DC DRIVES

1.Aim : To discuss the concept of DC drives and performance of DC drives.

Objectives : To explain the performance of DC drives in terms of

- Concept of Electric Drives.
- Performance characteristics and equations of DC motor.
- Speed control methods.
- Converter fed DC drives.
- Chopper fed DC drives.
- Simulation of Converter fed DC drive using PSIM.
- Applications of DC drives.

2.Pre-Test : MCQ Type

1. In a DC shunt motor, the electromagnetic torque developed is proportional to

____

a) I_a
b) I_a^2
c) I_a^3
d) $I_a^{.5}$

Answer:

a) I_a

2. Which of the following rule is used to determine the direction of rotation of D.C motor?

a) Coloumb's Law
b) Lenz's Law
c) Fleming's Right-hand Rule
d) Fleming's Left-hand Rule

Answer d.
Fleming's left-hand rule**.**

3. The efficiency of the DC motor at maximum power is

a)90%
b)100%
c)Around 80%
d)Less than 50%

Answer d.
Less than 50%

4. Choppers converts

a) AC to DC
b) DC to AC
c) DC to DC
d) AC to AC

Answer c.
DC to DC

5. The average output voltage is maximum when SCR is triggered at ωt =

a) π
b) 0
c) π/2
d) π/4
Answer b.
0

3.PRE-REQUESTIES
1.DC Motors
2.Power Electronics

4.Concept of Electric Drives

An electric motor together with its control equipment and energy transmitting device forms an ***electric drive.***

Example:

A motor and conveyer-belt without any material on its belt.

An electric drive together with its working machine constitutes an ***electric –drive system.***

Example:

A motor and conveyer-belt with material on its belt.

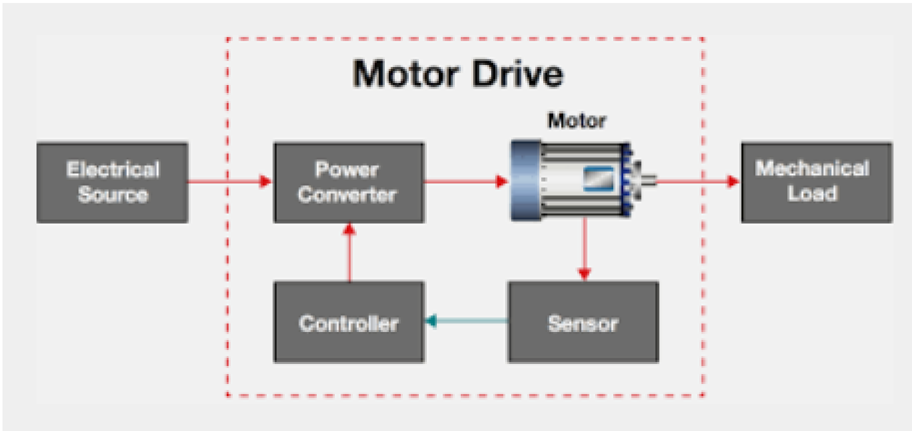


Fig.1. An Electric Drive System

4.1.DC Drives

DC motors are widely used in adjustable-speed drives and position control applications. Speed control methods of DC motors are comparatively less expensive than AC motors.

There are two methods to control the speed of DC motors:

1. Armature voltage control method
2. Field-flux control method

Armature voltage control method: Speeds below base speed are controlled.

Field-flux control method: Speeds above base speed are obtained

Depending on the type of available source and converters DC drives are classified as:

1. Single-phase DC drives
2. Three-phase DC drives
3. Chopper fed DC drives

4.2.Basic performance equation of Separately –excited DC motor

The equivalent circuit of a Separately –excited DC motor coupled with a load is shown in Fig.2. Under steady state conditions load torque T_L oppose the motor torque T_e.

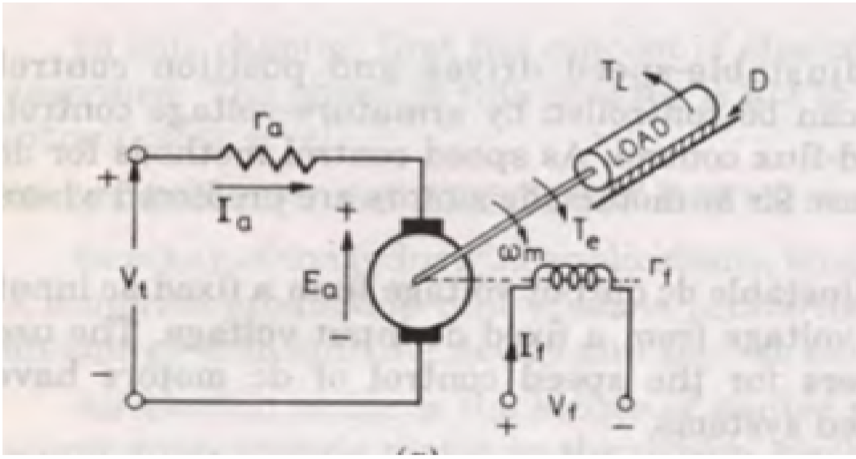


Fig.2. Equivalent circuit of a Separately excited DC motor

For field circuit, $V_f = I_f \, . \, r_f$ …………………(1)

