Tutorial 9, ESO 210: Introduction to Electrical Engineering

Problem 1

The magnetization curve for a separately excited dc generator is shown in Figure 1. The generator is rated at 6 kW, 120 V, 50 A, and 1800 r/min and is shown in Figure 2. Its field circuit is rated at 5A. The following data are known about the machine:

$R_A = 0.18\ \Omega$ $\qquad$ $V_F = 120\ \text{V}$

$R_{\text{adj}} = 0 \text{ to } 30\ \Omega$ $\qquad$ $R_F = 24\ \Omega$

$N_F = 1000$ turns per pole

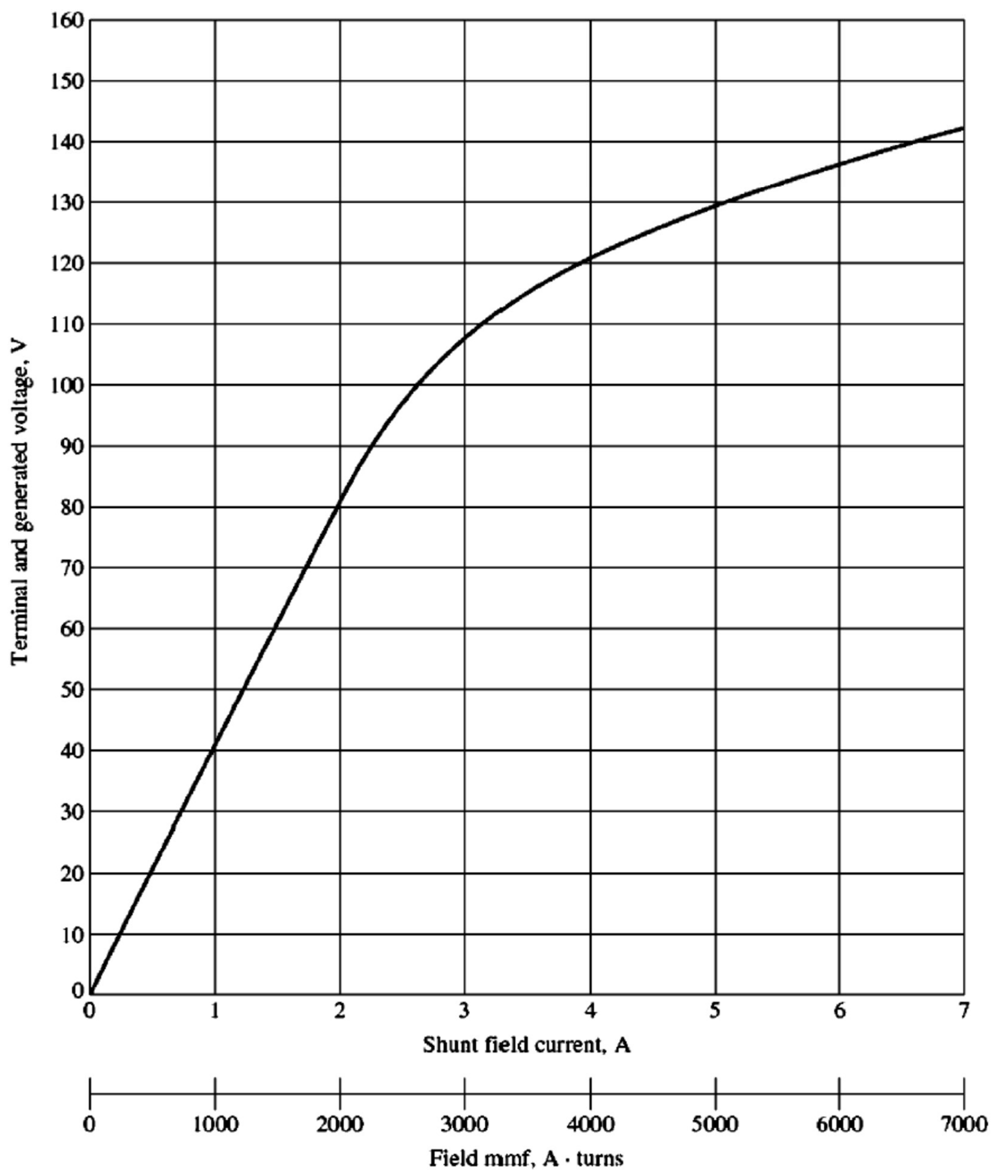

Figure 1

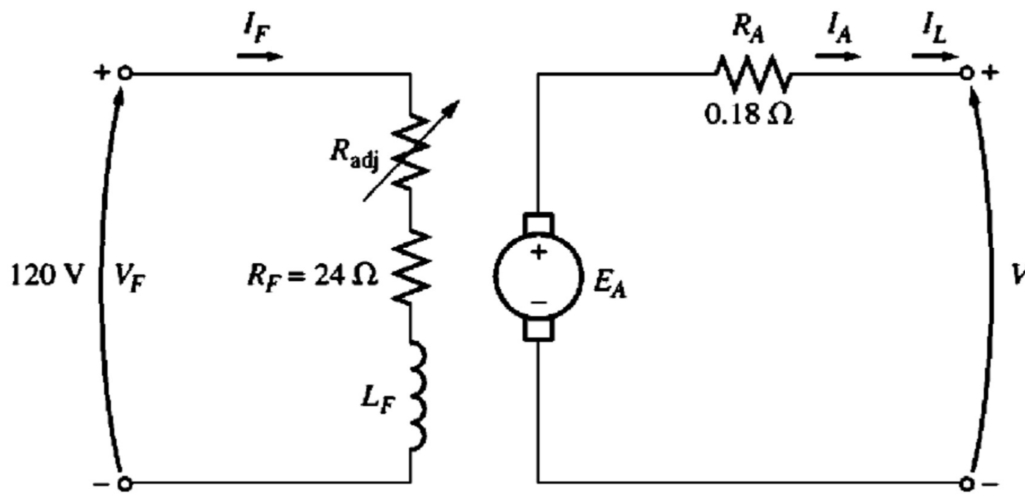

Figure 2

Answer the following questions about this generator, assuming no armature reaction.

(a) If this generator is operating at no load, what is the range of voltage adjustments that can be achieved by changing R_{adj}?

(b) If the field rheostat is allowed to vary from 0 to 30 Ω and the generator's speed is allowed to vary from 1500 to 2000 r/min. what are the maximum and minimum no-load voltages in the generator?

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 $R_{adj} = 0\ \Omega$. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{adj}} = \frac{120\ \text{V}}{24\ \Omega + 0\ \Omega} = 5\ \text{A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 129 V. Since the actual speed is 1800 r/min, the maximum no-load voltage is 129 V.

