الإجابة النموذجية لمادة تك الالات الكهربية ك ٠٦٠ يوم الاثنين الموافق ٢٠١٤/١٢/٢٩
د شوقى حامد عرفه ابراهيم

Benha University	**Time: 3hour**
Benha Faculty of Engineering	**Forth Year 2014/2015**
Subject: Tec.Elect. Mach. (E 60)	**Mech. Eng. Dept.**

Solve & draw as much as you can (questions in two pages)

Question (1) **[15] Points**

1.a) Explain the hysteresis and eddy-current losses?

1.b) A magnetic circuit has a mean length of 1 m and a cross sectional area of 0.06 m^2, and a relative permeability of 2000. A magnetizing coil of 100-turns and 10 Ω is connected to a DC circuit causes a 30 V drop across the coil.

Determine the flux and flux density in the core?

Question (2) **[15] Points**

2.a) What is meant by voltage regulation of a transformer?

2.b) The following data were obtained from open circuit and short circuit tests of a 75 kVA, 4600─230V, 60Hz transformer and $R_1=R'_2$ and $X_1=X'_2$.

open circuit test low side	**short circuit test high side**
Voc=230V	Vsc=160.8V
Ioc=13.04A	Isc=16.3A
Poc=521W	Psc=1200W

Determine:

(a) the equivalent circuit high side parameters;

(b) the load current if Z_l=(0.03+j0.04) Ω is connected to the low side and the input voltage is 4600V?

(c) the excitation current?

P.T.O.

Question (3) **[15] Points**

3.a) Sketch and explain the torque-speed characteristics of a 3-phase induction motor?

3.b) A 3-phase, 230-V 30-hp, 50-Hz, six pole induction motor is operating with a shaft load that requires 20 kW input to the rotor. The rotor copper losses are 1.05 kW, and the combined friction, windage, and stray power losses for this load is 200 W. **Determine** **(i)** shaft speed; **(ii)** mechanical power developed;

(iii) developed torque; **(iv)** shaft torque

Question (4) **[15] Points**

4.a) Explain the construction and theory of operation of a 3-phase Induction Motor?

4.b) A shunt generator delivers load current 60A at 480 V to a resistive load. The armature resistance is 0.2 Ω and the field resistance is 100 Ω.

Determine **(i)** the generated emf, **(ii)** armature current **(iii)** the efficiency?

4.c) A [15 hp, 220V, 2000 rpm] separately excited DC motor drives a load requiring a torque of 45 Nm at a speed of 1200 rpm. $R_a = 0.25\Omega, R_f = 147\Omega, K\Phi = 1.0524 Nm/A, V_f = 220V$.

Determine **(i)** the armature current and the field current? **(ii)** the armature voltage required? **(iii)** the efficiency? ?

With my Best Wishes

Answer

Question (1) **[15] Points**

1.a) Explain the hysteresis and eddy-current losses?

Magnetic Hysteresis Loss

If an alternating voltage is connected to the magnetizing coil, as shown in Figure 1.8(a), the alternating magnetomotive force causes the magnetic domains to be constantly reoriented along the magnetizing axis. This molecular motion produces heat, and the harder the steel the greater the heat. The power loss due to hysteresis for a given type and volume of core material varies directly with the frequency and the nth power of the maximum value of the flux density wave. Expressed mathematically,

$$P_h = k_h \cdot f \cdot B_{max}^n \qquad (1\text{–}11)$$

where:
P_h = hysteresis loss (W/unit mass of core)
f = frequency of flux wave (Hz)
B_{max} = maximum value of flux density wave (T)
k_h = constant
n = Steinmetz exponent[2]

The constant k_h is dependent on the magnetic characteristics of the material, its density, and the units used. The area enclosed by the hysteresis loop is equal to the hysteresis energy in joules/cycle/cubic-meter of material.

