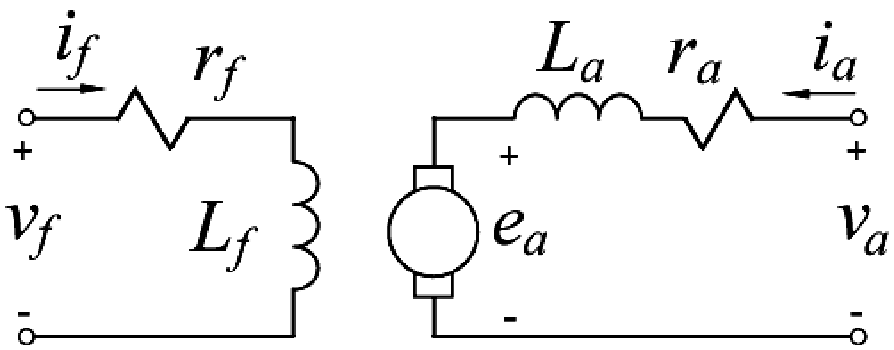
- Dynamic (State) equations of the separately-excited motor
- Dynamic (State) equations of the PM motor
- Possible model & implementations

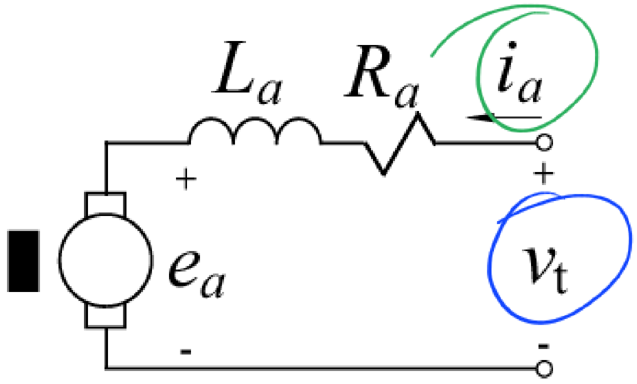
MATLAB / Simulink

- Read Chapter 10 of the textbook

# Motivation: Speed/Torque Control of DC Motors

Recall Separately Excited DC Motor and PM DC Motor




$$\omega_r = \frac{V_t}{K_a\Phi_p} - \frac{R_a}{(K_a\Phi_p)^2}T = \frac{V_t}{L_{af}I_f} - \frac{R_a}{(L_{af}I_f)^2}T$$

$$T = K_a\Phi_p I_a = L_{af} I_f I_a$$

Control methods:

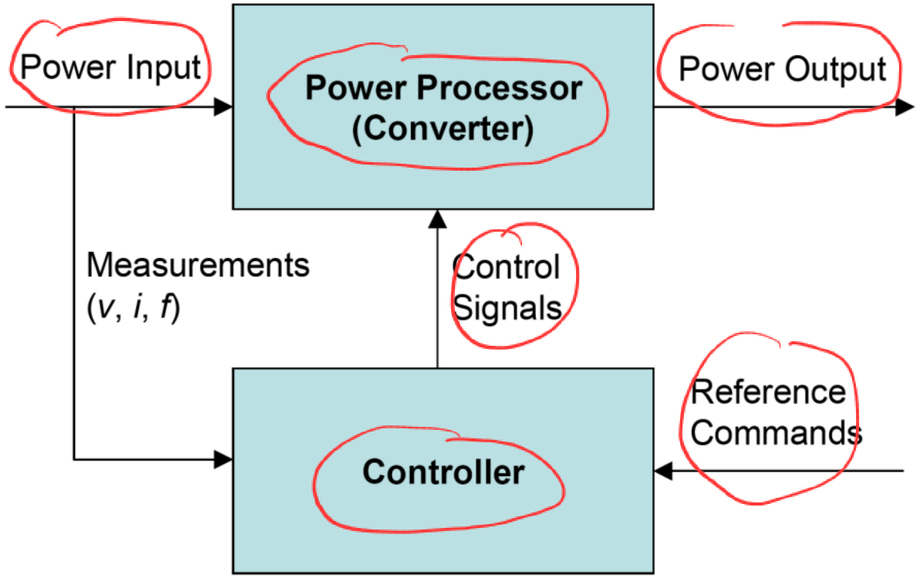
1. Varying armature resistance (not practical due to high losses)
2. Varying field (only for field winding)
3. Varying terminal voltage
4. Varying armature current

