Benha University	Time: 3 hours
Benha Faculty of Engineering	Forth Year : 14/1/2018
Subject: Electrical drive systems (E1439)	Elect.Eng.Dept.

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

Question (1) [15] Points

a-Define: Electrical drive- Mechanical transformer? [2] points

b-Explain in details the Speed control of DC motors? [4] points

c-Write the common types of electrical drives? [2] points

d-Write the main parts of the electrical drive? [2] points

e-A three phase- Y- induction motor has [**380V, 60Hz, 1700rpm, pf=0.85, η_m=0.8, 4 poles,** $J_m = 0.5 Nm.S^2$]. It is used to drive two loads together. The first load is of rotational motion [$J_L = 2Nm.S^2$, **100Nm**, **1000 rpm** across a gear box of $\eta_{gear} = 0.9$]. The second load is of linear (motion) lifting **1000Kg to 50m** in a one minute across a tool has η_{tool}**= 0.7**.

Find ω_s, S, I_s, P_m, T_{equ}, J_{equ}? [5] points

Question (2) [15] Points

a- Draw the block diagram of the closed loop control system used for speed control of a separately excited DC motor and write $\frac{\omega_r}{-T_L}, \frac{\omega_r}{V_r}$? [6] points

b- A separately excited DC motor [$\mathbf{50KW, 240V, 1700rpm}$, $R_a = 0.1\Omega$, B $= \mathbf{0.03}$K$\Phi = \mathbf{1.3\,V.S/rad.}$]The gain of the speed sensor is 95mV/rad/s. It used the close loop technique to control the motor speed. The field current is held constant.

i- Find V_r required to drive the motor at rated speed with no load? [3] points

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

iii- Find the motor speed if V_r is decreased by 15%? [3] points

Question (3) [15] Points

A separately excited DC motor has [$20hp, 300V, 900rpm, R_a = 0.25\Omega, L_a = 0.05H, R_f = 145\Omega,$

$K\Phi = 3.05Nm/A, \quad T_{losses} = constant = 1Nm, load\ torque = constant = 115Nm$].

a-Find the motor speed if the armature voltage is 200 V? [5] points b-If its armature is supplied by fully controlled single phase rectifier [firing angle = 30 degrees, 312 V, 60Hz AC supply] and assume constant armature current and field current. Draw the power circuit and the wave forms of voltages and currents and find the motor speed and (pf)? [5] points

c-If its field is supplied by a fully-controlled three phase rectifier [firing angle = 52 degrees, Y-208 V, 60Hz AC supply] and assume constant armature current and field current $K\Phi = 2.3 Nm/A$. Draw the power circuit and the wave forms of voltages and currents and find the motor speed and the field voltage? [5] points

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

A separately excited DC motor has[$\mathbf{230V}, \mathbf{1750rpm}, \ \boldsymbol{I_{rate}} = \mathbf{74A}, \boldsymbol{R_a} = \mathbf{0.18}\Omega, \ \boldsymbol{L_a} = \mathbf{2.93mH}$] is driven with the motor armature supplied from class A chopper [**240V dc source, duty cycle is 0.5 and chopping frequency is 0.5 KHz].** The. The field current is held constant at the value giving rated operation on 230V. The armature current is the rated value.

i-Find the minimum and maximum armature currents? [5] points

ii-Find the ripple factors of the armature current and the supply current? [5] points

iii- Draw the power circuit and current and voltage waveforms? [5] points

Question (5) **[30] Points**

a-Explain how to control the speed of a 3-phase induction motor? [5] points

b-Draw the equivalent circuit of a 3-phase induction motor and find T_{dev}? [5] points

c-A three phase wye-connected induction motor [460V, 60Hz, 4 poles, 1750 rpm, $R_s = 1.01\Omega$, $R_r = 0.69\Omega$, $X_m = 43.5\Omega$, $X_1 = 1.3\Omega$, $X_2 = 1.94\Omega$, $T_L = 100Nm$. The stator of the motor is connected to a 3-phase full wave AC/AC converter.

i-Find the motor speed when the AC/AC converter output voltage is 460V line to line? [3] points

ii-Find the motor speed when the AC/AC converter output voltage is 230V line to line? [3] points

iii-Draw the power circuit and current and voltage waveforms? [4] points

d-If the stator of the motor is connected to a 3-phase six step inverter.

i-Find the required DC supply to run the motor with speed of 1000 rpm? [3] points

ii-Find the required DC supply to run the motor with speed of 1750 rpm? [3] points

iv- Draw the power circuit and current and voltage waveforms? [4] points

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يوم الاحد الموافق 14/1/2018 د شوقي حامد عرفه ابراهيم

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

a-Define: Electrical drive- Mechanical transformer? [2] points

It is a system that converts electrical energy to mechanical energy with electronic control and used for controlling the speed, torque and direction of motion of motors.

