King Fahd University of Petroleum & Minerals
Department of Electrical Engineering

EE 360: Home Work # 3
Due Date (**April 7th, 2014**)

Key Solutions

Q1) Problem 7-7 (a, b, c)

Solution

(a) $E_A = K\phi\omega = \frac{ZP}{2\pi a}\phi\omega$

In this machine, the number of current paths is

$$a = mP = (2)(8) = 16$$

The number of conductor is

$$Z = (64 \text{ coils})(10 \text{ turns/coil})(2 \text{ conductors/turn}) = 1200$$

The equation for induced voltage is

$$E_A = \frac{ZP}{2\pi a}\phi\omega$$

so the required flux is

$$120 \text{ V} = \frac{(1200 \text{ cond})(8 \text{ poles})}{2\pi(16 \text{ paths})}\phi(3600 \text{ r/min})\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)$$

$$120 \text{ V} = 36{,}000\ \phi$$

$$\phi = 0.00333 \text{ Wb}$$

(b) At rated load, the current flow in the generator would be

$$I_A = \frac{25 \text{ kW}}{120 \text{ V}} = 208 \text{ A}$$

There are $a = mP = (2)(8) = 16$ parallel current paths through the machine, so the current per path is

$$I = \frac{I_A}{a} = \frac{208 \text{ A}}{16} = 13 \text{ A}$$

(c) The induced torque in this machine at rated load is

$$\tau_{\text{ind}} = \frac{ZP}{2\pi a}\phi I_A$$

$$\tau_{\text{ind}} = \frac{(1200 \text{ cond})(8 \text{ poles})}{2\pi(16 \text{ paths})}(0.00333 \text{ Wb})(208 \text{ A})$$

$$\tau_{\text{ind}} = 66.1 \text{ N}\cdot\text{m}$$

Q2) Problem 8-3

SOLUTION If R_{adj} is set to 250 Ω, the field current is now

$$I_F = \frac{V_T}{R_{adj} + R_F} = \frac{240 \text{ V}}{250 \ \Omega + 75 \ \Omega} = \frac{240 \text{ V}}{325 \ \Omega} = 0.739 \text{ A}$$

Since the motor is still at full load, E_A is still 218.3 V. From the magnetization curve (Figure P8-1), the new field current I_F would produce a voltage E_{Ao} of 212 V at a speed n_o of 1200 r/min. Therefore,

$$n = \left(\frac{E_A}{E_{Ao}}\right) n_o = \left(\frac{218.3 \text{ V}}{212 \text{ V}}\right)(1200 \text{ r/min}) = 1236 \text{ r/min}$$

Note that R_{adj} has increased, and as a result the speed of the motor n increased.

Q3) Problem 8-21

SOLUTION

(a) If R_{adj} = 100 Ω, the total field resistance is 140 Ω, and the resulting field current is

$$I_F = \frac{V_T}{R_F + R_{adj}} = \frac{120 \text{ V}}{100 \ \Omega + 40 \ \Omega} = 0.857 \text{ A}$$

This field current would produce a voltage E_{Ao} of 82.8 V at a speed of n_o = 1000 r/min. The actual E_A is

$$E_A = V_T - I_A R_A = 120 \text{ V} - (70 \text{ A})(0.12 \ \Omega) = 111.6 \text{ V}$$

so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{111.6 \text{ V}}{82.8 \text{ V}} (1000 \text{ r/min}) = 1348 \text{ r/min}$$

(b) The output power is 10 hp and the output speed is 1000 r/min at rated conditions, therefore, the torque is

$$\tau_{out} = \frac{P_{out}}{\omega_m} = \frac{(10 \text{ hp})(746 \text{ W/hp})}{(1000 \text{ r/min})\left(\frac{2\pi \text{ rad}}{1 \text{ r}}\right)\left(\frac{1 \text{ min}}{60 \text{ s}}\right)} = 71.2 \text{ N} \cdot \text{m}$$

(c) The copper losses are

$$P_{CU} = I_A^2 R_A + V_F I_F = (70\ \text{A})^2 (0.12\ \Omega) + (120\ \text{V})(0.857\ \text{A}) = 691\ \text{W}$$

