ELEC 342
Electromechanical Energy Conversion and Transmission

2025-26 Winter Term 2

Lecture 13

February 24, 2026

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Course Logistics

- Labs:
  - Please be on time and come prepared
  - Each person needs to complete prelab and submit as a part of the final lab report
  - You need to submit all five (5) lab reports in order to write the final exam

- Midterm will take place on Feb. 26
  - Detailed logistics are already announced on Canvas

- **No Tutorial this week**

Example 5

A dc machine is connected across a 240-volt line. It rotates at 1200 rpm and is generating 230 volts. The armature current is 40 amps.

(a) Is the machine functioning as a generator or as a motor?

(b) Determine the resistance of the armature circuit.

(c) Determine power loss in the armature circuit resistance and the electromagnetic power.

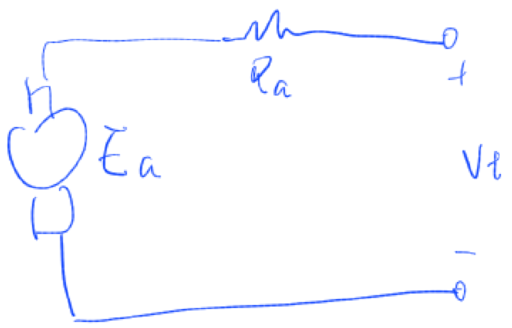
(d) Determine the electromagnetic torque in newton-meters.

(e) If the load is thrown off, what will the generated voltage and the rpm of the machine be

$\hookrightarrow T_m = 0 = T_e$ (ignore friction)

$\hookrightarrow T_e = k_t I_a \Rightarrow I_a = 0\,A$

Example 5



(a) $V_t = 240\ V$, $E_a = 230V$, $I_a = 40A$

$V_t > E_a$: motoring

(b) $R_a I_a + E_a = V_t \Rightarrow R_a = \dfrac{V_t - E_a}{I_a} = 0.25\,\Omega$

(c) $P_{loss} = I_a^2 R_a = 40^2 \times 0.25 = 400\ W$

$P_e = E_a I_a = 230 \times 40 = 9200\ W$

(d) $T_e = \dfrac{P_e}{\omega_r} = \dfrac{9200}{\frac{1200}{60} \times 2\pi} = 73.21\ N\cdot m$

(e) $I_a = 0\ A \Rightarrow E_a = V_t = 240V$

$\hookrightarrow \omega_r = ?$

$E_a = k_v \omega_r \Rightarrow$ ☆

$\left.\begin{array}{l} E_{a_1} = k_v \omega_{r_1} \\ E_{a_2} = k_v \omega_{r_2} \end{array}\right\}$ $\dfrac{E_{a_1}}{E_{a_2}} = \dfrac{\omega_{r_1}}{\omega_{r_2}}$

$E_{a_1} \rightarrow 230V$, $\omega_{r_1} \rightarrow 1200\ rpm$

$E_{a_2} \rightarrow 240V$, $\omega_{r_2} \Rightarrow 1252\ rpm$

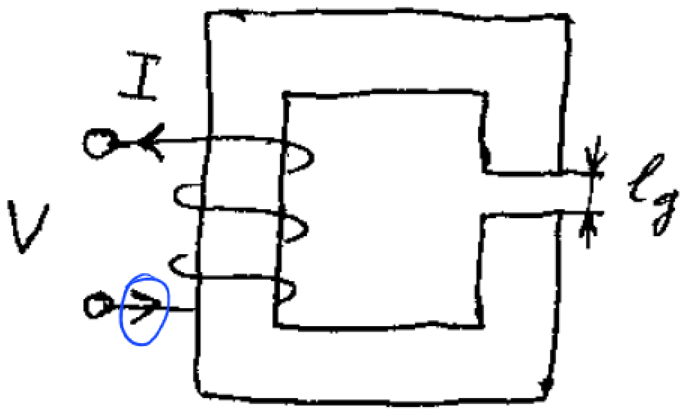
Example 6

Consider the magnetic system shown below. Assume that reluctance of the core path and the air-gap are $\Re_c = 2\times10^5\ At/Wb$ and $\Re_g = 8\times10^5\ At/Wb$, respectively. The coil has 100 turns and dc resistance $r = 2\ \Omega$.