EDDY CURRENTS AND EDDY-CURRENT LOSSES

Eddy currents are circulating currents produced by transformer action in the iron cores of electrical apparatus. Figure 1.15(a) shows a block of iron that may be viewed as an infinite number of concentric shells or loops. The eddy voltages generated in these shells by a changing magnetic field are proportional to the rate of change of flux through the window of the respective shells. Thus,

$$e_e \propto \frac{d\Phi}{dt}$$

Expressed in terms of frequency and flux density, as obtained from Eq. (1–25),

$$E_e \propto f \cdot B_{max} \qquad (1\text{–}28)$$

Slicing the core into many laminations and insulating one from the other will reduce the magnitude of the eddy currents by providing smaller paths, and hence lower eddy voltages. This is shown in Figure 1.15(b). Laminated cores are made by stacking insulated steel stampings to the desired thickness or depth. Each lamination is insulated by a coating of insulating varnish or oxide on one or both sides. Laminating the core results in much smaller shells, significantly reducing the heat losses in the iron.

The eddy-current loss, expended as heat power in the resistance of each shell, is proportional to the square of the eddy voltage.

$$P_e \propto E_e^2 \qquad (1\text{–}29)$$

Substituting Eq. (1–28) into Eq. (1–29) and applying a proportionality factor results in

$$P_e = k_e f^2 B_{max}^2 \qquad (1\text{–}30)$$

where: P_e = eddy-current loss (W/unit mass)
f = frequency of flux wave (Hz)

B_{max} = maximum value of flux density wave (T)
k_e = constant

The constant k_e is dependent on the lamination thickness, electrical resistivity, density and mass of the core material, and the units used.

1.b) A magnetic circuit has a mean length of 1 m and a cross sectional area of 0.06 m^2, and a relative permeability of 2000. A magnetizing coil of 100-turns and 10 Ω is connected to a DC circuit causes a 30 V drop across the coil.

Determine the flux and flux density in the core?

I=E/R=30/10=3A, mmf=N*I=H*l=100*3=300=H, H=300At/m

$\beta=\mu_o*\mu_r*H$=4pi*10^-7*2000*300=0.754T, β=Φ/A, Φ=0.75*0.06=45.24mWb

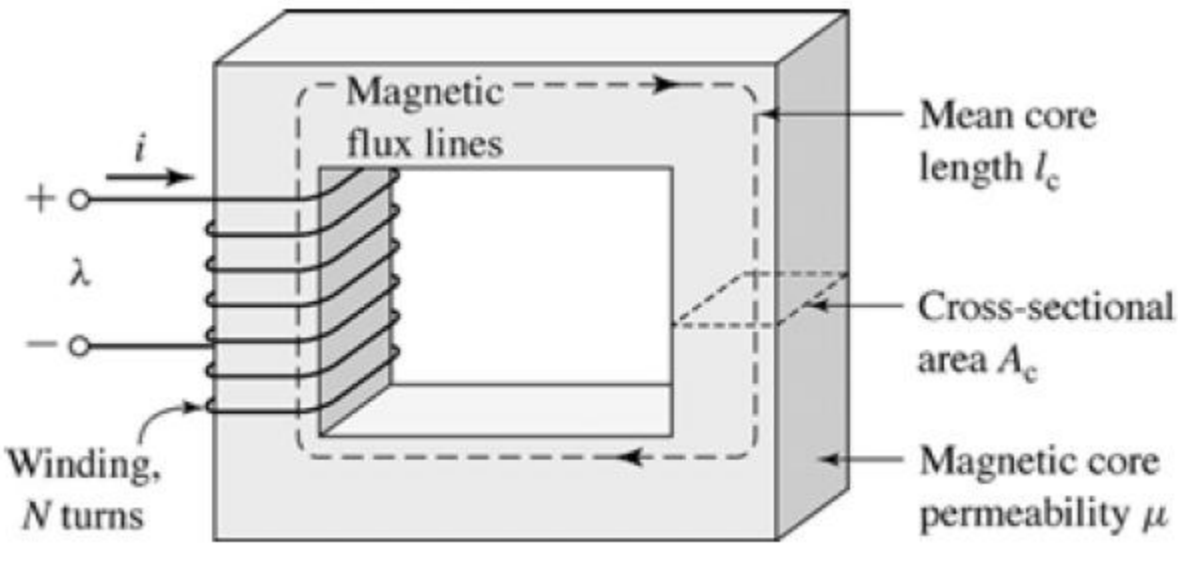


Figure 1.1 Simple magnetic circuit.