The power converted from electrical to mechanical form is

$$P_{conv} = E_A I_A = (111.6\ \text{V})(70\ \text{A}) = 7812\ \text{W}$$

The output power is

$$P_{OUT} = (10\ \text{hp})(746\ \text{W/hp}) = 7460\ \text{W}$$

Therefore, the rotational losses are

$$P_{rot} = P_{conv} - P_{OUT} = 7812\ \text{W} - 7460\ \text{W} = 352\ \text{W}$$

(d) The input power to this motor is

$$P_{IN} = V_T (I_A + I_F) = (120\ \text{V})(70\ \text{A} + 0.857\ \text{A}) = 8503\ \text{W}$$

Therefore, the efficiency is

$$\eta = \frac{P_{OUT}}{P_{IN}} \times 100\% = \frac{7460\ \text{W}}{8503\ \text{W}} \times 100\% = 87.7\%$$

(e) The no-load E_A will be 120 V, so the no-load speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{120\ \text{V}}{82.8\ \text{V}} (1000\ \text{r/min}) = 1450\ \text{r/min}$$

(f) If the field circuit opens, the field current would go to zero $\Rightarrow \phi$ drops to $\phi_{res} \Rightarrow E_A \downarrow \Rightarrow I_A \uparrow \Rightarrow$ $\tau_{ind} \uparrow \Rightarrow n \uparrow$ to a *very* high speed. If $I_F = 0$ A, $E_{Ao} = 8.5$ V at 1800 r/min, so

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{230\ \text{V}}{5\ \text{V}} (1000\ \text{r/min}) = 46{,}000\ \text{r/min}$$

(In reality, the motor speed would be limited by rotational losses, or else the motor will destroy itself first.)

(g) The maximum value of $R_{adj} = 200\ \Omega$, so

$$I_F = \frac{V_T}{R_F + R_{adj}} = \frac{120\ \text{V}}{200\ \Omega + 40\ \Omega} = 0.500\ \text{A}$$

This field current would produce a voltage E_{Ao} of 50.6 V at a speed of $n_o = 1000$ r/min. The actual E_A is 120 V, so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{120\ \text{V}}{50.6\ \text{V}} (1000\ \text{r/min}) = 2372\ \text{r/min}$$

The minimum value of $R_{adj} = 0\ \Omega$, so

$$I_F = \frac{V_T}{R_F + R_{adj}} = \frac{120\ \text{V}}{0\ \Omega + 40\ \Omega} = 3.0\ \text{A}$$

This field current would produce a voltage E_{Ao} of about 126.4 V at a speed of $n_o = 1000$ r/min. The actual E_A is 120 V, so the actual speed will be

$$n = \frac{E_A}{E_{Ao}} n_o = \frac{120\ \text{V}}{126.4\ \text{V}} (1000\ \text{r/min}) = 949\ \text{r/min}$$

Q4) Problem 8-22

SOLUTION

(a) If the generator is operating with no load at 1800 r/min, then the terminal voltage will equal the internal generated voltage E_A. The maximum possible field current occurs when R_{adj} = 0 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{20\ \Omega + 0\ \Omega} = 6 \text{ A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 135 V. Since the actual speed is 1800 r/min, the maximum no-load voltage is 135 V.

The minimum possible field current occurs when R_{adj} = 40 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{20\ \Omega + 40\ \Omega} = 2.0 \text{ A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 79.5 V. Since the actual speed is 1800 r/min, the minimum no-load voltage is 79.5 V.

(b) The maximum voltage will occur at the highest current and speed, and the minimum voltage will occur at the lowest current and speed. The maximum possible field current occurs when R_{adj} = 0 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{20\ \Omega + 0\ \Omega} = 6 \text{ A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 135 V. Since the actual speed is 2000 r/min, the maximum no-load voltage is

$$\frac{E_A}{E_{Ao}} = \frac{n}{n_o}$$

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{2000 \text{ r/min}}{1800 \text{ r/min}} (135 \text{ V}) = 150 \text{ V}$$

