الإجابة النموذجية لمادة نظم التشغيل الكهربية ك ٥٦٣ يوم الاثنين الموافق ٢٠١٥/١/١٩

د شوقي حامد عرفه ابراهيم

Benha University	**Time: 3hours**
Benha Faculty of Engineering	**Fifth Year 2014/2015**
Subject: Electrical drives (E563)	**Elect.Eng.Dept.**

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

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

a- Write about: Electrical drive- Speed control of a separately excited DC motor?

b- A [15 hp, 220V, 2000 rpm] separately excited DC motor drives a load requiring a torque of 50 Nm at a speed of 1200 rpm. $R_a = 0.25\Omega, R_f = 147\Omega, K\Phi = 1.5Nm/A, V_f = 220V.$

a- Find the armature current and the field current?
b- Find the armature voltage required?
c- Find the motor speed if it is supplied by fully controlled single phase rectifier with 30 degrees firing angle and 240 V, 60Hz AC supply and assume constant armature current?
d- Draw the wave forms of voltages and currents and the power circuit for c?

Question (2) **[10] Points**

a- Explain how to control the speed of the 3-phase induction motor?
b- A three phase 460V, 60Hz, 4 poles, wye-connected induction motor has a stator impedance of (0.4+j0.8) Ω/phase and (0.2+j0.8)Ω/phase of the rotor winding referred to the stator side. The exciting branch impedance viewed from the stator side is (0 Ω ∥ j25 Ω). The no load loss= 100 watt and may be assumed constant. The rated rotor speed is 1700rpm.

i-Draw the equivalent circuit? ii-Find the ω_{syn}, S, I_s, I_r , P_{gap}, P_{copper} , T_{dev}?

Question (3) **[10] Points**

a-Explain the AC/AC converter used to control the speed of the 3-phase induction motor?

b-If the motor in question 2 is connected to a 3-phase full wave AC/AC converter. Find the firing angle required to run the motor with speed range of 1000 rpm to 1700 rpm.

Question (3) **[10] Points**

a- A three phase 460V, 60Hz, 8 poles, wye-connected cylindrical rotor synchronous motor has a synchronous reactance of 2 Ω/phase. R_s is negligible and I_s=20A/phase and unity p.f.

i-Draw the equivalent circuit? ii-Find the rotor speed and the torque angle?

iii-Find the P_{out} and the maximum torque?

b-For a speed control of a separately excited DC motor using the closed loop control system. Draw the steady state block diagram and prove that

$$\frac{\omega_r}{V_r} = \frac{K_1 K\phi}{\mathrm{B}R_a + K\phi(K_1 K_2 + K\phi)} \qquad \frac{\omega_r}{-\mathrm{T}_w} = \frac{R_a}{\mathrm{B}R_a + K\phi(K_1 K_2 + K\phi)}$$

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

a- A 40 Kw, 240V,1150 rpm separately DC motor is to be used in a speed control system. The field current is held constant at a value for which $k\Phi = 1.95 V.s/rad$. Armature resistance and viscous friction factor are $R_a = 0.089\Omega$, $\mathrm{B} = 0.275\, N.m.s/rad$ The tachometer delivers10V/1000 rpm and the amplification of the controller and power modulator is 200.

i- Find V_r required to drive the motor with no load?

ii- Find the motor speed if V_r is not changed and the motor supplied rated torque?

b- If the motor in question 1 is connected to class A chopper with DC of 400 V and duty cycle is equal to 50% assume constant armature current?

i-Find the armature current??

ii-Find the motor speed ?

iii-Draw the wave forms of voltages and currents and the power circuit?

Answer

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

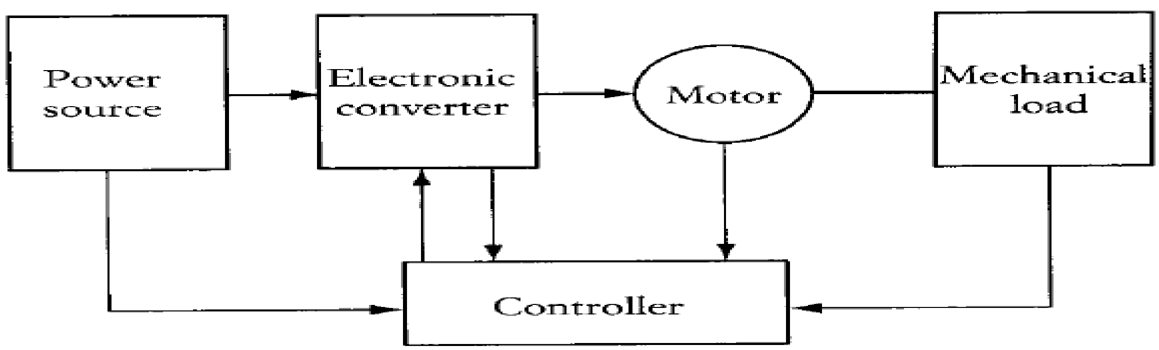
a- Write about: Electrical drive- Speed control of a separately excited DC motor?

The study of electric drive systems involves controlling electric motors in the steady state and in dynamic operations, taking into account the characteristics of mechanical loads and the behaviors of power electronic converters.

The electrical Drive is a system converts the electrical Energy to the mechanical energy with electrical control.

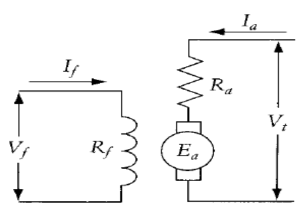
Drive types are: 1-line shaft drive 2-single motor single load drive 3-multimotor drives.