For armature circuit $V_t = E_a + I_a \, .r_a$ …………………(2)

Motor back emf , $E_a = K_a\Phi \; \omega_m = K_m . \; \omega_m = \; V_t - I_a \, .r_a$ ……(3)

$\omega_m = V_t - I_a \, .r_a \; / \; K_m = \; V_t - I_a \, .r_a \; / \; K_a\Phi$ ………………….(4)

$T_e = K_a\Phi \; I_a = K_m \; I_a$ …………………..(5)

Where,

V_t = motor terminal voltage, V

I_a= armature current , A

Φ= field flux/pole , Wb

$K_m = K_a\Phi$, torque constant , Nm/A.

r_a = armature resistance, Ω

ω_m = angular speed of motor, rad/sec.

r_f = field circuit resistance, Ω

From equation (4), it is seen that the speed can be controlled by varying the voltage V_t , Known ***as armature –voltage control***, and by varying the Φ, known as the ***field-flux control.***

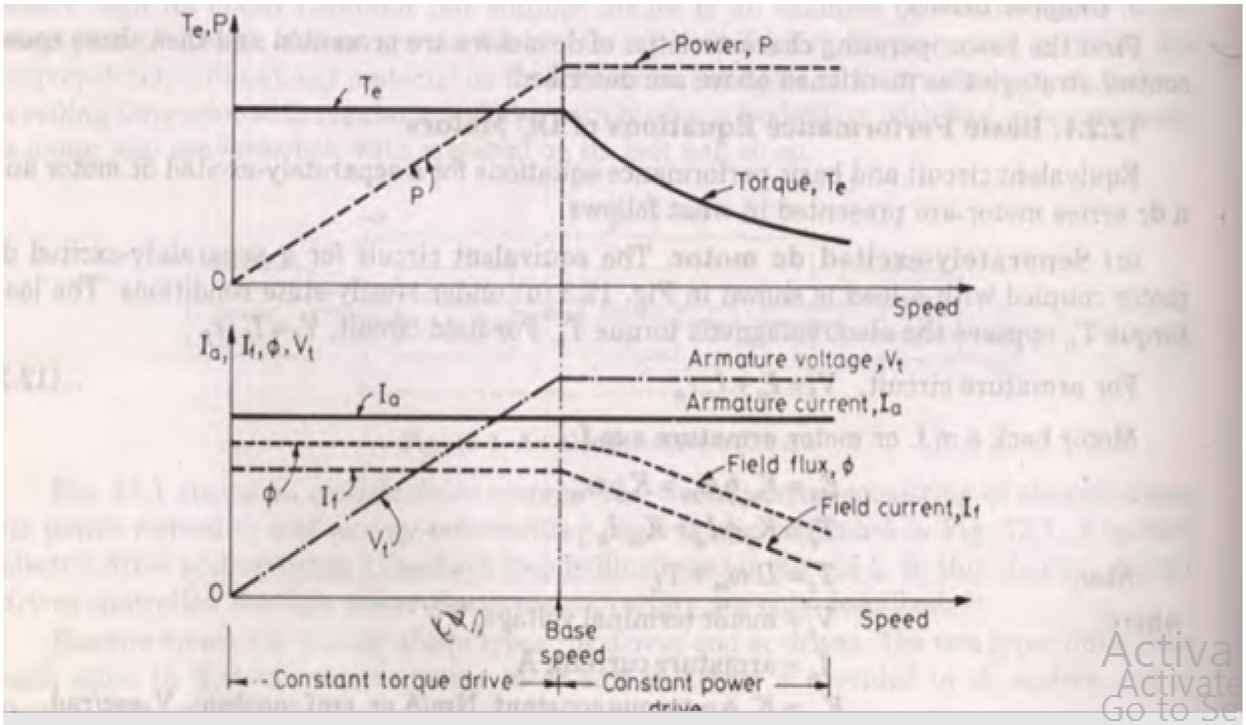


Fig.3. Characteristics of a Separately excited DC motor

Characteristics of a Separately excited DC motor is shown in Fig.3.

Base speed of the motor is defined as the speed at which the motor runs at its rated voltage, rated armature current and rated field current.

