Due date is November 6th 2019

Problem 1)

A four-pole dc machine has a simplex-wave winding of 250 turns. The flux per pole is 0.7 T. The armature radius is 15 cm and effective conductor length is 20 cm. The pole covers 80 % of the armature periphery. The machine rotates at 1000 rpm.

1. Determine the machine constant (see sec. 4.2.4 of the text book).
2. Determine the generated voltage.
3. Determine the kW rating if the rated current through a single-turn is 120 A.
4. The machine developed torque.

Solution:

For wave winding *a*=2

1. Machine constant

$$K_a = \frac{Np}{\pi a} = \frac{250 * 4}{\pi * 2} = 159.15\ Vs/Wb.rad.$$

2. Generated voltage:

$$E_a = K_a \emptyset \omega_m = K_a B A_{effctive} \omega_m$$

$$A = \frac{2\pi r l}{a} = \frac{2\pi * 0.15 * 0.2}{2} = 0.094248\ m^2$$

$$A_{effective} = 0.8 * A = 0.075398\ m^2$$

$$E_a = K_a B A_{effctive} \omega_m = 159.15 * 0.7 * 0.075398 * \frac{2\pi}{60} * 1000 = 879.6\,V$$

3. The current of one turn (or coil) $= \frac{I_a}{a}$. Therefore, the armature current is 120**a*=240 A

$$P_d = E_a I_a = 879.6 * 240 = 211.108\ \text{kW}$$

4. developed torque can be calculated as

$$T_d = \frac{P_d}{\omega_m} = \frac{211.108}{\frac{2\pi}{60} * 1000} = 2{,}016\ N.m.$$

Problem 2)

A dc machine of 10 kW, 250 V, 1000 rpm has R_a =0.2 Ω and R_{fw} =133 Ω. The machine is self-excited and is driven at 1000 rpm. The data for the magnetization curve is given as follows:

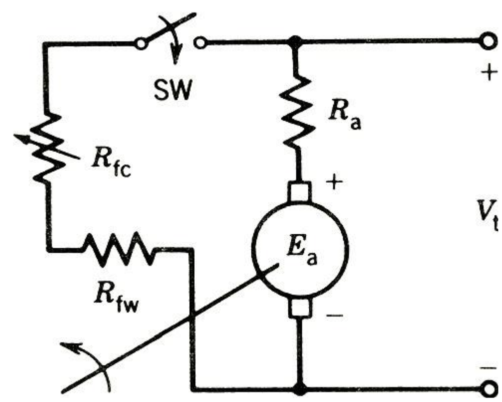
I_f (A)	0	0.1	0.2	0.3	0.4	0.5	0.75	1	1.5	2
E_a (V)	10	40	80	120	150	170	200	220	245	263

a) Determine the generated voltage with no field current.
b) The maximum generated voltage
c) Determine the critical field circuit resistance.
d) Determine the value of the field control resistance (R_{fc}) if the no-load terminal voltage is 250 V.

Solution:

Generated voltage at I_f = 0 is 10 V.

(a) The maximum generated voltage at R_{fc}=0 can be obtained by drawing the field resistance line of 133 Ω that intersects with magnetization curve at E_a=261.9 V which is corresponding to 1.96 field current.



(b) Draw the critical field resistance line is passing through the linear part of the magnetization curve. Then, use one point and the origin to get the slope of this line, which represents the total field resistance branch. For instance, at point of 0.5 A and 200 V

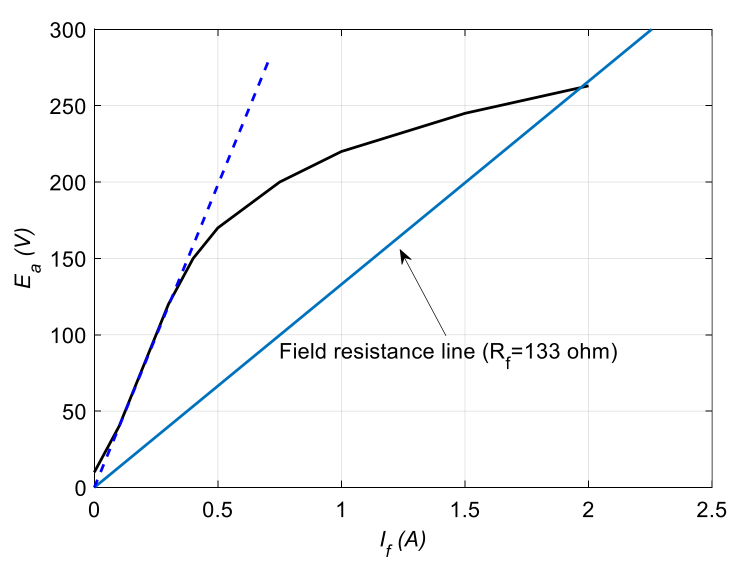
$R_{f\text{-}crit}$ = 200/0.5 = 400 Ω

So, R_{fc} =400 – 133 = 267 Ω

(c) Using magnetization curve, at E_a=250 V, I_f=1.6 A.

Therefore, R_{fc}+ R_{fw}=250/1.6 = 156.25 Ω

R_{fc} =156.25 – 133 = 23.25 Ω



Problem 3)

The dc machine in Problem 2 is reconfigured to separately excited DC machine. The rotational loss is 400 W at 1000 rpm, and the rotational loss is proportional to speed.

(a) For a field current of 1.0 A, with the generator delivering rated current, determine the terminal voltage, the output power, and the efficiency.