Question (2) **[15] Points**

2.a) What is meant by voltage regulation of a transformer?

2-11 Voltage Regulation

The effects of leakage flux and winding resistance in a transformer cause internal voltage drops that result in different output voltages for different loads. The difference between the output voltage at no load and the output voltage at rated load, divided by the output voltage at rated load, is called the voltage regulation of the transformer, and is commonly used as a figure of merit when comparing transformers. Expressed mathematically,

$$\text{reg} = \frac{E - V_{\text{rated}}}{V_{\text{rated}}} \qquad \textbf{(2-44)}$$

where:

E = voltmeter reading at the output terminals when no load is connected to the transformer

V_{rated} = voltmeter reading at the output terminals when the transformer is supplying rated apparent power

2.b) The following data were obtained from open circuit and short circuit tests of a 75 kVA, 4600─230V, 60Hz transformer and R_1=R'_2 and X_1=X'_2.

open circuit test low side	short circuit test high side
Voc=230V	Vsc=160.8V
Ioc=13.04A	Isc=16.3A
Poc=521W	Psc=1200W

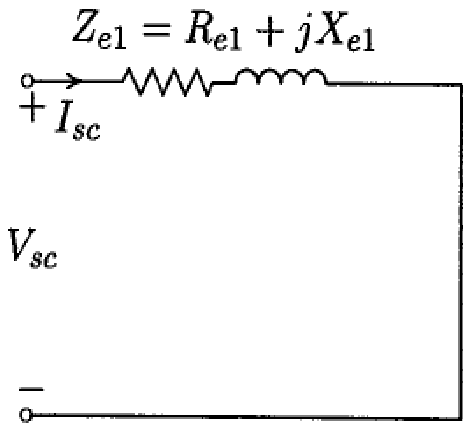
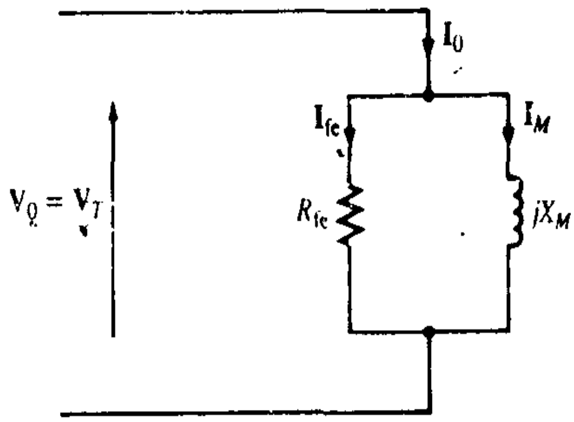


FIGURE 3.15
Equivalent circuit for the short-circuit test.



(b)

$$I_{SC} = \frac{V_{SC}}{Z_{eq.HS}} \quad P_{SC} = I_{SC}^2 R_{eq.HS} \quad Z_{eq.HS} = \sqrt{R_{eq.HS}^2 - X_{eq.HS}^2}$$

