CCY 14/15S1

EE3010 Tutorial 1

Magnetic fields and circuits

1. (a) The cross-sectional area of a bar magnet is 12 m^2. Determine the magnetic flux density if the flux in the magnet is 0.3 Wb. [0.025 T]

   (b) The flux in the bar magnet is 0.2 Wb and the magnetic flux density is 0.02 T. Determine the area of the magnet. [10 m^2]

   (c) A coil of 400 turns carries a current of 0.5 A and is wound uniformly on a magnetic circuit which is 20 cm in length. Calculate the mmf produced and the magnetic field intensity. [200 At; 1000 At/m]

   (d) A cast iron toroid has a mean length of 14 cm. It has a circular cross-section whose diameter is 1.5 cm. The core is wound by the coil of 200 turns and carries a current of 3 A. The value of the flux is 0.015 Wb. Calculate the flux density, mmf and the magnetic field intensity.

   [84.88 T; 600 At; 4285.7 At/m]

2. (a) A 120-turn coil is uniformly wound on a ferromagnetic ring of mean diameter 250 mm and cross-sectional area 1000 mm^2. If the current in the coil is 7 A and the magnetic flux in the core is 1 mWb, determine (a) the mmf and the magnetic field intensity at the mean circumference of the ring, (b) the relative permeability of the iron. [(a) 840 At; 1069.5 At/m; (b) 744]

   (b) An iron circuit has a cross-sectional area of 500 mm^2 and length 30 cm. If the flux density in the core is 1.25 T, and the relative permeability of the iron is 1800, determine the reluctance of the magnetic circuit, and the mmf needed to produce the flux. [0.265 x10^6 A/Wb; 165.6 At]

3. An iron circuit has three parts, all in series with one another, the length of each part being 0.25 m. The cross sectional area of one part is 250 mm^2, that of the second is 500 mm^2, and that of the third is 1000 mm^2. If the relative permeability of the first part is 400, and that of the other two parts is 600, calculate the mmf required to produce a magnetic flux of 0.5 mWb in the iron core. Neglect leakage and fringing.

   [1492 At]

4. A series magnetic circuit has an iron part of length 0.4 m and an air-gap of length 1.0 mm, the cross-sectional area of the iron being 550 mm^2, and the relevant part of the *B-H* characteristic of the iron is

H(At/m)	500	1000	2000	5000
B(T)	1.2	1.35	1.45	1.51

If the coil is wound uniformly on the iron has 500 turns of wire, estimate the current needed in it to produce a flux of 0.7 mWb in the air gap. Neglect leakage and fringing.

[2.6 A]

EE3010 Tutorial 2

Magnetic circuits and electromagnetic induction

1. The magnetic circuit in Figure 1 has a 308-turn coil wound on the center limb. The area of the outer limb is 4 cm^2, and that of the center limb is 8 cm^2. Given the following data for the iron circuit, calculate the current in the coil to give a flux of 0.42 mWb in each outer limb. Neglect leakage and fringing. [0.5 A]

H(At/m)	350	650	975	1200
B(T)	0.9	1.1	1.2	1.25

2. (a) Calculate the inductance of a non-magnetic toroid core with a 25 cm mean diameter and a circular cross-sectional area 6.25 cm^2 . The toroid is wound uniformly with 1000 turns of wire. Find the emf induced when a current increasing at a rate of 200 A/s flows in the winding [1 mH; 0.2 V]

   (b) A search coil having 50 turns enclosing a cross-sectional area of 2 cm^2 is placed at the middle of a solenoid having 500 turns of wire uniformly wound on a length of 12 cm and carrying an ac current of 0.2 A (rms) at a frequency of 5 kHz. Calculate the mutual inductance between the coils and the emf (rms) induced in the search coil. [52.4 uH; 0.329 V]

3. (a) Determine the energy stored in the magnetic circuit of a coil of self-inductance 2.5 H when it carries a current of 2.4 A. [7.2 J]