(1) ***Armature voltage control*** : armature voltage (V_t) is varied to obtain the speed below base speed. The armature current and field flux (Φ) are kept constant at their rated values. From equation (5), it is seen that when I_a and Φ are constant the torque remains constant at its rated value to meet the required demand. So this armature voltage control method is known as ***constant-torque drive*** method The armature voltage (V_t) is varied from its zero voltage to rated voltage the power $P= V_t \cdot I_a$ increases from its zero value to rated power.

(2) ***Field-flux (Φ) control***: this method of speed control is employed for the speeds above base speed. From equation (4) it is seen that speed and field flux are inversely proportional. During flux control method, armature

voltage and armature current are kept constant at rated values. So power remains constant and this method of control is termed as ***constant power-drive*** method. Field flux is decreased to increase the speed above base speed, the torque is directly proportion to flux so torque decreases with decrease in flux.

4.3.Single –phase Full Converter Drives

This converter fed DC drive has two full converters and a separately excited DC motor. One full converter feeding the armature circuit and the other feeding the field circuit. The converters convert the AC voltage into DC voltage and by varying the firing angle(α) of the converters the output voltage of the converters can be varied. Fig.4. shows the single-phase full converter fed separately excited DC motor.

Full converter fed DC drives offers two quadrant operation of the drive, first quadrant operation is the ***motoring mode*** and second quadrant operation is the ***regenerative braking*** of the motor. Fig.5. shows the two- quadrant diagram.

The motoring mode control is the first quadrant operation. During this mode, armature voltage is controlled by controlling the firing angle(α) of the armature side converter. The firing angle(α) can be varied from 0º to 90º for rectification of AC voltage into DC voltage and the output DC voltage of the converter can be varied from its maximum value to zero value. Thus the voltage fed to the armature is controlled varying the firing angle of the converter.

During regenerative braking control power must flow from motor to the AC source. This is possible only when the back emf of the motor is reversed. The SCRs present in the full converters are unidirectional devices so polarity of the back emf is reversed by reversing the direction of field current by making the firing angle(α_1) above 90º for the field side converter.

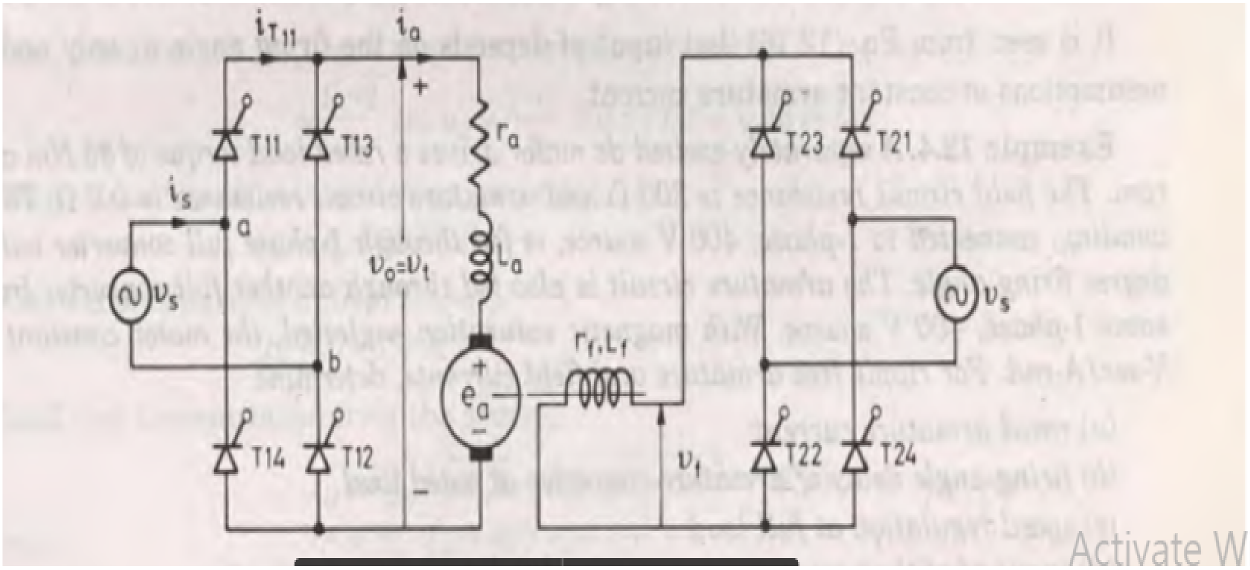


Fig.4. Single-phase full converter fed Separately excited DC motor

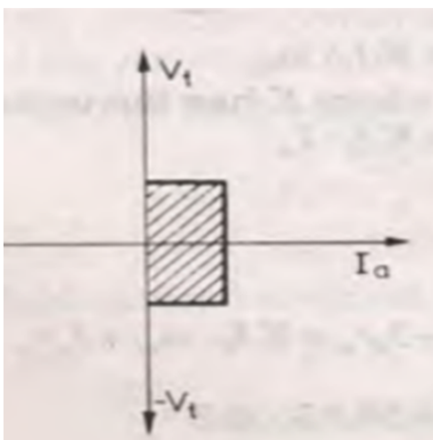


Fig.5.Two –quadrant diagram

The input AC voltage of the converter, output voltage and output current waveforms are shown in Fig.6.