$$P_{OC} = V_{OC} I_{fe} \qquad I_{OC} = \sqrt{I_{fe}^2 + I_M^2}$$

$$R_{fe,LS} = \frac{V_{OC}}{I_{fe}} \qquad X_{M,LS} = \frac{V_{OC}}{I_M}$$

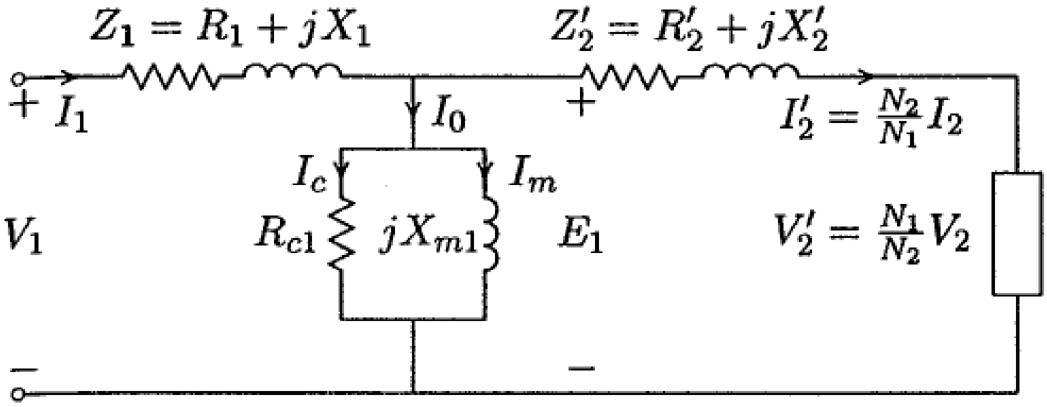


FIGURE 3.10
Exact equivalent circuit referred to the primary side.

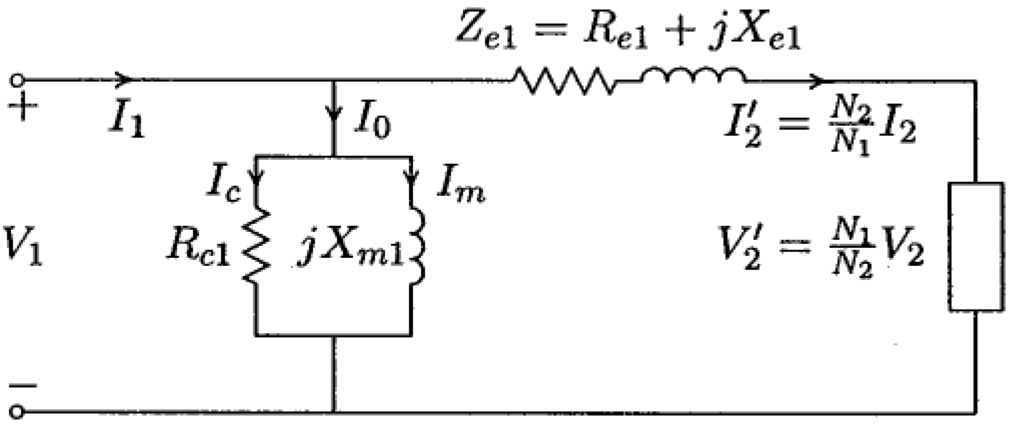


FIGURE 3.11
Approximate equivalent circuit referred to the primary.

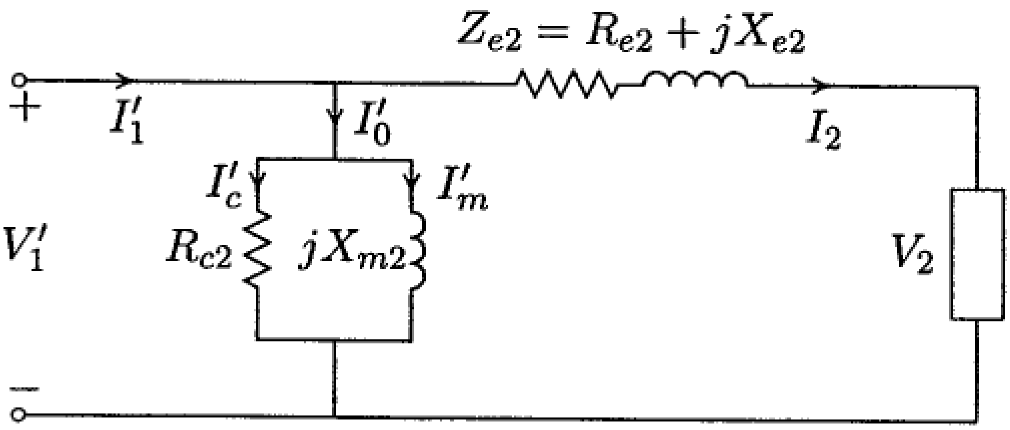


FIGURE 3.12
Approximate equivalent circuit referred to the secondary.