   (b) A 2000-turn coil is wound on a non-magnetic ring of length 1.0 m and cross sectional area of 2.5 cm^2. When a certain current passes through the coil, the flux density is found to be 0.06 T. Determine the energy stored in the magnetic circuit and the current required obtain the flux density of 0.06 T. [0.358 J; 23.87 A]

   (c) Repeat (b) for an iron core with a relative permeability of 2000. [0.179 mJ; 11.9 mA]

4. In the magnetic circuit of Figure 2, the cross-sectional area of the air gap is 0.0025 m^2 and its length is 0.05 cm. Moreover, the cast steel core has a mean length of 0.2 m and it is equipped with 1000 turns. It is desirable to operate the circuit with an air-gap density of 1 T. The relative permeability of the cast steel is 1205.
   (a) Determine the coil current needed to establish this gap density. [0.53 A]
   (b) Compute the energy stored in the air gap. [0.4975 J]
   (c) Find the energy stored in the cast steel section of the circuit. [0.165 J]
   (d) What is the inductance of this magnetic circuit? [4.72 H]

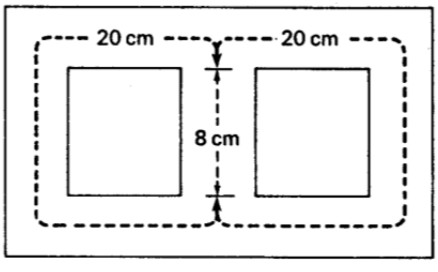


Figure 1.

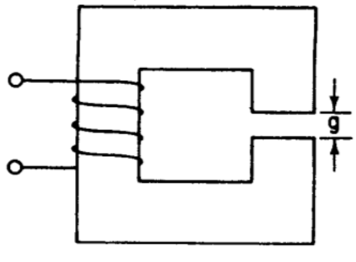


Figure 2.

EE3010 Tutorial 3

Core losses and magnetic force

1. In plotting a hysteresis loop, the following scales were used: H-axis, 1 cm = 393.7 At/m, B-axis, 1 cm = 0.3 T. The area of the hysteresis loop is found to be 6.2 cm^2. Calculate the hysteresis loss in J/cycle for the specimen tested if the volume is 400 cm^3. Also, find the hysteresis loss in Watts if the frequency is 50 Hz. [0.3 J/cycle; 14.65 W]

2. The core losses in a certain specimen of iron were found to be 4000 W at a frequency of 50 Hz. When the supply frequency is changed to 30 Hz maintaining the flux density unchanged, the core losses were found to be 1800 W. Calculate the eddy current loss at the frequency of 50 Hz. [2500 W]. (Since the flux density is the same for different f, express $P_h \propto f$ and $P_e \propto f^2$ and then obtain $\frac{P_h}{f} = A$, $\frac{P_e}{f} = Bf$. Solve for A and B.)

3. An inductor core is designed to operate at 120V at 60 Hz. Estimate the effect on the hysteresis and eddy current losses of operating at 150 V at 50Hz. Assume n = 1.6. [Note that the induced voltage $V_{rms} = 4.44 f N \phi_m$ or $V_{rms} = k f B_m$, k = constant. Use the expressions for P_h and P_e at different voltages and frequencies. Losses increase by 0.59 and 0.56, respectively.]

4. The electromagnet of Figure 1 has reluctance given by

$$\mathcal{R}(x) = 7x10^8(0.002 + x)\ At/Wb$$

   where x is the length of the variable gap in meters. The coil has 980 turns and 30-Ω resistance. For an applied voltage of 120 V DC, find
   (a) The energy stored in the magnetic field for x = 0.005 m. [1.568 J]
   (b) The magnetic force for x = 0.005 m. [-224 N]

5. A cylindrical solenoid is shown in Figure 2. The plunger may move feely along its axis. The air gap between the shell and the plunger is uniform and equal to 1mm, and the diameter d is 25 mm. If the exciting coil carries a current of 7.5 A, find the force acting on the plunger when x = 2 mm. Assume N = 200 turns, and neglect the reluctance of the steel shell. Assume l_g is negligible. [173. 5 N]

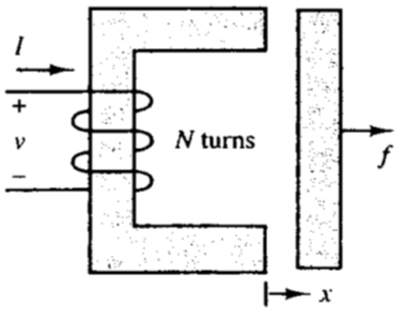


Figure 1.