(a) (4pts) Assume the current direction as shown, draw an equivalent **magnetic** circuit, show the direction of mmf F and the flux Φ

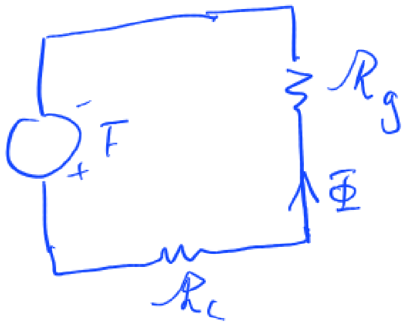
(b) (4pts) Calculate the inductance L

(c) (12pts) Assume that coil is connected to a 10V(rms) 60-Hz ac source. Calculate the rms values of current I, flux Φ, flux linkage λ.



Example 6

(a)



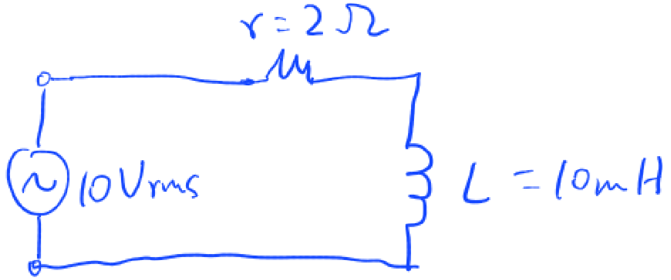
$$F = Ni = \Phi(\mathcal{R}_c + \mathcal{R}_g)$$

$N = 100$, $\mathcal{R}_c = 2\times10^5$, $\mathcal{R}_g = 8\times10^5$

(b)

$$L = \frac{N^2}{\mathcal{R}} = \frac{100^2}{\mathcal{R}_c + \mathcal{R}_g} = 10\ mH$$

(c) $V_{rms} = 10V$, $f = 60Hz$



$$I_{rms} = \frac{V_{rms}}{|Z|} = \frac{10}{\sqrt{2^2 + [(2\pi 60)(0.01)]^2}} = 2.34\ A_{rms}$$

$\hookrightarrow Z = 2 + j(2\pi 60)(10mH)$, $\omega = 2\pi f$

$$\Phi_{rms} = \frac{N i_{rms}}{\mathcal{R}_c + \mathcal{R}_g} = \frac{100 \times 2.34}{10\times10^5} = 2.34\times10^{-4}\ Wb$$

$$\lambda_{rms} = N\Phi_{rms} = 0.0234\ Wb\cdot t$$

Example 7

$W_f = W_c$

Assume an electromechanical system with one electrical and one mechanical inputs. The system may be assumed **magnetically linear** (similar to a solenoid). The system's state is shown in the $\lambda - i$ figure below, wherein the system can move from point A to point B, and from point A to point C, respectively. Using the numerical values given on this figure, **calculate the change in** W_f, W_c, W_e, and W_m for the two transitions. In other words, complete the Table given below. **Be sure to include the units and check the energy conversion balance!**