The mechanical transformer is a device transforms mechanical energy between two parts with different torque and speed such as gear box and chains.

b-Explain in details the Speed control of DC motors? [4] points

There are two methods are : 1-armature control as speed less than rated value

2-field control as speed larger than rated value

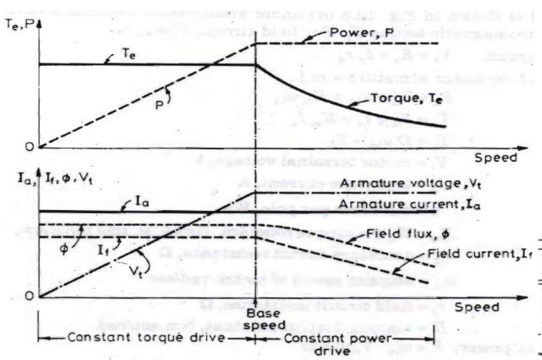
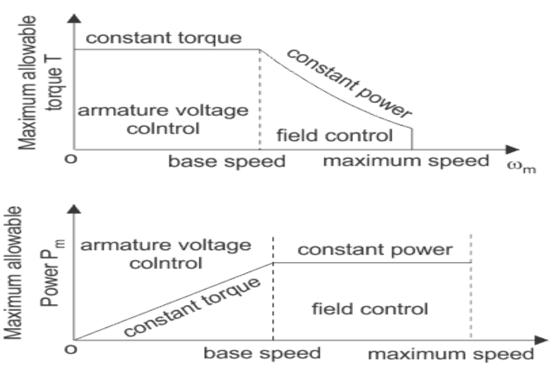


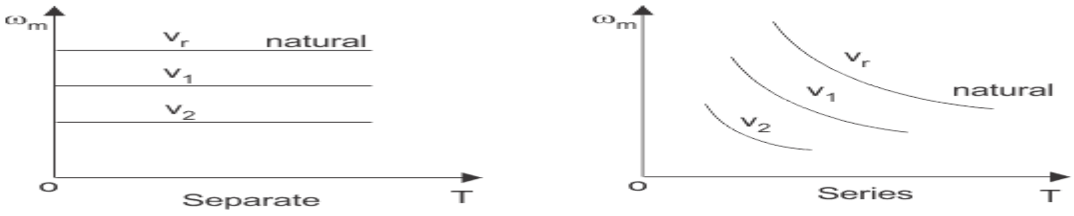
Fig. 12.4. Characteristics of a separately-excited dc motor.



the speed of a motor can be controlled by the following methods

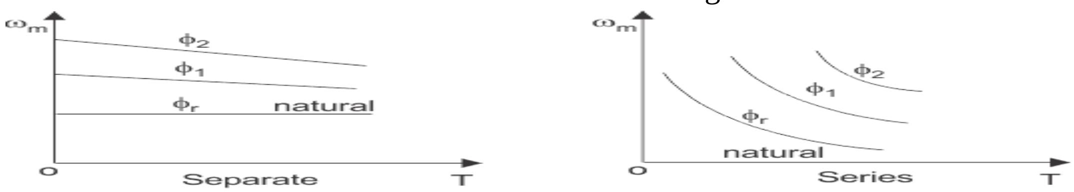
1-Armature voltage control 2-Field flux control 3Armature resistance control

Among all of these, armature voltage control is preferred because of high efficiency and good speed regulation and good transient response. But the only disadvantage of this method is that it can only operate under the rated speed, because the armature voltage cannot be allowed to exceed rated value. The speed torque curve for armature voltage control is shown below.



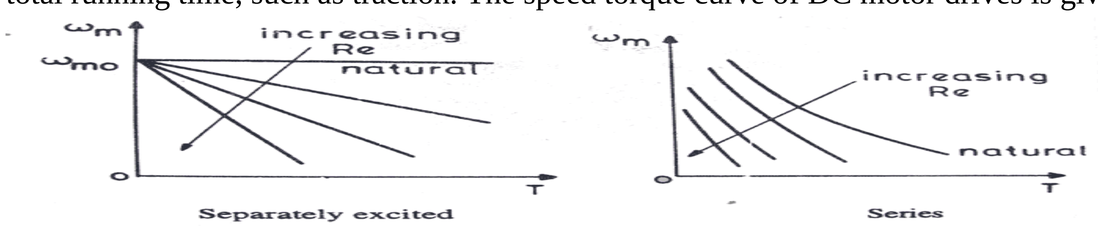
Armature Voltage Control V_r (rated) > V_1 > V_2

When speed control is required above the rated speed, field flux control is used. Normally in ordinary machines, the maximum speed can be allowed up to twice of the rated speed and for specially designed machines this can be allowed up to six times of the rated speed. The torque speed characteristics for field flux control are shown in the figure below.

