MT → Oct 16 → Wednesday → 4 pm to 6 pm

2hrs → length

4 problems
- → equivalent circuit of the transformer
- → voltage regulation, η of the transformer
- → DC generator
- → DC motor

Formula sheet → will be posted on BB

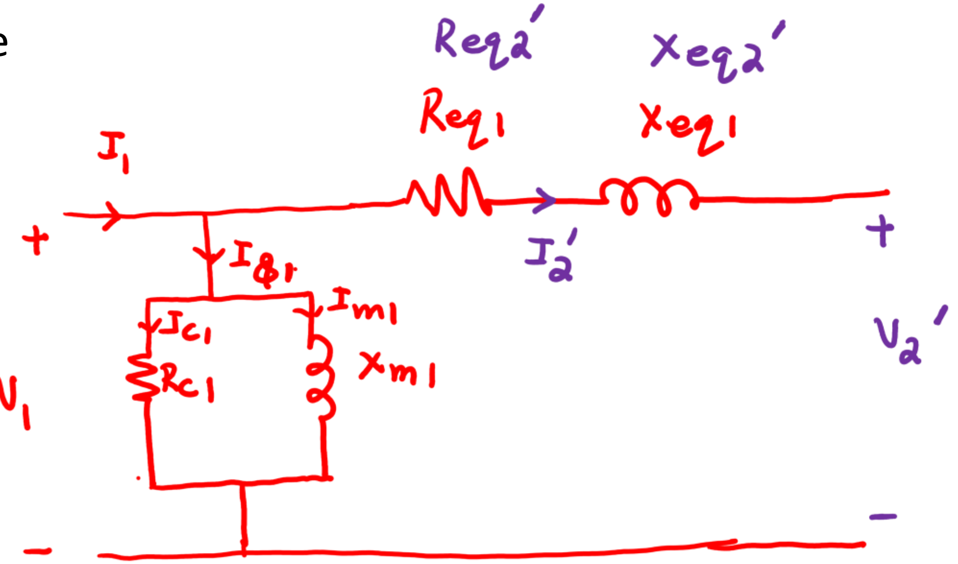
Electric Motors

Mid Term Review

A 1-phase, 100 kVA, 11000/2200 V, transformer has the following parameters: (V_1 over 11000, V_2 over 2200)

$R_{HV} = 6\ \Omega$, $X_{HV} = 30.16\ \Omega$, $X_{m(HV)} = 60\ k\Omega$, $R_{C(HV)} = 125\ k\Omega$, $R_{LV} = 0.28\ \Omega$, $X_{LV} = 1.21\ \Omega$.
Obtain an equivalent circuit of the transformer

1. Referred to the high voltage side
2. Referred to the low voltage side



$11000^V = V_1$

$R_1 = 6\,\Omega$

$X_1 = 30.16\,\Omega$

$R_2 = 0.28\,\Omega$

$X_2 = 1.21\,\Omega$

$X_{m1} = 60\,k\Omega$

$R_{c1} = 125\,k\Omega$

$$a = \frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{11000}{2200}$$

$$a = 5$$

$$R_{eq1} = R_1 + a^2 R_2$$
$$= 6 + (5^2 \times 0.28)$$
$$= 13\,\Omega$$

$$\frac{V_1}{V_2} = a$$

$$V_2' = V_1 = aV_2 = 5 \times 2200$$
$$= 11000^V$$

$$X_{eq1} = X_1 + a^2 X_2 = 30.16 + (5^2 \times 1.21)$$
$$= 60.41\,\Omega$$

A 1-phase, 100 kVA, 11000/2200 V, transformer has the following parameters:

R_{HV} = 6 Ω, $\cancel{L}_{HV}$ = 30.16 Ω, $\cancel{L}_{m(HV)}$ = 60 kΩ, $R_{C(HV)}$ = 125 kΩ, R_{LV} = 0.28 Ω, $\cancel{L}_{LV}$ = 1.21 Ω.
Obtain an equivalent circuit of the transformer