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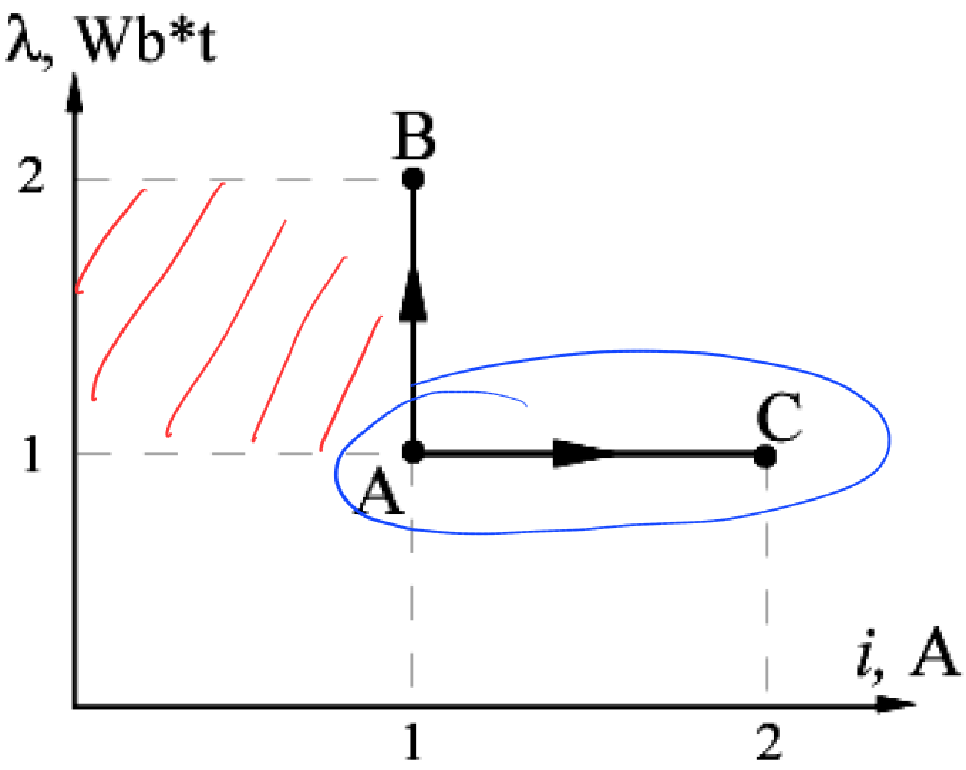
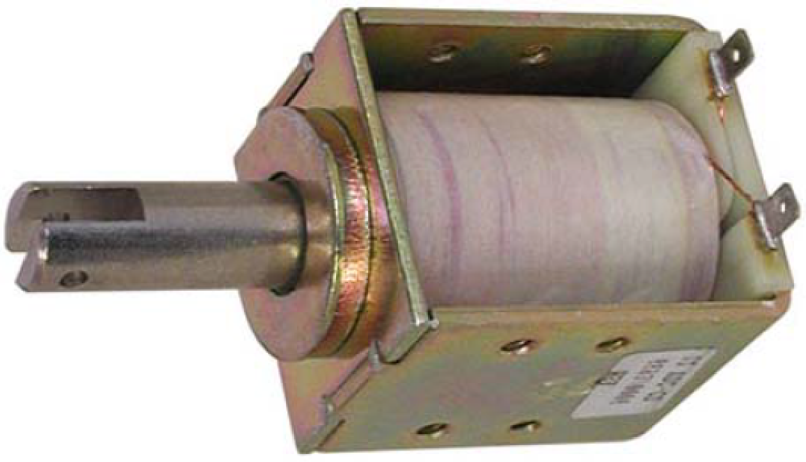




$\Delta W_e = \int i \, d\lambda$

Example 7

Transition	From A to B	From A to C
(3pts) Change in coupling field energy, ΔW_f	$1 - 0.5 = +0.5\,J$	$1 - 0.5 = +0.5\,J$
(3pts) Change in co-energy, ΔW_c	$+0.5\,J$	$0.5\,J$
(3pts) Change in electrical input, ΔW_e	$+1\,J$	$\emptyset\,J$
(3pts) Change in mechanical input, ΔW_m	$\Delta W_e = \Delta W_m + \Delta W_f \Rightarrow \Delta W_m = 0.5\,J$	$-0.5\,J$
(4pts) The energy was supplied to **(and how much)**	Coupling field + mechanical system $\downarrow$ 0.5 J $\quad\downarrow$ 0.5 J	Coupling field 0.5 J
(4pts) The energy was taken from **(and how much)**	Electrical system 1 J	mechanical system 0.5 J
Plunger IN or OUT?	IN	OUT

Example 8

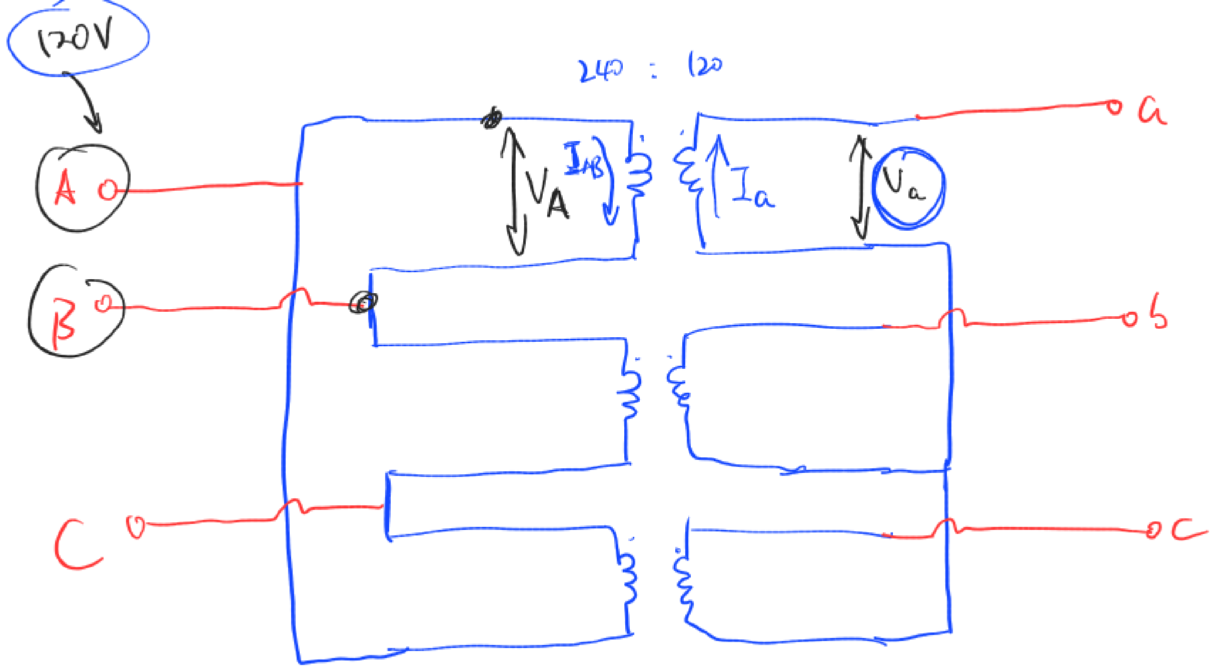
Assume that you have three identical 240/120V transformers. The transformers may be assumed ideal. These transformers are connected into Δ/Y to supply a $60\ \Omega$ (per-phase) Y-connected resistor load ~~form~~ from a 120V (line-to-neutral) source.