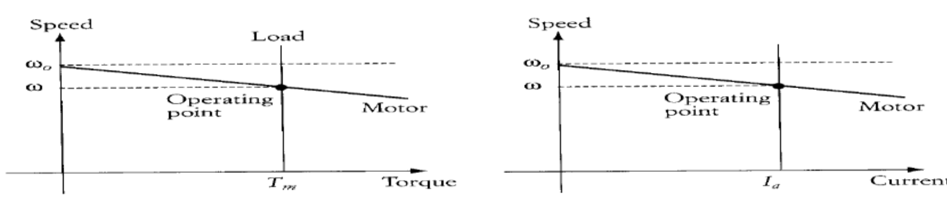


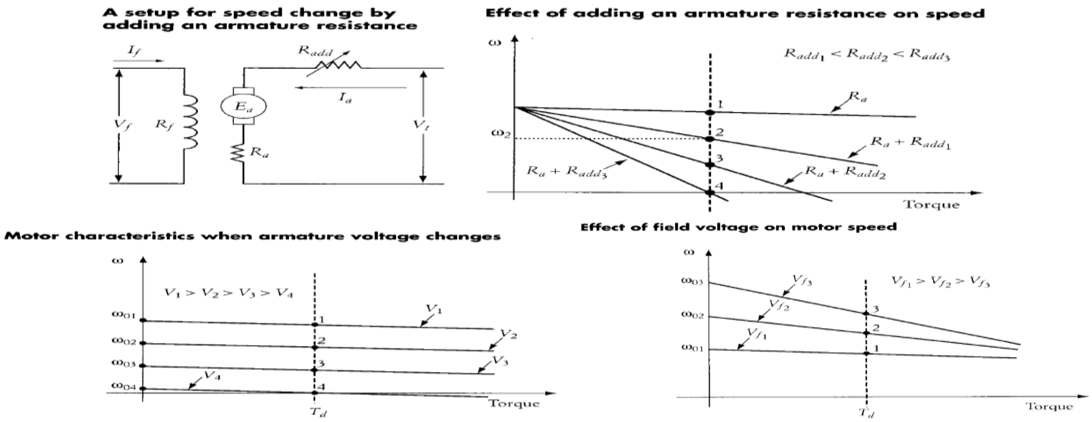
Filed flux control ϕ_r (rated) > ϕ_1 > ϕ_2

How the armature voltage control and field flux control is made to operate below and above the rated speed is shown in the figure below. Now, finally coming to resistance control method. Here speed is varied by wasting power in an external [resistor] that is connected in series with the armature. This method is not used very much because it is an inefficient method of controlling speed and it is only used in the places where the speed control time forms only a fraction of the total running time, such as traction. The speed torque curve of DC motor drives is given below.



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





c-Write the common types of electrical drives? [2] points

2-Types of drive:1- According to motor types:-a) DC drive b) AC drive c) Special drive.

2-According to size:a) large. b) medium. c) small . d)micro drive.

3-According to load connection with motor

a) single motor single load (SMSL) b) multi motor single load(MMSL)

c) single motor multi load(SMML) d) multi motor multi load(MMML)

4-According to control loop types: a-Open loop b- closed loop.

d-Write the main parts of the electrical drive? [2] points

2.3Main Components of electrical drive system:-

1-main power supply 2-controller with sensor 3-power modulator 4-electrical motor

5-mechanical load with mechanical transformer

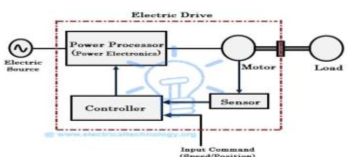


Figure 2.3The block diagram of the electrical drive

e-A three phase- Y- induction motor [**380V, 60Hz, 1700rpm, pf=0.85, η_m=0.8, 4 poles, $J_m = 0.5Nm.S^2$**]. It used to drive two loads together. The first is of rotational motion [$J_L = 2Nm.S^2$, **100Nm**, **1000 rpm** across a gear box of $\eta_{gear} = 0.9$]. The second is of linear motion lifting **1000Kg to 50m** in one minute across a tool has **η_{tool}= 0.7**i- Find **ω_s**, S, I_s, P_m, T_{req}, J_{equ}?