The minimum possible field current occurs when $R_{adj} = 30\ \Omega$. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{adj}} = \frac{120\ \text{V}}{24\ \Omega + 30\ \Omega} = 2.22\ \text{A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 87.4 V. Since the actual speed is 1800 r/min, the minimum no-load voltage is 87 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 $R_{adj} = 0\ \Omega$. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{adj}} = \frac{120\ \text{V}}{24\ \Omega + 0\ \Omega} = 5\ \text{A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 129 V. Since the actual speed is 2000 r/min, the maximum no-load voltage is

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

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{2000 \text{ r/min}}{1800 \text{ r/min}} (129 \text{ V}) = 143 \text{ V}$$

The minimum possible field current occurs when $R_{\text{adj}} = 30\ \Omega$. The current is

$$I_{F,\max} = \frac{V_F}{R_F + R_{\text{adj}}} = \frac{120 \text{ V}}{24\ \Omega + 30\ \Omega} = 2.22 \text{ A}$$

From the magnetization curve, the voltage E_{Ao} at 1800 r/min is 87.4 V. Since the actual speed is 1500 r/min, the maximum no-load voltage is

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

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{1500 \text{ r/min}}{1800 \text{ r/min}} (87.4 \text{ V}) = 72.8 \text{ V}$$

Problem 2

If the armature current of the generator in Problem 1 is 50 A, the speed of the generator is 1700 r/min, and the terminal voltage is 106 V, how much field current must be flowing in the generator?