Functional blocks of an electric drive system

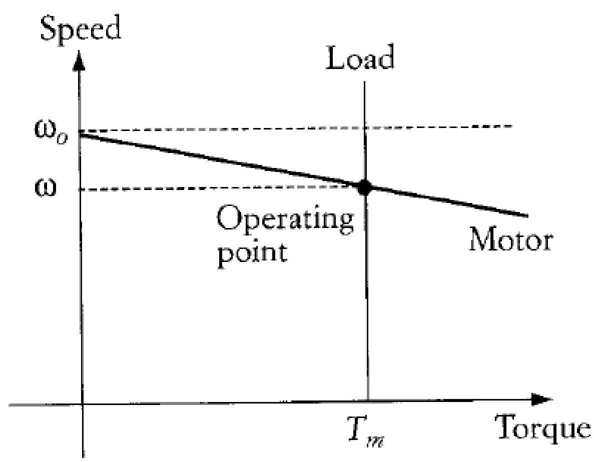


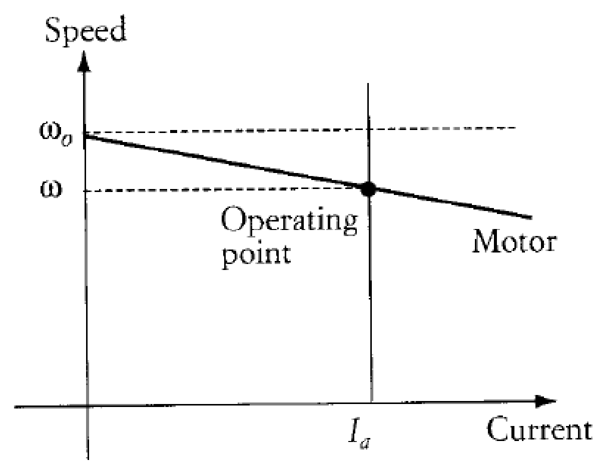
1. *Separately excited machines.* The field winding is composed of a large number of turns with small cross-section wire. This type of field winding is designed to withstand the rated voltage of the motor. The field and armature circuits are excited by separate sources.

Equivalent circuit of a dc motor in steady-state operation

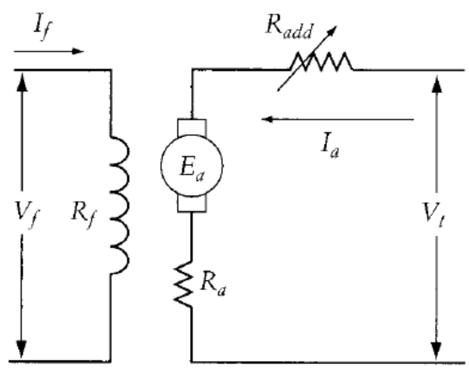


$$\omega = \frac{V_t}{K\phi} - \frac{R_a}{(K\phi)^2} T_d \qquad \omega = \frac{V_t}{K\phi} - \frac{R_a I_a}{K\phi}$$

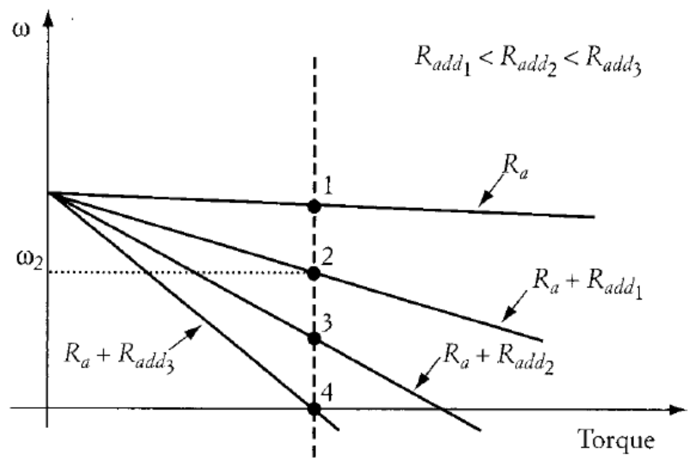




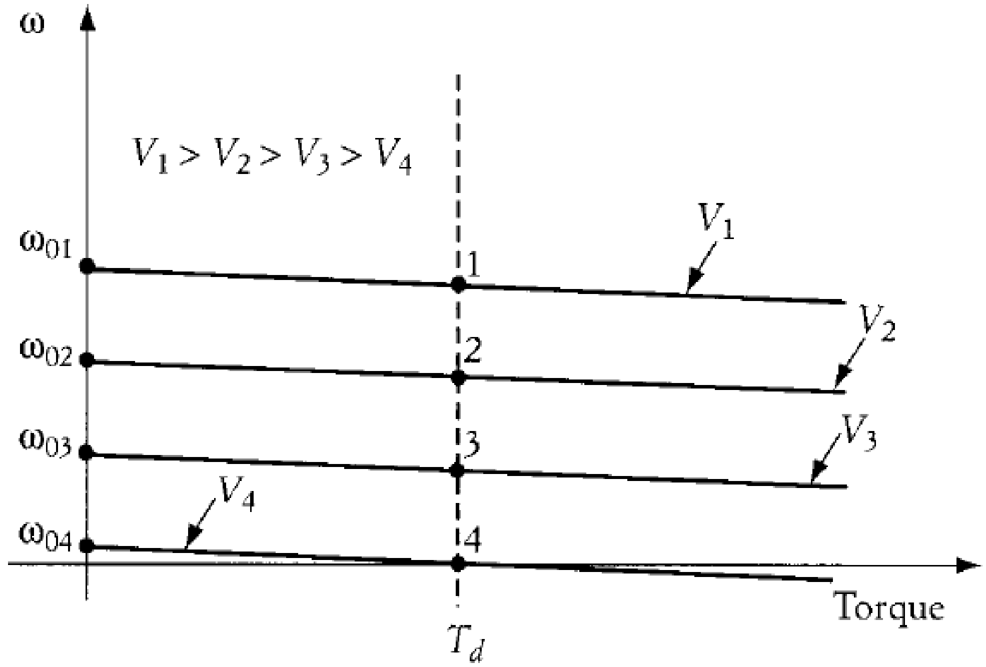
A setup for speed change by adding an armature resistance