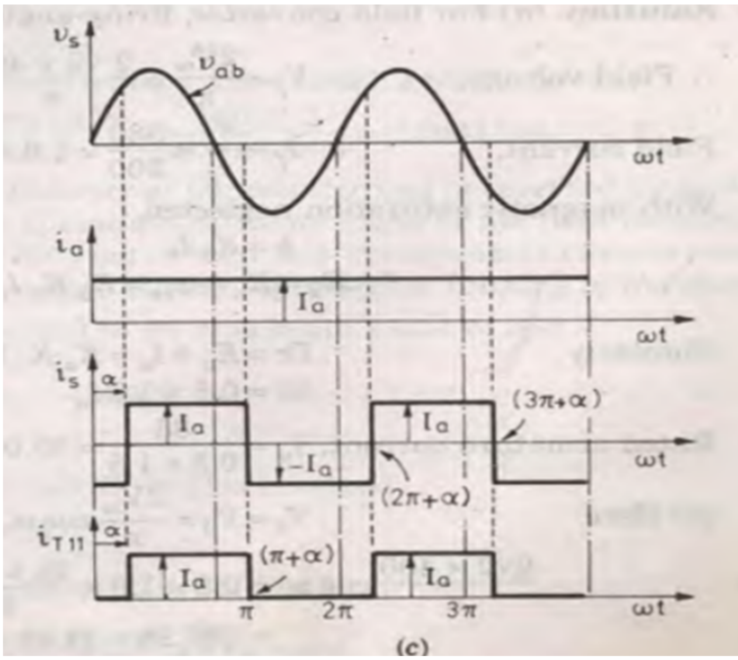


Fig.6.Waveforms

The output voltage of the armature circuit converter 1,

$V_o = V_t = 2V_m/\pi \cos \alpha$ for $0 \le \alpha \le \pi$ ……..(6)

$V_f = 2V_m/\pi \cos \alpha_1$ for $0 \le \alpha_1 \le \pi$ ……..(7)

rms value of source current, $I_{sr} = \sqrt{I_a^2 \cdot \frac{\pi}{\pi}} = I_a$

rms value of thyristor current, $I_{tr} = \left[I_a^2 \cdot \frac{\pi}{2\pi} \right]^{1/2} = \frac{I_a}{\sqrt{2}}$

From Eq. (12.9), input supply $\text{pf} = \frac{V_t \cdot I_a}{V_s \cdot I_{sr}} = \frac{2V_m}{\pi} \cos \alpha_1 \cdot \frac{I_a \cdot \sqrt{2}}{V_m \cdot I_a}$

$$= \frac{2\sqrt{2}}{\pi} \cos \alpha_1$$

4.4.DC Chopper fed DC Drives

Chopper circuit converts fixed DC voltage into variable DC voltage. Chopper circuit can be interfaced between fixed DC voltage source and DC motor armature circuit. By varying the duty cycle(δ) of the DC chopper, variable voltage can be applied to the armature terminals of the DC motor to obtain the speed control below the speed.

Chopper circuit is adoptable for regenerative braking of DC motor and kinetic energy can be returned to the DC source. Choppers can be used for dynamic braking also.

The following controlled modes are explained in detail.

1.Power control or motoring control.

2.Regenerative –braking control.

4.4.1.Power control or motoring control

The Fig.7. shows the circuit for motoring control of Chopper fed DC series motor which is the first quadrant operation. By modifying chopper circuit configuration all four quadrant operation of DC motor drive is possible. Chopper fed DC drives are widely employed in traction systems.