SOLUTION The internal generated voltage of this generator is

$$E_A = V_T + I_A R_A = 106 \text{ V} + (50 \text{ A})(0.18\ \Omega) = 115 \text{ V}$$

at a speed of 1700 r/min. This corresponds to an E_{Ao} at 1800 r/min of

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

$$E_{Ao} = \frac{n_o}{n} E_A = \frac{1800 \text{ r/min}}{1700 \text{ r/min}} (115 \text{ V}) = 121.8 \text{ V}$$

From the magnetization curve, this value of E_{Ao} requires a field current of 4.2 A.

Problem 3

Assuming that the generator in Problem 1 has an armature reaction at full load equivalent to 400 A-turns of magnetomotive force, what will the terminal voltage of the generator be when I_F = 5 A, n_m= 1700 r/min, and I_A = 50 A?

SOLUTION When I_F is 5 A and the armature current is 50 A, the magnetomotive force in the generator is

$$\mathcal{F}_{\text{net}} = NI_F - \mathcal{F}_{\text{AR}} = (1000 \text{ turns})(5 \text{ A}) - 400 \text{ A} \cdot \text{turns} = 4600 \text{ A} \cdot \text{turns}$$

or $$I_F^* = \mathcal{F}_{\text{net}} / N_F = 4600 \text{ A} \cdot \text{turns} / 1000 \text{ turns} = 4.6 \text{ A}$$

The equivalent internal generated voltage E_{Ao} of the generator at 1800 r/min would be 126 V. The actual voltage at 1700 r/min would be

$$E_A = \frac{n}{n_o} E_{Ao} = \frac{1700 \text{ r/min}}{1800 \text{ r/min}} (126 \text{ V}) = 119 \text{ V}$$

Therefore, the terminal voltage would be

$$V_T = E_A - I_A R_A = 119 \text{ V} - (50 \text{ A})(0.18\ \Omega) = 110 \text{ V}$$

Problem 4

A DC shunt motor shown in Figure 3 is having the following parameters:

$P_{\text{rated}} = 15$ hp	$I_{L,\text{rated}} = 55$ A
$V_T = 240$ V	$N_F = 2700$ turns per pole
$n_{\text{rated}} = 1200$ r/min	$N_{SE} = 27$ turns per pole
$R_A = 0.40\ \Omega$	$R_F = 100\ \Omega$
$R_S = 0.04\ \Omega$	$R_{\text{adj}} = 100$ to $400\ \Omega$

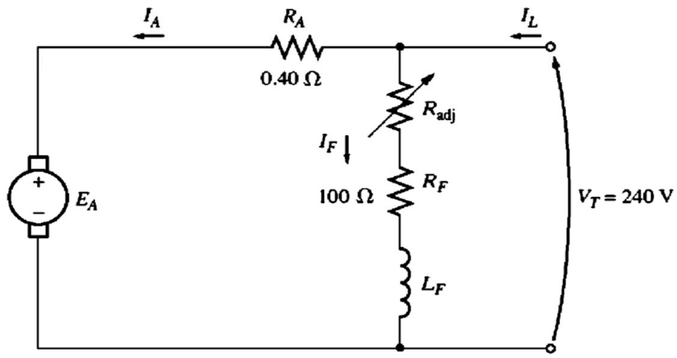

Figure 3

Rotational losses are 1800 W at full load. Magnetization curve is as shown in Figure 4. If the resistor R_{adj} is adjusted to 175 Ω, what is the rotational speed of the motor at no-load conditions?