Determine:

(a) the equivalent circuit high side parameters;

(b) the load current if Z_l=(0.03+j0.04) Ω is connected to the low side and the input voltage is 4600V?

(c) the excitation current?

$R_{fe}=(230)^2/521=101.54\Omega$, $X_m==(230)^2/\sqrt{[(230)^2-(521)^2]}=17.91\Omega$

$R_{eq}=1200/(16.3*16.3)=4.52\Omega$, $Z_{eq}=160.8/16.3=9.87\Omega$, $X_{eq}^2=(9.8)^2-(4.5)^2=(8.8)^2$ Ω

$Z'_L=a^2\ Z_L=12+j16$, $Z'_{in}=16.52+j124.8\Omega$

$I_o=(4600/101.54)+(4600/j\,17.91)=45.3-j256.84=260.8\angle-80$A

$I'_L=(4600/16.52)+(4600/j\,24.8)=278.5-j185.5=334.62\angle-33.7$A

<u>**Question (3)**</u> **[15] Points**

3.a) Sketch and explain the torque-speed characteristics of a 3-phase induction motor?

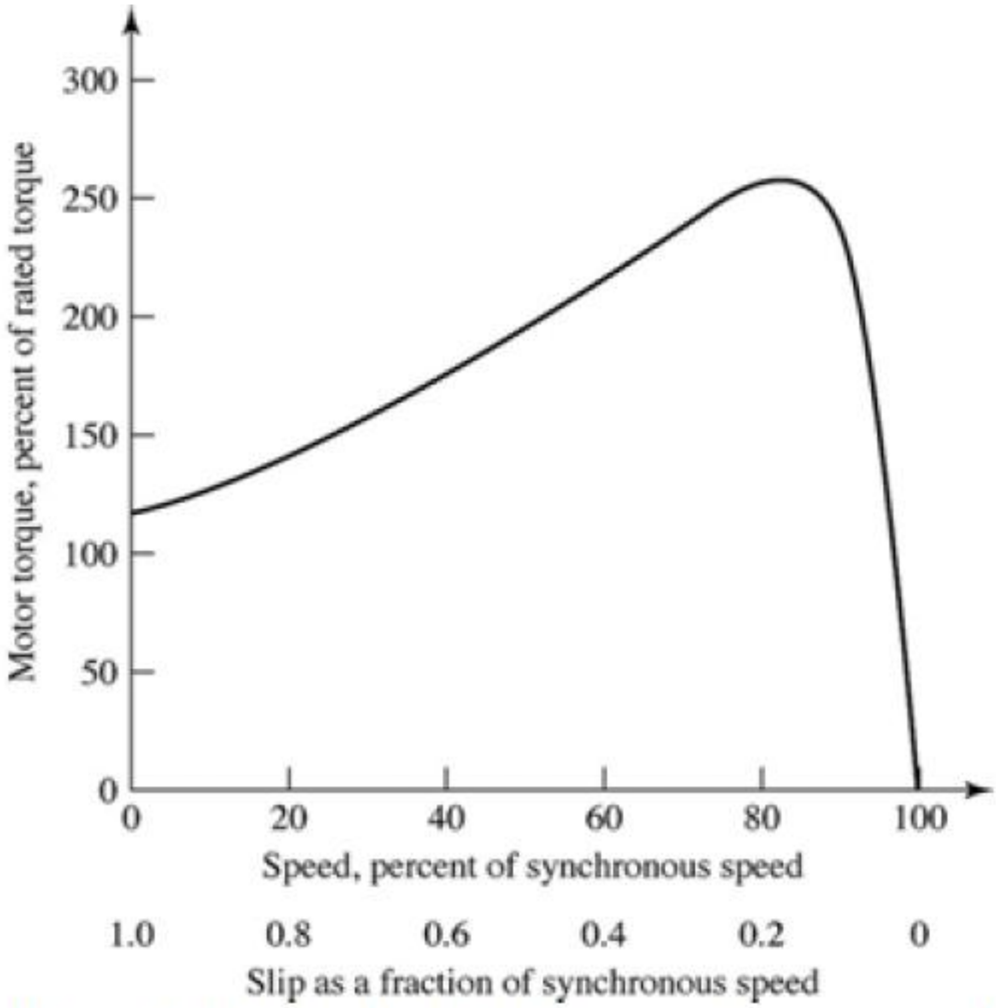


Figure 6.4 Typical induction-motor torque-speed

$$P_{gap} = n_{ph} I_2^2 \left(\frac{R_2}{s} \right)$$

$$P_{rotor} = n_{ph} I_{2s}^2 R_2$$

$$P_{rotor} = n_{ph} I_2^2 R_2$$

$$P_{mech} = P_{gap} - P_{rotor} = n_{ph} I_2^2 \left(\frac{R_2}{s} \right) - n_{ph} I_2^2 R_2$$

$$P_{mech} = n_{ph} I_2^2 R_2 \left(\frac{1-s}{s} \right)$$

$$P_{mech} = (1-s) P_{gap}$$

$$P_{rotor} = s P_{gap}$$

$$s = \frac{n_s - n}{n_s}$$

The slip is often expressed in percent.