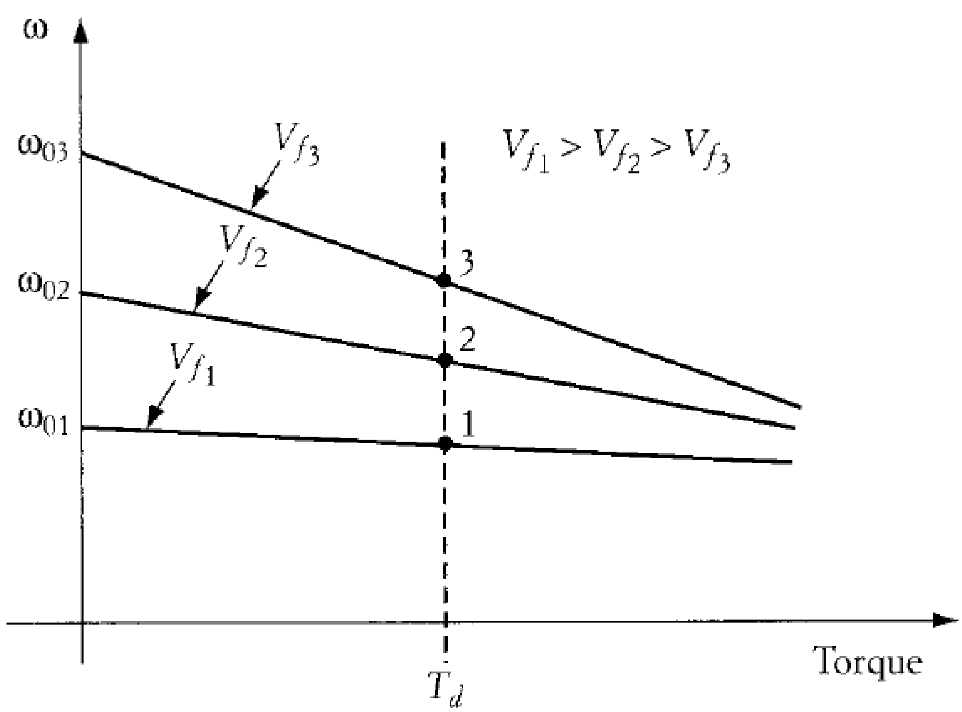
Effect of adding an armature resistance on speed



Motor characteristics when armature voltage changes



Effect of field voltage on motor speed



b- A [15 hp, 220V, 2000 rpm] separately excited DC motor drives a load requiring a torque of 50 Nm at a speed of 1200 rpm. $R_a = 0.25\Omega, R_f = 147\Omega, K\Phi = 1.5 Nm/A, V_f = 220V$.

a-Find the armature current and the field current?

b-Find the armature voltage required?

c-Find the motor speed if it is supplied by fully controlled single phase rectifier with 30 degrees firing angle and 240 V, 60Hz AC supply and assume constant armature current?

d-Draw the wave forms of voltages and currents and the power circuit for c?

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

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

$$V_a = E_a + I_a R_a \tag{7.11}$$

$$I_a = \frac{V_a - E_a}{R_a} \tag{7.12}$$

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=220/147=1.5A, I_a=50/1.5=33.3A, E_a=1200*2pi*1.5/60=188.5V

