National University of Singapore

Department of Electrical & Computer Engineering

EE1002:Circuits and Systems

Tutorial - 9 Solution (Linear and Rotational DC Machines)

Year 2013-14

Q.1 The parameters given are:

$$V_B = 120 \text{ V}\,, R_b = 0.3\,\Omega\,, \mathbf{B} = 0.1 \text{ Wb.m}^2, l = 10\, m$$

(a) At starting the bar is stationary and therefore the induced emf is zero.

$$i_{st} = \frac{V_B}{R_b} = \frac{120 \text{ V}}{0.3\,\Omega} = 400 \text{ A}$$

At steady-state we have

$$u_{ss} = \frac{V_B}{\mathbf{B}l} = \frac{120 \text{ V}}{0.1\text{Wb.m}^2 \times 10 \text{ m}} = 120 \text{ m/s}$$

Note that the starting current is very high as the induced-emf is not present to oppose the supply voltage.

(b) At steady-sate we have

$$F_{ind} = F_{load} \Rightarrow Bil = 30\text{N} \Rightarrow i = \frac{30\text{N}}{0.1\text{Wb.m}^2 \times 10 \text{ m}} = 30 \text{ A}$$

This gives

$$e_{ind} = 120 \text{ V } - 30 \text{ A } \times 0.3\Omega = 111 \text{ V} \Rightarrow u_{ss} = \frac{111\text{V}}{0.1\text{Wb.m}^2 \times 10 \text{ m}} = 111 \text{ m/s}$$

The developed power is given by

$$P_{dev} = F_{load} \times u_{ss} = 30 \text{ N} \times 111 \text{ m/s} = 3330\, W$$

The input power is given by

$$P_{in} = V_B \times i = 120 \text{ V} \times 30 \text{ A} = 3600 \text{ W}$$

The difference between P_{in} and P_{dev} is the power lost in the series resistance

$$P_R = P_{in} - P_{dev} = 3600 \text{ W} - 3330 \text{ W} = 270 \text{ W}$$

The linear DC machine is operating as a motor drawing electrical power input (3600 W) and converting to mechanical power (3330 W) and delivering to the load.

Q.2 The motor parameters given are:

$$V_a = 440\text{ V}\,,\, R_a = 0.1\,\Omega\,,\, P_{out} = 37.3\;kW\;,\, I_a = 103\text{ A}\,,\, and\; N = 1500\text{ rpm}$$

(a) We have

$$E_a = 440\text{ V} \;-\; 103\text{ A} \;\times 0.1\Omega = 429.7\text{ V}$$

The developed power is given by

$$P_{dev} = E_a \times I_a = 429.7\text{ V} \;\times 103\text{ A} \;= 44.26\text{ kW}$$

(b) We have

$$P_R = {I_a}^2 \times R_a = 103^2 \times 0.1\,\Omega \;= 1.06\text{ kW}$$

(c) We have

$$P_{rot} = P_{dev} - P_{out} = 44.26\;kW \;-\; 37.3\;kW \;= 6.96\text{ kW}$$

Q.3 The motor parameters given are:

$$V_a = 230\text{ V}\,,\, I_a = 12\text{ A}\,,\, R_a = 0.8\,\Omega\,,\, N = 995\text{ rpm}$$

We have

$$\text{(a)}E_a = 230\text{ V} \;-\; 12\text{ A} \;\times 0.8\Omega = 220.4\text{ V}$$

The developed torque is given by

$$\text{(b) } T_{dev} = \frac{E_a \times I_a}{\omega_m} = \frac{220.4\text{ V} \;\times 12\text{ A}}{\frac{2\pi}{60} \times 955\text{ rpm}} = 26.5\text{ N.m}$$

$$\text{(c) } P_{dev} = T_{dev} \times \omega_m = 26.5\text{ N.m} \;\times 100\text{ rad/sec} \;= 2644.8\text{ W}$$

The power-loss across the armature is given by

$$\text{(d) } P_{a-loss} = {I_a}^2 \times R_a = 12^2 \times 0.8 = 115.2\text{ W}$$

Q.4 The motor has the following parameters:

$$V_T = 220\;V, R_a = 0.15\;\Omega, R_f = 110\;\Omega,$$

(a) At no-load we have $I_L = 5\;A$, thus we have

$$I_f = \frac{220\;V}{(R_f = 110\;\Omega)} = 2\;A, I_{a,NL} = I_L - I_f = 5\;A - 2\;A = 3\;A$$

$$E_{a,NL} = V_T - I_{a,NL} \times R_a = 220\;V - 3\;A \times 0.15\;\Omega = 219.55\;V$$

When the motor is loaded we have

$$I_{L,L} = \frac{P_{in}}{V_T} = \frac{12,000\;W}{220\;V} = 54.54\;A$$

$$I_{a,L} = I_L - I_f = 54.54\;A - 2\;A = 52.54\;A$$

$$E_{a,L} = V_T - I_{a,L} \times R_a = 220\;V - 52.54\;A \times 0.15\;\Omega = 212.12\;V$$

$$N_L = \left(\frac{E_{a,L}}{E_{a,NL}}\right) \times N_{NL} = \left(\frac{212.12\,V}{219.55\,V}\right) \times 1200\,rpm = 1159.4\,rpm$$

(b)

$$P_{dev,L} = E_{a,L} \times I_{a,L} = 212.12\,V \times 52.54\,A = 11,144.8\,W$$

$$\omega_L = N_L \times (\frac{2\pi}{60}) = 1159.4\,rpm \times (\frac{2\pi}{60}) = 121.41\,rad/s$$

$$T_{dev} = \frac{P_{dev,L}}{\omega_L} = \frac{11,144.8\,W}{121.41\,rad/s} = 91.8\,N.m$$

$$P_{rotational,loss} = E_{a,NL} \times I_{a,NL} = 219.55\,V \times 3\,A = 658.65\,W$$

$$P_{out} = P_{dev,L} - P_{rotational,loss} = 11,144.8\,W - 658.65\,W = 10,486.15\,W$$

$$\eta = \frac{P_{out,L}}{P_{in,L}} = \left(\frac{10,486.15\,W}{12,000\,W}\right) \times 100\% = 87.38\,\%$$

Q.5 The motor parameters given are:

$$V_s = 12\text{ V and } N_{no-load} = 1700\,\text{rpm}$$

The armature voltage needed to operate at a no-load speed of 1000 rpm is

$$E_{ano-load,1000} = \frac{n_{no-load,1000}}{n_{no-load,1700}} \times E_{ano-load,1700} = \frac{1000}{1700} \times 12\,V = 7.06\,V$$

The duty-cycle of the MOSFET switch is given by

$$D = \frac{V_a \simeq E_{a,no-load}}{V_s} = \frac{7.06\,V}{12\,V} = 0.588 \simeq 0.6$$

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