Problem Set 3 DC Machines

1. Consider a 240 V separate excited DC motor with an armature resistance of 0.06 Ω. When it is connected to a 240 V supply, it can draw 90 A and rotates at 1200 rpm.
   a. Find the developed torque at this operating condition.
   b. Under same excitation, if the developed torque is 280 Nm, find the speed and armature current.

2. Consider a 25 kW, 120 V separately excited DC machine with an armature resistance of 0.025 Ω. When it is operated with a constant field current and constant speed of 2500 rpm, its open circuit armature voltage becomes 120 V.
   a. If the DC machine is connected to a 125 V supply, will it operate as a generator or a motor?
   b. Find the armature current, supply power and developed torque.
   c. Repeat (a) and (b) if the DC machine is connected to a 115 V supply.

3. A DC machine is connected across a 240-volt line. It rotates at 1200 rpm and produces 230 V with armature current of 40 A.
   a. Is the machine operating as a generator or a motor?
   b. Find the resistance of the armature circuit, power losses in armature circuit resistance, electromagnetic power and electromagnetic torque.

4. A 500 V DC shunt motor consists of an armature resistance of 0.25 Ω and field resistant of 240 Ω. It drives a mechanical load that needs a torque proportional to speed. When the system is connected to a 500 V supply, it takes 100 A and rotates at 1100 rpm. By inserting a resistance in series with the armature, the speed is able to reduce to 900 rpm. Find the value of the added series resistance.

5. A 125 V, 5 kW, 1800 rpm DC shunt motor needs only 5 V to send full-load current through the armature when the armature is held stationary.
   a. If full-line voltage is impressed across the armature at starting, find the armature current.
   b. If the starting current is limited to 1.5 times of the full-load current, find the value of the external resistance needed.
   c. Neglect rotational losses and assume 10 % reduction due to armature reaction at full load.
      i. The motor is coupled to a mechanical load by a belt. Find the generated voltage at full-load conditions.
      ii. If the belt breaks, find the speed of the motor.

Answer

1.

(a) $E_a = 240 - 90 \times 0.06 = 240 - 5.4 = 234.6\text{V}$

$$\text{speed } \omega = \frac{1200}{60} \times 2\pi = 40\pi \text{ rad/sec}$$

$$k_a\phi = \frac{E_g}{\omega} = \frac{243.6}{40\pi} = 1.87\text{V}\cdot\text{s/rad}$$

$$T = k_a\phi I_a = 1.87 \times 90 = 168.3\text{N}\cdot\text{m}$$

(b) $I_a = \frac{T}{k_a} = \frac{280}{1.87} = 149.7\text{A}$

$$E_g = 240 - 149.7 \times 0.06 = 240 - 8.98 = 231\text{V}$$

$$\omega = \frac{231}{1.87} = 123.53\text{rad/sec}$$

$$n = \frac{60 \times \omega}{2\pi} = 1180.2\text{rpm}$$

2.

(a) $V_a = 125\text{V}, E_g = 120\text{V}$

$V_a > E_g \rightarrow$ machine is operating as a motor

$$I_a = \frac{125 - 120}{0.025} = 200\text{A}$$

$$P_{in} = 125 \times 200 = 25\text{kW}$$

$$P_g = 120 \times 200 = 24\text{kW}$$

$$\omega_m = \frac{2500}{60} \times 2\pi = 261.7\text{rad/sec}$$

$$T = \frac{P_g}{\omega_m} = \frac{24000}{261.7} = 91.7\text{N}\cdot\text{m}$$

(b) $V_a = 125\text{V}, E_g = 120\text{V}$

$V_a < E_g \rightarrow$ machine is operating as a generator

$$I_a = \frac{120-115}{0.025} = 200\text{A}$$

$$P_{in} = 115 \times 200 = 23\text{kW}$$

$$P_g = 120 \times 200 = 24\text{kW}$$

$$\omega_m = \frac{2500}{60} \times 2\pi = 261.7\text{rad/sec}$$

$$T = \frac{P_g}{\omega_m} = \frac{24000}{261.7} = 91.7\text{N}\cdot\text{m}$$

3.

(a) $V_t < E_a \rightarrow I_a$ into the machine

$\rightarrow$ motor

(b) $R_a = \frac{240-230}{40} = 0.25\text{A}$

(c) $I_a^2 R_a = 40^2 \cdot 0.25 = 400\text{W}$

$E_a I_a = 230 \cdot 40 = 9200\text{W}$

(d) $\omega_m = \frac{1200}{60} \cdot 2\pi = 125.7\text{rad/sec}$

(e) $T = \frac{9200}{125.7} = 73.19\text{N}\cdot\text{m}$

4.

$$E_a|_{1100} = 500 - 100 \cdot 0.25 = 475\text{V}$$

$$E_a|_{900} = 475 \cdot \frac{900}{1100} = 388.6\text{V}$$

$$I_a|_{1100} = 100\text{A}$$

$$I_a|_{900} = 100 \cdot \frac{900}{1100} = 81.8\text{A}$$

$$IR = V - E_a = 500 - 388.6 = 111.4\text{V}$$

$$R = \frac{111.4}{81.8} = 1.36\Omega$$

$$R_{series} = 1.36 - 0.25 = 1.11\Omega$$

5.

(a) $R_a = \dfrac{5}{40} = 0.125\Omega, I_a = \dfrac{125}{0.125} = 1000\text{A}$

$I_{a(\text{rated})} = \dfrac{5000}{125} = 40\text{A}$

(b) $I_a = 40 \times 1.5 = \dfrac{125}{0.125 + R_{ex}} \rightarrow R_{ex} = 1.9583\Omega$

(c) $E_a = 125 - 40 \times 0.125 = 120\text{V}$

$125 = k_a \phi n$

$120 = k_a (0.9\phi) 1800$

$n = \dfrac{125}{120} \times 0.9 \times 1800 = 1687.5\text{rpm}$