(b) Repeat part (a) if the generator is driven at 1200 rpm.

Solution

Separately excited DC machine, (10 kW, 250 V, 1000 rpm), R_a =0.2 Ω and R_{fw} =133 Ω.

(a) $I_f = 1A$ and $E_a = 220\ V$ at the same speed (1000 RPM).

The machine rated current can be calculated from the rated data as

$$I_a = \frac{P}{V_t} = \frac{10{,}000}{250} = 40A$$

Therefore,

$$V_t = E_a - I_a R_a = 220 - 40 * 0.2 = 212\ V$$

$$P_{out} = P_{dev} - P_{cu} = E_a I_a - I_a^2 R_a$$

$$= 220 * 40 - 40^2 * 0.2 = 8480\ W$$

$$P_{in} = P_{dev} + P_{rot} = 220 * 40 + 400 = 9200\ W$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{8480}{9200} * 100\% = 92.17\%$$

(b) At 1200 RPM, the emf will be $220 * \frac{1200}{1000} = 264\ V$

So,

$$V_t = E_a - I_a R_a = 264 - 40 * 0.2 = 256\ V$$

Therefor,

$$P_{out} = P_{dev} - P_{cu} = E_a I_a - I_a^2 R_a$$

$$= 264 * 40 - 40^2 * 0.2 = 10{,}240\ W$$

$$P_{in} = P_{dev} + P_{rot\_1200rpm} = 264 * 40 + 400 * \frac{1200}{1000} = 11{,}040\ W$$

$$\eta = \frac{P_{out}}{P_{in}} = \frac{10{,}240}{11{,}040} * 100\% = 92.75\%$$

Problem 4)

A 500 V DC shunt motor has an armature resistance of R_a =0.2 Ω and field circuit resistance of R_f =250 Ω. The motor drives a mechanical load, which requires a torque proportional to speed. When the motor-load system is connected to a 500 V supply, it takes 100 A and rotates at 1100 rpm. The speed is to be reduced to 900 rpm by inserting a resistance in series with the armature. The field current is kept the same. Determine the value of the added series resistance.

Solution

Case 1

$E_{a1}=V_t-I_{a1} R_a = K_a\varphi\ \omega_{m1}$

$E_{a1} = 500 - 100 * 0.2 = K_a\varphi * \frac{2\pi}{60} * 1100 = 480$ V

$K_a\varphi = 4.167$ V.s/rad

Therefore, $T_1= K_a\varphi\ I_{a1} = 4.167 * 100 = 416.7$ N.m.

Case 2

Since the flux is const., comparing the two cases,

$E_{a2}/E_{a1}= \omega_{m2}/ \omega_{m1}$

So, Ea2= 480*900/1100 = 392.7273 V

Since T is directly proportional to ω_m, $T_2/T_1= \omega_{m2}/ \omega_{m1}$. So, T_2 = 416.7*990/1100 = 375 N.m.

Therefore, I_{a2}= T2 / ($K_a\varphi$) = 90 A

Applying KVL for the DC motor in case 2

$V_t = E_{a2} + I_{a2} (R_a + R_s)$ → $500 = 392.7273 + 90 (0.2 + R_s)$

$R_s = 0.9919\ \Omega$

Problem 5)

A long shunt 600 V, 1200-rpm DC motor has a series field winding resistance of 0.05 Ω, a shunt field winding resistance of 200 Ω, and an armature resistance of 0.1 Ω. The machine is connected to 600 V DC source. The rotational loss is 3.2 kW. If the machine draws a 100 A from the supply, calculate

a. Back EMF

b. Determine the machine's converted power (or developed power) and its efficiency.

c. Determine the speed regulation if the machine draws 165 A at full load.

Solution:

a)
$$I_f = \frac{V_t}{R_f} = \frac{600}{200} = 3A$$

$$I_a = I_l - I_f = 100 - 3 = 97\ A$$
$$E_a = V_t - I_a(R_a + R_s) = 600 - 97 * (0.1 + 0.05) = 585.45\ V$$

b)
$$P_{conv} = E_a I_a = 585.45 * 97 = 56{,}788.65\ W$$
$$P_o = P_{conv} - P_{rot} = 56{,}788.65 - 3200 = 53{,}588.65\ W$$
$$\eta = \frac{P_o}{P_{in}} = \frac{53{,}588.65}{600 * 100} * 100\% = 89.314\ \%$$

c) Speed regulation

The full load speed is 1200 RPM.

No load speed is assumed to be at zero torque. Therefore, $\omega_{NL} = \frac{V_t}{K_a \emptyset}$.

$K_a \emptyset$ can be calculated at rated condition as follows:

$$E_{a-fl} = V_t - I_a R_t = 600 - 162 * 0.15 = 575.7\ V$$
$$K_a \emptyset = \frac{E_{a-fl}}{\omega_{FL}} = \frac{575.7}{\frac{2\pi}{60} * 1200} = 4.58127\ V.\frac{s}{rad}$$
$$\omega_{NL} = \frac{V_t}{K_a \emptyset} = \frac{600}{4.58127} = 130.96\ rad/s$$
$$\%\ speed\ regulation = \frac{\omega_{NL} - \omega_{FL}}{\omega_{FL}} * 100\ \% = \frac{130.96 - 1200 * \frac{2\pi}{60}}{1200 * \frac{2\pi}{60}} * 100\%$$

$$\%\ speed\ regulation = 4.22\ \%$$