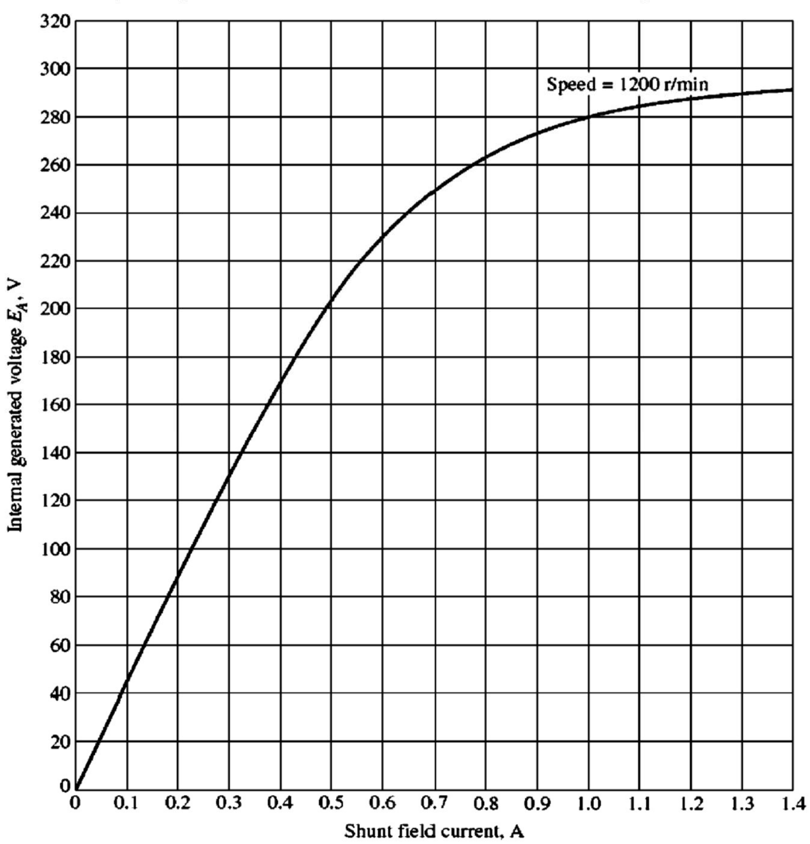

Figure 4

SOLUTION At no-load conditions, $E_A = V_T = 240\text{ V}$. The field current is given by

$$I_F = \frac{V_T}{R_{\text{adj}} + R_F} = \frac{240\text{ V}}{175\ \Omega + 100\ \Omega} = \frac{240\text{ V}}{250\ \Omega} = 0.873\text{ A}$$

From Figure 4 this field current would produce an internal generated voltage E_{Ao} of 271 V at a speed n_o of 1200 r/min. Therefore, the speed n with a voltage E_A of 240 V would be

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

$$n = \frac{E_A}{E_{Ao}}\ n_o = \frac{240\text{ V}}{271\text{ V}}\ (1200\text{ r/min}) = 1063\text{ r/min}$$

Problem 5

In above question, assuming no armature reaction, what is the speed of the motor at full load?

SOLUTION At full load, the armature current is

$$I_A = I_L - I_F = I_L - \frac{V_T}{R_{\text{adj}} + R_F} = 55\text{ A} - 0.87\text{ A} = 54.13\text{ A}$$

The internal generated voltage E_A is

$$E_A = V_T - I_A R_A = 240\text{ V} - (54.13\text{ A})(0.40\ \Omega) = 218.3\text{ V}$$

The field current is the same as before, and there is no armature reaction, so E_{Ao} is still 271 V at a speed n_o of 1200 r/min. Therefore,

$$n = \frac{E_A}{E_{Ao}}\ n_o = \frac{218.3\text{ V}}{271\text{ V}}\ (1200\text{ r/min}) = 967\text{ r/min}$$

Problem 6

In Q 4, if the motor is operating at full load and if its variable resistance R_{adj} is increased to 250 Ω, what is the new speed of the motor? Compare the full-load speed of the motor with R_{adj} = 175 Ω to the full-load speed with R_{adj} = 250 Ω. (Assume no armature reaction, as in the previous problem).