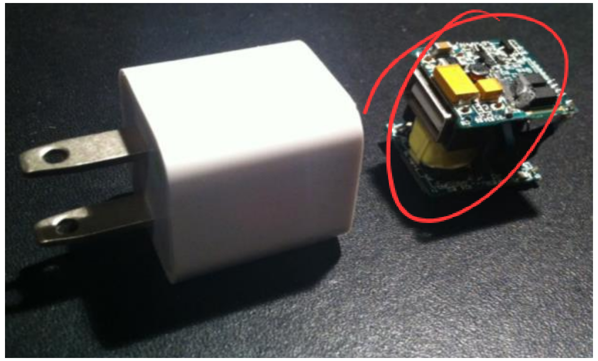
# Power electronics

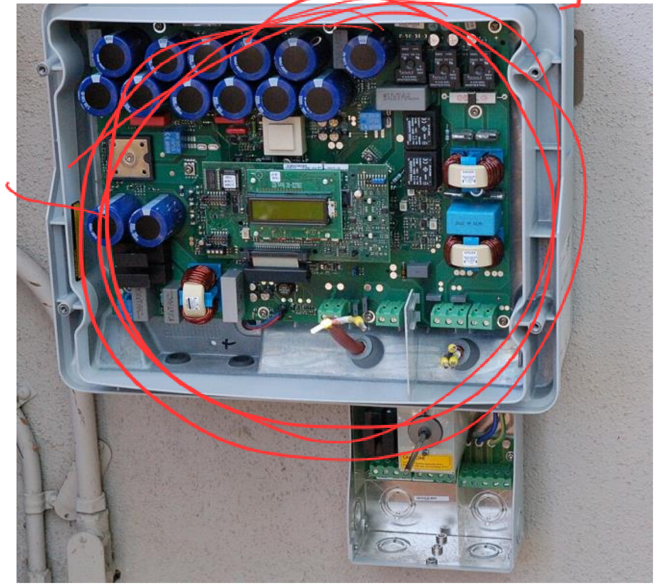
V, I, f

- Power electronics refers to the study of electronic circuits which efficiently process and transfer the electric power from the available form to a desired form using semiconductor switching devices → solid-state circuits

Input = Output





# Conversion types

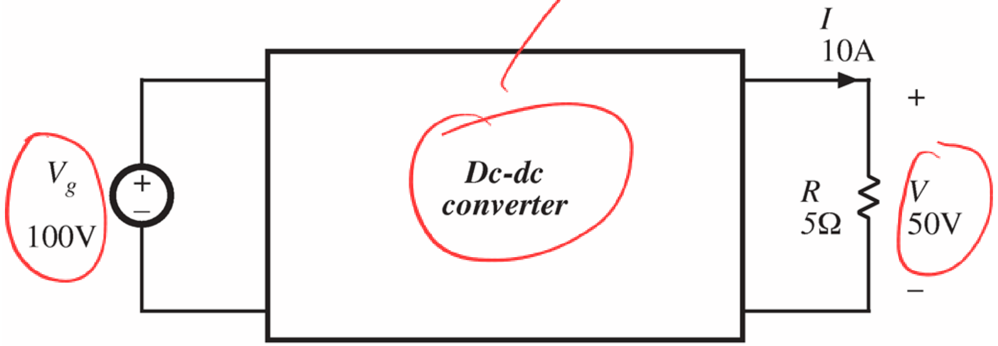
→ ELEC 451
→ EECE 571D
↳ PE for grid level application

input output

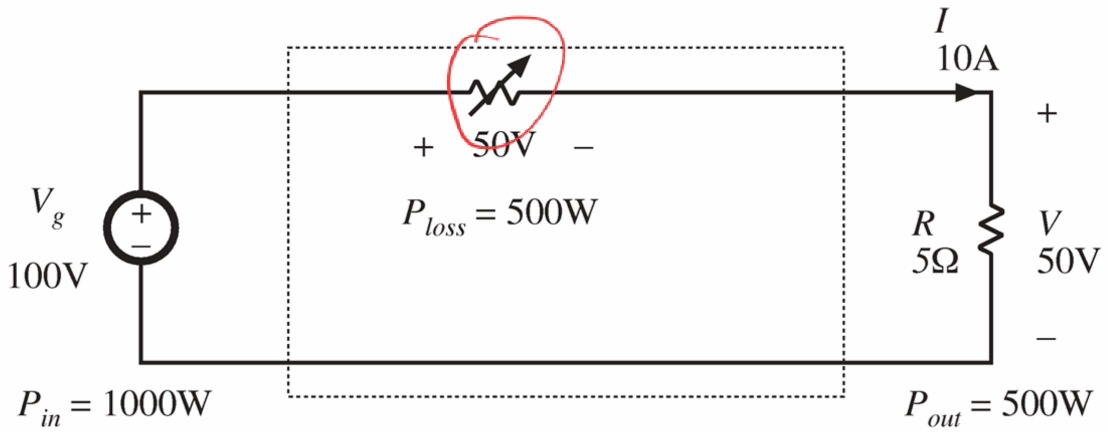
- DC-DC converters (choppers)
  - For small & large DC motor drives
- AC-DC rectifiers
  - For large DC motor drives
- DC-AC inverters → solar, battery
- AC-AC cycloconverters