Va=E_a+IaRa =188.5+33.3*0.25=196.82V

V_a=2V_{max}sinα=(2*240*1.414sin30)/pi=108V

ω_r =(108-8.325)/1.5=66.5rad/s=66.5*30/pi=635rpm

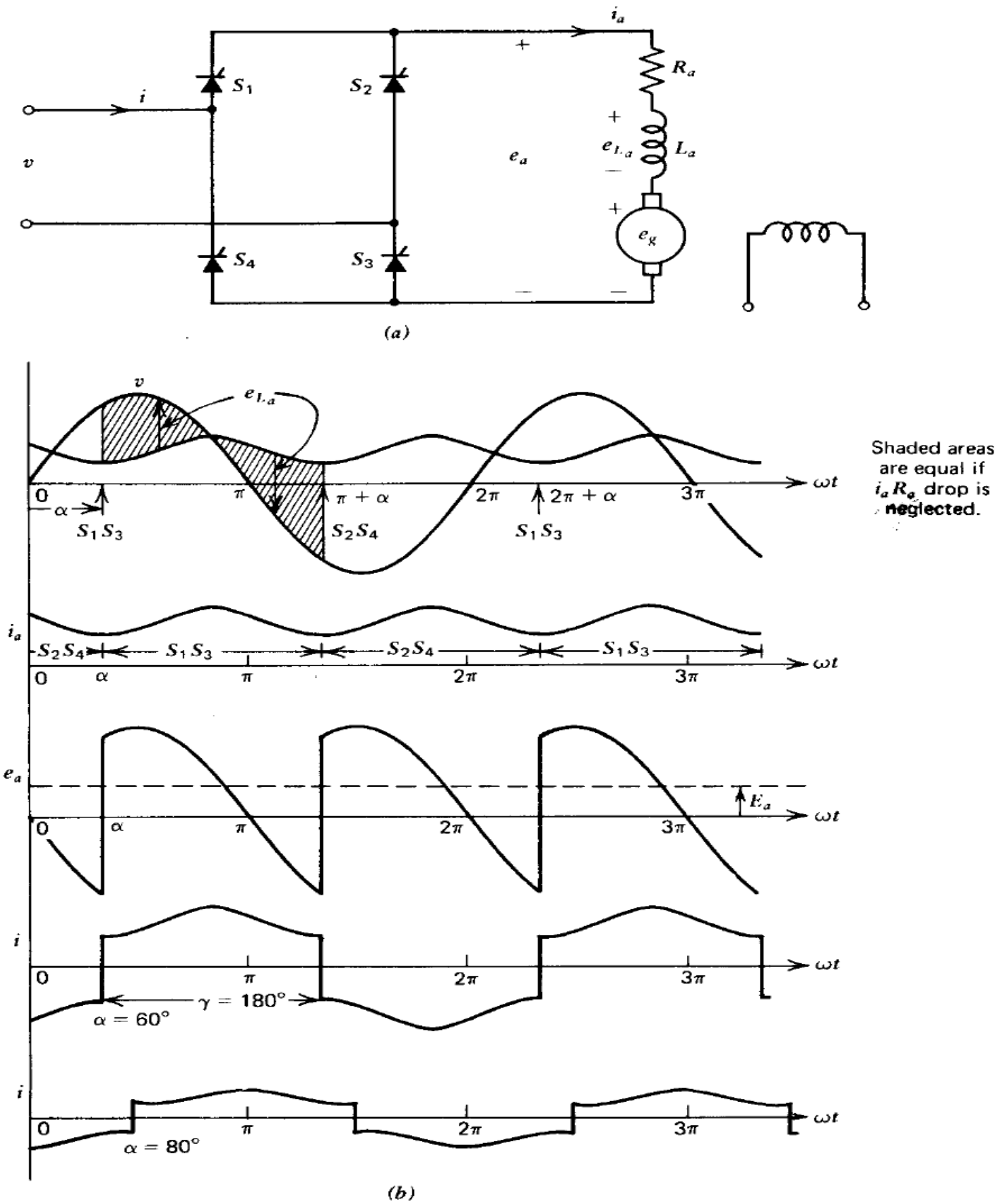


Fig. 2.3 **Speed control of a separately excited dc motor by a single-phase full-converter. (*a*) Power circuit. (*b*) Voltage and current waveforms for continuous motor current (motor operation). (*c*) Waveforms for inversion operation.**

Question (2) **[10] Points**

a-Explain how to control the speed of the 3-phase induction motor?

The speed control of an induction motor requires more elaborate techniques than the speed control of dc machines. First, however, let us analyze the basic relationship for the speed–torque characteristics of an induction motor given in Equation (5.57).

$$T_d = \frac{P_d}{\omega} = \frac{V^2 R'_2}{s\omega_s\left[\left(R_1 + \frac{R'_2}{s}\right)^2 + X_{eq}^2\right]} \quad (7.1)$$

By examining this equation, one can conclude that the speed ω (or slip *s*) can be controlled if at least one of the following variables or parameters is altered:

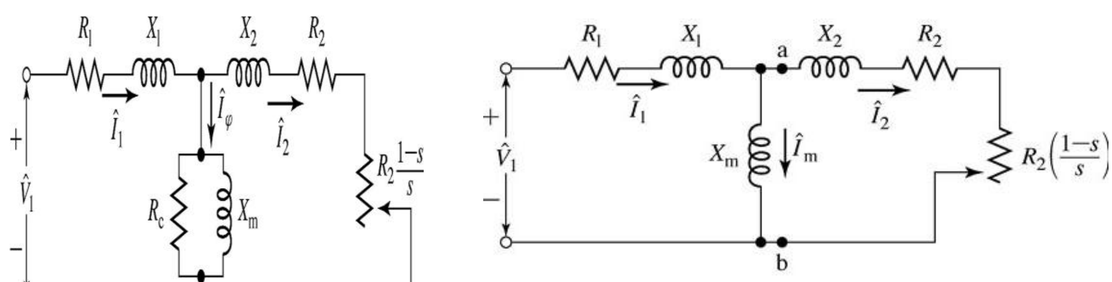
1. armature or rotor resistance
2. armature or rotor inductance
3. magnitude of terminal voltage
4. frequency of terminal voltage

Using three tools are 1-inverter 2-AC/AC converter 3-cycloconverter

b-A three phase 460V, 60Hz, 4 poles, wye-connected induction motor has a stator impedance of (0.4+j0.8) Ω/phase and (0.2+j0.8)Ω/phase of the rotor winding referred to the stator side. The exciting branch impedance viewed from the stator side is (0 Ω∕∕ j25 Ω). The no load loss= 100 watt and may be assumed constant. The rated rotor speed is 1700rpm.

i-Draw the equivalent circuit?

ii-Find the ω_{syn}, S, I_s, I_r , P_{gap}, P_{copper} , T_{dev}?