(a) (10pts) Sketch the system and label the input (primary side) terminals with ***ABC*** and the load (output) terminals with ***abc***. Also label the voltages and currents including directions.

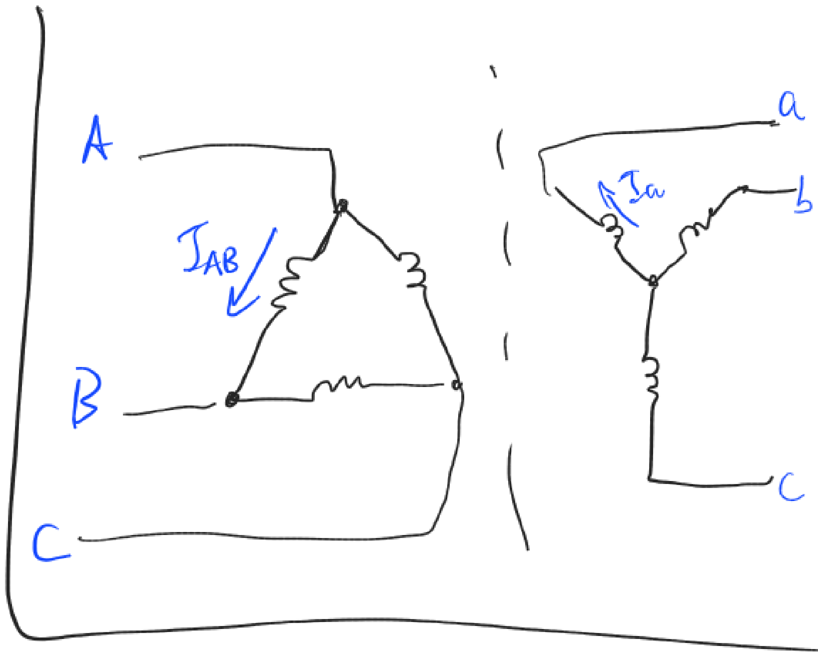
(b) (10pts) Calculate the currents I_A, I_{AB}, the voltages V_a, V_{ab}, the power supplied from the source P_{source}, and the power consumed by the load P_{load} (show that $P_{source} = P_{load}$).

Example 8

(a)