n_s=120*60/4=1800rpm, ω_s=1800*pi/30=188.5rad/s, S=(n_s-n_r)/ n_s =(1800-1700)/1800=0.056

P_{L1}=T_L* ω_L=100*1000*pi/30=10472W, $P_{inp\ gear}$= P_L/ η_{gear}=10472/0.9=11635.5W

P_{L2}=F*V=m*g*h/t=1000*9.81*50/60=8175W, $P_{inp\ ele}$= P_L/ η_{ele}=8175/0.7=11678.57W, P_{req}=P_{L1}+P_{L2}=23314W

$P_{inp\ m}$= P_{outm}/ η_m=(11635.5+11678.57)/0.8=29196.4W=√3 $V_L I_L \cos\Phi$, I_L=29196.4/(√3*380*0.85)=52.2A

$J_{eq}=J_m + J_{l1}(\frac{\omega_l}{\omega_m})^2 + M_{l2}(\frac{V_l}{\omega_m})^2$= 0.5+2*(1000/1700)^2+1000*((5/6)/1700(pi/30))^2=0.5+0.692+0.022=1.214N.m.sec^2

T_{req}=p_{req}/ω_m=23314.07/(1700(pi/30))=131Nm

Q2a- The closed loop control system is used for speed control of a separately excited DC motor. Draw the steady state block diagram and write $\frac{\omega_r}{V_r} = \frac{K_1 K\phi}{BR_a + K\phi(K_1K_2 + K\phi)}$ $\frac{\omega_r}{-T_w} = \frac{R_a}{BR_a + K\phi(K_1K_2 + K\phi)}$

1.1 Mathematical model

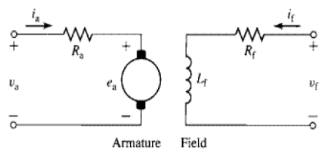


Figure (1) **Equivalent Circuit of** Separately Excited Dc Motor.

$$va = ia\,Ra + La\frac{d\,ia}{dt} + eb, \quad \textit{Armature Equation}$$

$$vf = if\,Rf + Lf\frac{d\,if}{dt} \quad \textit{Field Equation},$$

$$T = K\emptyset\,ia = Tl + BW + J\frac{dw}{dt} \quad \textit{Mechanical Equation}$$

1.2 Laplace transform with zero initial condition

$$Va(s) = Ia(s)(Ra + SLa) + k\emptyset W(S),$$

$$VF(s) = If(s)(Rf + SLf)$$

$$T(s) = K\emptyset\, Ia(s) = Tl(s) + W(S)(B + JS)$$

3- Armature control to separately dc motor.

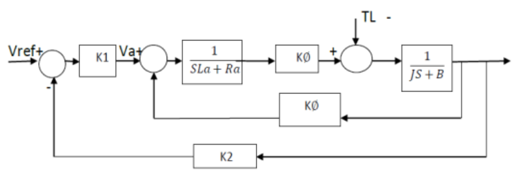


Figure (3) Closed Loop Block Diagram of Separately Excited Dc Motor.

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$$\frac{W(S)}{Vref\,(s)} = \frac{k1\,K\emptyset}{JLaS^2 + (JRa + \beta La)S + \beta Ra + K\emptyset(K\emptyset + K1K2)}$$

$$\frac{W(S)}{Tl(s)} = \frac{-(Ra + S\,La)}{JLaS^2 + (JRa + \beta La)S + \beta Ra + K\emptyset(K\emptyset + K1K2)}$$

Steady State Analysis. (S=0)

$$\frac{W(S)}{Vref\,(s)} = \frac{K1K\emptyset}{\beta Ra + K\emptyset(K\emptyset + K1K2)}$$

$$\frac{W(S)}{Tl(s)} = \frac{-Ra}{\beta Ra + K\emptyset(K\emptyset + K1K2)}$$

b- A [50KW, 240V, 1700 rpm] separately excited DC motor $[50KW, 240V, 1700rpm,\ R_a = 0.1\Omega, B = 0.03\ N.m.s/rad]$ is controlled by a power converter has a gain =100. The gain of the speed sensor is 95mV/rad/s. It used the close loop technique to control the motor speed. The field current is held constant at a value for which $K\Phi = 1.3\ V.S/rad$.

i- Find V_r required to drive the motor at rated speed with no load? [3] points

ii- Find the motor speed when the motor supplied the rated torque and V_r is not changed? [3] points

iii- Find the motor speed if V_r is decreased by 15%? [3] points

i- P=T ω =(2pi/60)(1700*T)=50000, T=281Nm, rated speed=1700rpm=178rad/s.