(b)

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

Equivalent circuits with the core-loss resistance *R*c neglected

n_s=120*60/4=1800rpm, ω_s=1800*pi/30=188.5rad/s

S1=(n_s-n_r)/ n_s =0.056, ω_r=1700*pi/30=178.02rad/s, S2=(n_s-n_r)/ n_s =0.44

$$\frac{R_2'}{S1} = \frac{0.2}{0.056} = 3.6, \quad Z'_2 = 3.6 + j0.8 = 3.7\llcorner 12.53\ \Omega,$$
$$j25\ //\ Z'_2 = 3.54\llcorner 20.5 = 3.32 + j1.24\ \Omega$$

$(j25\ //\ Z'_2)$+ Z_1 = $3.72 + j2.04\ \Omega = 4.24\llcorner 29\Omega$, 460/√3=265.6∟0V

I_{s1}=(265.6∟0/4.24∟29)=62.64∟-29A

I'_r=

Copper losses= $3I_L{}^2R_{eq}$=W

Output power= Pgap-losses=

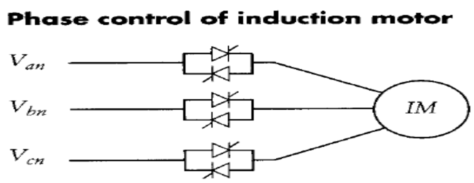
$\eta=p_{out}/p_{in}= p_{out}/(p_{out}$+losses)=

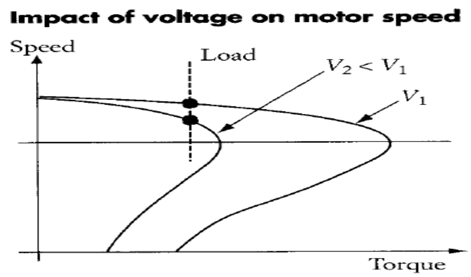
P_{mech}=   = W, T_{mech}= = Nm

P_{shaft}= W, T_{shaft}= Nm

Question (3) **[10] Points**

a-Explain the AC/AC converter used to control the speed of the 3-phase induction motor?





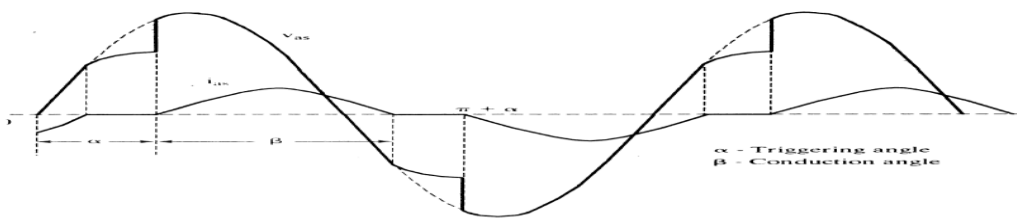
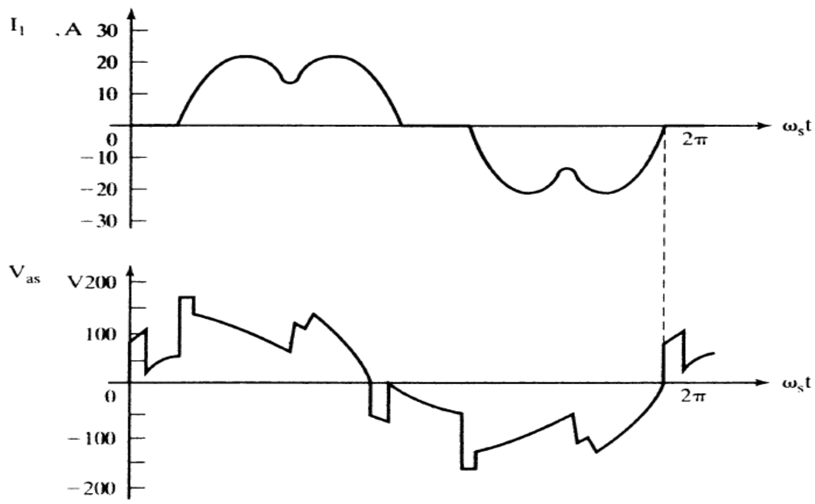


Figure 6.4 Phase voltage and current waveforms



e 6.10 Typical line-current and phase-voltage waveforms of a phase-controlled induction motor drive

b-If the motor in question 2 is connected to a 3-phase full wave AC/AC converter. Find the firing angle required to run the motor with speed range of 1000 rpm to 1700 rpm.

n_s=120*60/4=1800rpm, ω_s=1800*pi/30=188.5rad/s

S1=(n_s-n_r)/ n_s =0.056, ω_r=1700*pi/30=178.02rad/s, S2=(n_s-n_r)/ n_s =0.44

I_{a1}=(265.6$\angle$0/4.24$\angle$29)=62.64$\angle$-29A, I_{a2}= ,

(I_a/$I_{a\ rat}$)^2= [S(1-S)^2]/ [S_{rat}(1-S_{rat})^2]=(ST/$S_{rat}$$T_{s\ rat}$)

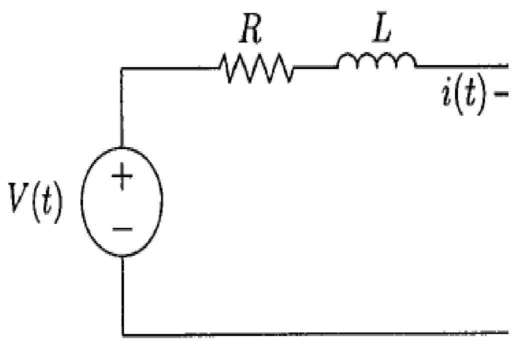
I_N=I_{s2}/I_{s1}=
From table or chart

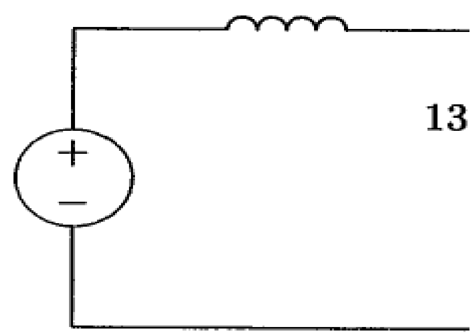
Question (3) **[10] Points**

a- A three phase 460V, 60Hz, 8 poles, wye-connected cylindrical rotor synchronous motor has a synchronous reactance of 2 Ω/phase. R_s is negligible and I_s=20A/phase and unity p.f.