$a = \frac{240}{120} = 2$



(b) $V_a = V_A \times \frac{120}{240} = 103.9V$

↳ $V_{AB} = 120\sqrt{3}$

$V_{ab} = \sqrt{3} \times V_a = 180V$

$I_{AB} = I_a \times \frac{120}{240} = 0.866\ A$

↳ $\frac{V_a}{60} = \frac{103.9}{60}$

$I_A = I_{AB}\sqrt{3} = 1.5A$

$P_{source} = V_{LN} \times I_{Line} \times 3$

Primary

$= 120V \times 1.5A \times 3$

$= 540\ W$

$P_{load} = \left(\frac{V_a}{Z}\right)^2 \times 3$

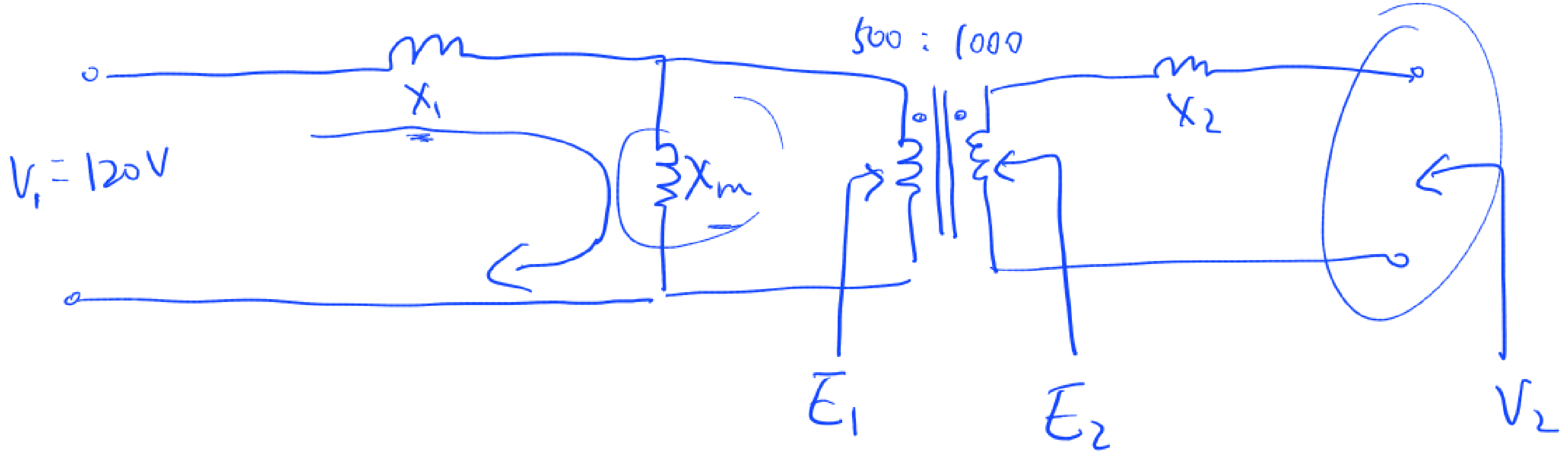
$= \frac{(103.9V)^2}{60\Omega} \times 3 = 540W$

Example 9

A 60-Hz **step-up** transformer with $N_1 = 500$ and $N_2 = 1000$ has leakage reactances are $X_1 = 1.2\Omega$, $X_2 = 4\Omega$ (each referred to its own side), and the magnetizing reactance $X_m = 238.8\Omega$ (referred to the primary side). The core and copper losses can be neglected. Assume 120V is applied to the primary side:

(a) (10pts) Calculate the open-circuit primary current $I_{1,oc}$ and the secondary voltage $V_{2,oc}$ (their rms values)

(b) (10pts) Assume a resistive load $R_{Load} = 20\Omega$ is connected to the secondary side. Calculate the voltage regulation (VR). Also calculate the input (primary side) power-factor angle φ in degrees.



Example 9

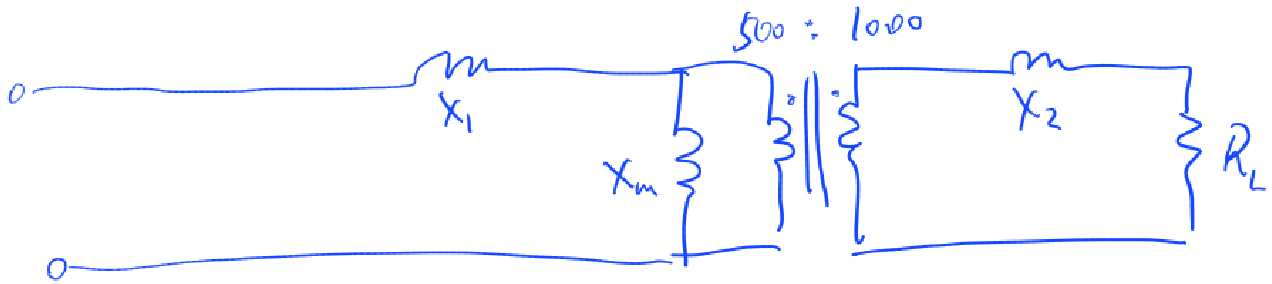
(a) $I_{oc} = \dfrac{V}{|Z|} = \dfrac{120}{238.8 + 1.2} = 0.5A$