$$\frac{\omega_r}{V_r} = \frac{K_1K\phi}{BR_a + K\phi(K_1K_2 + K\phi)} = \frac{100*1.3}{13.9785} = 9.3,\ V_r = \frac{178}{9.3} = 19.14V$$

$$\frac{\Delta\omega_r}{-\Delta T_w} = \frac{R_a}{BR_a + K\phi(K_1K_2 + K\phi)} = \frac{0.1}{14} = 0.007,\ \Delta\omega_r \quad = -0.007 * 281 = -\frac{2rad}{s}$$

$$\omega_r = 178 - 2 = \frac{176.rad}{s} = 1680..7rpm$$

iii-As Vr decreased to =0.85*19.14=16.3V, wr=16.3*9.3=151.3rad/s

As motor loaded then wr=151.3-2=149.3rad/s=1425.7rpm

Q3- A separately excited DC motor has [$20hp, 300V,\ 900rpm,\ R_a = 0.25\Omega,\ L_a = 0.05H, R_f = 145\Omega,\ K\Phi = 3.05Nm/A,\quad T_{losses} = constant = 1Nm, load\ torque = constant = 115Nm$].

a-Find the motor speed if the armature voltage is 200 V? [5] points

b-If its armature is supplied by fully controlled single phase rectifier [firing angle = 30 degrees, 312 V, 60Hz AC supply] and assume constant armature current and field current. Draw the power circuit and the wave forms of voltages and currents and find the motor speed and (pf)? [5] points

c-If its field is supplied by a fully-controlled three phase rectifier [firing angle = 52 degrees, Y-208 V, 60Hz AC supply] and assume constant armature current and field current $K\Phi = 2.3Nm/A$. Draw the power circuit and the wave forms of voltages and currents and find the motor speed and the field voltage? [5] points

a-I_a=[115+1]/3.05=38A, E_a=200-38*0.25=187.4V, w=187.4/3.05=62.46rad/s, n=596.4rpm ,Va=E_a+IaRa

b-For a single phase rectifier with continuous armature current Va>Ea

α=30 degrees , V_a=[2V_{max}cosα]/pi=(2*312*1.414cos30)/pi=243.3V, w=[243.3-38*0.25]/3.05=76.7rad/s, n=732rpm ,Va=E_a+IaRa, pf= cosα=0.9cos30=0.78, pf_1(fundamental)= cosα=cos30=0.87

c-For a three phase rectifier with continuous field current

α=52 degrees , V_a=[3V_{max}cosα]/pi=(3*208*1.414cos52)/pi=173V, w=[300-38*0.25]/2.3=20126.3rad/s, n=1206rpm ,Va=E_a+IaRa, pf= cosα=0.955cos52=0.59, pf_1(fundamental)= cosα=cos52=0.62

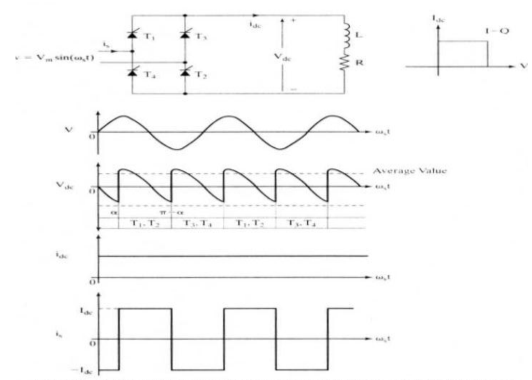


Figure 3.6 A single-phase controlled-bridge converter operating as a rectifier in steady state

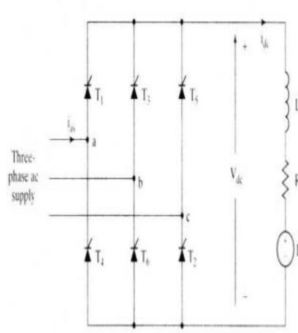


Figure 3.10 Three-phase controlled converter

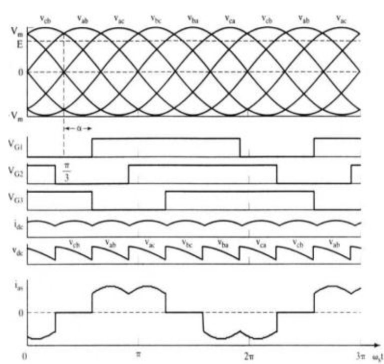


Figure 3.11 Rectification in the three-phase converter in steady state (first-quadrant operation)