i-Draw the equivalent circuit? ii-Find the rotor speed and the torque angle?

iii-Find the P_{out} and the maximum torque?





n_r =n_s=120*60/8=900rpm, ω_r =ω_s=900*pi/30=94.25rad/s

$V_f = V_t - jI_aX_s$ =460/√3=265.6∟0-j20*2=265.6-j40=268.6∟-8.6V

Torque angle=δ=-8.6°, $P_{out} = \frac{3V_f * V_t * \sin\delta}{X_s} = \frac{3*268.6*265.6 \sin 8.6}{2} = 15936.3W$

$$T_{max} = \frac{3V_f * V_t}{\omega s X_s} = \frac{3 * 268.6 * 265.6}{94.25 * 2} = 1135.4Nm$$

b-For a speed control of a separately excited DC motor using the closed loop control system. Draw the steady state block diagram and prove that

$$\frac{\omega_r}{V_r} = \frac{K_1 K\phi}{BR_a + K\phi(K_1K_2 + K\phi)} \qquad \frac{\omega_r}{-T_w} = \frac{R_a}{BR_a + K\phi(K_1K_2 + K\phi)}$$

$$e_a = e_g + R_a i_a + L_a \frac{di_a}{dt}$$

where

$$e_g = K_a \Phi n$$

The torque balance equation is

$$t = T_L + Bn + J\frac{dn}{dt}$$

where

$$t = K_a \Phi i_a$$

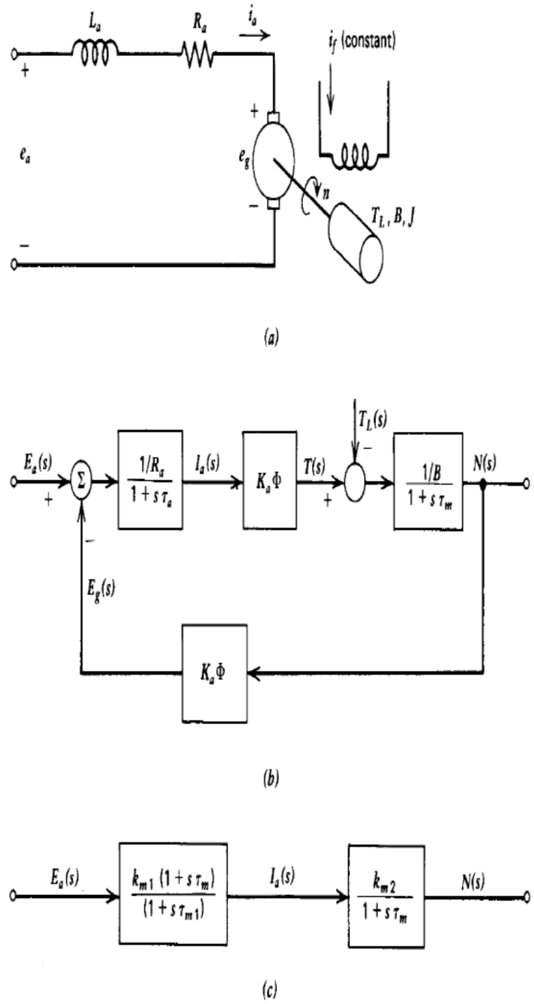


Fig. 6.2 **Development of motor transfer function. (*a*) Separately excited dc motor model. (*b*) Functional block diagram. (*c*) Simplified functional block diagram.**

In the Laplace domain, equations 6.1 through 6.4 can be written as

$$E_a(s) = E_g(s) + R_a I_a(s) + L_a s I_a(s) \qquad (6.5)$$

$$E_g(s) = K_a \Phi N(s) \qquad (6.6)$$

$$T(s) = T_L(s) + BN(s) + JsN(s) \qquad (6.7)$$

$$T(s) = K_a \Phi I_a(s) \qquad (6.8)$$

$$I_a(s) = \frac{E_a(s) - E_g(s)}{R_a + sL_a} = \frac{[E_a(s) - E_g(s)]1/R_a}{1 + \tau_a s}$$

where $\tau_a = L_a / R_a$ = electrical time constant of the motor armature

$$N(s) = \frac{T(s) - T_L(s)}{B + Js} = \frac{[T(s) - T_L(s)]1/B}{1 + \tau_m s}$$

where $\tau_m = J/B =$ mechanical time constant of the motor.

$$\frac{N(s)}{E_a(s)} = \frac{K_a\Phi}{(K_a\Phi)^2 + R_aB + sR_aB\tau_m} = \frac{k_m}{1 + s\tau_{m1}}$$

$$\frac{N(s)}{E_a(s)} = \frac{K_a\Phi}{(K_a\Phi)^2 + R_aB(1 + s\tau_a)(1 + s\tau_m)}$$

$$\tau_{m1} = \frac{R_aB}{(K_a\Phi)^2 + R_aB}\tau_m$$

$$k_m = \frac{K_a\Phi}{(K_a\Phi)^2 + R_aB}$$

$$\tau_{m1} < \tau_m$$

2*b*

$$\frac{N(s)}{I_a(s)} = \frac{K_a\Phi/B}{1 + s\tau_m} = \frac{k_{m2}}{1 + s\tau_m}$$