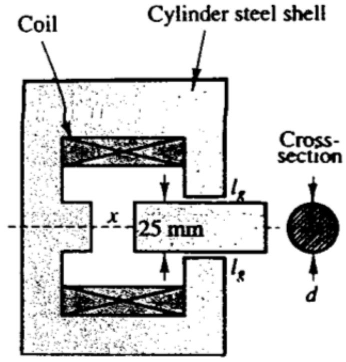


Figure 2.

Tutorial 4

Ideal and Practical transformers

1. (a) A 50-Hz single-phase transformer having 2080 turns on one winding and 104 turns on the other winding, has a sinusoidal core flux of peak value of 1.4 mWb. Determine the rms voltage induced in each winding. [646.5 V; 32.32 V]

   (b) A single-phase, 250-KVA, 11kV/415 V, 50-Hz transformer has 80 turns on the secondary. Calculate (i) the values of the primary and secondary currents, (ii) the number of primary turns, and (iii) the maximum value of the flux. [22.7 A; 602 A; 2121; 23.4 mWb]

   (c) A 6600/400 V, 50-Hz, single phase core type transformer has a net cross-sectional area of the core of 428 cm^2. The maximum flux density in the core is 1.5 T. Calculate the number of turns in the primary and secondary windings. [463, 28]

2. To achieve maximum power transfer from a source with an internal resistance of R_s, we want the effective load resistance R_L' to equal R_s. Find the turns ratio that would result in maximum power delivered to the load in Figure 1. [$\frac{N_1}{N_2} = \frac{1}{\sqrt{10}}$]

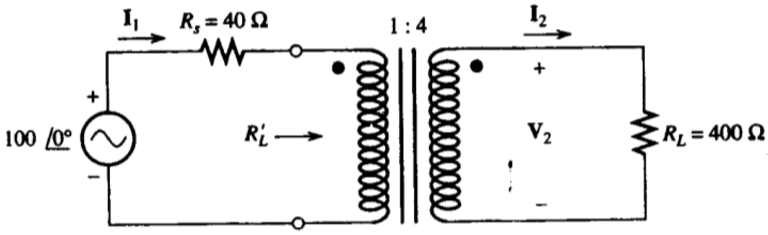


Figure 1.

3. (a) The no-load current of a single-phase transformer is 5.0 A at 0.3 power factor when supplied from a 240-V, 50-Hz source. The number of turns on the primary is 200. Calculate (i) the maximum value the flux in the core, (ii) the core losses, and (iii) the magnetizing current. Ignore resistance and leakage reactances. [5.4 mWb; 360 W; 4.77A]

   (b) A 100-kVA transformer has 400 turns on the primary and 80 turns on the secondary winding. The primary and secondary resistances are 0.3 Ω and 0.1 Ω, respectively. The primary and secondary leakage reactances are 1.1 Ω and 0.035 Ω, respectively. Calculate the equivalent impedance referred to the primary side. Use the approximate equivalent circuit of the transformer. [3.426 Ω]

4. A single-phase, 100-kVA, 1100/220 V transformer has the following parameters; R_1 = 0.1 Ω, X_1 = 0.3 Ω, R_2 = 0.004 Ω and X_2 = 0.012 Ω. Determine (a) the equivalent resistance and leakage reactance as referred to the high voltage winding, and (b) the equivalent resistance and leakage reactance as referred to the low voltage winding. Use the approximate equivalent circuit of the transformer. [0.2 Ω, 0.6 Ω; 0.008 Ω, 0.024Ω]