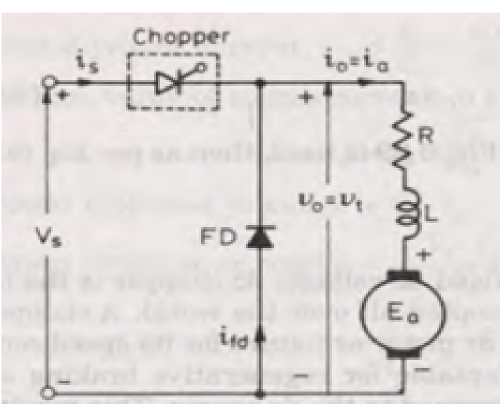


Fig.7.motoring mode operation

of chopper fed DC series motor

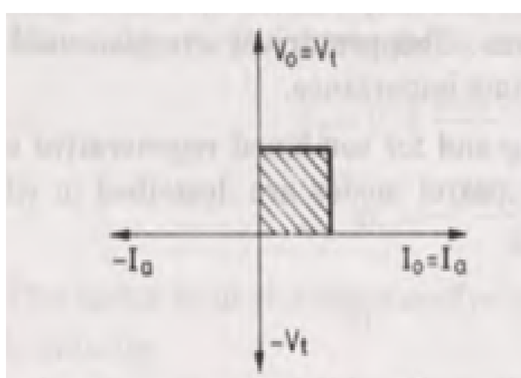


Fig.8. forward motoring mode operation

First -quadrant

In the above circuit configuration ***when the chopper (CH) is ON***, the motor armature terminal is connected with the DC source. The current is conducted by the chopper from source to armature of the DC motor. The output voltage of chopper $V_O = V_t$ is fed to the motor armature. I_o=I_a is chopper output current flows through the armature winding. R and L are the armature winding output voltage of the chopper is controlled by varying the duty cycle(δ) according to the speed requirement.

When the chopper is OFF and the CH operates like an open switch, the motor armature terminals are disconnected from the DC source. Now the stored energy in the inductance and back emf of the motor drives the armature current through the freewheeling diode FD. During this period rmature terminals are short circuited by FD. Now the output voltage $V_O = 0$, but I_o flows through armature circuit continuously.

The average motor voltage , $V_O = V_t = T_{on}/T .V_s = \delta. V_s$

Where V_s is the input DC voltage

And $\delta = T_{on}/T$, is the duty cycle of the chopper, T_{on} is the ON time of the chopper, T_{off} is OFF time of the chopper, T is the total time period.

$T = T_{on} + T_{off}$

Chopping frequency of the circuit is, $f = 1/T$

The duty cycle δ can be varied by varying the ON time and OFF time of the chopper. Thus the output voltage and in-turn speed of the DC motor drive is controlled during the motoring mode operation to obtain the speeds below base speed.

The input fixed DC voltage , output DC voltage and output currents are shown by waveforms in Fig.9.

The input fixed DC voltage , output DC voltage and output currents are shown by waveforms in Fig.9. The ON time and OFF time of chopper also indicated in the waveforms given.

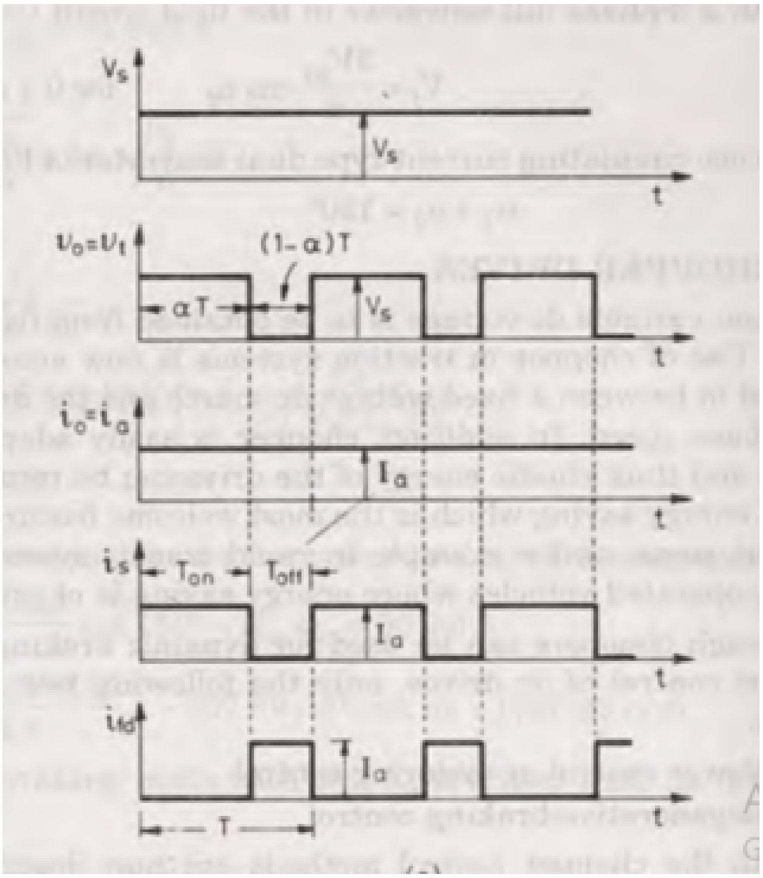


Fig.9. Waveforms

4.4.2.Regenerative Braking Control.