om equations 6.12a and 6.13

$$\frac{I_a(s)}{E_a(s)} = \frac{N(s)}{E_a(s)} \times \frac{I_a(s)}{N(s)}$$

$$= \frac{k_mB(1 + s\tau_m)}{K_a\Phi(1 + s\tau_{m1})} = \frac{k_{m1}(1 + s\tau_m)}{1 + s\tau_{m1}}$$

$$k_{m1} = \frac{B}{(K_a\Phi)^2 + R_a B} = \frac{k_m}{K_a\Phi/B}$$

$$k_{m2} = \frac{K_a\Phi}{B}$$

$$k_m = k_{m1}k_{m2}$$

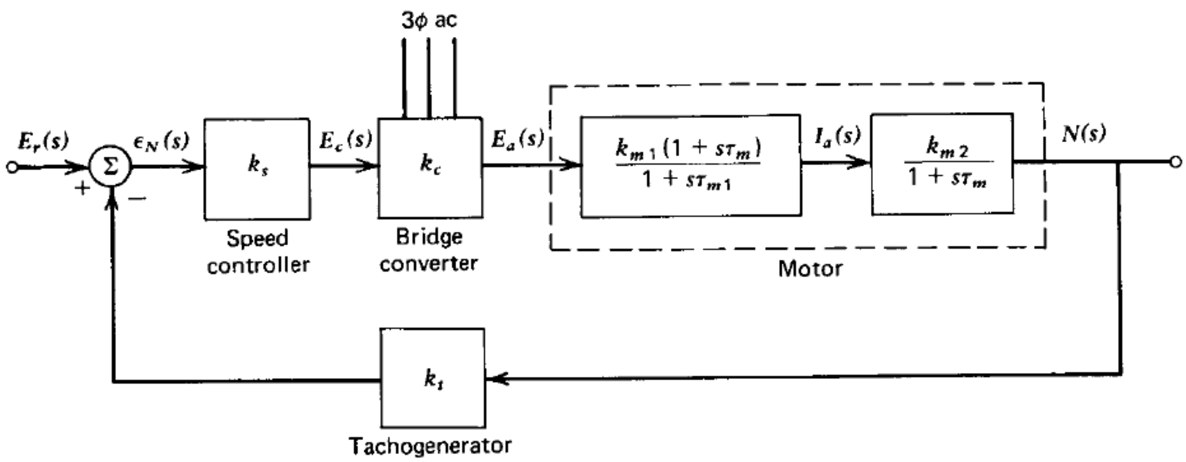


Fig. 6.3 Speed-control loop.

E_c and the armature voltage E_a can be obtained. If the small time delay associated with the converter is neglected then

$$\frac{E_a(s)}{E_c(s)} = k_c = \frac{3\sqrt{2}\, V_{LL}}{\pi \hat{E}_c}$$

where $\hat{E}_c$ corresponds to 0° firing angle and V_{LL} is the ac line to line rms voltage.

Proportional (P) Controller

Several types of speed controllers[2] are possible. Two of the more co ones are proportional (P) and proportional-integral (PI). First, a P cor is considered.