$a = 5$

1. Referred to the high voltage side
2. Referred to the low voltage side

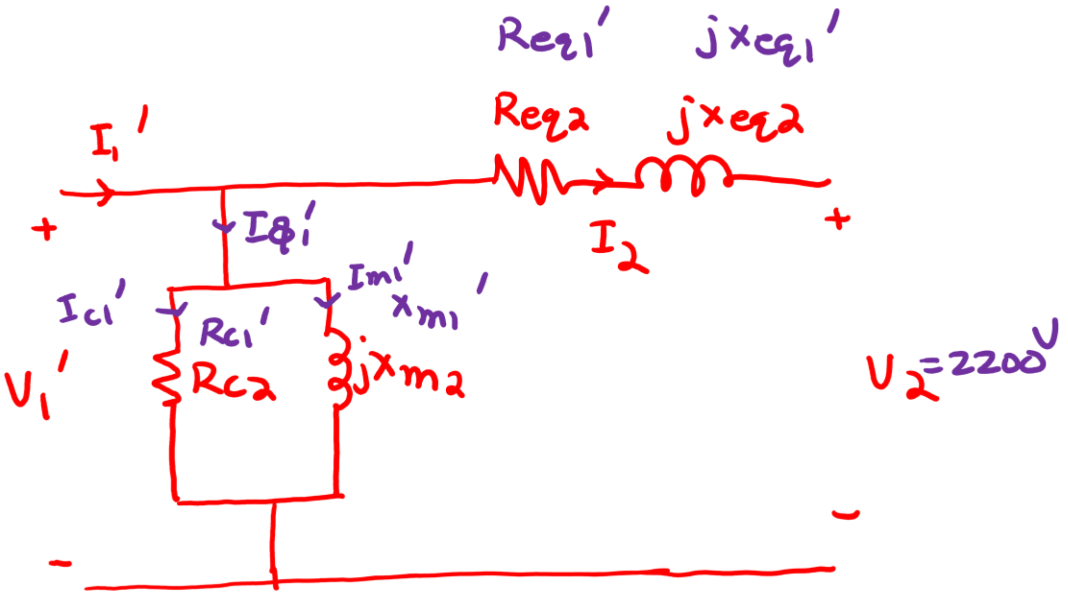
$R_1 = 6\,\Omega$

$x_1 = 30.16\,\Omega$

$x_{m1} = 60\,k\Omega$

$R_{c1} = 125\,k\Omega$

$R_2 = 0.28\,\Omega$ $\quad x_2 = 1.21\,\Omega$



$$R_{eq2} = \frac{R_1}{a^2} + R_2 = \frac{6}{5^2} + 0.28 = 0.52\,\Omega = \frac{R_{eq1}}{a^2}$$

$$x_{eq2} = \frac{x_1}{a^2} + x_2 = \frac{30.16}{5^2} + 1.21 = 2.42\,\Omega$$

$$R_{c2} = R_{c1}' = \frac{R_{c1}}{a^2} = \frac{125\,k\Omega}{5^2} = 5\,k\Omega$$

$$x_{m2} = x_{m1}' = \frac{x_{m1}}{a^2} = \frac{60\,k\Omega}{5^2} = 2.4\,k\Omega$$

$$V_1' = V_2 = \frac{V_1}{a} = 2200\,V$$

$$a = \frac{V_1}{V_2}$$

A 1-phase, 10 kVA, 2200/220 V, 60 Hz transformer has the following parameters:

R_{eq} = 10.4 Ω, X_{eq} = 31.3 Ω referred to high voltage side. If the transformer supplies a 10 kVA, 220 V load whose power factor is 0.85 (lagging), determine