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

A separately excited DC motor has[$\mathbf{230V, 1750rpm,\ I_{rate} = 74A, R_a = 0.18}\Omega,\ \mathbf{L_a = 2.93mH}$] is driven with the motor armature supplied from class A chopper and 240V dc source. The chopping frequency is 0.5 KHz and the duty cycle=0.5. The field current is held constant at the value giving rated operation on 230V. The armature current is the rated value and assumed to be continuous.

i-Find the minimum and maximum armature currents? [5] points

ii-Find the ripple factors of the armature current and the supply current? [5] points iii- Draw the power circuit and current and voltage waveforms? [5] points

w=1750rpm=183.3rad/s, $K\Phi = \frac{230-74*0.18}{183.3} = 1.182\, V.S/rad,$ E(rate)=1.182*183.3=216.7V, as K=0.5 and continuous current then V=0.5*240=120V, E=120-74*0.18=106.68V, E/Vdc=106.68/240=0.4445,

Ta=La/Ra=0.00293/0.18=0.0163S,Tp=1/500=2mS, Tp/Ta=0.123, $t_{on\ critical} = \tau \ln\left[1 + \frac{E}{V_{dc}}\left(e^{T_p/\tau} - 1\right)\right] =$

0.92msec. $K_{critical} = \frac{\tau}{T_p}\ln[1 + \frac{E}{V_{dc}}\left(e^{T_p/\tau} - 1\right)]$=0.461, K=$t_{on}/T_p$=$V_{av}/V_{dc}$=120/240=0.5> Kc then continuous

current mode $I_{max} = \frac{V_{dc}(1-e^{-t_{on}/\tau})}{R_a(1-e^{-T_p/\tau})} - \frac{E}{R_a}$ =100A, $I_{min} = \frac{V_{dc}(e^{t_{on}/\tau}-1)}{R_a(e^{T_p/\tau}-1)} - \frac{E}{R_a} = 54A$

motor current: I_{ave}=74A, I_{1rms}=1.414*V_{dc}/piW_0L_a =1.414*240/pi*2*pi*500)*0.00293=11.74A,RF=11.74/74=0.16

Source current: I_{ave}=74*K=37A, I_{1rms}=1.414*I_a/pi =1.414*74/pi=33.3A,RF=33.3/37=0.9

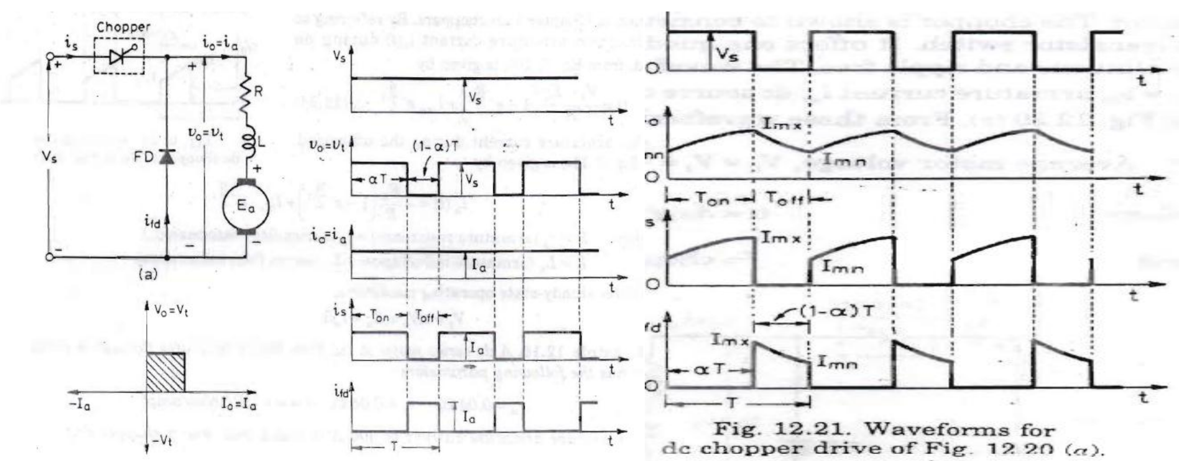


Fig. 12.21. Waveforms for dc chopper drive of Fig. 12.20 (a).