$E_1 = 120 - 0.5 \times 1.2 = 119.4\,V$

$E_2 = 119.4 \times 2 = 238.8\,V \Rightarrow V_{2oc} = E_2 = 238.8\,V$

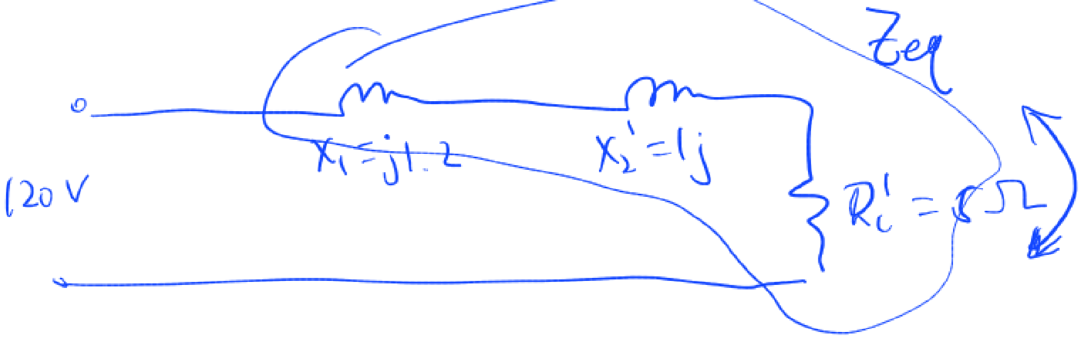
$V_{2,oc}$

(b)



$X_2' = X_2 \times \left(\frac{1}{2}\right)^2 = 1\,\Omega$

$R_L' = R_L \times \left(\frac{1}{2}\right)^2 = 5\,\Omega$



$V_2' \Rightarrow V_2 = V_2' \times \dfrac{1000}{500}$

$VR = \dfrac{V_{2oc} - V_2}{V_2}$

$V_1 = 120\angle 0^\circ$

$Z_{eq} =$

$I_1 = \dfrac{V_1}{Z_{eq}}$

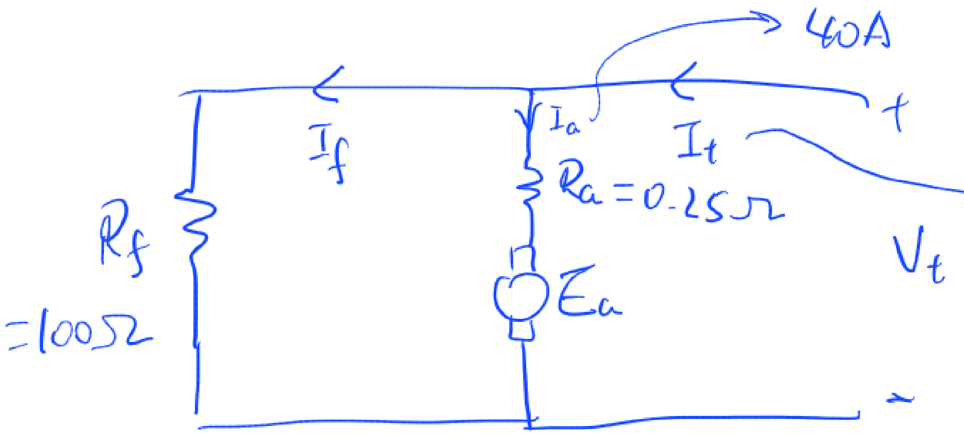
Example 10

A DC shunt machine has $R_a = 0.25\ \Omega$. The machine is connected to a 250 V DC supply, draws armature current of 40 A, and rotates at 1200 rpm.

(a) Calculate the induced back emf E_a

(b) Determine the useful mechanical load torque T_m. The rotational losses are 100 W.

(c) Determine the efficiency of the motor η. The field circuit resistance is $R_f = 100\ \Omega$.