n : rotor speed in rpm

$$n = (1 - s)n_s$$

ω_m : mechanical angular velocity

$$\omega_m = (1 - s)\omega_s$$

$$P_{mech} = \omega_m T_{mech} = (1 - s)\omega_s T_{mech}$$

$$T_{mech} = \frac{P_{mech}}{\omega_m} = \frac{P_{gap}}{\omega_s} = \frac{n_{ph} I_2^2 (R_2 / s)}{\omega_s}$$

$$\omega_s = \frac{4\pi f_e}{\text{poles}} = \left(\frac{2}{\text{poles}}\right)\omega_e$$

$$P_{shaft} = P_{mech} - P_{rot}$$

$$T_{shaft} = \frac{P_{shaft}}{\omega_m} = T_{mech} - T_{rot}$$

3.b) A 3-phase, 230-V 30-hp, 50-Hz, six pole induction motor is operating with a shaft load that requires 20 kW input to the rotor. The rotor copper losses are 1.05 kW, and the combined friction, windage, and stray power losses for this load is 200 W. **Determine** **(i)** shaft speed; **(ii)** mechanical power developed;

(iii) developed torque; **(iv)** shaft torque

S=1050/20000=0.053, n_s=120*50/6=1000rpm, ω_s=1000*pi/30=104.7rad/s

n_r=(1-S)ns=(1-0.053)1000=947.5rpm, ω_r=947.5*pi/30=99.17rad/s

P_{mech}=(1-0.053)20000=18940W, T_{mech}=18940/99.17=191Nm

P_{shaft}= 18940-200=18740W, T_{shaft}=18740/99.17=189Nm

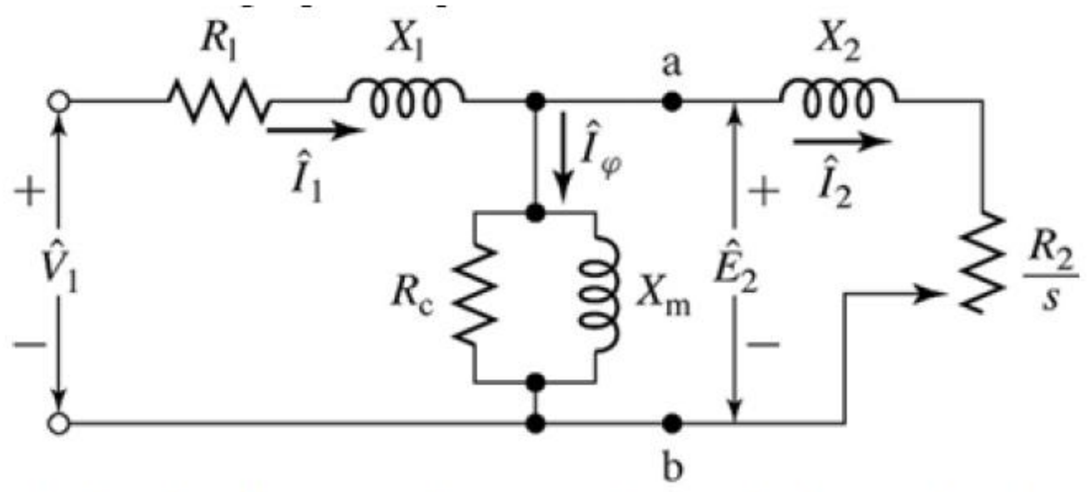


Figure 6.9 Single-phase equivalent circuit for a polyphase induction motor.