Question (5) **[30] Points**

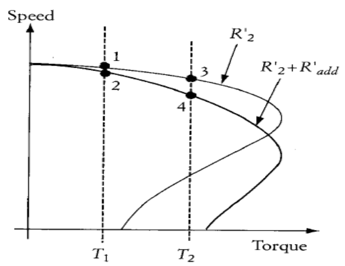
a-Explain how to control the speed of a 3-phase induction motor? [5] points

n_r=(1-s)n_s, n_s=120f/P, the speed parameters are frequency, number of poles and slip. The speed is controlled by:

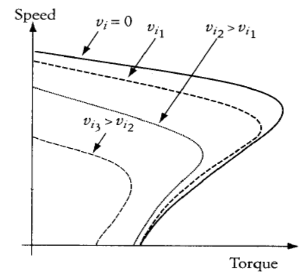
1- control the slip 2-control the frequency 3-control the number of poles.

The slip is controlled by controlling: 4- rotor resistance 5-rotor inductance 6- stator resistance 7-stator inductance 8-magnitude of stator input voltage 9- frequency of stator input voltage 10-inject voltage in the rotor 11-V/f control of the stator voltage. There are three tools: 1-inverter 2-AC/AC converter 3-cycloconverter.

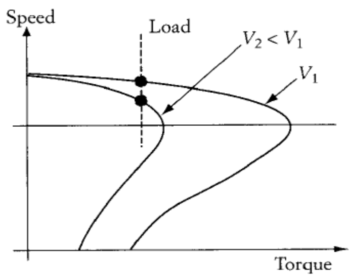
Effect of rotor resistance on motor speed



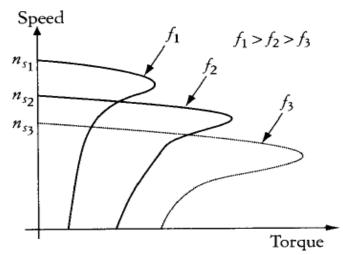
Speed–torque characteristics of induction motor with rotor-injected voltage



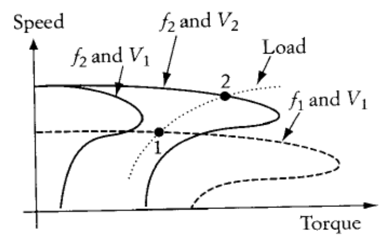
Impact of voltage on motor speed



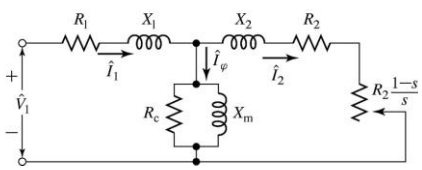
Impact of frequency on motor speed



Impact of change in frequency and voltage



b-Draw the equivalent circuit of a 3-phase induction motor and find T_{dev}? [5] points



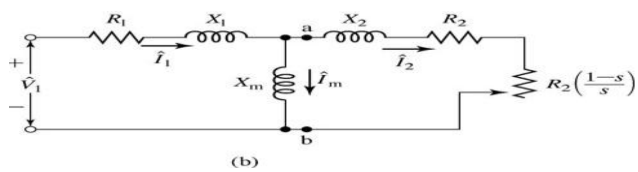


Figure 6.9 Single-phase equivalent circuit for a three-phase induction motor.

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

c-A three phase wye-connected induction motor [460V, 60Hz, 4 poles, 1750 rpm, $R_s = 1.01\Omega$, $R_r = 0.69\Omega$, $X_m = 43.5\Omega$, $X_1 = 1.3\Omega$, $X_2 = 1.94\Omega$, $T_L = 100Nm$. The stator of the motor is connected to a 3-phase full wave AC/AC converter.

i-Find the motor speed when the AC/AC converter output voltage is 460V line to line? [3] points

ii-Find the motor speed when the AC/AC converter output voltage is 230V line to line? [3] points

iii-Draw the power circuit and current and voltage waveforms? [4] points

n_s=120*60/4=1800rpm, ω_s=1800*pi/30=188.5rad/sec., ω_r=1740*pi/30=182.2rad/sec.

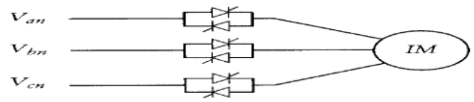
$$motor\ torque = \frac{3V'^2 S}{R_2\omega_s} = load\ torque = 100Nm = \frac{460'^2 S}{0.96 * 188.5},$$

$$S = 0.0855, n = (1 - 0.0855) * 1800 = 1646rpm$$

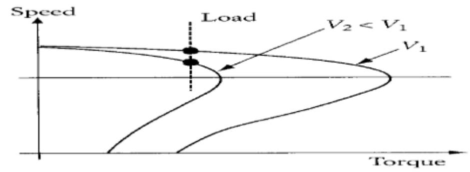
$$motor\ torque = 100Nm = \frac{230'^2 S}{0.96 * 188.5}, S = 0.342, n = (1 - 0.342) * 1800 = 1184.26rpm$$