The chopper circuit configuration for Regenerative Braking mode is shown in Fig.10. During this mode of operation the motor acts as a generator, kinetic energy of the motor and the load is returned to the supply. For active loads like downward motion of electric train in a hill or descending hoist, assume the back emf E_b of the motor is greater than supply voltage V_s.

With the chopper circuit configuration shown in Fig.10., when the chopper is ON , chopper CH short circuits the armature terminals of the motor and the current I_o=I_a is conducted by the chopper to the armature .The current is driven by the back emf of the motor and stored energy in the inductance. The ouput voltage V_o = 0.

When the CH is OFF, being E_b is greater than V_s, diode D conducts and the stored energy in the armature inductance is transferred to the source, during T_{off} $V_t = V_s$.

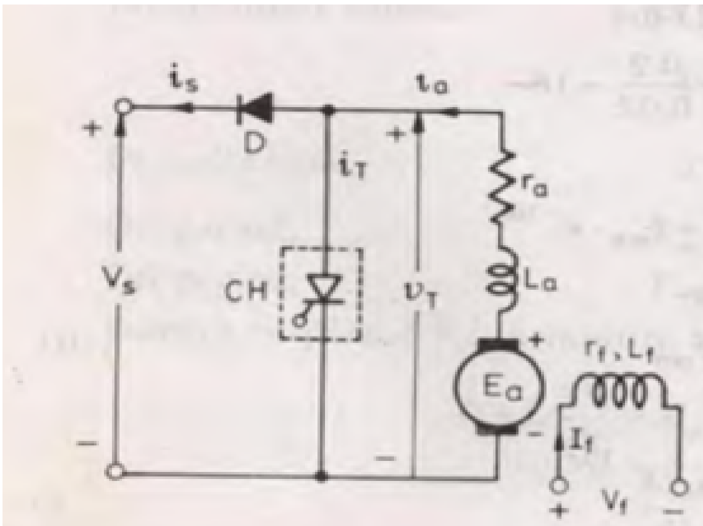


Fig.10. Copper circuit configuration for Regenerative braking control of Separately Excited DC motor.

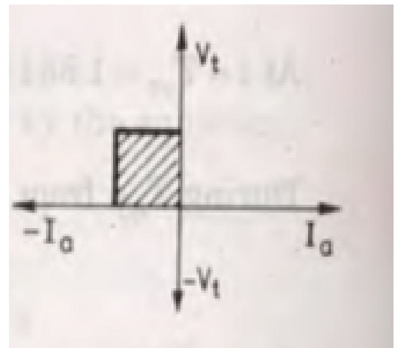


Fig.11. Quadrant diagram

Regenerative braking control is the second quadrant operation which is shown in Fig.11.

The average output voltage of chopper is

$$V_t = T_{off} / T . V_s = (1-\delta). V_s$$

Power generated by the motor = $V_t . I_a = (1-\delta). V_s . I_a$

Motor emf generated, $E_a = K_m \omega_m = V_t + I_a r_a$

$$= (1 - \alpha) V_s + I_a r_a$$

Motor speed during regenerative braking,

$$\omega_m = \frac{(1 - \alpha) V_s + I_a r_a}{K_m}$$

The voltage and current waveforms are shown in Fig.12.