Tutorial 5

Voltage regulation, efficiency and parameter determination

1. The parameters of the equivalent circuit of a 150-kVA, 2400/240 V transformer are $R_1 = 0.2\ \Omega$, $R_2 = 2\ m\Omega$, $X_1 = 0.45\ \Omega$, $X_2 = 4.5\ m\Omega$, $R_c = 10\ k\Omega$, and $X_m = 1.55\ k\Omega$. Using the equivalent circuit referred to the secondary, determine the (a) voltage regulation and (b) efficiency of the transformer, operating at rated load with 0.8 lagging power factor. [2.3 %; 98.2 %]

2. The maximum efficiency of a 100-kVA transformer is 98.4 percent and occurs at 90 per-cent of full load. Calculate the efficiency of the transformer at unity power factor at (a) full load and (b) 50 percent of full load. [Hint: Use the expression for efficiency and note the condition for maximum efficiency and the iron losses are constant] [98.39; 98.12]

3. In a 50-kVA, 11-kV/400-V, single-phase transformer, the iron and copper losses are 500 W and 600 W, respectively under rated conditions. Calculate (a) the efficiency at unity power factor at full load, (b) the load for maximum efficiency, and (c) the iron and copper losses for this load. [97.85 %; 45.64 kVA; 500 W; 500 W]

4. Open-circuit and short circuit tests were performed on a 10-kVA 220/110-V 60-Hz transformer. Both tests were performed with instrumentation on the high-voltage side, and the following data were obtained:

   Open-circuit test: $V_o = 220\ V,\ \ I_o = 3.16\ A, W_o = 500\ W$

   Short-circuit test: $V_s = 65\ V, \quad I_s = 10\ A, \quad W_s = 400\ W$

   Determine the parameters of the approximate equivalent circuit from the above data. Refer the circuit to the high voltage side. [$R_c = 96.8\ \ \Omega$; $X_m = 100\ \Omega$; $R_{1e} = 4\ \Omega$; $X_{1e} = 5.1\ \ \Omega$]

Tutorial 6

Autotransformer and three-phase transformers

1. A 1000/200 V, 25-kVA transformer is connected as an autotransformer to yield a transformation ratio of 1000/1200. Calculate its kVA rating. Calculate also the currents in the two windings when the autotransformer is fully loaded. [150 kVA; 125 A; 25 A]

2. The primary and secondary voltages of an autotransformer are 440 and 360 V, respectively. If the secondary current is 80 A, determine the primary current. Calculate the power transferred to the load inductively and conductively. Also, determine the kVA rating of the autotransformer.
[65.45 A; 5.235 kVA; 23.56 kVA; 28,8 kVA]

3. A three-phase transformer bank is to handle 500 kVA and have a 34.5/11-kV voltage ratio. Find the rating of each individual transformer in the bank (high voltage, low voltage, and apparent power) if the transformer bank is connected in the following arrangements: (a) Y-Y, (b) Y-Δ, (c) Δ-Y, (d) Δ-Δ. [Y-Y 19.9 kV 6.35 kV 167 kVA; Y-Δ 19.9 kV 11.0 kV 167 kVA; Δ-Y 34.5 kV 6.35 kV 167 kVA; Δ-Δ 34.5 kV 11.0 kV 167 kVA]

4. An ideal three-phase step down transformer, connected Δ-Y delivers power to a balanced three-phase load of 120 kVA at 0.8 power factor. The input line voltage is 11 kV and the turns-ratio of the transformer, phase to phase is 10. Determine the line voltage, line currents, phase voltages and phase currents on both the primary and the secondary sides. What is the power (kW) consumed by the load? [V_{LY} = 1.9 kV; $V_{L\Delta}$ = 11 kV; I_{LY} = 36.4 A; $I_{L\Delta}$ = 6.3 A; $I_{\phi\Delta}$ = 3.64 A; 96 kW]