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

$$I_F = \frac{V_T}{R_{\text{adj}} + R_F} = \frac{240\text{ V}}{250\ \Omega + 100\ \Omega} = \frac{240\text{ V}}{325\ \Omega} = 0.686\text{ A}$$

Since the motor is still at full load, E_A is still 218.3 V. From the magnetization curve (Figure 2), the new field current I_F would produce a voltage E_{Ao} of 247 V at a speed n_o of 1200 r/min. Therefore,

$$n = \frac{E_A}{E_{Ao}}\ n_o = \frac{218.3\text{ V}}{247\text{ V}}\ (1200\text{ r/min}) = 1061\text{ r/min}$$

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

Problem 7

Assume that the motor is operating at full load and that the variable resistor R_{adj} is again 175 Ω. If the armature reaction is 1200 A-turns at full load, what is the speed of the motor? How does it compare to the result for Problem 5?

SOLUTION The field current is again 0.87 A, and the motor is again at full load conditions. However, this time there is an armature reaction of 1200 A·turns, and the *effective* field current is

$$I_F^* = I_F - \frac{\text{AR}}{N_F} = 0.87\ \text{A} - \frac{1200\ \text{A}\cdot\text{turns}}{2700\ \text{turns}} = 0.426\ \text{A}$$

From Figure 4, this field current would produce an internal generated voltage E_{A0} of 181 V at a speed n_0 of 1200 r/min. The actual internal generated voltage E_A at these conditions is,

$$E_A = V_T - I_A R_A = 240\ \text{V} - (54.13\ \text{A})(0.40\ \Omega) = 218.3\ \text{V}$$

Therefore, the speed n with a voltage of 240 V would be

$$n = \frac{E_A}{E_{Ao}}\ n_o = \frac{218.3\ \text{V}}{181\ \text{V}}\ (1200\ \text{r/min}) = 1447\ \text{r/min}$$

If all other conditions are the same, the motor with armature reaction runs at a higher speed than the motor without armature reaction.

Problem 5

If R_{adj} can be adjusted from 100 to 400 Ω in Q4, what are the maximum and minimum no load speeds possible with this motor?

SOLUTION The minimum speed will occur when $R_{\text{adj}} = 100\ \Omega$, and the maximum speed will occur when $R_{\text{adj}} = 400\ \Omega$. The field current when $R_{\text{adj}} = 100\ \Omega$ is:

$$I_F = \frac{V_T}{R_{\text{adj}} + R_F} = \frac{240\ \text{V}}{100\ \Omega + 100\ \Omega} = \frac{240\ \text{V}}{200\ \Omega} = 1.20\ \text{A}$$

From Figure 4, this field current would produce an internal generated voltage E_{Ao} of 287 V at a speed n_o of 1200 r/min. Therefore, the speed n with a voltage of 240 V would be

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

$$n = \frac{E_A}{E_{Ao}}\ n_o = \frac{240\ \text{V}}{287\ \text{V}}\ (1200\ \text{r/min}) = 1004\ \text{r/min}$$

The field current when $R_{\text{adj}} = 400\ \Omega$ is:

$$I_F = \frac{V_T}{R_{\text{adj}} + R_F} = \frac{240\ \text{V}}{400\ \Omega + 100\ \Omega} = \frac{240\ \text{V}}{500\ \Omega} = 0.480\ \text{A}$$

From Figure 4, this field current would produce an internal generated voltage E_{Ao} of 199 V at a speed n_0 of 1200 r/min. Therefore, the speed n with a voltage of 240 V would be

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

$$n = \frac{E_A}{E_{Ao}}\ n_o = \frac{240\ \text{V}}{199\ \text{V}}\ (1200\ \text{r/min}) = 1447\ \text{r/min}$$