# DC-DC conversion

As efficient as possible




Input source: 100V
Output load: 50V, 10A, 500W
How can this converter be realized?

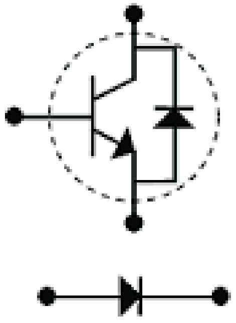



Power losses

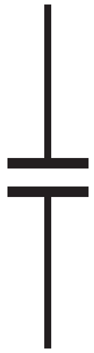
# Components available for lossless power processing

Semiconductor Switches

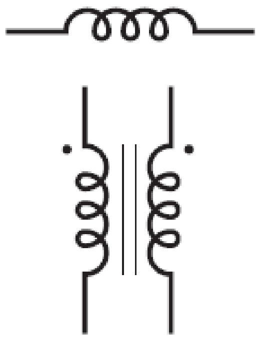
Solid-state switches

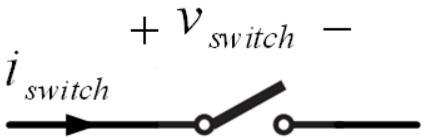


Capacitor



Magnetics






**Switch can be realized using:**

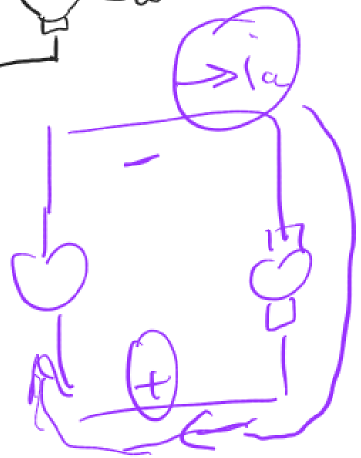
- Insulated Gate Bipolar Transistor (**IGBT**)
- Metal Oxide Semiconductor Field Effect Transistor (**MOSFET**)