Tutorial 7

Three-phase transformers

1. Three 20-kVA 24,000/277-V distribution transformers are connected in Δ-Y. The open-circuit test was performed on the low-voltage side of this transformer bank (with measurement taken on the low-voltage side) and the following data were recorded:

$$V_{\text{line,OC}} = 480\text{ V}, \qquad I_{\text{line,OC}} = 4.10\text{ A}, \qquad P_{3\phi,\text{OC}} = 945\text{ W}$$

The short-circuit test was performed on the high-voltage side of this transformer bank (with measurement taken on the high-voltage side) and the following data were recorded:

$$V_{\text{line,SC}} = 1400\ V, \qquad I_{\text{line,SC}} = 1.80\text{ A}, \qquad P_{3\phi,\text{SC}} = 912\text{ W}$$

Find the approximate equivalent circuit of this transformer bank referred to the primary side.

2. A three-phase transformer is assembled by connecting three 480-VA, 240/80-V, single-phase transformers. The constants for each transformer are R_1 =12.6 Ω, X_1 = 14.4 Ω, R_2 = 1.4 Ω, X_2 = 1.6 Ω, R_c = 5.76 kΩ, and X_m = 0.456 kΩ. If the transformer bank is connected in the Y-Y, Y-Δ, Δ-Y and Δ- Δ configurations, draw the per-phase Y-Y equivalent circuit for each configuration.

3. Three single-phase 100 kVA, 2400/240 V 50 Hz transformers are connected to form a three-phase, 4157/240, Y-Δ transformer bank. The 3-phase transformer supplies a 150-kVA, 240 V, three phase load with a power factor of 0.8 lagging. The equivalent impedance for each transformer referred to the low voltage winding is 0.015 + j0.018 Ω. Determine the transformer winding currents and the primary voltage to produce the rated output. [$I_\Delta = 208.3\ A$; $I_Y = 20.83\ A$; $V_{\phi p} = 2447.3\ V$; $V_{Lp} = 4238.88\ V$]

EE3010 ELECTRICAL DEVICES AND MACHINES

TUTORIAL 8 – Induction Motors 1

Q1. A 3-phase, 440-V, 50-Hz, 4-pole, Y-connected induction motor has a stator resistance of 0.12 ohm/phase. The rotational losses, which include the core losses, of the motor are 2.4 kW. At full-load, the motor takes an input power of 42.5 kW at a power factor of 0.85 lagging and runs at 1470 rpm. Determine

a. The input current and stator copper losses.
b. The air-gap power and rotor copper losses.
c. The developed torque, shaft torque and efficiency of the motor.

[Ans : (a) 65.61 A, 1.55 kW (b) 40.95 kW, 0.819 kW, (c) 260.69 N-m, 245.1 N-m, 88.78 %]

Q2. A 4-pole, 440-V, 50-Hz, Y-connected, 3-phase induction motor has a stator impedance of (0.15 + *j* 0.8) ohm/phase and a rotor impedance (referred to the stator) of (0.2 + *j* 0.8) ohm/phase at standstill. The magnetizing reactance is 30 ohms/phase. The rotational losses, which include the core losses, of the motor are 750 W. Using the equivalent circuit, determine the following when the motor operates at full-load slip of 4 %.

a) Input current and power factor
b) Air-gap power and developed power.
c) Load torque and efficiency of the motor.

[Ans : (a) 47.84 A, 0.899 lag (b) 31.746 kW, 30.476 kW (c) 197.12 N-m, 90.69%]

EE3010 ELECTRICAL DEVICES AND MACHINES

TUTORIAL 9 – Induction Motors 2

Q1. A 3-phase, 440-V, 50-Hz, 4-pole, Y-connected induction motor has the following per phase parameters referred to the stator.

$$R_1 = 0.4\ \Omega, R_2 = 0.5\ \Omega, X_1 = 1.2\ \Omega, X_2 = 1.5\ \Omega, X_M = 80\ \Omega$$

a) Determine the speed at which maximum torque is developed.
b) Determine the corresponding maximum torque, input current and power factor.
c) Determine the starting torque. What resistance should be added to the rotor circuit to obtain maximum starting torque.