From Fig. 6.3

$$\frac{N(s)}{E_r(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

where

$$G(s) = \frac{k_s k_c k_{m1} k_{m2}}{1 + s\tau_{m1}}$$

$$H(s) = k_t$$

From equations 6.15, 6.15a, and 6.15b

$$\frac{N(s)}{E_r(s)} = \frac{k_1}{1 + s\tau_1}$$

where

$$k_1 = \frac{k_s k_c k_{m1} k_{m2}}{k_s k_c k_{m1} k_{m2} k_t + 1}$$

$$\tau_1 = \frac{\tau_{m1}}{k_s k_c k_{m1} k_{m2} k_t + 1}$$

If $k_s k_c k_{m1} k_{m2} k_t \gg 1$, then

$$k_1 \simeq \frac{1}{k_t}$$

$$\tau_1 \simeq \frac{\tau_{m1}}{k_s k_c k_{m1} k_{m2} k_t}$$

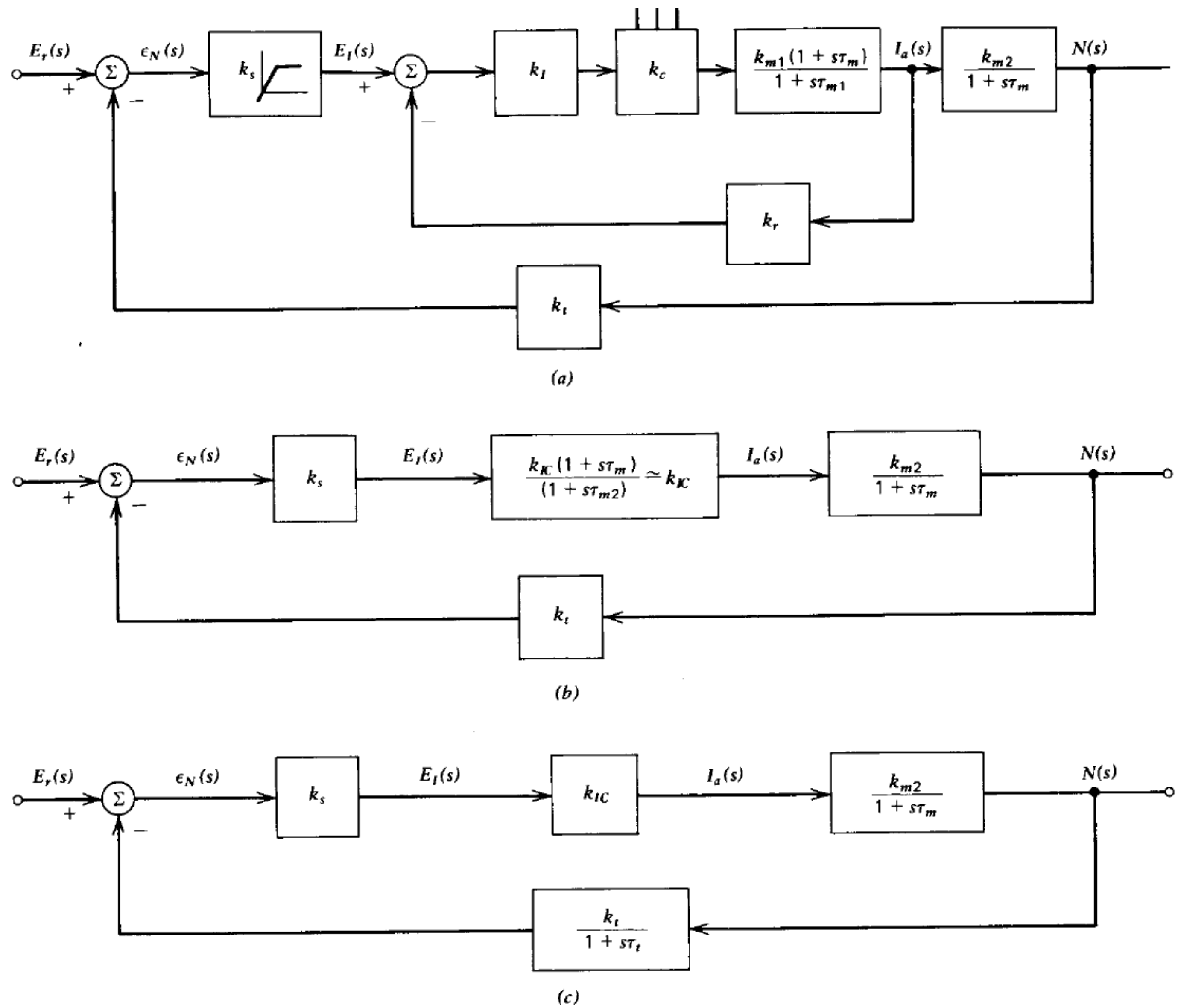


Fig. 6.5 Proportional speed control with inner current-control loop. (*a*) Functional block diagram. (*b*) Simplified functional block diagram. (*c*) Functional block diagrams with added tachogenerator filter.

$$\frac{N(s)}{E_r(s)} = \frac{k_s k_{IC} k_{m2}}{1 + k_s k_{IC} k_{m2} k_t} \frac{(1 + s\tau_t)}{1 + s\frac{(\tau_m + \tau_t)}{k^1} + \frac{s^2 \tau_m \tau_t}{k^1}}$$

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

a- A 40 Kw, 240V,1150 rpm separately DC motor is to be used in a speed control system. The field current is held constant at a value for which $k\Phi = 1.95 V.s/rad$. Armature resistance and viscous friction factor are $R_a = 0.089\Omega$, $B = 0.275\ N.m.s/rad$ The tachometer delivers10V/1000 rpm and the amplification of the controller and power modulator is 200.

i- Find V_r required to drive the motor with no load?

ω_{nL}=(240)/1.95=123.1rad/s=1175.5rpm, T_{rat}=40000*30/(1150*pi)=332.15Nm

ω/V_r=300/30.922=9.7, V_r=9.7*123.1=12.7V

ii- Find the motor speed if V_r is not changed and the motor supplied rated torque?

$-\omega/T_w$=0.089/30.922=0.0029, $-\omega$ =0.0029*332.15=0.96rad/s

ω =123.1-0.96=122.14rad/s=1166.4rpm

b- If the motor in question 1 is connected to class A chopper with DC of 400 V and duty cycle is equal to 50% assume constant armature current?

i-Find the armature current??

ii-Find the motor speed ?

iii-Draw the wave forms of voltages and currents and the power circuit?

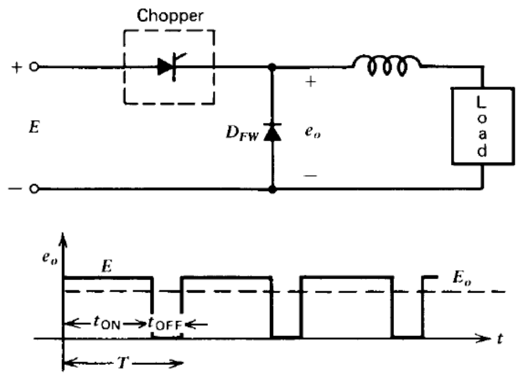
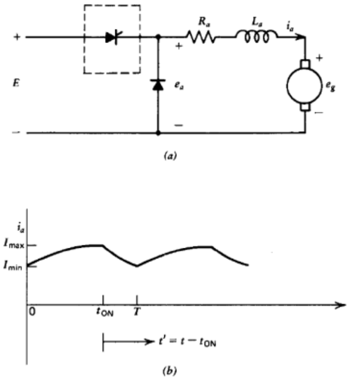


Fig. 4.2 Basic chopper circuit configuration and operation.



$$E_o = E\frac{t_{ON}}{t_{ON} + t_{OFF}}$$

$$= E\frac{t_{ON}}{T}$$

$$= \alpha E$$

t_{ON} = on-time

t_{OFF} = off-time

$T = t_{ON} + t_{OFF}$ = chopping period

$\alpha = \frac{t_{ON}}{T}$ = duty cycle.

$I_{a\ rat}$=(40000/240)=166.7A, V_{ave}=0.5*400=200V,

ω=(200-166.7*0.089)/1.95=94.96rad/s=906.8rpm