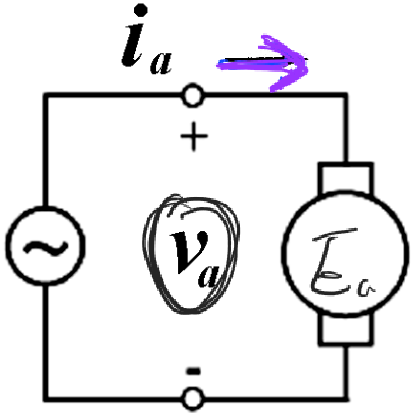
# DC-DC Converters Quadrants

Define CCW as positive rotation, CW as negative rotation

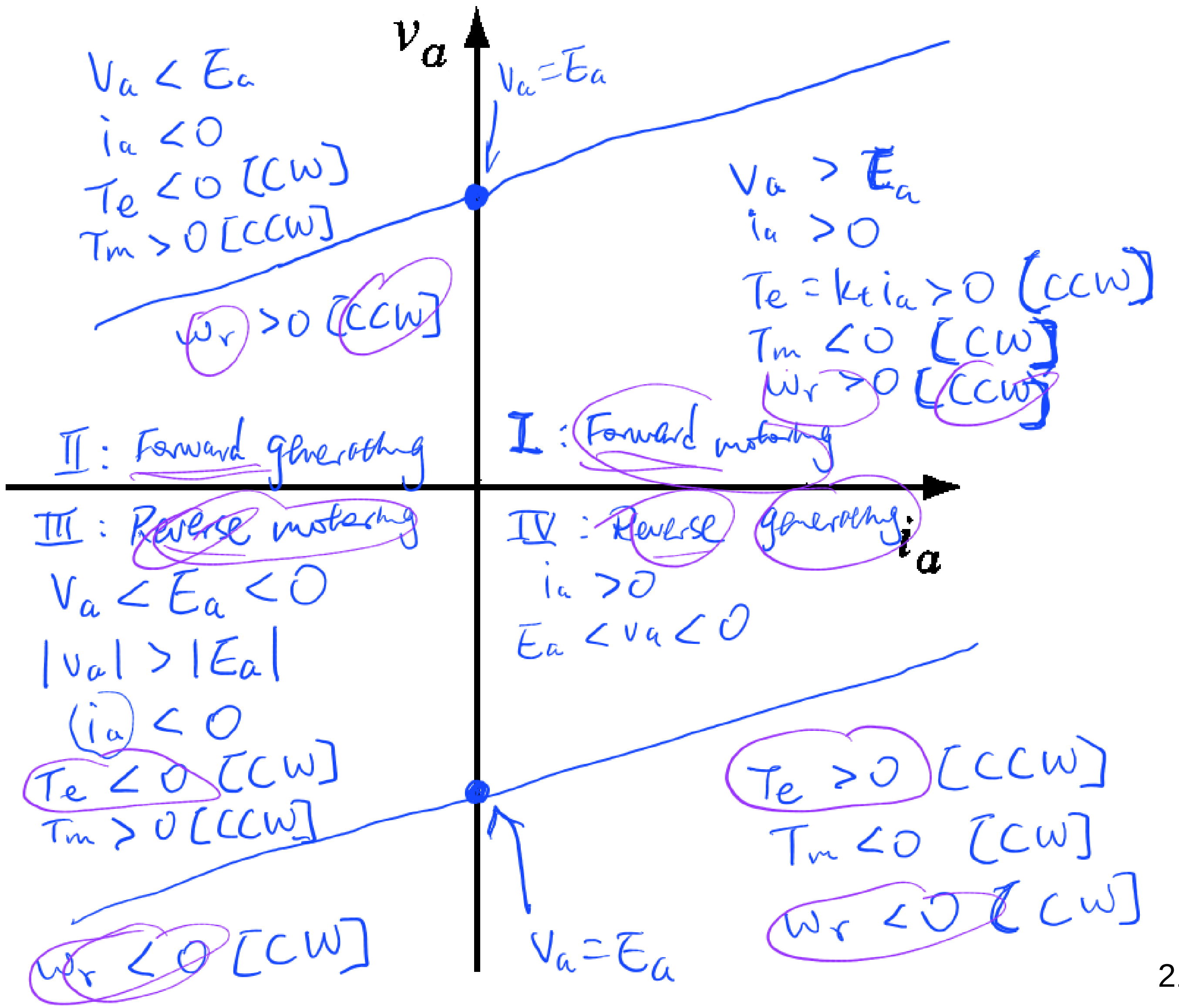
Assume a DC voltage source wherein the averaged output voltage can be controlled

Test material


$$\bar{V}_a = \frac{1}{T}\int_0^T v_a(t)\,dt$$



# DC-DC Converters Quadrants - Summary

| | Quadrant I | Quadrant II | Quadrant III | Quadrant IV |
|---|---|---|---|---|
| **Name** | Forwarding motoring | Forward generating | Reverse motoring | Reverse generating |
| $\boldsymbol{E_a, Va}$ | $V_a > E_a > 0$ | $E_a > V_a > 0$ | $V_a < E_a < 0$ | $E_a < V_a < 0$ |
| $\boldsymbol{I_a}$ | $I_a > 0$ | $I_a < 0$ | $I_a < 0$ | $I_a > 0$ |
| $\boldsymbol{T_e}$ | Positive (CCW) | Negative (CW) | Negative (CW) | Positive (CCW) |
| $\boldsymbol{T_m}$ | Negative (CW) | Positive (CCW) | Positive (CCW) | Negative (CW) |
| $\boldsymbol{\omega_r}$ | Positive (CCW) | Positive (CCW) | Negative (CW) | Negative (CW) |
| **Example** | Car in forward (drive) mode going uphill | Car in forward (drive) mode going downhill | Car in reverse mode going uphill | Car in reverse mode going downhill |

# Looking ahead…

- Continue **Module 4**