$$I_a + I_f = 40\text{ A} + \frac{250}{100} = 42.5\text{ A}$$

Example 10

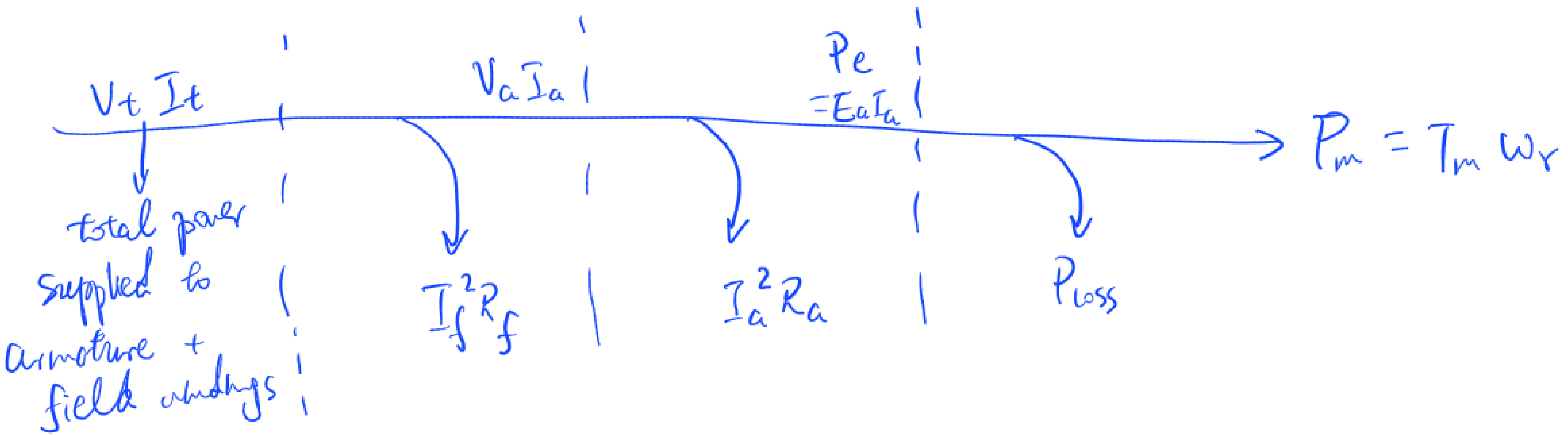
(a) $E_a = V_a - I_a R_a = 250V - 0.25 \times 40 = 240V$

(b) $P_e = P_m + P_{loss}$ (motoring mode) $\Rightarrow P_m = 9500W$

$P_e = E_a I_a$, $E_a = 240$, $I_a = 40$; $P_{loss} = 100W$

$$T_m = \frac{P_m}{\omega_r} = \frac{9500\,W}{\frac{1200}{60} \times 2\pi} = 25.6\ N{\cdot}m$$

(c)



$$\eta = \frac{P_m}{V_t I_t} = \frac{9500}{250 \times 42.5} = \frac{9500}{10625} = 89.4\%$$

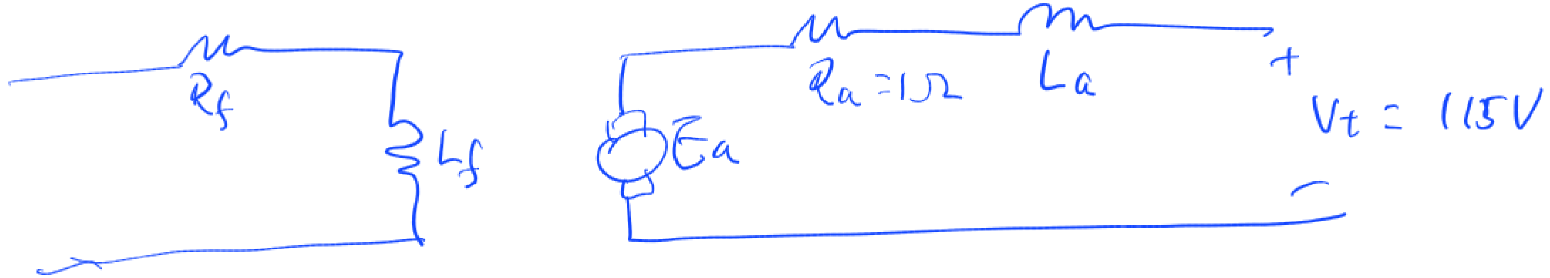
Example 11

Consider a 115V **Separately-Excited DC Machine** with the armature resistance $R_a = 1\Omega$ and field-to-armature inductance $L_{af} = 0.111\text{H}$. The machine is supplied from a constant dc source $V_t = 115\text{ V}$ and the shaft is connected to a mechanical system with constant speed $n = 1800\text{ rpm}$ in CCW direction. Friction can be neglected.