[Ans : (a) 1224 rpm (b) 193.02 N-m, 62.15 A, 0.738 lag (c) 74.81 N-m, 2.212 ohms]

Q2. A 3-phase, 220-V, 1410 rpm, 50-Hz, 4-pole, Y-connected induction motor is tested with the following results:

No-load :	220 V, 5.7 A, 380 W
Locked rotor :	79.5 V, 18.57 A, 675 W
DC test :	9.02 V, 17.2 A

a) Determine the parameters of the induction motor.
b) Determine the efficiency and power factor of the induction motor under rated conditions.

[Ans : (a) $R_1 = 0.262\ \Omega, R_2 = 0.39\ \Omega, X_1 = 1.192\ \Omega, X_2 = 1.192\ \Omega,$
$X_M = 21.09\ \Omega$ (b) 0.823 lag, 83.54%]

EE3010 ELECTRICAL DEVICES AND MACHINES

TUTORIAL 10 – Induction Motors 3

Q1. A 3-phase, 460-V, 60-Hz, 4-pole Y-connected induction motor has a full-load speed of 1740 rpm and the per phase parameters referred to the stator is as follows.

$$R_1 = 0.25\ \Omega, R_2 = 0.2\ \Omega, X_1 = X_2 = 0.5\ \Omega, X_M = 30\ \Omega$$

The rotational losses, which include the core losses, of the motor are 1700 W. Find

a) (i) Starting current when started direct on full voltage.
   (ii) Starting torque.

b) (i) Full-load slip.
   (ii) Full-load current.
   (iii) Ratio of starting current to full-load current.
   (iv) Full-load power factor.
   (v) Full-load torque.
   (vi) Motor efficiency at full load.

c) (i) Slip at which maximum torque is developed.
   (ii) Maximum torque developed.
   (iii) Ratio of maximum torque developed to full-load torque.

d) What resistance should be added to the rotor circuit to obtain maximum starting torque.

[Ans : (a) 244.12 A, 183.52 N-m, (b) 0.0333, 42.84 A, 5.7, 0.941 lagging, 163.28 N-m, 87.3 % (c) 0.1956, 429.19 N-m, 2.6285 (d) 0.8227 ohms]

Q2. A certain 3-phase induction motor has a full-load slip and torque of 0.01 and 345 N-m, respectively. The rotor copper loss at full-load is 5.69 kW. If the rotor-circuit resistance is increased by 5 times, determine

a) The full-load torque if the slip is also increased by 5 times to 0.05.
b) The rotor copper loss at full-load torque.

[Ans : (a) 345 N-m (b) 28.4 kW]