The minimum possible field current occurs and minimum speed and field current. The maximum adjustable resistance is R_{adj} = 30 Ω. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{20\ \Omega + 30\ \Omega} = 2.4 \text{ A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 93.1 V. Since the actual speed is 1500 r/min, the maximum no-load voltage is

$$\frac{E_A}{E_{Ao}} = \frac{n}{n_o}$$

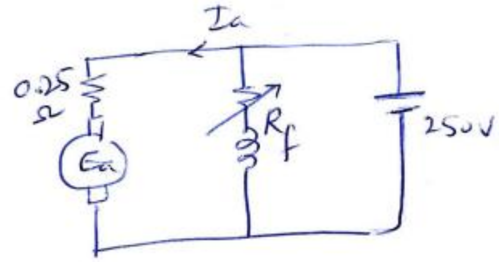
$$E_A = \frac{n}{n_o} E_{Ao} = \frac{1500 \text{ r/min}}{1800 \text{ r/min}} (93.1 \text{ V}) = 77.6 \text{ V}$$

Extra Problems:

Q5) A 250 V DC shunt motor has an armature resistance of 0.25 ohms and a variable field resistance. At a certain loading condition, the motor's generated (induced) voltage is 245 V. Find what will be the motor's new armature current when there is 1% decrease in the flux value?

Q5)

$E_a = 245V$



$E_a = K\phi\omega$

cond. 1 → $E_a = 245$ V

cond 2. → $E_a = ?$

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

$$I_{a_1} = \frac{250 - 245}{0.25} = 20\ A$$

$$\frac{E_{a1}}{E_{a2}} = \frac{K\phi_1\omega_1}{K\phi_2\omega_2} \Rightarrow \left(\begin{matrix}\omega_1 = \omega_2 \\ K \text{ const}\end{matrix}\right).$$

$$\frac{E_{a_1}}{E_{a_2}} = \frac{K\phi_1\omega_1}{K\, 0.99\phi_1\,\omega_2} \Rightarrow E_{a_2} = 0.99\, E_{a_1}$$

$$\boxed{E_{a_2} = 242.55\ V}$$

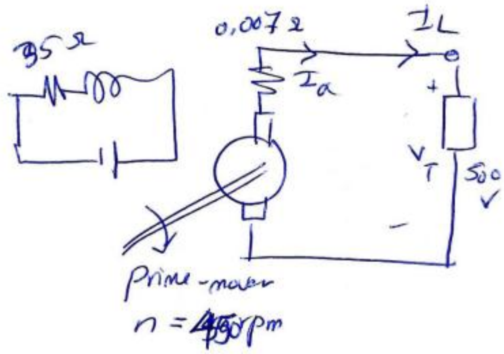
$$\Rightarrow I_{a_2} = \frac{V_T - E_{a_2}}{0.25} = \frac{250 - 242.55}{0.25} = 29.8A$$

Q6) A4-pole, 500V DC separately excited generator is running at a speed of 450 rpm. Its field and armature resistances are 35 and 0.007 ohms respectively. If the generator is supplying a 750 kW load and the rotational power loss is 12180 W, find:

a) The armature induced voltage,

b) The input power

Q6) Load = 750 kW



$$E_a = V_T + I_a(R_a)$$

$$I_a = I_L = \frac{P_{load}}{V_T} = \frac{750\times10^3}{500}$$

$$I_a = 1500A$$

(a)

$$\Rightarrow E_a = 500 + 1500(0.007)$$

$$\boxed{E_a = 510.5\ V}$$

(b)

$$P_{in} = P_{out} + P_{losses}$$

$$= 750\times10^3 + (1500)^2(0.007) + 12180$$

$$\boxed{P_{in} = 777.93\ KW}$$

(This is neglecting the field winding Losses)

Q7) A 10-kVA, 60-Hz, 2400/240-V distribution transformer is reconnected for use as a step-up autotransformer with a 2200-V input.

a) What is the secondary voltage of the autotransformer

b) Determine the rated current for common and series windings of the autotransformer

c) Determine the maximum kVA of the autotransformer with 2200-V input

Solution:

a) The secondary voltage V_H of the transformer is given by

$$V_H = \frac{N_{SE} + N_C}{N_C} \times V_L$$

$$= \frac{240 + 2400}{2400} \times 2200 = 2420\ V$$

b) The rated current for the common and series windings of the autotransformer must be limited to the same ratings as in 2-winding transformer. Therefore,

$$I_{SE\_rated} = I_{S\_rated} = \frac{10\ kVA}{240\ V} = 41.67\ A$$

$$I_{C\_rated} = I_{P\_rated} = \frac{10\ kVA}{2400\ V} = 4.167\ A$$

c) The maximum kVA of the autotransformer is given by:

$$S_{out} = V_H I_{SE\_rated} = 2420 \times 41.67 = 100.84\ \text{kVA}$$

Q8) A 3-phase Δ/Y transformer is assembled by connecting three 830-VA, 240/120-V single phase transformers. Each transformer parameters are as follow:

$R_P = 15.5\ \Omega$, $X_P = 18.2\ \Omega$, $R_{CP} = 6.54\ k\Omega$, $X_{MP} = 4.64\ k\Omega$
$R_S = 2.4\ \Omega$, $X_S = 2.8\ \Omega$

a) Determine the voltages and power ratings

b) Draw the winding arrangements, equivalent Y/Y connections, and per-phase equivalent circuit

Problem (8)

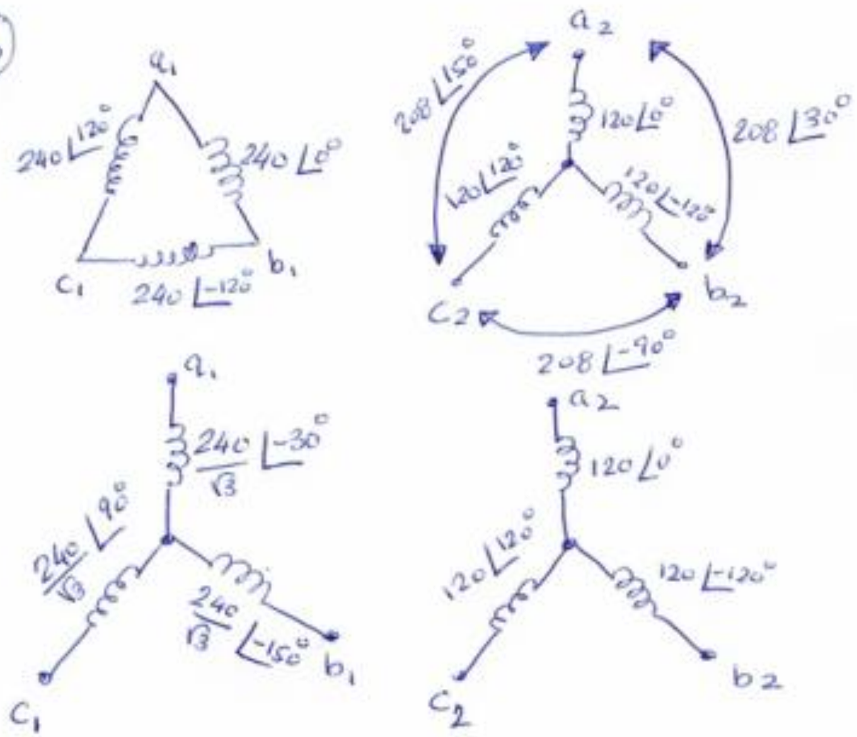
(a)

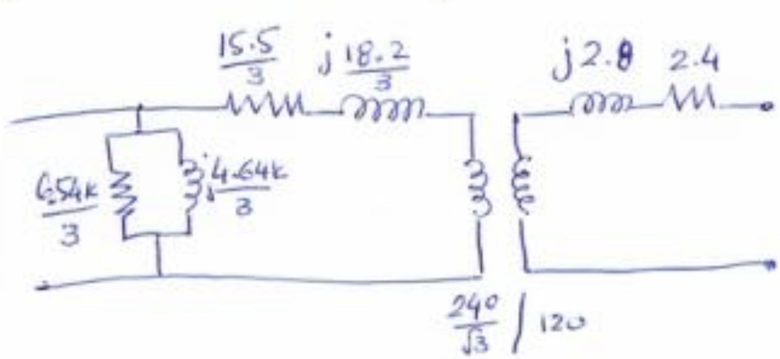
$S_{3\phi} = 3 \times 830 = 2.49$ kVA

$V_{LP}(\Delta) = V_{\phi P} = 240$ V

$V_{LS}(Y) = \sqrt{3}\, V_{\phi S} = \sqrt{3} \times 120 = 208$ V

(b)





$a = 1.155$