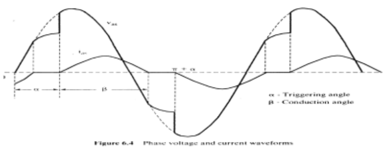
$$\frac{T_{cont.}}{T_{rate}} = \left[\frac{(1-S_{cont.})}{1-S_{rate})}\right]^2 = \frac{S_{rate}}{S_{cont.}}\left(\frac{I_{cont.}}{I_{rate}}\right)^2 \quad I_{cont.} = 10.3\frac{0.444}{0.028} * [\frac{1-0.444}{1-0.028}]^2 = 53.44A$$

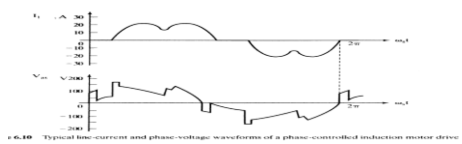
Phase control of induction motor



Impact of voltage on motor speed







d-If the stator of the motor is connected to a 3-phase six step inverter.

i-Find the required DC supply to run the motor with speed of 1000 rpm and of 1750rpm

iv- Draw the power circuit and current and voltage waveforms? [4] points

S1=(n_s-n_r)/ n_s = (1800-1750)/ 1800= 0.028, ω_{r1}=1750*pi/30=183.3rad/sec.

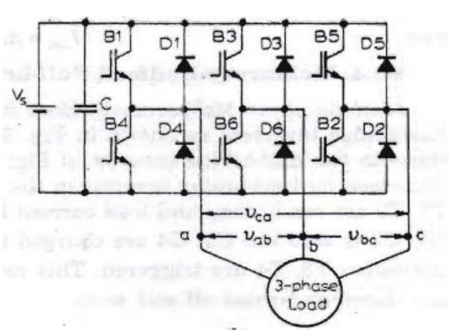
S2=(n_s-n_r)/ n_s = (1800-1000)/ 1800= 0.444, ω_{r2}=1000*pi/30=104.72rad/sec.

$$\text{motor torque} = \frac{3V'^2 S}{R_2 \omega_s} = \text{load torque} = 100\text{Nm} = \frac{0.444*3V'^2}{0.96*188.5}, or = \frac{0.028*3V'^2}{0.96*188.5}$$

for six-step inverter $V_{ph} = \sum_{n=6k\pm1}^{\infty} \frac{2*V_{dc}}{n*pi} sinn\omega t$, $V_{1-ph-rms} = \frac{\sqrt{2}*V_{dc}}{pi}$

$$\text{V1.ph.rms} = 116.6\text{V} = 1.414 * \frac{\text{Vdc}}{\text{pi}}, \text{Vdc} = 259\text{V or Vphrms} = 116.6\text{V} = 1.414 * \frac{\text{Vdc}}{3}, \text{Vdc} = 247.35\text{V}$$

$$V1.ph.rms = 464.14V = 1.414 * \frac{Vdc}{pi}, Vdc = 1031V\ or\ Vph - rms = 464.14V = 1.414 * \frac{Vdc}{3}, Vdc = 984.3V$$



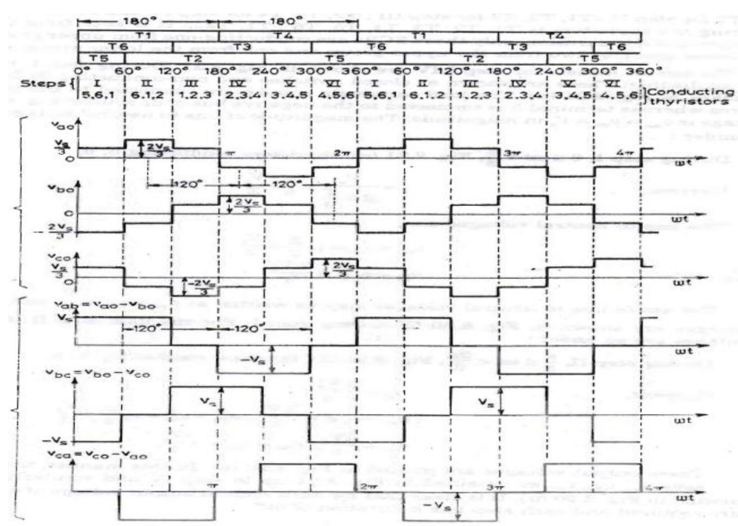


Fig. 8.20. Voltage waveforms for 180° mode 3-phase VSI.