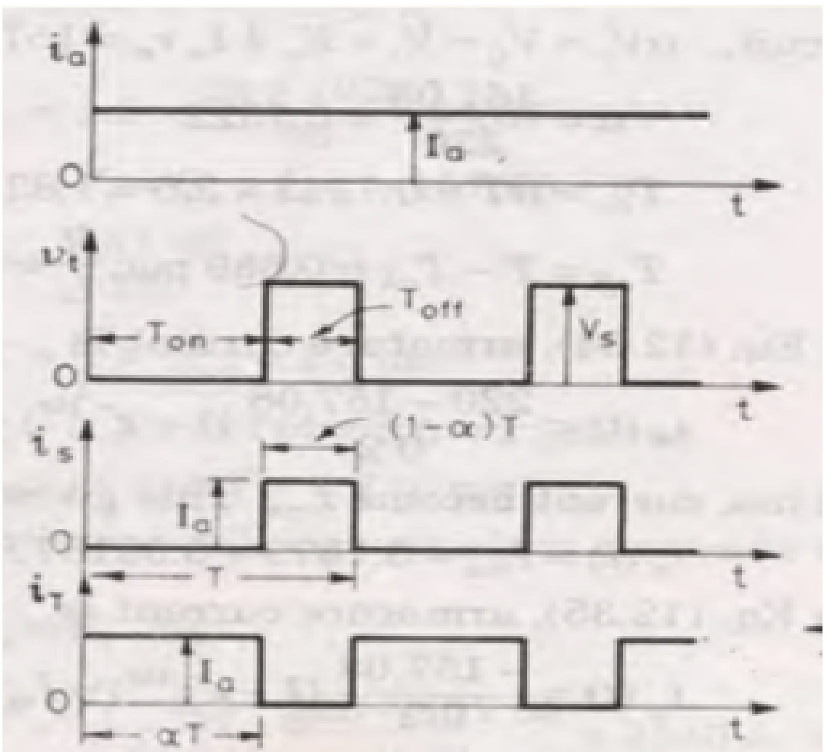
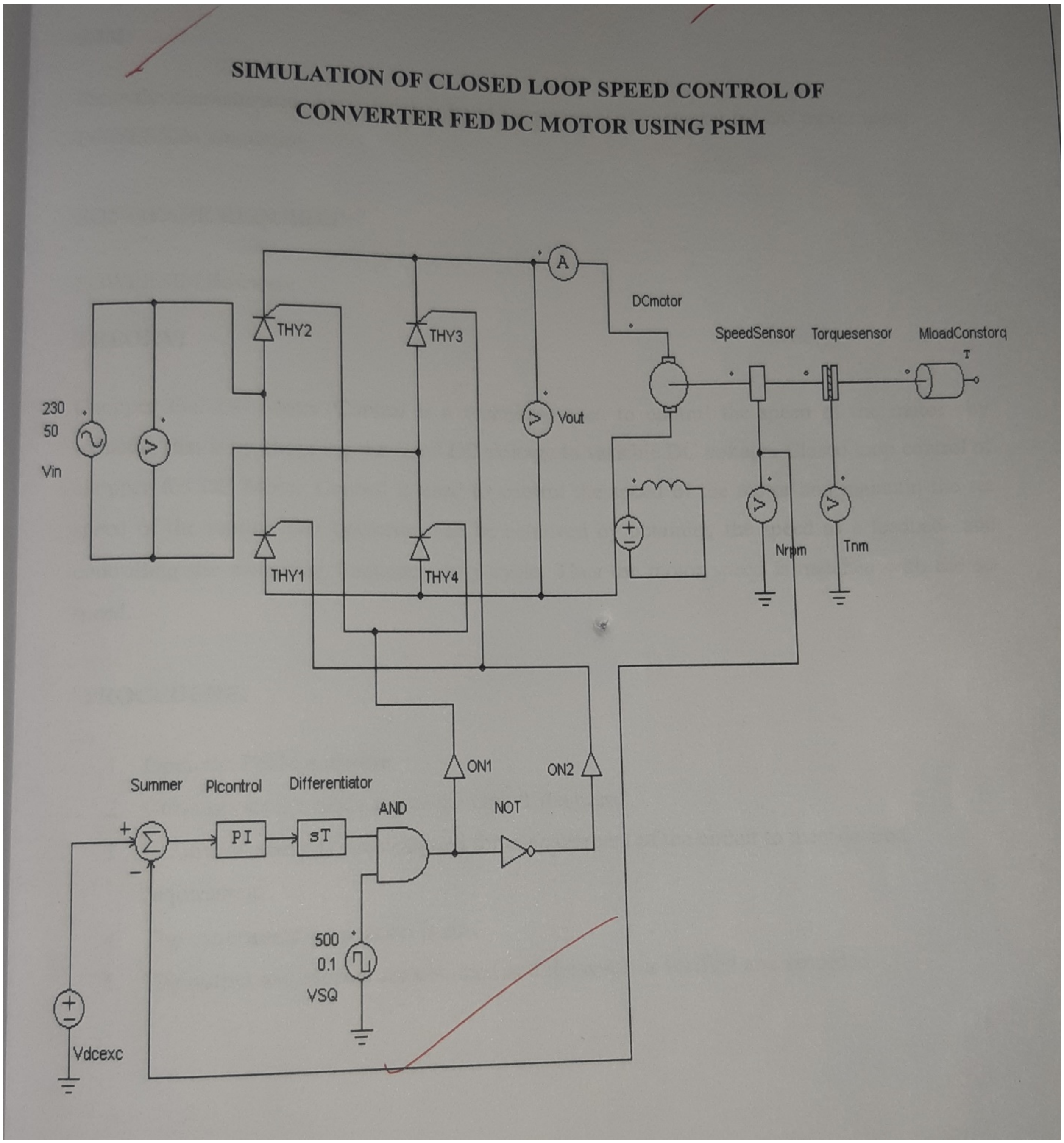