Question (4) **[15] Points**

4.a) Explain the construction and theory of operation of a 3-phase Induction Motor?

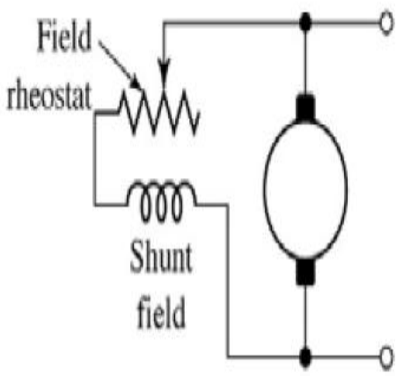
An induction machine is one in which alternating current is supplied to the stator directly and to the rotor by induction or transformer action from the stator.

- The stator winding is excited from a balanced polyphase source and produces a magnetic field in the air gap rotating at synchronous speed.
- The rotor winding may one of two types.
  - → A wound rotor is built with a polyphase winding similar to, and wound with the same number of poles as, the stator. The rotor terminals are available external to the motor.
  - → A squirrel-cage rotor has a winding consisting of conductor bars embedded in slots in the rotor iron and short-circuited at each end buy conducting end rings. It is the most commonly used type of motor in sizes ranging from fractional horsepower on up.
- The difference between synchronous speed and the rotor speed is commonly referred to as the slip of the rotor. The fractional slip s is

$$s = \frac{n_s - n}{n_s} \tag{6.1}$$

4.b) A shunt generator delivers load current 60A at 480 V to a resistive load. The armature resistance is 0.2 Ω and the field resistance is 100 Ω.

Determine **(i)** the generated emf, **(ii)** armature current **(iii)** the efficiency?



$$T_{mech} = K_a \Phi_d i_a \quad e_a = K_a \Phi_d \omega_m$$

In a motor the relation between the emf E_a generated in the armature and and the armature terminal voltage V_a is

$$V_a = E_a + I_a R_a \quad (7.11)$$

$$I_a = \frac{V_a - E_a}{R_a} \quad (7.12)$$

Torque and power:

The electromagnetic torque T_{mech}

$$T_{mech} = K_a \Phi_d I_a$$

The generated voltage E_a

$$E_a = K_a \Phi_d \omega_m$$

$$K_a = \frac{\text{poles} C_a}{2\pi m}$$

$E_a I_a$: electromagnetic power

$$T_{mech} = \frac{E_a I_a}{\omega_m} = K_a \Phi_d I_a$$

I_f=480/100=4.8A, I_a=60+4.8=64.8A, E_a=480+64.8*0.2=492.96V

P_{inp}=492.96*64.8=31943.8W, P_{out}=480*60=28800W, η=28800/31943.8=90.2%

4.c) A [15 hp, 220V, 2000 rpm] separately excited DC motor drives a load requiring a torque of 45 Nm at a speed of 1200 rpm. $R_a = 0.25\Omega, R_f = 147\Omega, K\Phi = 1.0524 Nm/A, V_f = 220V$.

Determine **(i)** the armature current and the field current? **(ii)**the armature voltage required? **(iii)** the efficiency? ?

I_f=220/147=1.5A, I_a=45/1.0524=42.8A, E_a=1.0524*2pi*1200/60=132.3V

Va=E_a+IaRa=132.3+42.8*0.25=143V, P_{inp}=143*42.8+1.5*220=6449.8W,

P_{out}=45*2pi*1200/60=5656.5W, η=5656.5/6449.8=88%