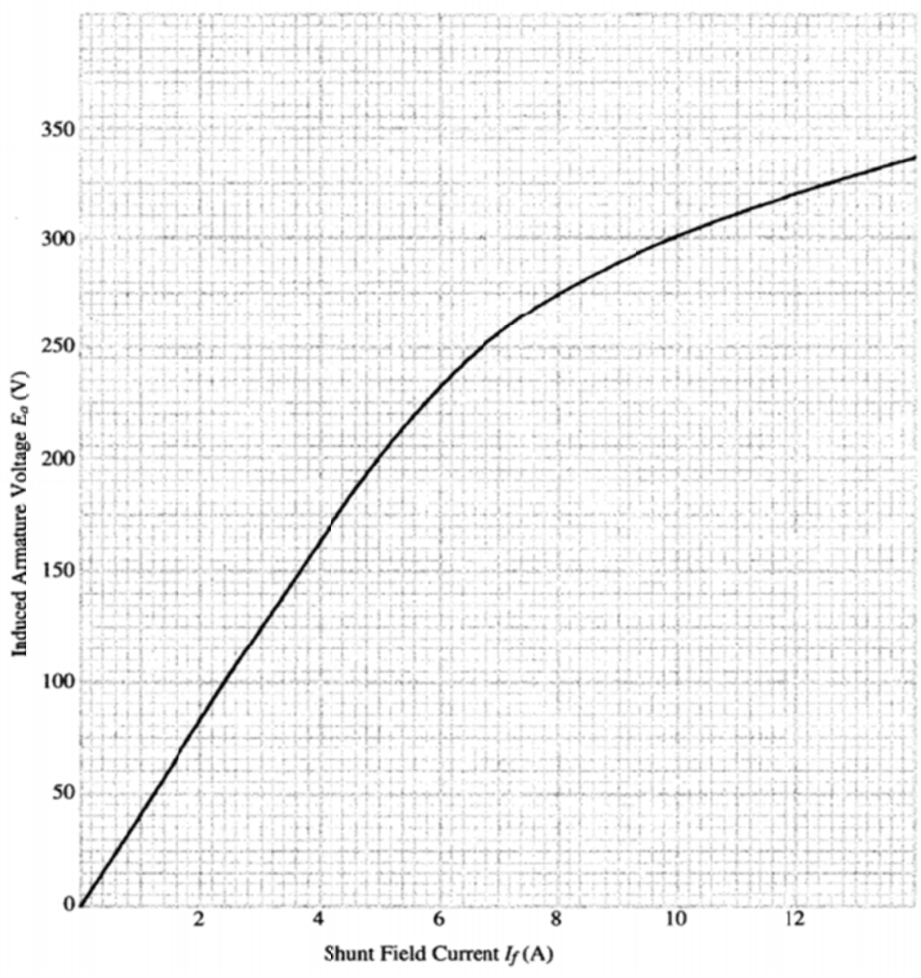
EE3010 ELECTRICAL DEVICES AND MACHINES

TUTORIAL 11 - DC Motors

Q1. The magnetisation curve of a DC machine obtained at 1200 rpm is shown below. The armature resistance (including the brushes, interpoles and compensating windings) is 0.125 ohm and the field resistance is 15 ohms. The DC machine operates as a separately-excited motor with an armature voltage supply of 250 V. Its field circuit is connected to a separate 120 V supply. The motor has a no-load speed of 1085 rpm. Determine

a) The rotational losses of the motor.
b) The load torque, rotational speed, and efficiency of the motor when it draws its rated current of 200 A.
c) The required armature voltage when the motor runs at 800 rpm and its developed torque reduces to 70% of the value in part (b).

[Ans :(a) 2.68 kW (b) 411.59 N-m, 981.82 rpm, 83.05 % (c) 200.83 V]



Q2. A 240-V DC shunt motor has an armature resistance of 0.3 ohm and shunt field resistance of 120 ohms. The rotational losses and armature reaction in the motor are negligible. At full load, the motor takes an input power of 10 kW and runs at 1000 rpm.

a) Calculate the internal generated voltage and developed torque of the motor at full load.
b) Derive and sketch the torque-speed characteristics of the motor.
c) Determine the speed and armature current of the motor when it drives a load having a torque-speed characteristic given by $T_{load} = 10\sqrt{\omega_m}$.
d) Determine the speed of the motor when a 60 ohms resistance is added to the field circuit. Assume that the motor is running with 50% full load torque and is operating in the linear part of the magnetisation curve.

[Ans : (a) 228.1 V, 86.4 N-m (b) $\omega_m = 110.19 - 0.0632 T_{dev}$ (c) 990.74 rpm, 46.77A (d) 1519.12 rpm]

Q3. A 240-V DC shunt motor has an armature resistance of 0.25 ohm and rotational losses of 500 W. The shunt field resistance is 120 ohms.

a) Determine the internal generated voltage, developed power, output torque and efficiency of the motor if it takes an input power of 20 kW at 240 V while running at 1200 rpm.
b) If the internal generated voltage is 230 V, determine the input current, motor speed, output power and developed torque of the motor.
c) What would be the input current and speed of the motor if the load is disconnected from the motor shaft?