1. The Voltage Regulation
2. The efficiency if the core loss 100 W is at the rated terminal voltage

$R_{eq1} = 10.4\,\Omega$

$X_{eq1} = 31.3\,\Omega$

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

$V_{FL} \rightarrow V_{2,rated}$

$$VR = \frac{|V_1'| - |V_2|}{|V_2|} \times 100\%$$

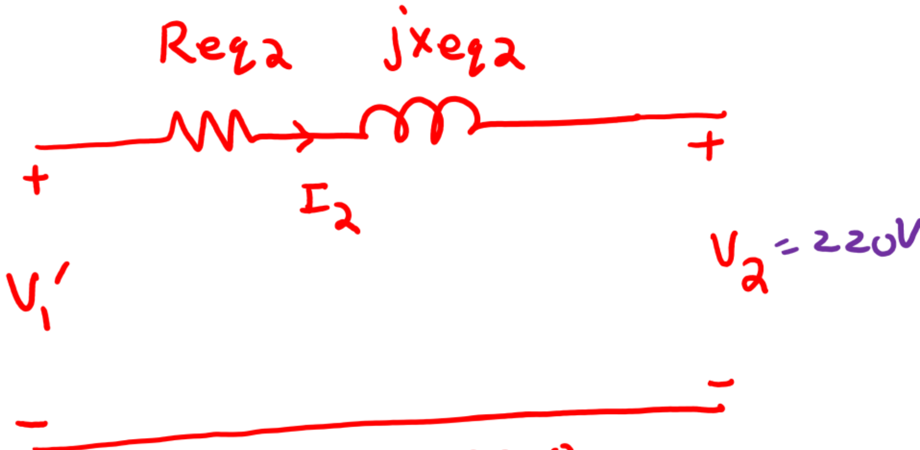
$|V_2| = 220\,V$

$$\bar{V}_1' = \bar{V}_2 + \bar{I}_2 (R_{eq2} + jX_{eq2})$$

$$|I_2| = \frac{10000}{220} = 45.45\,A$$

$\bar{I}_2 = 45.45 \angle -31.78^\circ$ A

$\cos^{-1}(0.85) = 31.78^\circ$



$$a = \frac{2200}{220} = 10$$

$$R_{eq2} = R_{eq}' = \frac{R_{eq1}}{a^2} = \frac{10.4}{100} = 0.104\,\Omega$$

$$X_{eq2} = \frac{31.3}{10^2} = 0.313\,\Omega$$

A 1-phase, 10 kVA, 2200/220 V, 60 Hz transformer has the following parameters:

R_{eq} = 10.4 Ω, X_{eq} = 31.3 Ω referred to high voltage side. If the transformer supplies a 10 kVA, 220 V load whose power factor is 0.85 (lagging), determine

1. The Voltage Regulation
2. The efficiency if the core loss 100 W is at the rated terminal voltage

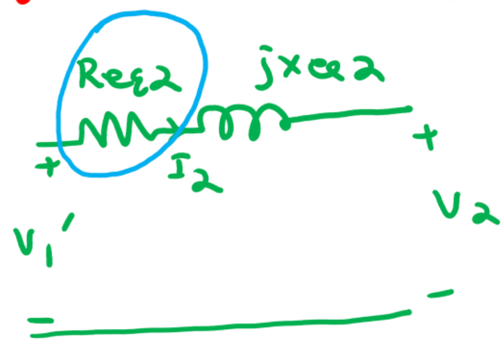
P_{core}

$P_{core} = \frac{V_1'^2}{R_c}$

$$\bar{V}_1' = [220\angle 0^\circ] + [(45.45\angle -31.78^\circ)(0.104 + j0.313)]$$

$$\bar{V}_1' = 231.71\angle 2.38^\circ \text{ V}$$

$$VR = \frac{231.71 - 220}{220} \times 100\% = 5.32\%$$



(2)
$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{P_{out}}{P_{out} + P_{cu} + P_{core}} \times 100\%$$

$$P_{out} = V_2 I_2 \cos\theta_2 = 10000 \times 0.85 = 8500 \text{ W}$$

$$P_{core} = 100 \text{ W}$$

$$P_{cu} = (I_2^2) R_{eq2} = (45.45)^2 \times 0.104 = 214.83 \text{ W}$$

$$\eta = \frac{8500}{8500 + 100 + 214.83} \times 100\% = 96.43\%$$

In a DC machine the constant K_a is given by $K_a = Z/2\pi$, where Z is the total number of conductors in the armature. The armature winding has 40 coils each having 8 turns of wire. If the air gap flux per pole is 0.0293 Wb, what voltage will this machine generate if its shaft spun at 1000 rpm?

ϕ (0.0293), N (1000 rpm)

$$K_a = \frac{Z}{2\pi} = \frac{40 \times 8 \times 2}{2\pi} = 101.86$$

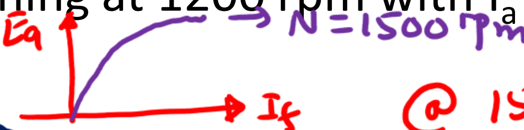
$$E_a = K_a \phi \omega$$

$$\omega = \frac{1000}{(60/2\pi)} \text{ rad/sec}$$

$$E_a = \left(\frac{320}{\pi}\right)(0.0293)\left(\frac{1000}{(60/2\pi)}\right)$$

$$E_a = 312.54 \text{ V}$$

The magnetization curve for a separately excited DC motor is given below (the magnetization curve is at 1500 rpm) and is running at 1200 rpm with I_a = 20 A and I_f = 2.5 A. The armature resistance R_a = 0.15 Ω.