Fig.12.Waveforms

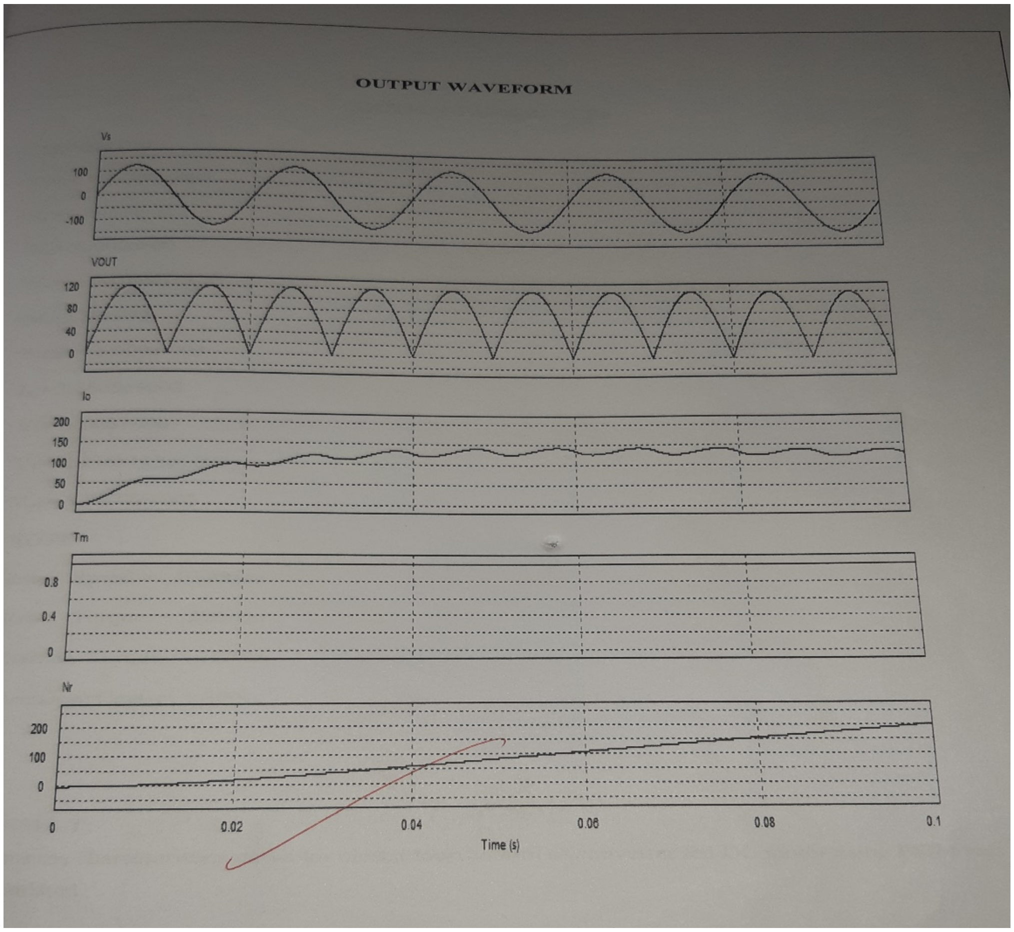
5.1Simulation of DC drives

5.1.1. Converter fed DC drive is simulated using PSIM.



5.1.2. Simulation results

The simulation results are presented interms of converter input AC voltage, DC output voltage of converter, output current, Motor torque and speed waveforms.



5.2.Applications of DC drives:

- Traction systems, Electric locomotives.
- Paper mills
- Lathes, milling machines, boring machines
- Hoists and Cranes
- Spindles and feeds of machine tools
- Roller mills
- Rubber mixers
- Motor braking systems
- Position control mechnisms

6. MCQ POST-TEST

1.To save energy during braking-----------------braking is used?

(A) dynamic
(B) plugging
(C) regenerative
(D) all of the above

Answer:
(C) regenerative

2.How many quadrants does a full converter work?
(A) one
(B) two
(C)three
(D) four

Answer:
(B) two

3.Full-converter can be used in DC motor for regenerative braking in _______________

(A)constant operation
(B)variable operation
(C)Inversion operation
(D) opposite operation

Answer:
(c)

4. Which of the following method is employed when regenerative braking is necessary?

(A)DC chopper
(B)inverter
(C)variable resistor
(D) rectifier

Answer
(A)

7.CONCLUSION

DC drives are widely used in various industries. Converters employed in DC drives gives smooth and wide range of speed control without much expensive. Moreover these drives and controller occupies lesser area and provide precise control of DC drives.

8.REFERENCES

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9.ASSIGNMENTS

1. Discuss the four quadrant operation of Chopper fed DC drives.
2. Explain the inverter operation of single phase converter circuit.