[Ans :(a) 219.67 V, 17.86 kW, 138.15 N-m, 86.8% (b) 42 A, 1256.4 rpm, 8.7 kW, 69.9 N-m (c) 4.09 A, 1308 rpm]

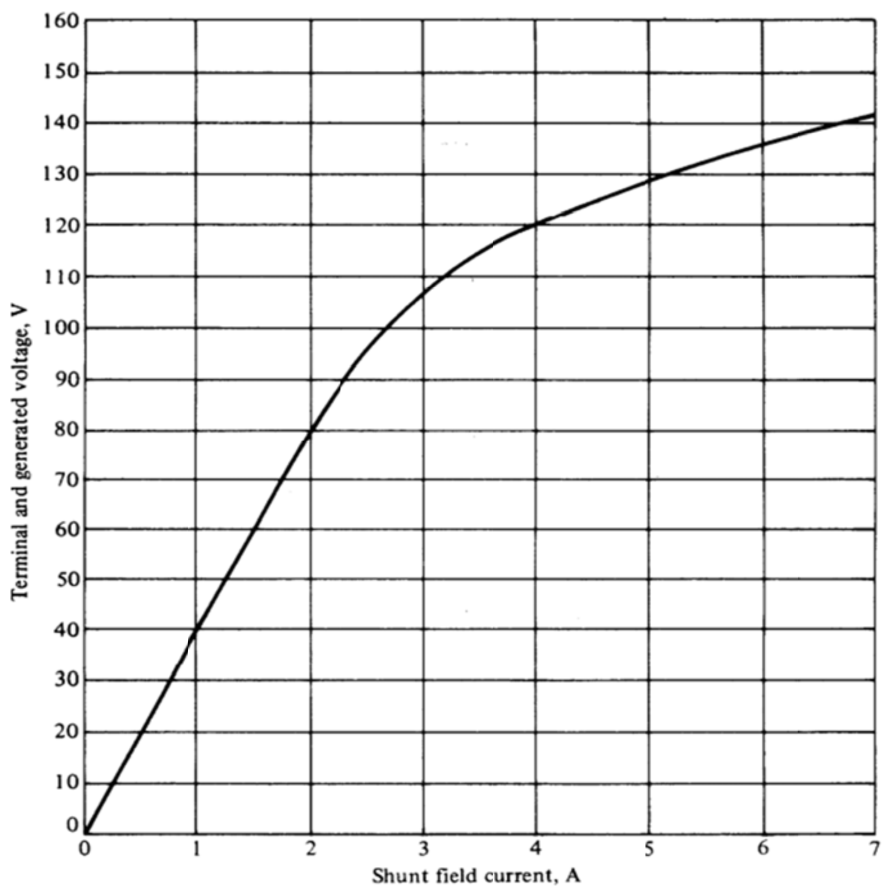
EE3010 ELECTRICAL DEVICES AND MACHINES

TUTORIAL 12 - DC Generators

Q1. The magnetisation curve of a 120-V, 10-kW, 1800-rpm DC machine is given below. The armature and field winding resistances of the machine are 0.20 ohm and 18 ohms, respectively. The field winding has 1000 turns/pole. The field circuit also has a rheostat of 0-15 ohms. The rotational losses of the machine are 650 W. The DC machine operates as a separately-excited generator with a field circuit voltage of 130 V. Calculate

a) The field rheostat setting to obtain the rated voltage at no-load condition.
b) The field rheostat setting when the generator supplies power to 80 incandescent lamps of 100 W each at rated terminal voltage. Neglect armature reaction.
c) The efficiency of the generator for the above load condition.

[Ans :(a) 14.5 ohms (b) 5.64 ohms (c) 78.02 %]



Q2. The DC machine in Q 1 is now operated as a shunt-connected DC generator. Determine

a) The field rheostat setting to obtain the rated voltage at no-load condition.
b) The terminal voltage when the generator delivers an armature current of 50 A. Neglect armature reaction. Use the field rheostat setting as obtained in (a).
c) The input shaft torque and efficiency of the generator for the above load condition.

[Ans :(a) 12 ohms (b) 105 V (c) 33.95 N-M, 76.28 %]