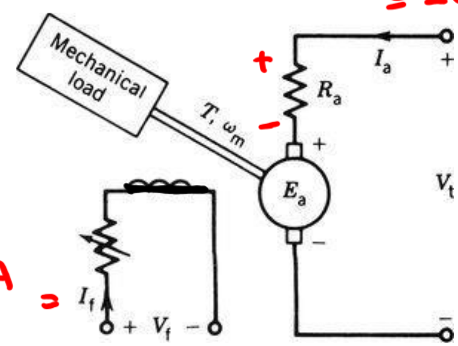


@ 1500 rpm

I_f (A)	0	0.2	0.5	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
E (V) Ea	14	19	31	54	72	100	124	140	156	168	180	185	187	188

Calculate:

1. The voltage Vt applied to the armature circuit
2. The developed torque
3. The developed power



$N = 1200$ rpm

① $V_t = E_a + I_a R_a$

$E_a\big|_{1200} = ?$ $\qquad E_a\big|_{1500\,rpm} = 140^V$

$I_f = 2.5^A$ $\qquad I_f = 2.5^A$ [field current remains constant]

$E_a = K_a \phi \omega \Rightarrow E_a \propto \omega \Rightarrow E_a \propto N$

$1500^{rpm} \rightarrow 140^V$

$1200^{rpm} \rightarrow 140 \times \frac{1200}{1500} = 112^V$

$V_t = 112 + (20 \times 0.15)$

$V_t = 115^V$

The magnetization curve for a separately excited DC motor is given below (the magnetization curve is at 1500 rpm) and is running at 1200 rpm with I_a = 20 A and I_f = 2.5 A. The armature resistance R_a = 0.15 Ω.

I_f (A)	0	0.2	0.5	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
E (V)	14	19	31	54	72	100	124	140	156	168	180	185	187	188

Calculate:

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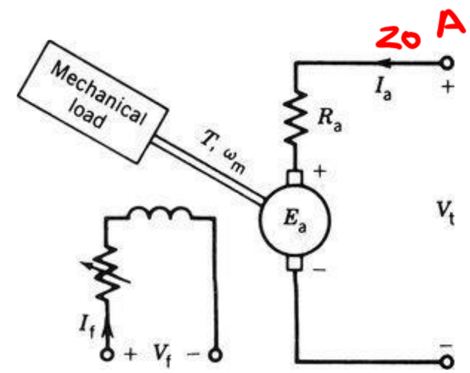


② $T = K_a \Phi i_a$

$$E_a = K_a \Phi \omega \Rightarrow K_a \Phi = \frac{E_a}{\omega} = \frac{140}{(1500/9.55)} = \frac{112}{(1200/9.55)} = 0.8913$$

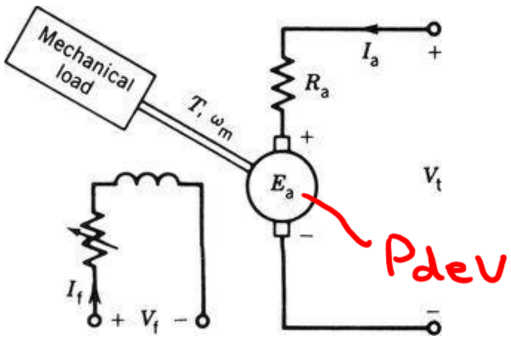
$$T = 0.8913 \times 20 = 17.83 \text{ N-m}$$

The magnetization curve for a separately excited DC motor is given below (the magnetization curve is at 1500 rpm) and is running at 1200 rpm with I_a = 20 A and I_f = 2.5 A. The armature resistance R_a = 0.15 Ω.

I_f (A)	0	0.2	0.5	0.8	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
E (V)	14	19	31	54	72	100	124	140	156	168	180	185	187	188

Calculate:

1. The voltage V_t applied to the armature circuit
2. The developed torque
3. The developed power



$$P_{dev} = E_a I_a = 112 \times 20 = 2240^{W}$$

$$= \omega T = \frac{1200}{(9.55)} \times 17.83 = 2240^{W}$$