(a) (4pts) Draw an equivalent circuit

(b) (8pts) The field current is set to $I_f = 5\text{ A}$. Calculate the armature current I_a and torque T_e. Determine whether machine is motoring or generating. Is T_e in CW or **CCW** direction? (circle one)

(c) (8pts) The field current is increased to $I_f = 6\text{ A}$. Calculate the armature current I_a and torque T_e. Determine whether machine is motoring or generating. Is T_e in **CW** or CCW direction? (circle one)



$$L_{af} = k_a \frac{L_f}{N_f} = 0.111H$$

Example 11

(b) $I_f = 5\,A$

$\bar{E}_a = L_{af} I_f \omega_r = 0.111 \times 5 \times \frac{1800 \times 2\pi}{60} = 104.61V$ $\rightarrow k_t \omega_r$ (PM)

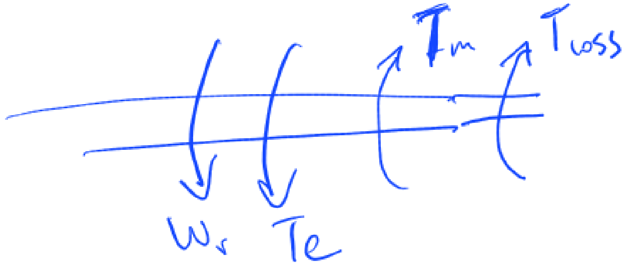
$E_a < V_t \Rightarrow$ motoring

$$I_a = \frac{V_a - E_a}{R_a} = 10.38\ A$$

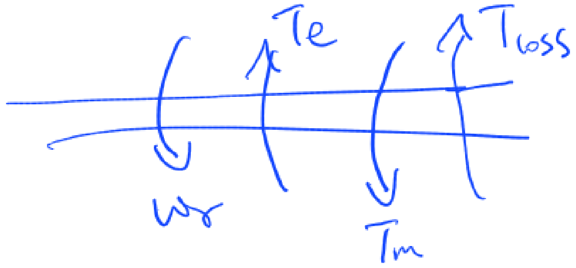
$$T_e = L_{af} I_f I_a = 0.111 \times 5 \times 10.38 = 5.76\ N\cdot m$$

$\Downarrow$

CCW



(motoring)



(generating)

(c)

$I_f = 6\,A$

$E_a = 125.53\,V > 115\,V \rightarrow$ generating

$I_a = 10.532\ A = \frac{E_a - V_a}{R_a}$

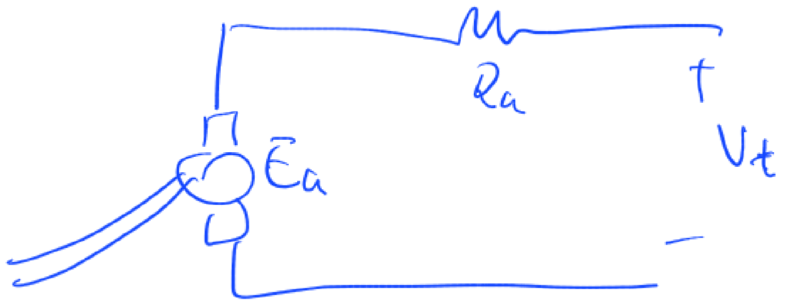
$T_e = 7.014\ N\cdot m \Rightarrow CW$

Example 12

Consider a **Permanent-Magnet DC Motor** with the following parameters: rated/nominal voltage $V_t = 12\,\text{V}$; armature resistance $R_a = 1.2\,\Omega$. Under the NO-LOAD test the armature current is $I_{a\_nl} = 0.2\,\text{A}$ and the motor speed is $n_{nl} = 1800\,\text{rpm}$.

(a) (10pts) Calculate the induced armature emf E_{a_nl}, torque constant K_t, and the friction torque T_{fric}

(b) (10pts) Assume T_{fric} is constant (doesn't depend on speed). A mechanical load with the torque $T_m = 4 \cdot T_{fric}$ is connected to the motor shaft. Calculate the motor speed n in rpm and speed regulation SR in %



$T_e = T_{fric}$

Example 12

(a) No load : $T_e = T_{fric}$

$$V_t - R_a I_a = 12 - 1.2 \times 0.2 = 11.76V = E_a$$

$$E_a = k_t \omega_r \Rightarrow k_t = \frac{E_a}{\omega_r} = 0.0624$$

$$T_e = k_t \times I_a = 0.0125\ N \cdot m = T_{fric}$$

(b) $T_{fric} = 0.0125\ N \cdot m$

$T_m = 4 \cdot T_{fric}$ (given)

$T_e = T_m + T_{fric} = 0.0625\ N \cdot m$

$I_a = \frac{T_e}{k_t} = 1A$

$E_a = 12 - 1.2 \times 1 = 10.8V \Rightarrow \omega_r = \frac{E_a}{k_t} = 173.08\ rad/s$

$$SR\% = \frac{\omega_{nl} - \omega_r}{\omega_r} = 8.9\%$$

Looking ahead…

- Start **Module 5**